The Minnesota Department of Transportation (MnDOT) Office of Materials Research and Engineering 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 Sections provide real-world feedback, raw data, and technical support for the overall effort. Liaison with MnDOT districts and local road authorities is essential for research implementation.

One section of Materials Research and Engineering, the Minnesota Road Research Project (MnROAD) Administrative Section, is responsible for contract administration, marketing, communication, and overall coordination of the MnROAD project. MnROAD is a pavement testing facility where researchers will be able to study and evaluate the performance of the materials used in highway construction when it is completed in summer 1994.

Other research performed by Physical Research 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.

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Mn/DOT’s Office of Materials Research and Engineering focuses its research resources to solve real-world transportation problems. Established practices and materials are challenged and reexamined through laboratory and field testing coordinated by the Physical Research section. The ultimate goal is to invent, develop, and implement improved or new methods or processes that are more economically efficient and environmentally friendly.

Accomplishments

Waste Products

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

Crumb Rubber Modified Bituminous: Results from this study will play a key role in Mn/DOT’s decision on how to best meet the federal mandate contained in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. This bill requires that a percentage of the federally funded hot mix asphalt pavement placed by state departments of transportation contain crumb rubber derived from scrap tires. The required percentage of federally funded hot mix will increase from 5% in 1994 to a maximum of 20% 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 Babbitt and on Trunk Highway 61 in Winona using crumb rubber from the Whirl-Air-Flow plant in Babbitt. The plant grinds tires into small particles of rubber that are then used to produce CRM and other products such as rubber mud flaps, floor mats, and golf range mats.

Results to date have shown no discernible performance difference between the CRM sections and the conventional mix. There is however, a 50% increase in the cost of constructing CRM sections.

Shredded Tires as Lightweight Fill: Waste tires have long been a disposal problem in the U.S. and are continuing to accumulate. Minnesota has become a leader in the use of shredded tires as lightweight fill for road construction with the first project on a logging road in 1985 and at least 24 other sites around the state to date. It has proved to be economical especially in areas with poor soils.

The Physical Research Section released a report in May 1994 that examines the advantages, disadvantages, engineering properties, and environmental aspects of
Shredded Tires as Lightweight Fill
Pine City Case Study

shredded tires as lightweight fill. Case studies of seven of the larger sites are reviewed for construction and performance. One site, a ramp from I-35 near Pine City, used approximately 900,000 tires and saved approximately $15,000 over conventional methods that failed during initial construction.

Using shredded tires below the water table has both engineering and economic advantages, but the long-term environmental impacts of using shredded tires are unknown. Current Minnesota Pollution Control Agency (MPCA) policy is based on a 1989 laboratory study and forbids shredded tires within one foot of the water table. A study involving laboratory analyses, bioassay techniques, and field studies is being conducted jointly with other agencies to examine this issue; the project is described further in the Environmental Services section of this Report.

**Scrap Shingle Mixtures:** Shingles contain the same raw materials found in asphalt pavement, asphalt, and aggregate, making waste shingle scrap a logical component of hot mix pavement. Laboratory testing was done by the University of Minnesota on both fiberglass and felt shingle scrap obtained from manufacturing plants. No tear-off or re-roof material was used. The shingles were ground into small chunks about the size of a quarter and then added to the hot mix at the plant.

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

**Waste Glass in Highway Construction:** Glass that is dirty or mixed in color is not accepted for recycling. This study sought highway uses for this glass.

One of the applications was in base aggregate in Sibley County where 330 tons of glass that would have been dumped into a landfill with tipping fees of $20,000 was crushed with a low grade aggregate to make Class 5 gravel base. This “Glass 5” aggregate was used in a 1,000-foot test section on the 3.7-mile construction pro-
ject. Three lifts of 3 inches each were covered with a final lift of 4 inches of virgin Class 5 aggregate and 3 inches of bituminous.

**Pavement rehabilitation/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 life, 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.

**Unbonded Concrete Overlays:** Mn/DOT has refined a relatively new paving technique, unbonded concrete overlays, as a more cost-effective pavement rehabilitation strategy. The Physical Research Section completed an interim report in January 1993 that evaluates the long-term performance of the 10 unbonded concrete overlay projects constructed since 1977. The experience gained in both the design and construction of these projects is also summarized in the report.

The study found that unbonded concrete overlays are performing at least as well as conventional on-grade pavements. In addition, unbonded concrete overlays cost about $150,000 less per two-lane mile than reconstructed concrete pavements placed under similar conditions. As a result of this study Mn/DOT no longer considers unbonded concrete overlays experimental, and it is now included as one of the standards that can be used for pavement reconstruction.

The final report is not expected to change many of the basic recommendations of the interim report. However, the data obtained with the PaveTech pavement survey equipment will allow us to investigate in detail the various unique test sections constructed over the years.
Cold In-Place Recycling: One of the most promising new maintenance techniques for rehabilitating old bituminous pavement is cold in-place recycling (CIR). CIR involves milling either all or a portion of the existing bituminous mat, crushing it to a desirable size, adding asphalt emulsion, and then relaying it. The CIR material is allowed to cure for 7-10 days until the proper moisture is achieved. Hot mix is then laid over the CIR material, allowing the existing material to remain on-site and eliminating hauling costs. Because the CIR process removes the underlying cracks in the bituminous, CIR significantly reduces reflective cracking compared to pavement that simply gets overlaid.

D-Cracking of Concrete Pavements: Premature failure of concrete pavements nationwide has often been linked to a phenomenon known as D-cracking. A study completed in February 1994 found that placing high molecular weight methacrylate monomers over the D-cracked areas extended the life of a D-cracked concrete pavement by at least 18 months. Silanes were also tested but results to date show questionable effectiveness.

The freeze-thaw behavior associated with the aggregate in the concrete has been suspected as the root cause of D-cracking, and the Physical Research Section is studying ways to help identify which aggregates cause D-cracking and methods to mitigate their effects.

Seal Coat Study: This study determined the applicability of using a seal coat design procedure in Minnesota. This procedure was first developed in 1960 by Norman McLeod of Ontario, Canada. The Strategic Highway Research Program (SHRP) used this design procedure to determine the application rates on their pavement test sections constructed in 1991.

Over 100 miles of pavement have been seal coated as part of this study in seven cities and two counties. Test sections were constructed using both the design procedure and the agency's normal application rates. The design procedure reduced the aggregate application rate by 50% in some cases with no loss of performance. To date, all of the sections are performing as well as or better than the control sections. Changes to the Mn/DOT seal coat specification will occur as a result of this study.

Soybean Oil to Control Dust: Soapstock, an oil byproduct of soybean processing, was applied as a dust palliative on Nicollet County Road 64 (a gravel road) near Swan Lake. The soapstock was donated by Honeymead Products Company of Mankato. Two test sections of 500 ft each were established, with application rates of 0.15 and 0.25 gal/yd². The application was done by Nicollet County's asphalt distributor truck without any difficulty. Dust in this area was greatly reduced according to observations by Nicollet County personnel.

Water samples were taken before and after the soybean oil was applied at
appropriate times during rainstorms. The water samples were tested by the Environmental Engineering unit of Mn/DOT; the Minnesota Pollution Control Agency reviewed the results and found no water quality problems.

Pavement Design

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

Pavement Drainage: Premature distress of properly designed and constructed pavement structures in Minnesota is often caused by excess water. The Physical Research Section and the Pavement Design Unit are studying the effectiveness of several drainage methods and how they affect pavement performance.

Research to date has concentrated on various types of edge drains and permeable bases. Several of these test pavement sections have been instrumented to measure base moisture conditions, rainfall, and outflow from the drainage system. Preliminary findings indicate that these systems are removing far more moisture from the base than conventional pavement designs.

One section has also had far fewer transverse cracks in the permeable base section than the control section. With the help of new inspection techniques such as a remote underground video inspection camera, researchers have also been able to examine the condition of the edge drains over time. Continuing research will review the cost-effectiveness of these systems, maintenance requirements, future design modifications, and long-term pavement performance, with the goal of reducing long-term pavement costs and increasing service life.

SHRP Implementation: Mn/DOT is currently implementing various products of the Strategic Highway Research Program (SHRP). The SHRP Implementation Committee within Mn/DOT directs this effort. Each SHRP product has a “champion” within Mn/DOT who leads testing and evaluation efforts for the product and then makes a recommendation to the Implementation Committee to either reject or adopt the product as part of Mn/DOT’s daily operations. People are kept informed through a brief newsletter every two months. The following products are currently being evaluated, tested, or developed for use by Mn/DOT.

Asphalt Program
- Asphalt Binder Equipment: Viscometer, pressure aging vessel, and bending beam rheometer
- Mixture Test Equipment: Gyratory compactor and shear tester
- Supercrave Design System: Asphalt mix design, mix specification, asphalt binder specification, and the Regional Supercrave Implementation Plan (Mn/DOT as lead agency)
Pavement Engineering Program
- Long Term Pavement Performance: 24 general pavement studies, 7 specific pavement studies
- Weigh-in-Motion: 19 sites installed, 2 more planned
- Regional Calibration Site for FWD: Over 30 calibrations performed in last 1.5 years
- Pavement Distress Manual
- Dipstick Profile Software Device
- Georgia Digital Faultmeter

Concrete and Structures Program
- Alkali-Silica Reactivity Handbook
- D-Cracking Screening Test

Highway Operations Program
- Snow Fence: 2 installations
- Remotely Driven Vehicle: 2 vehicles
- Traffic Safety Products: Stop/slow paddie, rumble strip, intrusion alarms, multidirection bencicade
- Snow Plow: Scoop and SHRP cutting edge
- Weather Information Systems
- Anti-Icing Equipment

Mn/ROAD

In spring 1994, Mn/DOT completed construction of two adjacent roadways with forty pavement test sections: one was a new section of I-94 and the other was a closed loop track. Also completed at the pavement test site was the new building that includes research and conference facilities, and a new pole building that houses the truck for the low volume test road. When it is completed and opens to traffic in July 1994, it will be the largest pavement testing facility of its kind in the world. At that time, all vehicles traveling west on I-94 will be diverted onto the new mainline road and will become part of the Mn/ROAD experiment. Actual interstate traffic is being used so researchers can directly measure and evaluate the effects of commercial trucks and a cold climate on Minnesota roads.

Researchers from Mn/DOT, the University of Minnesota, FHWA, Federal Aviation Administration (FAA), and the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL) are investigating the materials and methods used to build interstate, state, county, and municipal roads.

Information gained from Mn/ROAD will be used to update the 30-year-old pavement design model now being used, and help Mn/DOT design better, longer lasting roads.

Specific research and data collection projects are discussed below.

Mn/ROAD Sensor Installation: A major objective of the Mn/ROAD project is to develop pavement engineering tools that better account for the mechanical reactions of pavement structures to traffic and environmental loadings. The key to accomplishing this goal is to monitor the mechanical responses of pavement structures using electronic sensors. In fall 1993 the Physical Research Section finished inspecting
4,572 pavement sensors. The initial survival rate of installed sensors was an amazing 98%, although environmental conditions will reduce this number over time.

Mn/DOT Physical Research and University of Minnesota personnel have developed significant expertise in installing and using electronic sensors for pavement research, and are publishing several definitive reports on this subject. More importantly, results from preliminary sensor monitoring show reasonable engineering readings.

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

Mn/ROAD research activities intensified during March and April 1994 because of the annual spring thaw of pavement sections. During this period pavement structures in northern climates are most vulnerable to damage because supporting materials can become saturated and thus greatly weakened.

This intense cooperative research effort captured data and performed an initial analysis of the environmental conditions and engineering responses of the thawing Mn/ROAD test sections. Mn/DOT's Physical Research Section collected daily environmental data from sensors embedded in the roadway structure including temperature, moisture (frozen and unfrozen), and frost line location. They also took measurements of the water table level and frost heave.

Another team of University of Minnesota and Mn/DOT Physical Research personnel used the sophisticated data collection trailer to monitor sensors near the pavement surface measuring strains, stresses, and deflections. A Mn/DOT Falling Weight Deflectometer (FWD) performed a week-long deflection test routine on all test sections.

CRREL sent their FWD to Mn/ROAD to perform a cycle of deflection tests twice every day during the thaw period as well as specialized loading tests of pavement sensors. They also sent expert research staff to support the data collection process and analyze the data as they were collected.

Because the test section was not yet open to traffic, this spring offered a unique opportunity to collect important baseline information about Mn/ROAD thaw conditions. The data collected in the spring will support a number of Mn/ROAD research projects looking at 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 tools to more effectively design for these worst-case conditions for pavement during spring thaw.

**Mn/ROAD Data Collection System:** Collecting and tabulating data from the large number of electronic sensors installed in Mn/ROAD test sections is a huge task. Many sensors are embedded in asphalt or Portland cement concrete and respond to every heavy (truck) axle that passes over them. These must be monitored rapidly and continuously as relevant data are collected, doing this requires...
Mn/ROAD Data Collection System

26 roadside cabinets with protocol converters
Pavement Structure
Fiber optic cable
4,200 Sensors

2 RISC 6000 Model 320
2 RISC 6000 Model 550

On-Site Shelter
T-1 cable

University of Minnesota

Mn/DOT Materials Research and Engineering Laboratory

Minnesota via internet to the World

an automated system. Other sensors monitor environmental conditions within the pavement. These conditions change less rapidly so some environmental sensors are monitored manually while others are done automatically.

The on-site automated data collection system consists of 42 microcomputer-based data collection devices in 26 outdoor cabinets, 5 microcomputers, and an on-site midsize computer. All these components communicate continuously through a complex fiber optic communication network. Several times per day data are transmitted from the site to the Mn/ROAD Physical Research database in Maplewood via a large (T1) communications line. It is expected that 40,000 MB of data per year will be amassed in this manner. The complex data collection system is currently installed and partially operational, with full operation expected in summer 1994.

Mn/ROAD Data Analysis Tool: The Mn/ROAD database is unique in size and also because it is a research database requiring tremendous flexibility to extract, summarize, correlate, analyze, and report on the data it contains. The University of Minnesota Computer Science Department has developed a customized Graphical User Interface (GUI) that will allow researchers to work with Mn/ROAD data in a wide variety of ways. Many different processes can be linked and shown graphically to perform complex modifications of data tables. This allows the desired analytical results to be displayed as tailored reports or graphs. Researchers began using the GUI tool in spring 1994 and a fully operational version will be delivered
in summer 1994.

**Mn/ROAD Dynamic Cone Penetrometer:** The Dynamic Cone Penetrometer (DCP) was first used by Mn/DOT Physical Research to test the strengths of soil and aggregate pavement layers at the Mn/ROAD project.

The concept of this test device is quite simple but results can be correlated to more complex engineering parameters.

The test procedure is to drop the sliding hammer from the top onto the anvil in the middle and record how far the pointed tip at the bottom is driven into the soil or aggregate. The DCP is now used by Mn/DOT to monitor the compaction of material back-filled into trenches around pavement drains, and has been used to help prevent pavement structure settlement above drains. Another significant development is the automation of the DCP by Physical Research staff. The newly automated DCP can be operated by only one person, compared to the manual DCP that required two. The cost of automating the DCP ($42,000) was fully funded by Mn/DOT’s Breakthrough Innovations Program (see that section of this Report).

### Directions

#### Pavement Rehabilitation/Maintenance

**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 will attempt to develop and refine these test methods and attempt to develop methods to improve the performance of the marginal aggregates. A variety of issues including reducing the maximum size of coarse aggregate, heavy-media separation, blending, concrete mix proportioning, coatings or impregnations, and heat-treating aggregates will be examined. The ultimate goal is to reduce the long-term costs of concrete pavements by increasing their service life.

**Sawing and Sealing Bituminous Pavements:** This procedure was developed in New York and is sometimes referred to as New York saw and seal. It involves sawing joints in bituminous pavements and then sealing the joints with rubberized sealant material. When a concrete pavement is overlaid with bituminous, the overlay is normally thicker than required for sufficient strength in order to minimize the rate of reflective cracking that occurs when the underlying concrete joints expand and contract. Since the saw and seal technique allows for joint movement, no additional thickness is required.

Over 50 test sections have been constructed since 1986 using the saw and seal
technique. The performance of these sections is being monitored to find their effective life. If this technique works, the overlay thickness can be reduced on many bituminous overlays of concrete pavements.

**Performance of Bituminous Roadways:** This study correlates inplace air voids with the performance of bituminous roads. Phase one is an ongoing study to determine the effect of traffic on roadway compaction. Cores were taken in and between wheel paths immediately after construction and yearly thereafter. Most of the roads are in the third of five years of testing. Phase two correlates inplace air voids in existing roads to road condition. Roads that have lasted longer than expected and roads that have not lasted as long as expected are included. Phase three is a variation of phase two comparing inplace air voids from low volume county roads. Phase four includes inplace air void testing of special mixes.

Susceptibility of bituminous mixes to moisture damage (stripping) is also being tested. Mix from various jobs from around the state is being tested using the modified Lottman test with and without a freezing cycle. Three tests with three different curing times are also 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. Testing procedures and specifications will be developed if deemed necessary.

**Noncorrosive Deicing 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 was initiated to determine the effectiveness of several noncorrosive deicers 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.

**Pavement Design**

**SHRP/SMA Mixtures:** The Strategic Highway Research Program's (SHRP) Long-term Pavement Performance Program has developed a new mix design,
known as Superpave. This design procedure is a performance based specification that relies on lab testing to determine the likely performance of the roadway.

There are currently two test sections built in Minnesota using this design: the first was constructed in October 1992 (T.H. 61, south of Lake City) and the second in June 1993 (T.H. 169, south of Belle Plaine). Control sections were placed at the same locations using current Mn/DOT mixes.

Along with the SHRP mixes, Mn/DOT also built companion sections using a European technology known as Stone Matrix Asphalt (SMA). SMAs are very rocky mixes with mostly uniformly sized coarse aggregate, a polymer additive or fiber to prevent asphalt drain-down, and a mineral filler. This results in stone-on-stone contact that is desirable for rut resistant mixes. European countries use SMAs on their most heavily truck-traveled motorways.

An evaluation of these test and control sections will provide insight into the enhanced performance these mixes claim to provide. Once the performance is determined, the cost/benefit of using these new mixes can be determined.

ISTEA Polymer Study: Several demonstration projects have been funded as part of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. One of these is a study of polymer-modified asphalts being conducted jointly by Mn/DOT and the University of Minnesota. Mixtures containing polymers are more durable than conventional mixtures, and the study involves extensive laboratory testing to determine which polymers show the most promise when used with certain base asphalts. Based on the results of the lab testing, field test sections will be constructed to study the performance of these mixes.

Mn/ROAD

Mn/ROAD Research Program: The successful construction of the Mn/ROAD research facility has been a high priority during the last several years. The overall quality of the facility will directly affect the integrity of the Mn/ROAD research. As construction efforts near completion in summer 1994 the focus returns to the multi-year research program. A key objective is to verify and calibrate the pavement engineering models currently being used. A series of research projects focuses on engineering factors affecting pavement response to traffic and environmental loadings as well as long-term pavement performance. In combination these projects will provide a knowledge base for forming a new, more mechanically based pavement engineering model. The results of this research will be applied to engineering and economic problems associated with Minnesota pavement structures.

Other state and federal transportation agencies have already expressed an interest in cooperative Mn/ROAD research. These cooperative agreements will continue
to contribute expertise and resources to the Mn/ROAD project agenda.

**Research Expenditures**

Materials Research funds support research studies, technology transfer, technical support, preparation of technical reports, and administrative costs. Funding is allocated to materials research, and Mn/ROAD administration, research, consultant services, and professional services. The chart below shows approximate expenditure distributions for 1993.

- 7% Mn/ROAD Professional Services
- 9% Mn/ROAD Consultant Services
- 19% Materials Research
- 30% Mn/ROAD Administration
- 35% Mn/ROAD Research