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The Minnesota Department of Transportation (Mn/DOT) Office of Minnesota Road Research studies materials used to construct the transportation infrastructure. The Physical Research Section conducts investigations or experiments on methods and materials used in transportation facilities, especially pavements, and revises accepted conclusions and practices in the light of newly discovered facts. The Pavement Engineering, Materials Engineering, and Geotechnical Engineering Sections of the Office of Construction and Materials Engineering provide real-world feedback, raw data, and technical support to the overall effort. Liaison with Mn/DOT districts and local road authorities is essential for research implementation.

The Minnesota Road Research Project (Mn/ROAD) Operations Section is responsible for contract administration, marketing, communication, and overall coordination of the Mn/ROAD project. Mn/ROAD is a pavement testing facility where researchers are able to study and evaluate the performance of the materials used in highway construction; it opened in August 1994.

Other research, performed by the Physical Research Section, includes a variety of materials-related issues including the use of waste products, subsurface drainage, noncorrosive deicers, pavement rehabilitation and maintenance methods, and pavement design techniques.

For further information about research conducted by the Office of Minnesota Road Research, contact George Cochran, Physical Research Engineer, Mn/DOT Materials Research and Engineering, 1400 Gervais Avenue, Maplewood, MN 55109, Phone: 612-779-5525, Fax: 612-779-5516, Internet: glenn.engstrom@dot.state.mn.us
Accomplishments

Waste Materials

Mn/DOT continues to take a proactive role in recycling waste products into useful construction materials. Mn/DOT takes into consideration the performance, cost, and potential environmental effect before making a final recommendation. The product is often the result of creating an appropriate balance between these factors.

**Crumb Rubber Modified Bituminous:** This study will play a key role in Mn/DOT's decision on how to best meet the federal mandate in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. ISTEA requires a certain percentage of the federally funded hot mix asphalt pavement placed by state DOTs to contain crumb rubber derived from scrap tires. The required percentage of federally funded hot mix increases from 5 percent in 1994 to a maximum of 20 percent in 1997.

This study involved laboratory testing and field test section construction of crumb rubber modified (CRM) hot mix. Test sections were constructed on St. Louis County Road 112 through the city of Babbitt and TH 61 in Winona. Both of these locations used crumb rubber from the Whirl-Air-Flow plant in Babbitt, which grinds old tires into crumb rubber. This rubber is then used to produce CRM products such as rubber mud flaps, floor mats, golf range mats, etc. A cooperative research study with the University of Minnesota Department of Civil and Mineral Engineering included a process using this CRM product, modified with an extender oil.

To date, no discernible difference has been found between the CRM sections and the conventional mixes' performance. There is, however, a substantial increase in the cost of constructing CRM sections.

**Scrap Shingle Mixtures:** Shingles contain the same raw materials found in asphalt pavement, asphalt, and aggregate, making hot mix asphalt pavement a logical use. The University of Minnesota completed laboratory testing on both fiberglass and felt shingle scrap. Obtained from manufacturing plants, the scrap consists of the tabs and cut outs that occur during the manufacturing process. No tear-off or reroof material was used. The shingles are ground into small chunks about the size of a quarter and then added to the hot mix plant.

Test sections were built, and the results are very favorable. As a result of this study, Mn/DOT is amending its current allowable salvage material specification to allow shingle scrap as a permitted material.

Pavement Rehabilitation and Maintenance

The majority of streets and highways in Minnesota have been in place for many
years. As these roads reach the end of their service lives, they will require some sort of maintenance or rehabilitation. Reconstruction is generally not an option because of a lack of resources. New techniques must be developed to extend the life of these pavements.

**Seal Coat Study:** This project reviewed the applicability of the current Mn/DOT specifications and design procedure for bituminous seal coating, as well as comparing them to those in the Asphalt Institute's MS-19, "A Basic Emulsion Manual" (first reported in 1960 by Norman McLeod). The Strategic Highway Research Program (SHRP) used this design procedure to determine the application rates on their pavement test sections constructed in 1991.

The Asphalt Institute's design procedure produces seal coats that are only one stone thick rather than multiple stones thick. Over 100 miles of pavement have been seal coated as part of this study in several cities and counties. Additions to the study this year included adding test sections on Mn/DOT trunk highways and testing a new chip spreader calibration procedure (ASTM 5624-94). Meetings with seal coat contractors and aggregate and asphalt suppliers were held to gather input concerning possible changes to the current Mn/DOT specifications. Changes to the Mn/DOT seal coat specifications and design procedures will be completed and distributed by the end of the 1995 construction season.

**Sawing and Sealing Bituminous Pavements:** This procedure involves sawing joints in bituminous pavements and then sealing the joints with rubberized sealant material. Normally, when a concrete pavement is overlaid with bituminous, the overlay is thicker than is required for sufficient strength. This additional thickness minimizes the rate of reflective cracking that occurs when the underlying concrete joints or bituminous cracks expand and contract.

The saw and seal technique does not require this additional thickness because it allows the joints to move. In addition, saw and seal test sections placed in new asphalt pavements have shown strong indications of enhancing pavement performance. Since cracks normally occur at about 40-foot spacing in pavements, sawed-in control cuts have been found to perform well. Over 50 test sections have been constructed since 1986 using the saw and seal technique. The performance of these sections was monitored to determine their effective life. Using this technique reduces the overlay thickness required on many bituminous overlays of concrete pavements. In addition, tests showed that sawing joints in new bituminous pavements delayed cracking for a significant period of time.

A final report is available from the contact person listed at the beginning of this section. An advisory committee is currently determining how best to implement the study's findings.
Pavement Design

Pavement design research is difficult and often frustrating because of the number of variables affecting performance and the time it takes to clearly determine the success or failure of a method. Given the immense amount of money spent each year on pavements, however, pavement design research is a high priority.

Pavement Drainage: Research to date has concentrated on various types of edge drains and permeable bases. Test pavement sections on I-94 near Fergus Falls have been instrumented to measure base moisture conditions, rainfall, and outflow from the drainage system. Findings indicate that nearly 40 percent of all rainfall infiltrates the pavement and that drainable pavement systems are removing far more moisture from the base in a shorter time than conventional pavement designs. Research also has shown that sealing the transverse joints and the longitudinal edge joint reduces moisture penetration for only a limited time.

Drainable pavement base sections were built with recycled bituminous and concrete either alone or in combination with crushed rock. Experimental test beds were placed adjacent to I-35 in Lakeville and pavement sections were constructed on TH 15 north of Hutchinson. Findings indicate that using the fraction of crushed concrete larger than the #4 sieve provides adequate pavement drainage without plugging of drain pipes. As a result of this research, modifications have been proposed to the Mn/DOT Standard Specifications regulating the use of recycled concrete in pavement bases.

Geostatistical Analysis of Falling Weight Deflectometer Data: The University of Minnesota and a Mn/DOT technical advisory panel composed of district, laboratory, and research personnel is applying geostatistics to Mn/DOT's vast file of falling weight deflectometer data. The study is extracting useful roadway information from the data to produce an atlas of roadway soil modulus by trunk highway throughout Minnesota. Copies are available from the contact listed at the beginning of this section.

Full-Depth Asphalt Pavement Task Force: Task force members from pavement engineering, physical research, Mn/ROAD operations, district materials, the Federal Highway Administration (FHWA), the University of Minnesota, and industry approved sweeping changes in Mn/DOT pavement designs. These changes improve pavement performance and ease construction and reconstruction during
our short construction season. The changes establish a moratorium on the construction of full-depth asphalt pavements and incorporate frost-free (clean granular) material into the pavement structures. Following the design practices of the Federal Aviation Administration (FAA), U.S. Army Corps of Engineers, AASHTO Guide, and European experience, the new designs produce a higher quality subgrade to act as a superior paving platform.

**Pavement Selection Task Force:** With participation from pavement engineering, physical research, districts, and FHWA, the task force made significant changes in the pavement selection process. The changes affected a number of factors such as minimum length and premium enhanced designs. The changes give the districts flexibility, as well as promote more durable, higher quality, cost-effective pavements as determined by traffic levels and soils types.

**Mn/ROAD**

In June 1994 the low volume road (LVR) portion of Mn/ROAD opened to controlled loadings by a calibrated semi tractor-trailer. The inside lane of the two-lane roadway is loaded with a legal limit gross vehicle weight (GVW) of 80,000 lbs four days per week, and the outside lane is loaded by an overweight GVW of 102,000 lbs one day per week. The truck is currently averaging 60 laps per day.

![Diagram of truck loadings](image)

In July 1994, the mainline portion of Mn/ROAD opened to live traffic diverted from westbound I-94. Mn/ROAD calculates the traffic loadings for this part of the experiment using weigh-in-motion (WIM) data collected from the scale at the east end of the project. The outside lane of traffic is currently experiencing between 10,000 and 11,000 equivalent standard axle loads (ESALS) per week, while the inside lane is receiving approximately 2,000 ESALS per week. Actual interstate traffic is being used so that researchers can directly measure and evaluate the effects of the full spectrum of commercial trucks on Minnesota roadways under varying environmental conditions.

Mn/ROAD is currently in a "shakedown" phase for all systems and operations. Data from the load response sensors in the pavement and subgrade of both the
ILVR and mainline are being evaluated and analyzed. These data, along with physical test data provided by such devices as the falling weight deflectometer, weight-in-motion scale, ground penetrating radar, and Pave Tech, will allow researchers to verify and calibrate the pavement engineering design models currently in use. A series of research projects currently under way focuses on engineering factors affecting pavement response to traffic loadings and environmental effects. The long-term output from these projects will provide the knowledge base to develop a mechanistically based design model that will provide more accurate and cost-effective pavement designs. The wide range of variables included in this new design model will allow easier adjustment for use with locally available materials and conditions.

Approximately 80 percent of the pavement sensor instrumentation was still functioning properly as of spring 1995. Mn/ROAD personnel are performing qualitative performance testing of the sensor network on an ongoing basis. Data acquisition accuracy testing was performed in fall 1994. These data are being analyzed, and the results will be incorporated into a system accuracy statement, which will be available to data users. System troubleshooting, expansion of data acquisition capabilities, and intense data collection, validation, reduction, and storage have consumed much of Mn/ROAD's personnel resources. Recently, however, more emphasis is being placed on data analysis. From a mechanistic design standpoint, there has generally been good correlation between measured and calculated dynamic pavement load responses, which is a milestone in implementing mechanistically based pavement engineering practices.

In January 1995, Commissioner James Denn appointed a Board of Directors from government, academia, and industry to oversee the Mn/ROAD project. The board will operate as a high level goal-setting and decision-making entity, focusing on overall goals and strategic directions, governance, funding, entrepreneurship, major problem solving, management accountability, and research implementation.

At the Mn/ROAD facility, researchers from Mn/DOT, the University of Minnesota, FHWA, FAA, and the U.S. Army Corps of Engineers Cold Regions Research and Environmental Laboratory (CRREL) are investigating the materials and methods used to build interstate, state, county, and municipal roads.

Specific research and data collection projects are discussed on the following pages.

Directions

Pavement Rehabilitation and Maintenance

Statewide Falling Weight Deflectometer (FWD) Database: In fall 1993
Mn/DOT created an FWD Committee composed of physical research, pavement engineering and district materials and soils personnel. Subcommittees made progress in the following three areas of focus:

- Developing a process to administer the district FWD testing process: This was completed and implemented in spring 1995.
- Determining how to easily access the data for analysis and decision making: A consultant is currently creating a user-friendly database application to bring together pavement, traffic, and FWD data to allow analysis with completion scheduled for the end of 1995.
- Selecting the most appropriate software and associated procedures to analyze these data for pavement design and rehabilitation: This evaluation is being done parallel with the database development, and also will be available to the districts by the end of 1995.

The development of this user-friendly design tool for the districts is a significant step in the eventual adoption of a mechanistic empirical design process for Mn/DOT pavements.

**D-Cracking of Concrete Pavement:** Future cooperative research with the University of Minnesota will concentrate on identifying aggregates that cause D-cracking. A fast and accurate screening test is needed to eliminate the poorer performing aggregates. The Physical Research Section, under an LCMR contract with the University of Minnesota, will attempt to develop and refine these test methods, and develop methods to improve the performance of the marginal aggregates. The Washington hydraulic fracture test has the potential to quickly screen poor performing aggregates. A variety of methods will be examined, including reducing the maximum size of coarse aggregate, heavy-media separation, blending, concrete mix proportioning, coatings or impregnations, and heat-treating aggregates. The ultimate goal of the research is to reduce the long-term costs of concrete pavements by increasing their service life.

**Performance of Bituminous Roadways:** This four-part study compares inplace air voids to the performance of bituminous roads. Phase 1 is an ongoing study to determine the effect of traffic on roadway compaction. Cores were taken in wheel paths and between wheel paths after construction, and yearly thereafter. Most of the roads are in the fourth of five years of testing. Phase 2 compares inplace air voids of existing roads to their condition. Roads that have lasted longer than expected and roads that have not lasted as long as expected are included in the comparison. Phase 3 is a variation of Phase 2 comparing inplace air voids from low volume county roads. Phase 4 includes inplace air void testing of special mixes such as SHRP and stone matrix asphalt (SMA) mixes.
Moisture damage to hot mix asphalt pavements is a serious problem in Minnesota. Several concurrent studies are under way as a result of partnerships by physical research, bituminous engineering, Mn/DOT districts, the University of Minnesota, Bemidji State University, and the Local Road Research Board (LRRB). These studies include:

- Moisture Damage: Mn/DOT.
- Moisture Sensitivity in Asphalt Concrete Mixtures: University of Minnesota.
- Physico-Chemical Evaluation of Asphalt-Aggregate Interaction: University of Minnesota.
- Microbial Deterioration of Asphalt Materials and Its Prevention: Bemidji State University.
- Moisture Sensitivity of Asphalt Mixtures by Geological Region: LRRB and Mn/DOT.

Mn/DOT efforts in this study include obtaining mix samples from various jobs around the state, and testing using the modified Lottman test. Rice testing with three different cure times also is being performed on a trial mix with aggregate and bitumen from these jobs. The cure times are 3/4 hour, 2 hours, and 3 hours. The results of these tests will be compared to the performance of the roads. VMA (voids mineral aggregate) also is being tested. Testing procedures and specifications will be developed as necessary.

An additional study of moisture damage by geographical or geological areas of the state started in spring 1995. Additional material from various projects throughout the state will be submitted to district labs with the trial mix verification sample. Bituminous samples also will be collected from behind the paver by contractor personnel. The district labs will run modified Lottman and VMA tests on the additional materials and the inplace samples. VMA tests also will be run using the "quickie" Rice method. The University studies will supplement the data obtained in the performance vs. inplace air voids study on this very important aspect of asphalt mix design.

**Noncorrosive Delining Chemical Study:** Mn/DOT uses a great deal of salt and calcium chloride to keep roads clear in the winter. The chloride ions in these chemicals promote corrosion of the reinforcing bars in bridge decks. A laboratory study looked at the effectiveness of several noncorrosive deltins plus a series of migrating corrosion inhibitors.

Ninety concrete test slabs were formed to simulate a bridge deck. The top half of each slab had salt added to the concrete mix to support corrosion of the upper rebars. A poor quality concrete was used to accelerate the penetration of the test solutions. The slabs were ponded with test and control solutions for over 450
days. They were tested monthly for corrosion, and at the conclusion of ponding
the concrete was sampled for chloride, phosphate, and sulfate content.

Ultrasonic testing was done to find cracks and voids created in the slabs by the
force of corrosion byproducts, and the slabs were then broken to remove the
rebars for visual analysis. The effects and effectiveness of various salt substitutes
are still being analyzed.

**Smooth Pavement Task Force:** To attack maintenance problems associated
with pavements, particularly the pothole problem, the Office of Minnesota Road
Research is working with the Mn/DOT Office of Maintenance. The findings of the
SHRP maintenance studies are being evaluated and implemented. In addition, vari-
ous methods of pothole repair and preventive maintenance activities are being
evaluated.

**Pavement Design**

**ISTEA Polymer Study:** Several demonstration projects were funded as part of
the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. One of these
projects, a study of polymer modified asphalts is being conducted jointly by
Mn/DOT and the University of Minnesota. Asphalt mixes containing polymers are
generally more durable than conventional mixes. The University of Minnesota con-
ducted and summarized the results of an exhaustive literature search on polymers.
The summary defines the terms used in discussing asphalt rheology and explains
the interactions between various asphalts and polymers and their relationship to
chemical and civil engineering. Extensive laboratory testing to determine which
polymers show the most promise when used with certain base asphalts will con-
tinue through 1995. Based on the results of the lab testing, field test sections will
be constructed in 1996 and 1997 to study the performance of these mixes.

**Thin Bonded Overlay and Surface Lamination of Pavement:** (ISTEA discre-
tionary funds) The FHWA recently approved ISTEA funding for a thin bonded
overlay research project. The overlay project is located on Lor Ray Drive over U.S.
TH 169 in Mankato, Minnesota. The inplace structure is 14 inches of bituminous
pavement that is exhibiting rutting and shoving distress due to heavy truck traffic
and turning movements. The present proposal is to mill 3-6 inches of the bitumi-
 nous and inlay a thin concrete overlay bonded to the remaining bituminous pave-
m ent. Polyolefin fibers developed by the 3M Corporation will be added to the con-
crete mix to increase concrete life and reduce the severity of cracking within the
concrete surface. Construction is proposed for fall 1995 or spring 1996.

**Surface Texture and Pavement Tire Noise:** Three completed reports pub-
lished by and available from Mn/DOT's Noise Analysis Unit, relate the magnitude
and frequency of noise generated by a variety of concrete and bituminous pavement surface textures. The studies indicate that bituminous pavement surfaces are generally quieter than concrete surface textures, and that a 1.5-inch tine spacing should provide the quietest roadway surface texture for tined concrete pavements. In addition to studies concerning tire pavement noise, current research investigates how these various pavement surfaces and textures affect the wet weather accident rates of the pavement. All of this research data will provide a more comprehensive view of the effects of pavement surface texture on tire noise characteristics and safety.

**Retrofit Dowel Bars:** Mn/DOT retrofitted dowel bars into a one-mile section of U.S. TH 52 near Zumbrota between reference points 81.2 and 82.2 in fall 1994. This project evaluates the effectiveness of introducing load transfer devices across mid-panel cracks to control movement and prevent faulting across these cracks. The study will examine the installation procedure, patching material, dowel bar lengths, and various dowel bar numbers and placement patterns along the crack. Each section will be evaluated for performance by examining joint efficiency with the FWD, faulting with the SHRP faultmeter, and pavement surface distress data using field surveys and the PaveTech photologging equipment.

**Mn/ROAD**

**Mn/ROAD Research Program:** The successful construction of the Mn/ROAD research facility has been a high priority during the past several years. Now that the construction has been completed and the facility is open and under traffic, the focus has returned to the multi-year research program. A key objective of the program is to verify and calibrate the pavement engineering models that were used to design the test sections in the experiment. A series of research projects currently under way focuses on the engineering factors affecting pavement response to traffic loadings and environmental effects, and how they contribute to long-term pavement performance. In combination, the results from these projects will provide a basis of knowledge for developing new, more mechanistically based pavement design models. The new design models will be better able to accommodate the engineering, materials, and economic factors involved in designing pavements in Minnesota and elsewhere.

As the 40 test sections at Mn/ROAD fail, they will need to be repaired. The Mn/ROAD Maintenance and Rehabilitation Research Committee will develop a plan for future phases of research at the site and other satellite studies. The committee's mission is to "examine new, innovative, and cutting edge reconstruction, rehabilitation, and maintenance techniques and materials."
Subcommittees of Mn/DOT, county, and industry representatives are currently working on these issues for the Mn/ROAD concrete, aggregate, and bituminous test sections. The Aggregate Subcommittee has been especially busy designing fixes for the early failures in their sections. In addition, the Research Technical Advisory Committee, a panel of internationally recognized experts from academia, industry, and government, is being formed to investigate future rehabilitation strategies for all sections.

The Mn/ROAD project has attracted attention and support from other state transportation agencies, the FHWA, CRREL, and the FAA, as well as several international transportation agencies such as the Finnish National Road Administration (FinnRA) and Norwegian Public Roads Administration. Initial marketing efforts began in winter 1995 and have generated a significant amount of worldwide interest in the project. This broad interest will generate a wide range of cooperative research using Mn/ROAD data, and contribute additional expertise and resources to the project agenda.

**Mn/ROAD Critical Spring Data Collection to Feed Future Research:**

Mn/ROAD activities intensified during March and April 1995 because of the annual spring thaw of the pavement sections. During this time, pavement structures in northern climates are most vulnerable to damage because supporting materials become saturated and thus are greatly weakened.

During the spring thaw, the mainline sections were closed to traffic one day per week for daylight hours while two teams of researchers from Mn/DOT's Physical Research Section collected daily environmental and load response data from the sensors embedded in the pavement surface, base, and subgrade. During the remaining four days per week, similar data were collected from sensors embedded in the low volume road.

Additionally, three falling weight deflectometers, one each supplied by Mn/DOT, CRREL, and SHRP, collected deflection data from both the mainline and LVR sections. CRREL also sent expert research staff to support the data collection process and provide preliminary data analysis.

The data collected this spring will support a number of Mn/ROAD research projects to evaluate the effects of the environment on short-term pavement response and long-term pavement performance. The results of such research projects will give pavement engineers the tools to more effectively design for the worst-case conditions encountered during the spring thaw.

**Research Expenditures**

The Office of Minnesota Road Research uses its funding to support technology
transfer, research studies, technical support, technical reports, MnROAD site operations, and administrative costs. Funding is allocated by the categories shown below; these percentages are approximate expenditure distributions for state FY 95.

- 39% MnROAD Operations
- 6% Professional Services
- 9% Administration
- 9% Consultant Agreements
- 15% Materials Research
- 22% MnROAD Research