BENEFITS OF THE MINNESOTA ROAD RESEARCH PROJECT (MNROAD)

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ABSTRACT

The Minnesota Department of Transportation (Mn/DOT) began construction on the Minnesota Road Research Project (MnROAD) in 1991 and opened the full-scale pavement research facility to live traffic in 1994. Since the time of its construction, MnROAD, the first major test track since the AASHO Road Test of the 1950s and 1960s, has learned many lessons in pavement testing and pavement engineering on behalf of the greater pavement community. Researchers at the University of Minnesota reviewed these lessons from the first phase of MnROAD (the facility’s first ten years of operation) for a project titled MnROAD Lessons Learned. The Lessons Learned project involved over fifty interviews, three hundred published and unpublished reports, papers, and briefs, and an online survey of pavement professionals. This paper, based on the Lessons Learned project, presents a sample of the lasting benefits of MnROAD at the local, state, and national levels. Furthermore, the paper provides extensive references for these benefits in hopes of increasing awareness of this pavement test facility’s under-publicized contributions to pavement engineering.
BACKGROUND

In the 1980s, the Minnesota Department of Transportation (Mn/DOT) explored the idea of a Cold Regions Pavement Research Test Facility (CRPRTF), which led to a task force that consisted of Mn/DOT engineers and officials, Federal Highway Administration (FHWA) and Strategic Highway Research Program (SHRP) administrators, representatives of industry, and consultants from universities. In May 1987, the task force settled upon proposed interstate and low-volume test section plans for what would be called the Minnesota Road Research Project (MnROAD) \(^1\). The plans were then unveiled in a number of reports by Dr. Matthew Witczak, a consultant to the CRPRTF Task Force \(^2,3\).

Concurrent with the development of test section plans was the focus of the task force, with the specific assistance of Dr. Witczak, the University of Minnesota (UMN), and Mn/DOT engineers, on research objectives for MnROAD. This early focus on research lead to the determination of fourteen objectives in research for MnROAD that included the evaluation of mechanistic and empirical design methods; the verification and further development of frost prediction methods; and the investigation of base/subbase properties on pavement performance \(^4\). (More information on these research objectives and the development of MnROAD can be found in Tompkins and Khazanovich \(^5\).) Having both construction and research plans, various government and Mn/DOT officials broke ground near Albertville, Minnesota, in 1991 for the construction of a 3.5-mile interstate roadway and a 2.5-mile low-volume roadway, each roadway consisting of test sections and over 4500 sensors monitoring pavement response and environmental data. A schematic of the test sections at MnROAD is provided in Figure 1.

The interstate roadway, or the mainline, is subjected to live traffic redirected from westbound traffic on US Interstate 94, while the low-volume road is subjected to a controlled 5-axle loading of 80 kip in one lane and 102 kip in the other. The MnROAD facility opened to traffic in August 1994, and as of December 31, 2003, the mainline flexible test sections received roughly 5 million Equivalent Single Axle Loads (ESALs) and the mainline rigid sections received approximately 7.8 million ESALs \(^7\).
The following paper will describe some of the products of MnROAD in terms of its benefits to pavement engineers at the national, state, and local levels. It is hoped that by viewing a pavement test facility in this manner, the reader is not only able to better understand some of its products, but is also able to appreciate the far reaching effects of the kind of pavement research that occurs at a full-scale pavement test facility such as MnROAD.

CONTRIBUTIONS OF MNROAD AT THE NATIONAL LEVEL

MnROAD has been involved in a number of projects with national interest, and some of those projects are also detailed below.

Pavement Test Track Expertise

The challenge of forging a new path through the thirty years of changes to come about since the AASHO Road Test meant that MnROAD had many lessons to learn for test tracks and pavements to come. MnROAD engineers involved in the construction and installation of sensors at the MnROAD site had the foresight to closely detail their experience in Mn/DOT reports, exemplified by reports such as Baker et al. (8). This report presented step-by-step installation procedures for 16 surface sensors installed at MnROAD to collect data on loading in the test sections. The report also describes testing procedures to verify the operation of the 16 surface sensors and check for any malfunctions, and the report discusses the survivability of the sensors and possible sources of sensor failure.

Due to the large amount of sensors installed at MnROAD (over 4500), MnROAD gained considerable insight into the actual sensor life spans and durability to compare with the claims of the various manufacturers, and later work at MnROAD dealt with the problem of sensor failure, which MnROAD experienced on a large scale. One of the more prominent studies into this problem was conducted by MnROAD engineers and detailed by Burnham (9). This paper came about due to the failure of the original sensors embedded in MnROAD’s concrete test sections. To replace these sensors, MnROAD engineers had to determine the orientation of the original sensors. In doing so, MnROAD engineers discovered that the in-situ position of the sensors differed greatly from the position intended for them in the original design. Once a feasibility study was concluded for retrofitting the failed sensors, MnROAD engineers installed new sensors into holes in the test sections from full-depth coring. These new sensors were then subjected to loading and monitored to determine if retrofitted sensors provided reliable data on loading. In this case, the engineers involved felt that the data collected by these new sensors was at least as accurate as the data collected by the original sensors and thus effective (9).

MnROAD test track expertise was utilized in other major pavement test track facilities, such as WesTrack, the National Center for Asphalt Technology (NCAT), and the SHRP test road in Ohio. Officials from these and many other facilities have toured MnROAD and consulted with MnROAD engineers about the MnROAD facility itself. The willingness of MnROAD to offer information openly to all interested parties, be the subject test track expertise, data, or research, is the most significant benefit of its first ten years of operation.

MnROAD Database
The database at MnROAD is one of the main products of MnROAD’s first decade of operation. While the MnROAD database does not have the sheer volume of test sections and data of the LTPP database, in other aspects it offers an interested researcher many benefits not available through LTPP. The construction of all MnROAD cells is closely monitored, and data to characterize the pavement system across a number of variables is readily available. Many MnROAD-related reports by Mn/DOT engineers have taken great pains to detail the construction of individual cells and detail the various properties of each layer of the pavement system (10-16). Furthermore, an amazing spectrum of dynamic response data characterizing very narrow intervals in time is available for each section, and the same spectrum is available for data from regular monitoring of the sections. Table 1 presents a brief summary of the many types of data regularly collected at MnROAD.

**TABLE 1 Types of data collected at MnROAD (17)**

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Data Type</th>
<th>Examples of Data Collected at MnROAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell Info</td>
<td>Cell Data</td>
<td>Design, Construction, Maintenance, Cell Layer/Lift Thickness, Cell Events, Elevations, GIS Data</td>
</tr>
<tr>
<td>Field Monitoring</td>
<td>Rutting</td>
<td>Straight Edge, Automated Laser Profile System (ALPS), Paper Traces, Pathways, PaveTech, Dipstick</td>
</tr>
<tr>
<td></td>
<td>Ride</td>
<td>Pathways, PaveTech, Frost Pins, Faulting, Forensics, Friction</td>
</tr>
<tr>
<td></td>
<td>Cracking</td>
<td>Distress Surveys, Crack Mapping, Cupping</td>
</tr>
<tr>
<td></td>
<td>Strength</td>
<td>Dynamic Cone Penetrometer (DCP), Falling Weight Deflectometer (FWD)</td>
</tr>
<tr>
<td>Sensor Data</td>
<td>Pavement</td>
<td>Biaxial Strain Gage (BS), Concrete Embedment Strain Gage (CD, CE), Linear Variable Differential Transducer (DT), Horizontal Clip Gage (HC), Longitudinal Embedment Strain Gage (LE), Transverse Embedment Strain Gage (TE), Piezo-Accelerometer (PA), Dynamic Soil Pressure Cell (PG, PK), Steel Strain Gage (SS), Tiltmeter (TM), Vibrating Wire Strain Gage (VW)</td>
</tr>
<tr>
<td>Subsurface</td>
<td>Subsurface</td>
<td>Subsurface Thermocouple (TC), Moisture Block (WM), Dynamic Pore Water Pressure Cell (DW), Thermistor (XD, XL, XT, XS), Open Stand Pipe (OS), Static Lateral Pressure Cell (PL), Static Soil Pressure Cell (PT), Resistivity Probe (RP), Static Pore Water Pressure Cell (SW), Tipping Bucket (TB), Time Domain Reflectometer (TD)</td>
</tr>
<tr>
<td>Traffic</td>
<td></td>
<td>Mainline and LVR installations of Hydraulic Load cells, Kistler sensors</td>
</tr>
<tr>
<td>Lab Testing</td>
<td>Bituminous</td>
<td>Bituminous Dynamic Shear Rheometer, Bending Beam Rheometer, Direct Tension, Repeated Creep, Zero Shear Viscosity, Dynamic Modulus, Indirect Tension Test, Fracture Toughness, Mix Designs, Gradations</td>
</tr>
<tr>
<td></td>
<td>Concrete</td>
<td>Concrete Air Voids, Compression, Coefficient of Thermal Expansion, Poisson’s Ratio, Mix Designs</td>
</tr>
<tr>
<td></td>
<td>Unbound</td>
<td>Resilient Modulus, Proctor Curves, Field Density, Gradations, Unsaturated Material Properties</td>
</tr>
</tbody>
</table>
The database also includes non-traditional data such as the forensic trenching data done to diagnose pavement distresses in asphalt test sections (18-20).

Due to its in-depth response, design, and as-built data for over 40 test sections, MnROAD’s database has already been incorporated into NCHRP Project 1-37A, and institutions throughout the world have used MnROAD’s array of constitutive data in pavement design and research. For example, material property data was used extensively for research reports by the Finnish National Road Administration (FINRA) in laboratory tests on asphalt mixes and by the US Army Corps of Engineers Cold Regions Research and Engineering Lab (CRREL) in testing of frozen soils and modeling of frost depths in subgrades (21-25).

MnROAD Participation in TERRA

In 2004, a task force commissioned to expand the governance of and increasing research opportunities at MnROAD led to the creation of the Transportation Engineering and Road Research Alliance (TERRA). TERRA is a pooled-fund consortium whose membership includes representatives from transportation agencies, private-sector industry, and academic research. While TERRA was initially founded to support MnROAD, it has since become a more significant vehicle for national collaborations in pavement research that use MnROAD as a site for this research. In addition, TERRA also presents MnROAD with an efficient manner of passing along valuable pavement data and test track expertise to some of TERRA’s members. As noted by Stehr and Corrigan in TRB’s TR News, the TERRA model for partnerships in road research has lead to a number of recent partnerships that extend beyond Minnesota. These partnerships include collaborations between Mn/DOT and/or UMN researchers with the Center for Transportation Research and Education (CTRE) at Iowa State University, the Michigan DOT, and the Norwegian Public Roads Administration (26).

Evaluation of and Contributions to Pavement Design Methods

By closely studying MnROAD’s original research objectives, it is clear that MnROAD was originally designed as a so-called thickness, or structural, experiment. That is to say that Mn/DOT engineers set out to use the full-scale facility at their disposal to determine how thick a given pavement needed to be to perform adequately in a cold-region environment. However, MnROAD engineers quickly observed, with a little help from low-temperature cracking in their test sections, that the true question of a cold-regions pavement facility is eventually one of environment. The variety of MnROAD research in pavement design methods over its first ten years reflects this change in focus.

MnROAD and Pavement Design Calibration and Verification

Much of the early work at MnROAD consisted of characterizing the pavement systems in each of the test sections. An early partnership between MnROAD and CRREL involved the use of MnROAD data characterizing its test sections to predict the performance of these test sections according to the CRREL mechanistic-empirical model for cold regions pavements (27, 28). Other early work by Berg used MnROAD data to calibrate a frost depth prediction model (29). Another significant project at MnROAD, by Burnham and Pirkl, involved the application of data characterizing concrete test sections to the Mn/DOT rigid pavement design guidelines, the 1993 AASHTO Guide for Design of Pavement Structures (AASHTO-93), and the 1984
Portland Cement Association Thickness Design for Concrete Highway and Street Pavements (PCA-84). Burnham and Pirkl found that the predicted serviceable life of each test section was highly variable as the researcher moved between design methods and levels of reliability (30). The gross inaccuracies of these models and the discrepancies between their predictions as exposed by Burnham and Pirkl’s study was the first major use of full-scale test track data to evaluate existing pavement design methods, and this particular study illustrated that the design methods of the early 1990s were inadequate.

A number of researchers at universities have taken advantage of MnROAD data to conduct wide-ranging activities in:

- calibrations of finite element structural models;
- validations of mechanistic-empirical design parameters and methods;
- the development of models to predict low-temperature cracking performance of asphalt pavements;
- evaluations of drainage models for pavement systems; and
- investigations of tire-induced stresses and surface-initiated cracks.

These reports include and are not limited to the work of Alvarez and Thompson, Ariza and Birgisson, Bao, Forst, Holewinski et al., Marasteanu et al., Mateos and Snyder, Wu et al., and Zhang et al. (31-40).

Cold Regions Pavement Design Software (MnPave)

MnROAD’s first contribution to a mechanistic-empirical design specific to Mn/DOT was with the thickness design program ROADENT developed by UMN. Using the WESLEA model for layered elastic analysis as its basis, university researchers used MnROAD to verify and calibrate ROADENT for use as a design tool for flexible pavements (41-43). In response to their own work in seasonal variations in pavements, Mn/DOT and UMN researchers later developed MnPave, a mechanistic-empirical design software program with its basis in ROADENT but with many layers of additional sophistication. MnPave was developed using MnROAD performance data and, to a lesser extent, data from Minnesota highway sections (44, 45).

MnROAD and MEPDG

The NCHRP Project 1-37A design procedure, commonly known as the 2002 Mechanistic-Empirical Pavement Design Guide (MEPDG), has incorporated a large amount of MnROAD data and expertise in its on-going calibration. To calibrate MEPDG’s ability to predict rutting in the lifts of an asphalt pavement, the MEPDG team used forensic trenching data from trench studies done on MnROAD test sections and described in reports by Isackson et al. and Mulvaney and Worel (18-20). Furthermore, the thermal cracking model used by MEPDG was calibrated using MnROAD thermal cracking. PCC performance and temperature data were used to re-calibrate the rigid models of MEPDG and verify the Enhanced Integrated Climatic Model (EICM) predictions respectively (46).

Thin and Ultra-Thin Whitetopping

The process of overlaying asphalt pavements with thin concrete layers, known as whitetopping, is one that has been studied by Mn/DOT since 1993 and at MnROAD since 1997. Since that
time, Mn/DOT engineers at the Office of Materials and Road Research have produced a variety of reports and presented many papers on the design and construction of whitetopping. These reports detail MnROAD’s experience with a variety of full-scale thin and ultra-thin whitetopping designs in both high- and low-volume trafficked MnROAD test sections over a three and a half year period (47, 48). Mn/DOT researchers have also been involved in a number of whitetopping experiments on highways and low-volume roads around Minnesota that borrow their design, construction, and repair techniques from MnROAD test section experience (49-51). MnROAD has also been in the enviable position of being able to use its wide array of load response sensors to monitor the performance of these thin concrete slabs in real-time (52). In the course of just under four years, MnROAD engineers went from having little to no whitetopping experience to being a driving force behind the design and construction of whitetopping for asphalt pavements in the United States.

**Continuous Compaction Control (Intelligent Compaction)**

In the last years of its first ten years of operation, MnROAD engineers were closely involved with an exciting new tool in pavement construction quality control, continuous compaction control (more commonly known as “intelligent compaction” or IC). Through demonstrations at MnROAD and the involvement of MnROAD engineers in a statewide IC Task Force, many factors related to the use of IC in unbound material compaction have been uncovered through MnROAD. During the on-site demonstrations, MnROAD engineers confirmed the steps involved in the IC process and the tools used to complete each step. Engineers also confirmed the data transfer from compactor to server. Overall, MnROAD engineers found that intelligent compactors do an excellent job of ensuring uniformity in compaction and acquiring the soil modulus for the next generation of mechanistic-empirical pavement design (53). Thanks to MnROAD experience and initiatives, Minnesota has a docket of projects and demonstrations scheduled that involve IC, and this experience will likely play a large role in the development of IC in the United States (54).

**MNROAD AND THE STATE OF MINNESOTA**

The benefits of the Minnesota Road Research facility in the state of Minnesota began from the moment the facility site was chosen. There have been a number of legislative changes that have come about thanks to MnROAD’s work in the seasonal variation of pavements. In addition, Mn/DOT continues to benefit from MnROAD engineers’ experience with new equipment, construction methods, and pavement assessment techniques, many of which have become standards or specifications for Mn/DOT. The following sections detail some of the benefits of MnROAD to the state of Minnesota.

**Seasonal Variations in Pavements**

One of MnROAD’s most publicized benefits to the state of Minnesota has been in the field of seasonal variations in pavements. Using data from MnROAD, Ovik et al. 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. This so-called fifth season falls during the early
spring-thaw period, when an excess of moisture is present and the granular base has a minimal resilient modulus \(55\).

This innovation in the approach to pavement and environment lead to legislation concerning spring load restrictions for Minnesota’s roadways \(56, 57\). The Mn/DOT Office of Materials and Road Research continued to apply Ovik’s understanding of seasonal variation in flexible pavement systems to new winter load limits for Minnesota’s roadways \(58\). Strangely enough, the work also has indirectly lead to a closer examination of the need for spring-load restrictions altogether. A recent study found that the reduced maintenance costs due spring-load restrictions might not outweigh the increased revenue from roadways operating year-round at the maximum single-axle load \(59\). Despite the various legislative activity that was instigated by Ovik et al., the main benefit of this research is its new understanding of cold-regions pavements and the use of this understanding in developing and calibrating mechanistic-empirical pavement design methods such as Mn/DOT’s MnPave.

New Techniques for State Pavement Engineers

In addition to serving as a site for research, MnROAD has also served the state of Minnesota as a testing ground for new pavement technologies. In some cases, this has involved the use of MnROAD engineers in certifying practitioners in the use of equipment or the use of MnROAD as a demonstration site \(53, 60, 61\). Two notable techniques in pavement assessments, the dynamic cone penetrometer (DCP) and ground penetrating radar (GPR) have been first explored at MnROAD before seeing greater use by Mn/DOT across the state of Minnesota.

**Dynamic Cone Penetrometer**

MnROAD personnel have applied the dynamic cone penetrometer (DCP) to test sections since the initial stages of MnROAD beginning in June 1991. During the construction phase, MnROAD engineers conducted over 700 DCP tests at the MnROAD facility \(62\). Since that time, MnROAD has used the DCP regularly to evaluate newly constructed and rehabilitated pavements. MnROAD engineers have suggested and made a series of physical modifications to the device itself, modifications that have now become standard on the DCP as used by Mn/DOT. Furthermore, to avoid inaccurate results due to operator fatigue, Mn/DOT proposed the development of an automated DCP (ADCP) \(62-64\).

MnROAD’s entire efforts with DCP have influenced Mn/DOT and its assessment of subgrades and pavement systems in the field. Furthermore, MnROAD’s work with DCP prompted Mn/DOT to incorporate DCP testing in two specifications for pavement assessments: 1) quality control for the backfill compaction of pavement edge drain trenches (Mn/DOT Spec SP5-128) and 2) quality control of granular base layer compaction (Mn/DOT Spec 2211.3.C4). Mn/DOT has had the confidence to use DCP testing for a variety of non-specified work that includes an assessment of base and subgrade conditions under full-depth bituminous cracks and the foundation strength of footing pads for a building \(65, 66\).

**Ground Penetrating Radar**

MnROAD has also benefited Minnesota pavements through the adoption of ground penetrating radar (GPR) by Mn/DOT. In the earliest work using GPR at MnROAD in 1994, GPR was used
to evaluate the thicknesses of the test sections and compare these values against known design thicknesses (67). This early test acted as a pilot quality control for MnROAD (to confirm that sections were constructed to design) and simultaneously as a way for the researcher to compare the GPR’s assessment against actual thicknesses (determined through coring). In the last five years, Mn/DOT has purchased and maintains state-of-the-art GPR equipment. MnROAD is used to calibrate these antennas on a frequent (semi-annual) basis. Metal calibration plates have been placed at precise locations and depths within several test sections. Since the first use of GPR at MnROAD, Mn/DOT has expanded both its GPR equipment and user expertise. More importantly, Mn/DOT has expanded the use of GPR as a useful non-destructive method of testing and now applies GPR to profile subsurface conditions, to locate underground utilities, and to assess the condition of bridges (68).

SafeTruck

Some of the more noticeable non-pavement issues investigated at MnROAD have been assistive or autonomous vehicle guidance systems and the technologies associated with those systems. These issues arose out of Mn/DOT and MnROAD’s combined need for driver-assist technologies to ensure the safety of the operator of the truck that provides the load repetitions on the low-volume road at MnROAD (69). UMN researchers modified a Navistar 9400 truck tractor (called SafeTruck) that incorporated global positioning system (GPS) response data and a heads-up display (HUD) prototype that provides a driver with lane boundaries in conditions of poor visibility. SafeTruck was first successfully demonstrated for the public in April 1997 at the MnROAD facility (70). Later work used MnROAD to test the driver assistive system (DAS), a combination of SafeTruck with HUD, differential GPS, and the Virtual Bumper, a series of radar and laser sensors that detect and respond to potential collisions (71).

MNROAD AND MUNICIPAL AND COUNTY ENGINEERS

In its first decade of operation, MnROAD used its 2.5-mile low-volume road (LVR) for extensive experiments and continuous data collection on a variety of test sections. Despite the more highly publicized work on the live-traffic mainline sections, MnROAD has put a great deal of effort in studying the low-volume roads that make up the majority of Minnesota’s roadways. Many of these efforts are sponsored by the Minnesota Local Road Research Board (LRRB). This board consists of municipal and country engineers and exists to promote and fund research in low-volume roadways. The following benefits to pavement engineers on the local level act as a brief summary of the MnROAD-LRRB research partnership.

Low-Volume Road Design

The most noteworthy projects to benefit from the wealth of LVR data were those involving mechanistic-empirical design. LVR data from MnROAD were used by UMN researchers to verify and calibrate ROADENT, a thickness design program based on WESLEA and developed by UMN (38-40, 72). The calculated strains from the program were compared to the actual strains as captured by the many embedded sensors in the test sections. ROADENT was continuously calibrated in this way so that performance predictions by ROADENT would reflect the performance observed at MnROAD’s full-scale LVR test sections.
Furthermore, the report recommends that the Soil Factor and R-Value design procedures for low-volume roads be reconsidered, as ROADENT requires a thicker design than the other two for an equivalent roadway. This conclusion was significant for local agencies, most of whom used either the Soil Factor or R-Value design in planning their roadways, and the foundation of this conclusion was, of course, years worth of MnROAD LVR data. A later Mn/DOT report by Skok et al. builds upon the earlier work in LVR design by updating the design for Minnesota using MnPave (73). This work has benefited low-volume roadways at the city and country level by providing a reliable, consistent design based upon local environmental data and pavement response data to loading in that particular environment.

**Aggregate Road Studies**

Mn/DOT and LRRB commissioned a study on MnROAD’s aggregate road test sections shortly before the removal of those sections, later published in Lukanen (74). This work resulted in a number of interesting conclusions and recommendations, the foremost of which is on the nature of full-scale testing itself: the study describes the true measure of the aggregate sections’ performance as their ability to allow the loading truck to pass unimpeded. When the truck could no longer maintain its 30 mph speed on any single section, all aggregate sections (in addition to the section causing the problem) would be bladed to avoid safety concerns for the operator of the truck. Hence, rutting and washboarding were naturally the most closely studied modes of deterioration. The severity and frequency of these phenomena limited the observations due to the fact that when one section approached “failure” in terms of the safety concerns for the truck operator, all sections and ongoing observations were subsequently reset.

Despite this limitation, the study found a strong relationship between washboarding and the number of truck passes. Due to this relationship, more washboarding occurred in the 80 kip lane than in the 102 kip lane. Forensic cross-sections of the test cells revealed that the observed rutting occurred in the aggregate and not the subgrade. It was also found that the use of the chip seal reduced the likelihood of washboarding, though a comparison between the sections suggested nothing conclusive as regards chip sealing and rutting. Lukanen’s study concludes by noting that aggregate gradations are not reliable predictors of performance in an aggregate road.

Another report by Johnson and Baker concludes MnROAD’s experience with its aggregate test sections discusses the sections in every detail, from construction to load response to distress observations (75). This report makes a few interesting observations on the rate of freezing and thawing under aggregate roads. The freeze/thaw under aggregate roads was much different than the freezing and thawing under HMA sections at MnROAD: the subgrade under aggregate sections froze approximately 4 to 5 days sooner than the subgrade below the HMA. Furthermore, the subgrade under the aggregate sections took between 11 and 35 days longer to thaw than the subgrade under the HMA. This second report was the final report on MnROAD’s aggregate test sections and is an excellent review of one of the few full-scale, fully instrumented aggregate roads in the United States.

**Road Maintenance and Rehabilitation**

Thanks to a number of LRRB initiatives, a great deal of research immediately applicable to county and city roads was conducted at MnROAD. A number of these projects dealt with the
maintenance and rehabilitation practices of local engineers, and a few of these projects are discussed below.

**Edge-Joint Sealing**

In an experiment to determine the efficacy of sealing the longitudinal shoulder edge-joint, Olson and Roberson examined two similar concrete test sections at MnROAD with bituminous shoulders and edge drains (76). One of these sections acted as a control and did not have its longitudinal edge joint (the joint between the shoulder and the pavement) sealed. The second section was, therefore, the test. Before sealing the test section, the two sections were monitored and found to have no significant differences in the volume of water drained. After sealing and close monitoring for two years, the total volume of water entering the pavement system for a rain event was reduced by as much as 85% through the use of an edge seal. The authors recommend sealing of the longitudinal shoulder edge-joint as a component of any rigorous preventative maintenance program.

**Oil-Gravel Roads**

MnROAD has been involved with a number of experimental techniques and materials, and its experience with emulsified oil gravel is certainly unique to test tracks. This experience came about through a long-lasting partnership with FINRA. The oil gravel, which consists of a softer binder than a typical hot mix asphalt (HMA) mix, typically exhibits a long life and low amount of cracking in Finland. Given its experience with low temperature cracking, MnROAD officials implemented oil-gravel on three sections in the low-volume loop (77). One of the sections showed distresses shortly after construction, but a forensic trench study of the section suggested that the distress was due to the strength of the base material and not a fault of the oil-gravel surface (79). This section was replaced, but two of the original three oil-gravel sections remain at MnROAD. These sections have performed very well, and unlike their HMA counterparts, have resisted thermal cracking entirely (78, 79). MnROAD’s experience in oil-gravel roads combined with the remainder of Mn/DOT’s experience with oil gravel throughout the state has helped to educate municipal and city engineers about oil gravel, a new pavement technology for road rehabilitation that would have gone unexplored had it not been for MnROAD’s partnership with FINRA.

**CONCLUSIONS**

From the outset, Mn/DOT intended MnROAD not only as a site for cold regions research, but more importantly as a site for collaboration on the state, local, and federal levels in the study of pavement and pavement technologies. This desire for collaboration was first realized in planning and later the construction of MnROAD, which was funded by Mn/DOT, FHWA, and the Minnesota Local Road Research Board, a consortium of members interested in research of municipal and county roads, and the early spirit of partnership in full-scale pavement testing has continued to this day through MnROAD’s participation in TERRA and various pooled fund studies.

This paper presented a small selection of the accomplishments of MnROAD as they benefit local, state, and national practitioners and researchers of pavements. While many of
these benefits are tangible and can be found in new technologies, specifications, and so on, many of the benefits are as yet unrealized. One of the problems of the MnROAD project is that in spite of its significant pavement data, expertise, and large library of useful reports, MnROAD has either insufficiently publicized its findings on a national level or has been simply overlooked by other researchers outside of Minnesota. It is hoped that this paper will encourage readers interested in accelerated pavement testing or other pavement-related topics to further investigate MnROAD and incorporate the underutilized resource of MnROAD data, test track expertise, and pavement analysis into their own work.

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