The state’s roads and bridges carry a heavy load, with personal and commercial use continuing to rise. Developing effective pavement structures helps save maintenance and replacement dollars, as well as creating an infrastructure that meets the needs of Minnesota’s businesses and the motoring public.

Research on a variety of pavement structure topics have led to advancements in pavements and bridges that reap those benefits. The Minnesota Department of Transportation (Mn/DOT) organizes infrastructure research around a number of areas: pavement structures, bridges and structures, construction methods, hydraulics, and right of way and surveys. Each area sets its goals in accordance with Mn/DOT’s strategic plan. The area of bridges, for example, focuses its research efforts on exploring emerging technologies and design methods, on solving existing problems with materials, and on examining transportation policy and administration issues.

The long-term pavement testing facility, the Minnesota Road Research Project (Mn/ROAD) offers an important tool in the advancement of Minnesota’s pavements. Mn/ROAD gives researchers a unique real-life laboratory to study and evaluate the performance of the materials used in highway construction. Mn/ROAD already has provided enough data to conduct analyses—a strong start in making improvements that will pay off.

From the implementation of Superpave (Superior Performing Asphalt Pavements) to the implementation of research on high-strength concrete in bridge girders, Mn/DOT studies continue to point the way to new materials or methods that improve the quality of the state’s roads or provide more cost-efficient alternatives.
Superpave hits the road running

Mn/DOT, cities, and counties all share the common goal of wanting to cost effectively increase pavement life. Mn/DOT’s investment in implementing a national initiative offers the potential to help achieve that goal.

Typically, hot mix asphalt pavements are designed to perform for 20 years of service life, but severe thermal cracking and rutting often occurs well before that time. The development of the Superpave system, incorporates performance-based asphalt binder materials characterization with local environmental conditions to improve pavement performance.

“Superpave is a step in the right direction for improving Mn/DOT’s hot mix asphalt pavements,” says John Isackson, a research project engineer with Mn/DOT’s Minnesota Road Research Section. At the end of this paving season, 39 projects will have been constructed; three in 1996, five in 1997, and 31 in 1998. Overall, those pavements have been performing well, says Isackson, and Mn/DOT has used the information and experience that it gained during their construction to improve its 2360 Superpave specification. Mn/DOT is planning on having many additional Superpave projects in 1999.

Superpave, which stands for Superior Performing Asphalt Pavements, is a product of the Strategic Highway Research Program. Congress established SHRP in 1987 as a five-year research program to improve the performance, durability, and safety of roadways in the United States. The majority of states will have implemented Superpave by the year 2000.

Mn/DOT and other state transportation departments played an important role in the research and development of Superpave, which includes several key elements—the asphalt binder specification, mix design and analysis system, and a computer software system. Mn/DOT’s standard specification 2360 for Superpave hot mix asphalt incorporates the system’s strict criteria for high-quality aggregates and asphalt binder materials.

“The basic recipe for Superpave is still just aggregate and asphalt binder,” says Isackson. “However, Superpave criteria requires high-quality aggregates of all sizes and asphalt binders that will perform in a wide range of seasonal temperatures.”

Asphalt binders are now graded based on a Performance Grading (PG) system, which characterizes asphalt performance for a given set of high and low temperature conditions. Superpave criteria call for use of higher quality aggregates and of different gradation requirements. Additional changes in the mix design methodology acceptance testing have been designed to more closely approximate what happens to the hot mix asphalt in the field.
The new mix design and specifications will add to the cost of the pavement, according to Isackson. Superpave mixes are roughly $3 to $10 per ton more expensive than the old mixtures. In addition, Mn/DOT has made a significant investment in testing equipment and staff training. But the department expects the investment will pay off with a decrease in maintenance costs and increase in overall life of the Superpave pavements.

It is too early to predict if the Superpave projects will achieve or surpass the 20-year service life, says Isackson, but each newly constructed project adds to current performance data. Mn/DOT will use that data to improve specifications and construction methods in the future.

**A new tool makes measuring subgrade strength easier**

Before designing pavement, designers must know some information about the strength of underlying or subgrade soils. Soil samples of a proposed construction help characterize the subgrade soil type and quantify those strength values, known as the subgrade modulus.

General guidelines help designers determine the number of required samples, but not the spacing of samples. Designers face challenges in knowing where to take these samples. Because soil strength may vary considerably, designers need to take samples in the right areas to avoid insufficient design or overdesign.

To take some of the guesswork out of preliminary design, Mn/DOT and the University of Minnesota developed a new tool, which assists designers in selecting preliminary sample spacing for assessing the subgrade strength.

Users make some initial assessments about the local soils before using the tool, including obtaining a limited number of subgrade modulus values. The Falling Weight Deflectometer (FWD) determines those values. A non-destructive testing device, the FWD imparts a load on the soil surface. Sensors measure the resulting deformation in the underlying soil layers.

A computer program then back-calculates modulus values from the measured deflection. After assessing the sampled subgrade modulus values, the user subjectively determines the likely minimum subgrade modulus value within the area of interest. The program calculates intermediate constants for each sample set using provided equations. With a pocket calculator and provided nomographs, users then can take those constants to determine the number of required samples, the sample spacing, and the relative precision of the resulting data.

The program also presents some modified calculations for analyzing and summarizing subgrade modulus data and for determining preliminary subgrade
modulus design values. The values can then be correlated to the soil characterization values that Mn/DOT uses in pavement design.

The project has created a valuable tool, and its use will result in more accurate characterization of the underlying soil strength, that will lead to better and more efficient pavement design.

**Mn/DOT participates in cutting-edge friction research**

Friction devices can help make or break certain maintenance operations. Mn/DOT’s Office of Maintenance Research understands the importance of accurate friction measuring devices and agreed to lead a current study that may help improve snow and ice control operations throughout the country.

The American Association of State Highway and Transportation Officials (AASHTO) selected Mn/DOT maintenance to take the lead in testing and evaluating friction measuring devices for winter maintenance applications. Funded by the Federal Highway Administration (FHWA), the project began in October 1996 with a targeted completion date of August 1999.

Friction measurement devices help crews in their efforts to keep roads ice-free and non-slippery during the winter. This study calls for testing and evaluating the performance of a selected set of friction measuring devices, first as a tool for measuring snow and ice control performance and second as a decision-making tool for snow plow operators.

Project tasks included performing a complete technology survey, acquiring the friction measuring devices, developing test protocols, conducting baseline field tests, testing and evaluating the devices under simulated and actual conditions, conducting on-site field demonstrations, and coordinating the overall project. Maintenance evaluated five friction measuring devices, including the Cornila, Norsemeter Road Analyzer and Recorder, Swedish BV-14, RJ Law Device, and the Grip Tester.

Researchers conducted baseline field tests using all five of the devices under the same field conditions and road surfaces to calibrate the devices for later comparative testing. They conducted field tests in fall 1997 through winter 1998 at various sites. All sites contained asphalt surfacing but ranged from smooth to rough in surface texture. The project included tests performed under both wet and dry road conditions and at 20, 30, and 40 miles per hour.

After completing baseline tests, maintenance conducted simulated and actual condition field tests and evaluations during the winter season. Project staff tested the devices under five of the following 10 conditions:

- Dry loose snow less than one inch deep
- Dry loose snow more than two inches deep
- Wet loose snow less than one inch deep
- Wet loose snow more than two inches deep
- More than one inch of slush
- Less than one inch of slush
- Packed snow when the air temperature is less than 25 degrees Fahrenheit
- Packed snow when the air temperature is near 32 degrees Fahrenheit
- Ice when the air temperature is less than 25 degrees Fahrenheit
- Ice when the air temperature is near 32 degrees Fahrenheit

An interim report summarizes the tests completed to date. A private consultant currently is analyzing all test data. Project staff will compare the data from the five friction measuring devices and make recommendations that may be useful in all snow and ice operations.

PaveCool improves cold weather paving success

Poor compaction can lead to early deterioration of an asphalt pavement. It often happens when paving occurs during adverse weather conditions. Yet, in Minnesota, paving must often occur during adverse conditions.

A new tool now simulates the cooling of an asphalt mat behind the paver under a variety of environmental conditions. The software, PaveCool Version 2.0, offers users insights into how adverse climate conditions will affect their ability to produce a durable, quality road surface. Users input the type of existing surface, type of asphalt mix, and weather conditions. The output shows a cooling curve with recommended compaction starting and stopping times. Field tests confirm the value of this program as an aid to cold weather paving.

The software assists in determining the optimal temperature to begin and to end compacting, critical information to effective cold weather paving. As the pavement cools, it becomes increasingly more difficult to obtain required density. In cold weather, the material loses heat even more rapidly, resulting in a shorter window of opportunity for proper compaction. In the past, operators relied on subjective information to make decisions about optimal temperatures to start and stop compacting.

Researchers at the University of Minnesota developed PaveCool 2.0 with support from Mn/DOT and the Minnesota Asphalt Pavement Association. PaveCool 2.0 is the current version of the software.

The tool predicts the thermal profile through an asphalt concrete lift during construction by using a computation heat transfer model, predicting the transient cooling of the asphalt lifts during construction, the use of a comprehensive database containing the thermal properties of a range of asphalt types, the
coupling of a thermal model with compaction analysis, and the development of a user interface that allows for easy input of current environmental conditions and moisture variables.

Improvements in 2.0 include corrections to the aggregate thermal properties, a plot that users can view from the input window, and the recommended start compaction time and temperature.

Version 2.0 has fully documented aggregate and soil and thermal properties, with the aggregate base thermal properties verified in field tests. To date, no field data verifies thermal properties of subgrade soils, values used only for full-depth pavements placed directly on the subgrade soil.

PaveCool 2.0 is a Windows program that runs on laptops (Windows 95, 98, or NT required). The cooling curve appears to the right of the input screen. Recommended start and stop times are displayed as colored lines on the plot. The Performance Grade (PG) of the asphalt dictates the recommended start compaction temperature. The user must specify the high and low temperatures that make up the grading system.

After users enter information about paving date and time, environmental conditions, asphalt mixture specifications, and existing surface type, the program almost instantly calculates a recommended rolling start and stop time in minutes. PaveCool 2.0 helps extend the viable construction season as long as possible.

Mn/DOT distributed copies of PaveCool 2.0 in fall 1998, as well as sharing information about the tool with the Minnesota Asphalt Pavement Association, Wisconsin Department of Transportation, and the Wisconsin Asphalt Pavement Association. To download a copy of PaveCool Version 2.0, visit the following website: http://mnroad.dot.state.mn.us/restools/cooltool.html.
PAVEMENT RESEARCH HIGHLIGHTS

Research Accomplishments

Statistical Analysis of the Sources of Flexible Pavement Variability: This research identified, quantified, and statistically characterized the components of bituminous pavements that may lead to spatial variability of pavement performance. Researchers collected extensive data from Mn/ROAD flexible pavement test sections.

Data includes FWD readings, thickness obtained from Ground Penetrating Radar, cores, and traffic loadings. As part of this study, researchers completed an integrated Mn/ROAD Atlas, which combines databases of pavement strength, performance, environmental, traffic, and other variables. Mn/DOT published a report and atlas in a CD-ROM format in summer 1998. For more information, contact Dave Van Deusen at 651-779-5514.

Video Productions: The Minnesota Road Research Project (Mn/ROAD) recently made available four new videos, which help bring the impact of research to the field.

- Working With Your FWD Calibration Center. This video explains the importance of Falling Weight Deflectometer (FWD) data, the necessity of FWD calibration, and the calibration process.
- Laboratory Resilient Modulus Testing: Startup and Quality Control Procedures. This video helps technicians and engineers learn Federal Highway Administration (FHWA) procedures and testing protocols, as well as details about startup and quality control procedures.
- Laboratory Resilient Modulus Testing: Sample Preparation and Sample Test Procedures. This video helps technicians and engineers learn FHWA procedures and testing protocols, as well as details about sample preparation and test procedures.
- Laboratory Resilient Modulus Testing: Is This the Right Time? This video helps administrators and engineers in deciding when to conduct resilient modulus testing.

Benefits of these videos include standardization of FWD calibration and the testing of unbound materials using resilient modulus testing. For copies of videos, contact Mn/ROAD at 651-779-5500.
Research Directions

Retrofit Load Transfer in Concrete Pavements: Mn/ROAD is studying ways to reduce the cost and improve the performance of concrete pavement rehabilitation. This project examines the issue of long-term load transfer in concrete pavements with the goal of providing better ride on concrete pavements after rehabilitation and diamond grinding.

Completed projects include work on U.S. 52 in District 6, U.S. 12 in District 8, and on Highway 23 in District 1. The project’s next phase involves incorporating the information learned from the test sites into standard procedures. Implementing this research will lead to improved rides on concrete pavements, with minimal traffic disruption during any required retrofitting. For more information, contact Dave Pettner at 651-779-5516.

Investigation of Premature Concrete Pavement Deterioration: More than 200 roadway miles of Minnesota concrete pavement have failed or are failing to meet 70 percent of the 35-year anticipated design life. Several pavement sections have failed after less than 20 years of service. This project will attempt to determine the causes of premature deterioration, and outline a prevention plan.

To date, researchers have completed extensive materials testing, resulting in better specifications for concrete aggregates, cements, flyash, and concrete mixtures. Future work calls for additional evaluation of deteriorated pavements, including scanning electron microscope work and materials. After completing the project, Mn/DOT will further evaluate and refine specifications. Anticipated impacts from this research include extending the life of new concrete pavements in the state by 30-50 percent at no significant cost increase. For more information, contact Dave Pettner at 651-779-5516.

Mitigation of Alkali Silica Reaction (ASR) in Concrete Pavement Using Lithium Nitrate: This study looks at ways to extend the life of concrete pavement that exhibits distress from alkali silica reaction (ASR).

Researchers will evaluate the use of lithium nitrate as a way of preventing additional ASR, in hopes of extending concrete pavement life. Mn/DOT applied lithium on Highway 15 north of New Ulm in June and October 1998, and will apply it again in May 1999. Approximately 80 cores have been removed from the roadway for evaluation and testing, and approximately 40 more cores will be removed after the lithium treatment for analysis. The project calls for long-term monitoring. Several other pavements in southwestern Minnesota have experienced
the same problem with ASR, and based on the results of this research, may receive
the same treatment later. For more information, contact Eric Embacker at 651-779-5529.

**An Evaluation of In Situ Permeability Methods:** The goal of this study is to
develop a method or device to measure in situ drainage characteristics to improve
the performance of pavement systems containing excessive base and subgrade
moisture. Phase I of this study identified existing methods and technologies, and
Phase II will examine these methods in depth.

Mn/DOT will be publishing a report outlining the wide range of available
devices and methods. The ability to measure the drainage characteristics of base
and subgrade material will improve the design, construction, and performance of
roadways. For more information, contact Craig Schrader at 651-779-5526.

**Maximum Frost Depth Determination at Mn/ROAD and Revision of
Mn/DOT’s Geotechnical and Pavement Manual:** This project includes using a
Modified Berggren equation to calculate frost depth based on air temperature,
average annual temperature, and pavement structure. Researchers compared these
predictions to actual frost measurements taken at the Mn/ROAD site.

The study indicated that predicted frost depths were within 19 percent of
measured values and researchers made recommendations for improving the
model. As a design consideration for construction, frost depth plays an important
role in the decision when to remove or impose load restrictions. The ability to
predict frost depth from climatic data will help engineers make those decisions.
The next phase of the project involves rewriting the Mn/DOT Geotechnical and
Pavement Manual section on frost susceptibility based on earlier results. For more
information, contact Craig Schrader at 651-779-5526.

**Ultra-thin Whitetopping:** Ultra-thin whitetopping refers to placing a thin
concrete overlay directly on top of an existing asphalt pavement. In this project,
researchers evaluated whitetopping performance in Minnesota to determine design
features that optimize pavement life. Mn/DOT constructed two ultra-thin
whitetopping projects in 1997: the first on U.S. 160 in Elk River, and the other on
I-94 at the Mn/ROAD test facility. These heavily instrumented sections will allow
measurement of the static and dynamic response of the pavement under various
applied loadings and environmental conditions.

This research will help in more accurately modeling whitetopping projects to
develop a more efficient design and a method and performance prediction model.
Researchers have collected FWD and sensor data and conducted distress surveys periodically. Data collection will continue throughout the life of the overlay. For more information, contact Julie Vandenbossche at 651-779-5565.

Interpreting the Effects of Curling and Warping on Falling Weight Deflectometer (FWD) Data for Portland Cement Concrete Pavements: This project seeks to provide a method for analyzing FWD data that would allow engineers to account for the non-uniform support conditions under the slab due to the presence of a temperature or moisture gradient during testing. Current analysis procedures do not consider the presence of a temperature or moisture gradient, which means that load transfer efficiencies, backcalculated support values, and the size of voids under the slab can be either over or under estimated when using FWD data, depending on the gradient present.

The project includes a major data collection effort at the Mn/ROAD research site. Researchers recorded temperature, moisture, static and dynamic strain, and profile measurements in conjunction with FWD testing at various times of the year throughout a 24-hour period. Researchers currently are analyzing data. For more information, contact Julie Vandenbossche at 651-779-5565 or Mark Snyder at 612-626-7843.

Comparing, Testing, and Applying Curing Compounds for Concrete Pavements: The implementation of a 0.40 water-to-cement (w/c) ratio specification for concrete pavements has raised some concerns regarding the effectiveness of current curing practices. Properly cured pavement helps prevent plastic shrinkage cracking and ensures maximum performance. To ensure proper curing, researchers will assess the effectiveness of frequently used compounds and reexamine the test methods used to evaluate these compounds. The methods used by the contractors to apply these curing compounds also will be reviewed to ensure that they apply a uniform coat of acceptable thickness. For more information, contact Julie Vandenbossche at 651-779-5565.

An Evaluation of Aggregate and Chip Seal Surfaced Roads at Mn/ROAD: This study concluded the following: that a simplified test is needed to evaluate aggregate wearing materials, that a chip seal surface allows for decreased maintenance if the supporting base has adequate strength, that an aggregate with higher fines content performs better, and that a 6 percent cross slope allows better drainage from the aggregate surface. For more information, contact Greg Johnson at 651-779-5938.
Impact of Increased Winter Load Limits to 100,000 pounds Gross Vehicle Weight: Currently, Mn/DOT allows the gross vehicle weight of trucks on its roadways to increase by 10 percent during the winter months. This study will determine the effects of raising this limit to 20-25 percent in the winter; and the associated dates of this increase. Researchers are conducting a literature review and reviewing the Mn/DOT and Mn/ROAD data to determine the load carrying capabilities of pavement in the winter. Results are not yet available.

If this study shows that load limits can be increased, potential benefits include transporting more goods with the same effort, cost savings to the trucking industry, and reduction of spring truck traffic that may result in less damage to pavements in the spring when the pavements are most vulnerable to damage. For more information, contact Jill Ovik at 651-779-5532.

Seasonal Changes in Pavement Material Properties: In this project, researchers will monitor the changes in the parameters affecting pavement material properties, estimate material properties during various time periods by backcalculation of deflection data, compare the material properties from laboratory tests with those from field tests, and compare backcalculated moduli with those obtained from the FHWA Integrated Model for climate effects on pavements.

The relationships have been quantified among climate factors, such as temperature, pavement field conditions, like temperature and moisture condition, and pavement material properties, such as resilient modulus.

Currently, researchers are investigating long-term pavement performance project sites for similar relationships and comparing data to the FHWA Integrated Model. The relationship between temperature and asphalt concrete stiffness, and the relationship between moisture content to granular base and soil subgrade stiffness have been quantified. Since climate conditions greatly affect flexible pavement material properties, quantifying changes in the stiffness of a pavement structure on a seasonal basis helps in improving road design. For more information, contact Dave Newcomb at 612-626-0331 or Bjorn Birgisson at 612-626-1341.

Investigation of Ground Penetrating Radar (GPR) Survey Techniques in Minnesota: This project will help determine if Mn/DOT can use GPR survey equipment and techniques to detect subsurface defects, distresses, and other features in Minnesota pavements in a safe, precise, accurate, and economical fashion. GPR radar survey can yield information on various pavement features such as in-place thickness and subsurface defects in a nondestructive, continuous
fashion. As a result, GPR could prove a valuable asset to MnDOT's current pavement evaluation tools.

A cooperative project with FinRA (Finnish National Road Administration), this project will offer Mn/DOT a firm understanding of the relative advantages and disadvantages of GPR as applied to pavements, materials, and conditions unique to Minnesota. In addition, Mn/DOT will gain practical experience in GPR data processing, interpretation procedures, and associated software. The first phase involves:

- fabrication, installation, and calibration of the necessary hardware to conduct the radar surveys
- data collection from selected pavement sections around the state
- preparation of a report by the GPR experts from Finland

Researchers completed the first two tasks of Phase I in May 1998. Phase II of the project involves the validation of the GPR data. In this phase, both existing and new ground truth data will be compared to the GPR data to test its validity. For more information, contact Dave Van Deusen at 651-779-5514.

**Statewide Micro-Surfacing Study:** A surface rehabilitation treatment, microsurfacing involves the application of a high-performance mixture of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and other additives to an asphalt pavement. Curing times are typically specified to support traffic within an hour. Pavements benefit from micro-surfacing because of its hard, durable surface characteristics and sealing qualities. It can be used to repair raveling and flushing, and to fill ruts and level cracks.

As part of the project, researchers will study the performance of micro-surfacing under Minnesota conditions, using locally available materials; determine the cost-effectiveness of micro-surfacing as compared to other types of preventive maintenance treatments; and determine parameters for warranty specifications. Researchers will track the performance of several test sections around the state. For more information, contact Dave Van Deusen at 651-779-5514.

**Concrete Pavement Dowel Bar and Joint Alignment Study:** Good long-term performance of concrete pavement contraction joints relies on proper saw cut alignment during construction. The development of new design models relies on the existence of properly aligned contraction joints. Recent measurements of dowel bar and joint alignment in existing pavements have indicated less than satisfactory results.

This project aims to determine the alignment of the dowel bars in each of the
contraction joints of Mn/ROAD concrete test cells, which will aid researchers during future modeling of the concrete joints. Other dowel bar and joint alignment measurements taken throughout the state will be used for representative comparison to Mn/ROAD observations. Researchers have completed about 50 percent of the measurement of dowel bar and joint alignment at Mn/ROAD and have measured several outstate sites.

The next step involves completing the measurement of the dowel bar and joint alignment at Mn/ROAD, as well as determining and visiting additional outstate study sites. For comparison, researchers will measure newly constructed pavements to see if new non-skewed joints consistently result in better alignment than previous skewed joints. The information gained from this study will allow for more accurate modeling in future analyses, and the impact of new non-skewed joints on joint alignment will be determined as well. For more information, contact Tom Burnham at 651-779-5605.

**Geosynthetic Test Sections on TH72 in Waskish:** A portion of Trunk Highway (TH) 72 northeast of Upper Red Lake in northern Minnesota serves as a testing ground for new geosynthetic materials that may help reduce or prevent cracking in asphalt concrete. This research project compares the effectiveness of different types of geosynthetics on the prevention or reduction of longitudinal and transverse cracks in a 120 mm asphalt concrete (AC) pavement. The study includes the use of four geosynthetics: a geogrid, geocell, and two geotextiles, each placed in one-quarter mile test sections.

In August 1997, crews completely removed a one-mile section of the existing AC pavement on TH 72, as well as removing the underlying aggregate base and fill materials to a depth of 0.4 to 0.5 meters. They then placed geosynthetics on the section and covered the geosynthetics with select granular borrow, class 5 aggregate, and 120 mm of new AC.

In May 1998, test sections showed no transverse or longitudinal cracks, while the adjacent overlayed areas contained numerous cracks that had developed through the new overlay after only one winter. While initial results prove encouraging, they are based on only one winter. Researchers plan to monitor conditions annually over the next 10 years.

Another question involves determining the effectiveness of applying the geosynthetics versus the effectiveness of removing old AC surface and underlying material. Researchers may address this question by constructing additional test sections on nearby sections of TH 72 as a rehabilitation of this highway continues.
in 1999. These new test sections would compare various amounts of milling and reuse of the AC as base material. For more information, contact John Siekmeier at 651-779-5299.

**Frost Resistivity Probe Study:** Mn/ROAD has identified three areas for further study regarding the frost resistivity probe, a widely used tool in the state: frost probe sensor trouble shooting, frost resistivity probe analysis, and spring load restrictions. For this project, consultant Ron Atkins will provide expertise in those topics, including technical assistance to the research staff. For information, contact Craig Schrader at 651-779-5529.

**The Effects of Load Transfer on Concrete Pavement Performance:** This project provides a unique opportunity to study the long-term behavior of concrete pavement joint load transfer ability, using live traffic loadings. Understanding the deterioration of load transfer ability in concrete pavement transverse contraction joints is critical to the development of a mechanistic-empirical concrete pavement design model or method. The project supports a long-term goal of providing quantitative information on load transfer ability that would serve as an input to the new design method.

To date, Mn/ROAD has conducted transfer efficiency testing using the FWD periodically on the Mn/ROAD concrete pavement cells. Researchers will perform periodic FWD testing on all test cells and examine other parameters that impact joint load transfer behavior. Testing and analysis will continue until each of the test cells fail. Valuable and quantitative behavioral inputs should be available for the new mechanistic-empirical design method under development. For more information, contact Tom Burnham at 612-779-5605.

**Dynamic Cone Penetrometer (DCP) Loan Program:** An easy-to-use device, the DCP provides a quantitative measure of granular base and soil strength, and allows inspectors to identify and correct problem areas during construction, which contributes to better compaction and longer lasting pavement.

Mn/DOT launched the DCP Loan Program to increase use of the DCP throughout the state. Mn/DOT loans its nine DCPS to counties, cities and private organizations. The Office of Materials and Road Research plans to continue to loan the DCPS and collect survey data from users. For more information, contact John Siekmeier at 651-779-5299.
Deflection Testing at Mn/ROAD using the Falling Weight Deflectometer (FWD): As part of this project, researchers will quantify the change in deflection due to load, environmental factors, and time by measuring deflection in underlying pavement layers throughout the year. Deflection data has been gathered periodically since construction of Mn/ROAD test sections, and measurements will continue until the test sections fail. Deflection testing provides a measure of the most economical pavement designs when considering life-cycle costs. For more information, contact John Siekmiejer at 651-779-5299.

Accuracy Statement for On-Line Dynamic Sensors at Mn/ROAD: This project will quantify the accuracy of the online dynamic sensors at Mn/ROAD by documenting the operation of the existing system, by identifying the potential sources of error, by recommending modifications to the existing system, and by quantifying accuracy of the modified system.

Researchers have completed the documentation, identification, and recommendation steps, and are implementing the recommended modifications. For more information, contact John Siekmiejer at 651-779-5299.

Improving the Placement of Spring Load Restrictions: Local engineers often place load restrictions to reduce the damage to roads during spring thaw. This project explores ways to use readily available air temperature data and weather forecasts to predict the best times for placing and removing spring load restrictions. Researchers completed a literature review and developed a new thawing index equation using Mn/ROAD data. They also compared load restriction periods from 1986-1998, FWD measurements, and strain gage data to the thawing index.

Researchers now will conduct additional FWD testing, strain gage, measurements and thawing index comparisons. They also will quantify pavement damage during the spring thaw period by using mechanistic-empirical pavement design software developed at the University of Minnesota. The results of this project will help Mn/DOT districts and Minnesota counties and cities reduce spring time damage by more timely placement of spring load restrictions. For more information, contact John Siekmiejer at 651-779-5299.
Use of high-strength concrete reaps benefits

The recently constructed Lexington Avenue bridge over I-35W in Blaine not only improves the road for the driving public, it also provides another example of research in action.

Mn/DOT used high-strength concrete and the Lexington Avenue bridge, implementing the results of a long-term research project and reaping the benefits of that research. The use of high-strength concrete in the Lexington Avenue bridge construction resulted in a reduction from 34 to 28 beams, with an estimated cost savings of $80,000.

Mn/DOT began using prestressed concrete girders for bridges in 1957, with improvements in materials and fabrication techniques leading to steady increases in concrete strengths, steel stresses, and beam lengths. Recently, Mn/DOT collaborated with the Center for Transportation Studies at the University of Minnesota and the Minnesota Prestress Association to investigate the use of higher strength concrete mix designs for use in prestressed girders. With funding from all three partners, the research expanded its scope to include the study of the concrete durability, camber, and full size girder testing.

As part of the study, two 45-inch deep girders, each 131-feet, six-inches long were cast with different design mixes. Researchers designed test girders to meet an initial strength of 8925 psi and a final strength of 10500 psi. A local firm fabricated the girders using normal production practices as much as possible. They also instrumented them to measure losses, transfer length, creep and shrinkage, temperature effects, reinforcing steel and prestress strand strains, and strain in the concrete and steel because of bending and shear.

After 24 hours, the compressive strength reached 9500 psi for one girder and 10400 psi for another girder. It took 21 hours to obtain a 9000 psi release strength. The girders also passed fatigue, bending, and shear tests with satisfactory results. The beams failed at approximately 670 percent of the design load, and at the time of failure, the deflection at mid-span was 35 inches.

The research showed that the mix design worked in production. It also showed that a production plant could produce the girders in a normal plant production set up with one-day turnover by using conventional plant curing procedures.

Based on the research results, Mn/DOT revised the allowable concrete strengths for routine prestressed beam designs in February 1997. Mn/DOT increased the allowable strength at the time of release from 6500 to 7000 psi and the final strength from 7000 to 8500 psi. These increases allow for longer spans, wider girder spacings, shallower cross sections, and an overall decrease in the cost of new bridge construction.
Differences in conditions and loadings in individual bridge designs make it difficult to quantify overall cost savings from the use of high strength concrete. But significant cost savings result from the ability to design wider girder spacings and long spans. The use of shallower cross sections allows for easier transportation and placement of members, which in turn results in reduced embankment heights or increased underpass clearance heights.

Increased girder spacings result in cost savings by reducing the number of girders needed per bridge. The use of high-strength concrete also helps reduce material, transportation, and erection costs. In conclusion, the use of high strength concrete in girders offers a way to reduce costs, increase flexibility in bridge design solutions, and maintain bridge strength.
BRIDGE RESEARCH HIGHLIGHTS

Research Accomplishments

Transverse Cracking in Concrete Bridge Decks: Limiting cracking helps increase a bridge's life and reduces maintenance costs. This project sought to identify the factors that contribute to transverse cracking in bridge decks and to determine changes in material or construction specifications that might prevent this type of cracking. Completed in June 1998, the parametric study gave three recommendations, including advocating the use of additives in concrete to reduce shrinkage of deck concrete, using better curing practices, and minimizing continuity over piers.

The field study found that the following factors affect bridge deck cracking: girders and restraint, flexibility of girders, deck thickness, top rebar size, cement content, and aggregate quantity. Specifically, researchers learned that continuous girders crack more, that more flexible girders crack more, that 6 1/4" decks crack significantly, that decks constructed with 5 transverse bars crack less than 6 bars, that less cement shows less cracking, and that increased aggregate shows less cracking.

Implementing the findings from this study will increase the life expectancy of bridges by reducing the number of cracks in bridge decks. For more information, contact Paul Kivisto at 651-582-1149.

Epoxy Coated Rebar Study: Completed in June 1996, this research evaluated the performance of four bridge decks containing epoxy coated reinforcement. Researchers conducted a field investigation and took five core samples for laboratory testing. Results showed that epoxy coated rebars performed well, with a low amount of salt at the rebar level, which confirms the effectiveness of using this type of system. Mn/DOT changed its design policy based on results of this research and epoxy coated rebars are now specified for all bridge decks. For more information, contact Paul Kivisto at 651-582-1149.

Stress-laminated Timber Bridge Deck Performance: Stress-laminated timber bridge decks perform well as long as the stressing bars maintain their tensioning force and hold the timber laminated planks tightly together. A bridge built in northern Minnesota in 1989 experienced a change in bar force where stressing levels significantly reduced during periods of low winter temperatures and then returned to normal as the temperatures warmed. Subsequent studies determined
the loss related to the moisture content of the wood and cold temperatures. This study further quantified the thermodynamic characteristics of timber over a wide temperature range and a variety of moisture content levels.

The results of the research showed that sub-zero temperatures greatly affected stressed timber decks with moisture contents higher than 17 percent. The research quantified the rate of loss, the reduction of bar force, and the time needed for the bar force to return to normal levels when temperatures moderated.

The findings support the AASHTO Guide Specification for new stress-laminated timber bridges, which requires a moisture content of less than 19 percent. Findings also support close monitoring of existing stressed bridge decks with moisture content consistently greater than 19 percent. Until the content reaches levels consistently less than 19 percent, bridges should be posted for a reduced loading during winter months and the bars restressed as necessary. For more information, contact Erik Wolhove at 651-582-1130.

**Release Methodology of Prestressing Strands:** Tensioning of reinforced strands occurs during the manufacture of prestressed concrete beams. When these strands are cut, cracks appear in the concrete. This project identifies methods to eliminate these cracks.

The study found that cracking can be reduced or eliminated by modifying the strand cutting pattern, increasing the length of free strand between ends of girders and stressing abutment, and debonding the strands.

The cracks, which close when all of the strands are cut, don’t appear to decrease the ultimate capacity of the girder, researchers indicate. The durability of the beam ends, which may exhibit increased corrosion and spalling from the cracks, is an important issue for future study. For more information, contact Kevin Western at 651-582-1132.

**Research Directions**

**Stability of Pile Groups:** Bridge closings can occur when bridge pile footings are exposed due to scour during floods. This research will be used to develop a method for stability analysis of pile groups as a system, while considering a more realistic interaction between individual piles in the group and the interaction of the pile with the soil. This research will help determine how soil properties and geometry of the free and embedded parts of the system affect the stability properties of the group.

Factors will be developed using a three-dimensional model, and will be used as multipliers for the values obtained from a structural model, which could be run on
Windows NT computers in the field. Researchers will study three bridges with critical scour using this program. The research began in September of 1996, with a scheduled completion date of February 1999.

An enhanced stability analysis leads to a more accurate evaluation of the bridge condition, which in turn improves the safety for its users and allows for its continued use. For more information, contact Paochen Mna at 651-582-1130.

**Acoustic Emission Monitoring of Fatigue Cracks in Steel Bridge Girders:**
Several Minnesota bridges have exhibited fatigue cracks at the ends of welded cover plates. This research project looks at development of a method to determine the status of fatigue cracks and a way to test a possible repair method. Field tests began in June 1998, with project completion scheduled for March 1999. Results from this study will help in reducing repair costs on bridges that exhibit cover plate fatigue cracks. For more information, contact Dan Ruffelle at 651-582-1156.

**Monitoring and Assessment of Bridge No. 79000 at Wabasha:** This Wabasha County bridge exhibited wind-induced vibrations, and this project assessed its effect on the bridge. Information from this study will provide Mn/DOT with a method to address vibrations and other load-induced stresses in structures. A final report was submitted to the Office of Research Services in September 1998.

**Stresses in Steel Curved Girder Bridges:** With a lack of information about stresses in curved girders, designers need better information about the accuracy of computer programs that predict the stresses and deflections in the girders. To identify the correlation between computer programs and the actual conditions, a curved bridge over Interstate 94 near the University of Minnesota was instrumented and monitored to record stresses and deflections during and after construction. Researchers then compared the actual values to values predicted by the computer programs.

The measured stresses and deflections compared very closely to the computer program predictions for most readings, indicating that the programs have good accuracy. Low live load stresses made comparisons difficult. As a result, researchers extended the study to measure the use of a greater live load.

As part of the extended project, researchers will measure stresses and deflections once a year for three years to determine if changes in dead load stresses occur over time. In addition, researchers will increase live load stresses by using a much greater live load.

With this research complete, designers can use computer programs with greater
confidence, knowing that the output gives them valid results to use in their design. Also, the results confirm relatively low stresses, which means that designers may use less steel in girder design. For more information, contact Steve Ellis at 651-582-1135.

**Remote Monitoring of Distortional Fatigue in Multi-Girder Steel Bridges:**
A remote monitoring and assessment program began in August 1998 to evaluate distortional fatigue stresses in bridge #27734 (Brooklyn Center—eastbound on Highway 694 over westbound Highway 94).

Remote monitoring data acquisition (RMDA) equipment used in a previous project (Monitoring and Assessment Program for Wabasha County Bridge) is being upgraded for use in this study. For more information, contact Dan Ruffelle at 651-582-1156.
Greater demands on the state's highways create a challenging situation for the Minnesota Department of Transportation (Mn/DOT). Faced with the reality of more and more vehicles on the road, how can transportation architects keep traffic flowing at its maximum capacity? And, as the roads age and snow continues to fall, how can Mn/DOT maintain its roadway system in a safe and cost-efficient manner?

Research in maintenance operations and traffic engineering and management helps Mn/DOT directly address those questions. Maintenance operations established research directions that include developing the most effective maintenance strategies, procedures, materials, and equipment for Mn/DOT's maintenance work force; providing for the most effective and efficient transfer of transportation technology within and outside of Mn/DOT; and encouraging the investigation and implementation of new maintenance operations technologies. As a result, maintenance research focuses on several key areas: snow and ice control, pavement maintenance, roadside maintenance, maintenance management systems, building and bridge maintenance, work zone safety, and technology transfer.

Traffic management and engineering makes advancements by applying the power of new and emerging technologies to the problems at hand. Through the use of intelligent highway systems, traffic detection and control methods, accident analysis, expert systems, and other tools, Mn/DOT finds new cost-efficient ways to maximize traffic flow.

Research in both maintenance operations and traffic engineering and management helps Mn/DOT make the most of its current transportation system while exploring the potential of future innovations.
Salt Solutions

In 1996—a year that brought near record cold and snow to most of the state—snow plow operators in the Duluth district succeeded where other districts did not: They reduced their district’s salt and sand use, saving more than $175,000.

Operators in the Duluth district participated in the Salt Solutions Program, an experiment in bringing the latest in information and technology to operators. “The Salt Solutions Program moved beyond technology and looked at how our snow plow operators make their application rate decisions, giving them the tools and a system that allowed them to make better decisions,” says Tom Broadbent, the Salt Solutions Program director with the Minnesota Department of Transportation (Mn/DOT) Duluth District.

“Past snow and ice training has primarily been focused on teaching operators the mechanics of plowing and sanding,” he says. “The Salt Solutions Program focused more on how our operators decide on what mix of sand and salt they should use and at what rate they will apply that mix to the road.”

Operators tend to overuse salt because of their concern for safety, says Broadbent. This program sought to achieve the following objectives:

- develop a set of tools and a system that allowed operators to make better application rate decisions
- support those tools and systems with ongoing training
- develop controls and measurements to track the effectiveness of the tools and training
- recognize improved performance

Broadbent met with operators throughout the district to discuss and share information about application rates, sand salt mix, sanding speed, pre-wetting, types of storms, new technology, and pavement temperature. To help standardize application rates, Salt Solutions included new simple guidelines based on earlier materials created by the Federal Highway Administration, the Delaware Department of Transportation, Mn/DOT, and other agencies (see table for example).

Because guidelines vary according to pavement temperature, Salt Solutions also looked at a low-cost option to supply that information. A new infrared sensor tool was mounted on the trunk mirrors of one plow in each station. The tool gives a pavement temperature reading inside the cab. In addition, operators began to calibrate their trucks, which allows them to know more precisely the amount of salt or sand applied.

With an initial investment of $34,000, the program also proved cost-effective. In 1996, Mn/DOT estimates that without Salt Solutions, the Duluth district would
have used 10 percent more salt and 24 percent more sand.

The program derived those results by comparing data from cities and counties that provide a similar level of service. In the city of Duluth, salt use rose 24 percent and sand use 18 percent and in Pine County, salt and sand use increased by 17 percent. In contrast, the Duluth district's salt use was down 1 percent and sand use was down 24 percent.

The Salt Solutions pilot succeeded so well that Mn/DOT decided to expand it to the rest of the state in 1997 and 1998, with funds from the Maintenance Operations Research Office (MOR) and Office of Research Services. Expanding the program multiplied its benefits.

As a result of the program, Mn/DOT equipped one truck in each Mn/DOT truck station with the new sensor tool this year. Salt Solutions Program information also is included as part of the Circuit Training and Assistance Program, which travels throughout the state. Also in the works: a newsletter that explains the program and shares the latest in information.

As the program broadens, so, too, does its ability to develop improved standards, says Broadbent. Part of the program includes asking users for their experience and adjusting guidelines.

'Salt Solutions changes the culture from one based on guesses and experience, to one that empowers drivers with the new tools and practices to make the best decisions.'

<table>
<thead>
<tr>
<th>Application Rate Guidelines</th>
<th>Multilane Divided</th>
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<tr>
<td>PAVEMENT TEMPERATURE</td>
<td>WEATHER CONDITIONS</td>
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<tr>
<td>30°+</td>
<td>Snow</td>
</tr>
<tr>
<td></td>
<td>Freezing Rain</td>
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<tr>
<td>25°-30°</td>
<td>Wet Snow</td>
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<td></td>
<td>Freezing Rain</td>
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<tr>
<td></td>
<td>200 salt</td>
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<tr>
<td>20°-25°</td>
<td>Wet Snow</td>
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<td>Sleet</td>
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<td></td>
<td>Freezing Rain</td>
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<td>300 salt</td>
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<tr>
<td>15°-20°</td>
<td>Dry Snow</td>
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<td></td>
<td>Sleet</td>
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<td>Below 15°</td>
<td>Dry Snow</td>
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MAINTENANCE RESEARCH HIGHLIGHTS

Research Accomplishments

Remotely Driven Vehicle: This project involved developing and field testing the third-generation Remotely Driven Vehicle (RDV). The idea of a remote controlled unit to shadow work crews resulted from discussions that occurred after a fatal accident, which involved a conventional shadow vehicle on I-94 approximately nine years ago. Because the driver operates the RDV with a remote control unit from outside of the vehicle, the RDV offers an improvement to conventional shadow vehicles, which require operators inside the cab. RDVs also allow the operator to perform additional tasks and complete work with the crew.

As a result of field tests, evaluation procedures, and feedback from operators and crew members, researchers recommended the implementation of the RDV unit as a work zone safety vehicle and as a shadow vehicle for slow-moving maintenance operations on high-volume and high-speed multiple lane highways. For more information, contact Ken Nelson at 651-282-5435.

SAFETRUCK: Driver fatigue results in some serious on-the-road consequences. In one study, the Association of Professional Sleep Societies reports that falling asleep at the wheel causes up to 6,500 fatalities yearly. The SAFETRUCK project makes use of intelligent transportation systems that can sense a vehicle's location within a lane; provide a warning to the driver about a lane departure; take control from an inattentive driver, if necessary; steer the vehicle to the shoulder; and stop. Funded by Mn/DOT, the Federal Highway Administration, and the Center for Transportation Studies at the University of Minnesota, the SAFETRUCK Program involves several related projects. In one completed project, researchers demonstrated that their system can take full steering control of a Navistar 9400 tractor trailer and keep it in its lane using a high-band-width differential GPS system.

Other research involves methods to provide information to drivers via the steering wheel and a heads-up display projected onto the windshield. The heads-up display offers potential in showing snowplow drivers the location of lane edges during low-visibility conditions. Researchers also are exploring radar systems for applications on snowplows and collision avoidance strategies such as a virtual bumper that would provide a protective envelope around a vehicle.