WisDOT Research Program

Annual 2021 Report

Foreword

I am pleased to present the Wisconsin Department of Transportation's (WisDOT) 2021 annual report on research activities. This report highlights WisDOT's efforts to uphold its mission to provide leadership in the development and operation of a safe and efficient transportation system.

WisDOT's Research and Library Services Unit facilitates the department's research activities and provides access to information that fosters data-driven decision making. Over the last year, the team has continued its efforts to align research and the department's strategic priorities; to facilitate the accelerated implementation of research results; to promote the application of promising materials and technologies; and to support the adoption of associated policies and procedures to demonstrate accountability to our transportation stakeholders and the public.

WisDOT's award-winning $4.34 million research program funded 66 research projects, completing six of the 19 Wisconsin Highway Research Program (WHRP) projects and leading three of the 48 projects funded through the Transportation Pooled Fund (TPF) Program. The American Association of State Highway Transportation Officials (AASHTO) recognized WHRP's Protocols for Concrete Bridge Deck Protections and Treatments as one of the nation's highest-value research projects on construction, specifications and materials.

Research and library staff completed four synthesis reports and 24 literature searches; responded to 316 information requests; and delivered 369 resource items. The research program also collaborated with educational institutions, organizations within the transportation industry and state and federal agencies to develop and disseminate valuable, innovative ideas of shared interest by participating in national studies and panels.

I am proud to recognize these accomplishments and would like to thank the many staff that serve on research committees and panels at the national, state and department levels. Their expertise and guidance are critical to the success and implementation of research.

Craig Thompson, Secretary
Wisconsin Department of Transportation

This is a report of research and technology transfer activities carried out by the Wisconsin Department of Transportation through the Part B research portion of the State Planning and Research Program of the Federal Highway Administration, U.S. Department of Transportation. The report describes activities during Federal Fiscal Year 2021, covering October 1, 2020 through September 30, 2021.

Contents

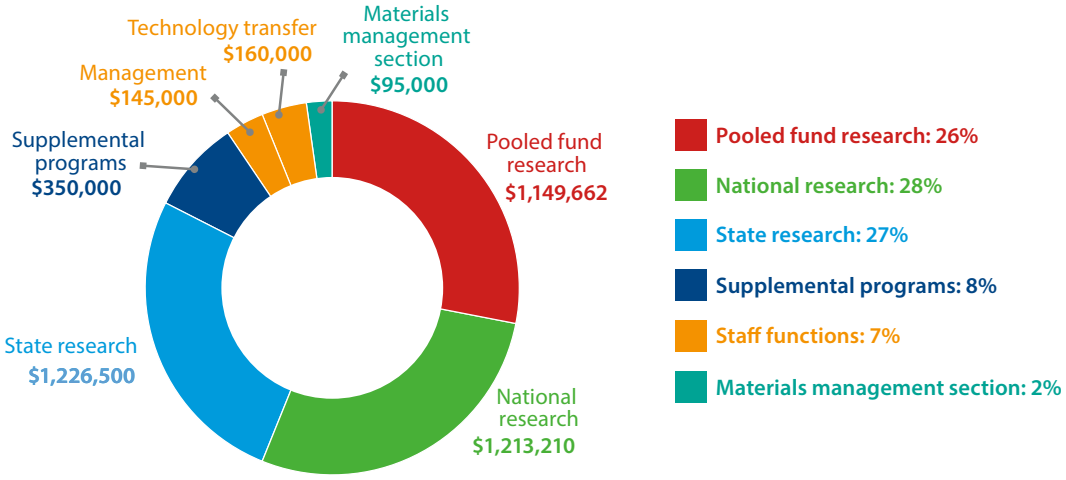
Common acronyms used in this document

AASHTO	American Association of State Highway and Transportation Officials
DBM	(WisDOT) Division of Business Management
DBSI	(WisDOT) Division of Budget and Strategic Initiatives
DMV	(WisDOT) Division of Motor Vehicles
DOT	U.S. Department of Transportation
DSP	(WisDOT) Division of State Patrol
DTIM	(WisDOT) Division of Transportation Investment Management
DTSD	(WisDOT) Division of Transportation System Development
EXEC	(WisDOT) Executive Offices
FFY	Federal Fiscal Year
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
SPR	State Planning and Research Program
TPF	Transportation Pooled Fund
TRB	Transportation Research Board
UW	University of Wisconsin
WHRP	Wisconsin Highway Research Program
WisDOT	Wisconsin Department of Transportation

Program overview

The Wisconsin Department of Transportation (WisDOT) managed a $4.34 million program for research and technology transfer services during federal fiscal year (FFY) 2021. The State Planning and Research Part B (SPR-B) federal program funded 91 percent ($3.96 million) of the program, while state funds covered the remaining nine percent ($0.38 million).

Research program funding



Pooled fund research

The Transportation Pooled Fund (TPF) program allows federal, state and local agencies and other organizations to combine resources to support transportation research studies of common interest. In FFY 2021, WisDOT research led three pooled fund projects and participated in 44 others. These projects include advances in safety and engineering methods and materials. For a full list of pooled fund projects, see pages 9–10.

National research

The department participates in national research initiatives through the Transportation Research Board (TRB), National Cooperative Highway Research Program (NCHRP) and American Association of State Highway Transportation Officials (AASHTO) Technical Services Program.

State research

The Wisconsin Highway Research Program (WHRP), established in 1998 by WisDOT in collaboration with the University of Wisconsin–Madison, aims to better design, build and reconstruct the state's transportation system. The four areas of focus include geotechnics, structures and flexible and rigid pavements. See pages 7–8 for all completed and in-progress projects.

Supplemental programs

WisDOT partners with the University of Wisconsin–Madison's Traffic Operations and Safety (TOPS) Laboratory and the University of Wisconsin-Milwaukee's Institute for Physical Infrastructure and Transportation on research projects.

Staff functions

Efficient management of transportation knowledge and research findings contributes to continuous performance improvement. Research and Library team conducts technology transfer activities and library services to coordinate dissemination of research recommendations to enhance operations within the department.

Materials management section

Funds for WisDOT's Materials Management Section (MMS) internal projects, including the investigation and implementation of new materials and methods, are also included in the research program.

Featured research

Examples of research that contribute to achieving the department's strategic mission are listed below. The realized or anticipated impacts to the state of practice are included for each project, to reaffirm the department's commitment to data-driven decision making through implementation of applied research recommendations.

Recycled Asphalt Binder Study

(WHRP 0092-19-04)

Project Brief and Final Report:
https://wisconsindot.gov/Pages/about-wisdot/research/flex-pave.aspx

The use of recycled asphalt materials (RAM), including reclaimed asphalt pavements (RAP) and recycled asphalt shingles (RAS), has significant economic and environmental benefits that include cost savings, conservation of natural resources and reduction in energy consumption and emissions. The objective of this research was to evaluate how the quantity and quality of RAM affects the performance of binder blends and to determine if WisDOT could allow higher binder replacement contents without sacrificing pavement performance.

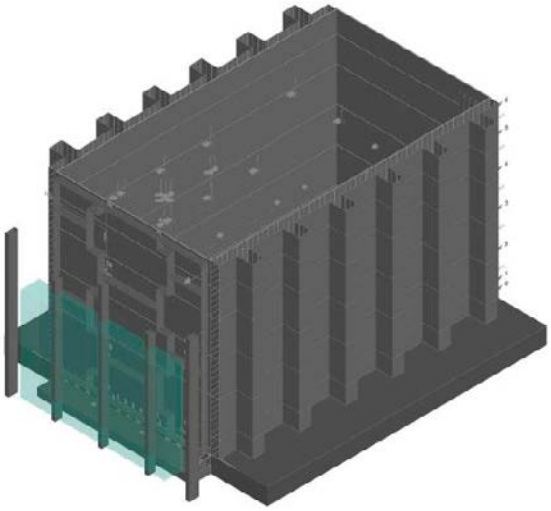
The research team found that adding RAM to virgin binders significantly increased the stiffness of recycled binder blends, which improved rutting resistance but decreased fatigue resistance, thermal cracking resistance and stress relaxation properties. These effects tend to be more pronounced as RAM content increased. However, the degree to which material properties changed depended on RAM source and use of recycled agents.

The results of this research were used to develop a step-by-step guide to evaluate the quality of asphalt blends with high RAM contents which enables WisDOT to approve highly recycled asphalt mixture designs without sacrificing quality.

Mechanically Stabilized Earth (MSE) Wall Backfill Water Infiltration

(WHRP 0092-18-07)

Project Brief and Final Report
https://wisconsindot.gov/Pages/about-wisdot/research/geotech.aspx



Mechanically stabilized earth (MSE) walls are structures comprising layers of compacted backfill and soil reinforcement behind concrete facing. MSE walls can support heavy loads, like traffic, and prevent earth from shifting or spilling out onto roads or rights-of-way. The stability of MSE walls may be compromised in undrained conditions such as during heavy rain, flooding or rapid drawdown. The objective of this research was to quantify how infiltration and drainage correspond with the stability of MSE walls subject to flooding and rapid drawdown.

The research team found that increasing the backfill friction angle from 30 to 35 percent and increasing reinforcement tensile strength increases stability factor of safety in both flooding and rapid drawdown conditions.

The research team produced a series of generalized charts for estimating the extent and timing of infiltration or drainage from flooding and drawdown which will help WisDOT in designing MSE walls near fluctuating bodies of water.

Featured research *(continued)*

Comparison of ASTM Standards for the Evaluation of Geogrid Strength

(WHRP 0092-19-06)

Project Brief and Final Report:
https://wisconsindot.gov/Pages/about-wisdot/research/geotech.aspx

Geogrids are grid-patterned geosynthetic materials used to reinforce soils, retaining walls and other structures. Geogrids interlock with soil, providing stabilization through tension in the ribs and junctions. Geogrid material and aperture shapes vary by manufacturer, and there are multiple test methods for determining strength. ASTM D6637 Method B gained popularity as agencies and producers have found it more representative of geogrid structure and observed load redistribution. The objective of this study was to assess and compare test methods ASTM D4595, ASTM D6637 and ASTM D7737 for determining geogrid tensile strength.

Results show that ASTM D6637 more accurately and consistently represents the tension strength of geogrid materials, with less variability and more accuracy across the roll.

This research allows WisDOT to transition to testing geogrids via method ASTM D6637, which will revise WisDOT's specifications accordingly.

Ground Tire Rubber (GTR) Asphalt Study

(WHRP 0092-19-05)

Project Brief and Final Report:
https://wisconsindot.gov/Pages/about-wisdot/research/flex-pave.aspx

The push for state transportation agencies to recycle ground tire rubber (GTR) into asphalt pavements originated as a strategy for disposing of scrap tires. Rubber slows oxidative aging, and thus the brittleness of asphalt cement that generally increases over time. Performance benefits include increases in rutting resistance, skid resistance, ride quality and pavement service life, and decreases moisture susceptibility, cracking potential and noise levels. The main objective of this research was to develop mixture specifications and testing parameters for incorporating GTR into Wisconsin pavements.

Results show that all GTR mixtures improved pavement performance to varying degrees, and that the biggest challenge in working with GTR mixtures was swelling. Any long-term pavement performance issues will likely appear after five- and 10-year time periods and offer a better perspective on performance.

This research points to the recommendation for WisDOT to update its specifications to be specific to Wisconsin, advancing WisDOT's efforts to successfully implement GTR in hot mix asphalt mixtures.

Featured research *(continued)*

Textured Epoxy Coated and Galvanized Reinforcement to Control Cracking in Concrete Bridges

(WHRP 0092-19-01)

Project Brief and Final Report:
https://wisconsindot.gov/Pages/about-wisdot/research/flex-pave.aspx

Bridge owners have searched for ways to control cracking in concrete bridge decks and components to slow deterioration. This project evaluated the influence of different reinforcing bar surface coatings on control performance in order to provide specifications and guidance for improving crack-control performance.

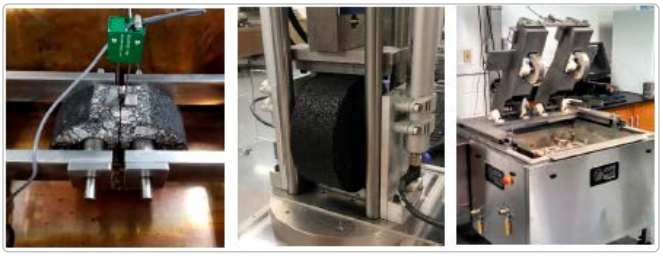
This study considered five different reinforcing bar coatings: black, conventional, epoxy, textured epoxy, hot-dipped galvanized and continuously galvanized. The research team conducted both a series of laboratory tests and field studies.

The research team recommends textured epoxy and hot-dipped galvanized bars as alternatives for reinforcement in concrete bridge decks. Continuously galvanized bars should receive consideration as an alternative reinforcement for concrete bridge decks. Future visits should be made to the bridge used in the field studies to evaluate the long-term performance of the textured epoxy and hot-dipped galvanized reinforcement.

Balanced Mixture Design Implementation Support

(WHRP 0092-20-04)

Project Brief and Final Report
https://wisconsindot.gov/Pages/about-wisdot/research/flex-pave.aspx



The Superpave system is the most commonly used asphalt mixture design system in the United States. WisDOT and several other state transportation agencies share concerns about asphalt durability and cracking issues associated with the system. WisDOT started implementing the regressed air voids approach in 2017, which proved effective.

WisDOT has interest in implementing performance tests for balanced mixture design (BMD) that will better assess resistance to common distresses. This project evaluated performance-based methodologies for asphalt mixture design with the intent of developing a preliminary implementable BMD specification for WisDOT projects.

Interviews with mixture designers did not reveal a consensus on which of the current Superpave volumetric criteria should be relaxed or eliminated for BMD. BMD optimization experiments affirmed that fixing one performance issue can create another elsewhere in the design modification process, highlighting the need for multiple performance tests.

The research team recommends that WisDOT continue using its current specifications for low-traffic mixtures. For medium-traffic, high-traffic and stone matrix asphalt mixtures, the researchers recommend a BMD approach to ensure satisfactory rutting and cracking resistance while allowing for innovation in the design.

Technology transfer and library activities

The Division of Budget and Strategic Initiatives' Research and Library Services Unit provides information services for WisDOT staff and supports implementation of research results.

Synthesis reports

A synthesis report is an evaluation of other state transportation agencies' policies and procedures made by comparing, contrasting and combining information gathered from agencies' websites or through electronic surveys. Four synthesis reports were completed in FFY 2021 on a range of topics, including: transportation equity; diversifying workforce recruitment; and traffic-demand modeling.

Literature searches

A literature search is a systematic and thorough search of all types of published literature to identify a breadth of quality references relevant to a specific topic. Customers apply the collected information to decision making for funding and crafting research efforts and for general policy improvement. Twenty-four literature searches were completed in FFY 2021. Topics included: non-driver mobility issues; freight forecasting; and cold-weather paving challenges.

WisDOT library services

Library staff handled 316 information requests, delivered 369 digital items (books, reports, periodicals and articles) and added 1,539 digital items to the Wisconsin Digital Archives.

Gateway to AASHTO ePublications

The American Association of State and Highway Transportation Officials (AASHTO) publishes many handbooks, design guides, best practices, standards and specifications essential to the operations of all state DOTs. The most popular and expensive publications are digitally secured and can only be retrieved by one point of contact at each state DOT. At WisDOT, Research and Library Services serves this purpose, fielding requests and providing access to staff across the department.

Completed research projects

PROGRAM	PROJECT ID	PERFORMING ORGANIZATION	PRINCIPAL INVESTIGATOR	PROJECT BUDGET	WISDOT PROJECT MANAGER	PROJECT TITLE	IMPLEMENTATION METHOD	COMPLE-TION DATE
WHRP – Geotechnics	0092-18-07	Iowa State University	Basak Bektas	$140,000	Jeffrey Horsfall	Mechanically Stabilized Earth Wall Backfill Water Infiltration	New design method or guidance	7/2021
WHRP – Structures	0092-19-01	Clemson University	Brandon Ross	$180,000	David Kiekbusch	Textured Epoxy Coated and Galvanized Reinforcement to Reduce Cracking in Concrete Bridge Decks and Components	New product implementation	7/2021
WHRP – Flexible Pavements	0092-19-04	NCAT at Auburn University	Carolina Rodezno	$200,000	Erik Lyngdal	Recycled Asphalt Binder Study	New design method or guidance	5/2021
WHRP – Flexible Pavements	0092-19-05	Behnke Materials Engineering	Signe Reichelt	$165,000	Erik Lyngdal	Rubber Asphalt Study for Wisconsin	New product implementation	10/2020
WHRP – Geotech	0092-19-06	University of Wisconsin – Milwaukee	Elhajjar Rani	$100,000	Andrew Zimmer	Comparison of ASTM Standards for the Evaluation of Geogrid Strength	Revise a specification	2/2021
WHRP – Flexible Pavements	0092-20-04	NCAT at Auburn University	Randy West	$150,000	Steve Hefel	Balanced Mixture Design Implementa-tion Support	Develop a new acceptance procedure for Hot Mix Asphalt	3/2021

Ongoing research projects

PROGRAM	PROJECT ID	PERFORMING ORGANIZATION	PRINCIPAL INVESTIGATOR	PROJECT BUDGET	WISDOT PROJECT MANAGER	PROJECT TITLE	ANTICIPATED IMPLEMENTATION STATUS
WHRP – Rigid – Pavement	0092-17-07	Behnke Materials Engineering, L.L.C.	Signe Reichelt	$275,000	Myungook Kang	Evaluation of Current WI Mixes Using Performance Engineered Mixtures Testing Protocols	Revise a specification
WHRP – Structures	0092-19-02	CTL Group - Materials & Mechanics	Jose Pacheco	$194,555	William Oliva	Internal Curing of Bridge Decks and Concrete Pavement to Reduce Cracking	Revise a specification
WHRP – Rigid Pavement	0092-19-03	University of Wisconsin - Madison	Pavana Prabhakar	$150,000	Myungook Kang	Roadway Concrete Barrier Design and Performance – Material Durability Issue	New design method or guidance
WHRP – Structures	0092-20-01	Iowa State University	Brent Phares	$220,000	Alex Pence	Analytical and Testing Methods for Rating Longitudinal Laminated Timber Slab Bridges	New design method or guidance
WHRP – Rigid Pavement	0092-20-02	Applied Research Associates, Inc.	Shreenath Rao	$200,000	Myungook Kang	Evaluation of Concrete Pavement Buckling in Wisconsin	New design method or guidance
WHRP – Flexible Pavement	0092-20-03	Applied Research Associates, Inc.	Harold Von Quintus	$215,000	Erik Lyngdal	Expansion of AASHTOWare ME Design Inputs	New product implementation
WHRP – Geotech	0092-20-05	University of Wisconsin - Milwaukee	Hani Titi	$175,000	Erik Lyngdal	Quality Testing of Wisconsin Aggregates	Revise a specification
WHRP – Structures	0092-21-01	Wiss, Janey, Elstner Associates Inc.	John Pearson	$150,000	Adam Swierczek	Development of Design Procedures for Concrete Adhesive Anchors	New design method or guidance
WHRP – Structures	0092-21-02	Northwestern University	James Hambleton	$80,000	Steve Neary	Optimizing Bridge Abutment Slope Protection at Stream Crossings	Revise a specification
WHRP – Rigid Pavements	0092-21-03	University of Wisconsin – Platteville	Danny Xiao	$150,00	Kevin McMullen	Evaluating the Impact of Anti-Icing Solutions on Concrete Durability	Revise a specification
WHRP – Flexible Pavements	0092-21-04	Advanced Asphalt Technologies, LLC	Donald Christensen	$175,000	Tirupan Mandal	Interlayer Mixture Design	New product implementation
WHRP – Flexible Pavements	0092-21-05	University of Wisconsin – Madison	Hussain Bahia	$80,000	Daniel Kopacz	Material Specifications for Longitudinal Joint Construction, Remediation, and Maintenance	New design method or guidance
WHRP - Geotech	0092-21-06	BGC Engineering USA, Inc.	Scott Anderson	$140,868	Dave Staab	Geotechnical Asset Management for Slopes	New product implementation

Pooled fund participation

PROJECT NUMBER	TITLE	FFY 2021 FUNDING AMOUNT	WISDOT TECHNICAL REPRESENTATIVE	LEAD AGENCY/ STATE
TPF-5(176)	Traffic Analysis and Simulation	N/A	Vicki Haskell	FHWA
TPF-5(183)	Improving the Foundation Layers for Concrete Pavements	N/A	Jeff Horsfall	Iowa
TPF-5(255)	Highway Safety Manual Implementation	N/A	Brian Porter	FHWA
TPF-5(267)	Accelerated Testing for the NCAT Pavement Test Track	N/A	Steve Krebs Barry Paye	Alabama
TPF-5(281)	Center for the Aging Infrastructure: Steel Bridge Research, Inspection, Training and Education Engineering Center – SBRITE (Purdue)	N/A	Scot Becker	Indiana
TPF-5(283)	The Influence of Vehicular Live Loads on Bridge Performance	N/A	Alex Pence	FHWA
TPF-5(305)	Regional and National Implementation and Coordination of ME Design	N/A	Tirupan Mandal	FHWA
TPF-5(316)	Traffic Control Device Consortium	N/A	Jay Hille	FHWA
TPF-5(317)	Evaluation of Low Cost Safety Improvements	N/A	Brian Porter	FHWA
TPF-5(319)	Transportation Management Center Pooled Fund Study	$50,000	Stacey Pierce	FHWA
TPF-5(335)	2016-2020 Biennial Asset Management Conference and Training on Implementation Strategies	N/A	Scot Becker Justin Shell	Iowa
TPF-5(341)	National Road Research Alliance (NRRA)	N/A	Barry Paye	Minnesota
TPF-5(347)	Development of Maintenance Decision Support System (MDSS)	$30,000	Mike Adams	South Dakota
TPF-5(351)	Self De-icing LED Signals	N/A	Brian Klipstein	Kansas
TPF-5(352)	Recycled Materials Resource Center (RMRC – 4th Generation	N/A	Barry Paye	Wisconsin
TPF-5(353)	Clear Roads Phase II	$25,000	Emil Juni	Minnesota
TPF-5(359)	Evaluating New Technologies for Roads Program Initiatives in Safety and Efficiency (ENTERPRISE) Phase 2	$30,000	David Karnes	Michigan
TPF-5(368)	Performance Engineered Concrete Paving Mixtures	$15,000	Jim Parry	Iowa
TPF-5(370)	Fostering Innovation in Pedestrian and Bicycle Transportation Pooled Fund Study	$25,000	Jill Mrotek-Glenzinski	FHWA
TPF-5(372)	Building Information Modeling (BIM) for Bridges and Structures	$40,000	Scot Becker	Iowa
TPF-5(374)	Accelerated Performance Testing on the 2018 NCAT Pavement Test Track with MnROAD Research	N/A	Steve Hefel	Alabama
TPF-5(375)	National Partnership to Determine the Life Extending Benefit Curves of Pavement Preservation Techniques (MnROAD/NCAT Joint Study Phase 2)	$50,000	Myungook Kang	Minnesota
TPF-5(377)	Enhanced Traffic Signal Performance Measures	N/A	Jeremy Iwen	Indiana

Pooled fund participation (continued)

PROJECT NUMBER	TITLE	FFY 2021 FUNDING AMOUNT	WISDOT TECHNICAL REPRESENTATIVE	LEAD AGENCY/ STATE
TPF-5(379)	Technology Exchange on Low Volume Road Design, Construction and Maintenance	N/A	Rodney Taylor Justin Shell	Iowa
TPF-5(381)	Evaluation of Lateral Pile Resistance Near MSE Walls at a Dedicated Wall Site Phase 2	N/A	Jeff Horsfall	Utah
TPF-5(382)	Drivers Failing to Yield at Multi-Lane Roundabout Exits	N/A	Rebecca Szymkowski	FHWA
TPF-5(385)	Pavement Structural Evaluation with Traffic Speed Deflection Devices (TSDDs)	$77,000	Myungook Kang	Virginia
TPF-5(388)	Developing Implementation Strategies for Risk Based Inspection (RBI)	N/A	Scot Becker	Missouri
TPF-5(389)	Connected Vehicle Pooled Fund Study	$50,000	Anne Reshadi	Virginia
TPF-5(395)	Traffic Disruption-Free Bridge Inspection Initiative with Robotic Systems	$50,000	Rick Marz	Missouri
TPF-5(396)	Mid-America Freight Coalition Phase 3 (MAFC-3)	$37,000	Shaun Destrampe	Wisconsin
TPF-5(399)	Improve Pavement Surface Distress and Transverse Profile Data Collection and Analysis, Phase 2	$20,000	Andrew Schilling	FHWA
TPF-5(430)	Midwest Roadside Safety Pooled Fund Program	$65,000	Erik Emerson	Nebraska
TPF-5(432)	Midwest Bridge Preservation Partnership	N/A	Bill Oliva	Wisconsin
TPF-5(435)	Aurora Program	$25,000	Mike Adams	Iowa
TPF-5(437)	Technology Transfer Concrete Consortium	$8,000	Jim Parry	Iowa
TPF-5(438)	Smart Work Zone Deployment Initiative	$25,000	Erin Schwark	Iowa
TPF-5(441)	No Boundaries Transportation Maintenance Innovations	$10,000	Chris Ohm	Colorado
TPF-5(442)	Transportation Research and Connectivity	$15,000	John Cherney	Oklahoma
TPF-5(443)	Continuous Asphalt Mixture Compaction Assessment using Density Profiling System	$12,500	Michael Bohn	Minnesota
TPF-5(447)	Traffic Control Device (TCD) Consortium III	$10,000	Matt Rauch	FHWA
TPF-5(448)	Integrating Construction Practices and Weather into Freeze Thaw Specifics	$20,000	Jim Parry	Oklahoma
TPF-5(460)	Flood-Frequency Analysis in the Midwest: Addressing Potential Nonstationary Annual Peak-Flow Records	$55,600	Steve Neary	South Dakota
TPF-5(465)	Consortium for Asphalt Pavement Research and Implementation (CAPRI)	$10,000	Steve Hefel	Alabama
TPF-5(466)	National Road Research Alliance (NRRA) Phase II	$150,000	Barry Paye	Minnesota
TPF-5(467)	Research Project Tracking System	$3,500	Ethan Severson	Kentucky
TPF-5(472)	2021 Innovations in Freight Data Workshop	$14,000	Dan Thyes Elizabeth Peckham	Iowa
TPF-5(478)	Demonstration to Advance New Pavement Technologies Pooled Fund	$10,000	Erik Lyngdal	FHWA

Committees and contacts

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Research Brief

Wisconsin Highway Research Program
Project 0092-18-07
October 2021

Mechanically Stabilized Earth (MSE) Wall Backfill Water Infiltration

Research Objectives

- Quantify how infiltration and drainage correspond with the stability of mechanically stabilized earth (MSE) walls subject to flooding and rapid drawdown

Research Benefits

- Produced generalized charts for estimating the extent and timing of infiltration or drainage from flooding and drawdown and corresponding impacts to wall stability

Principal Investigator

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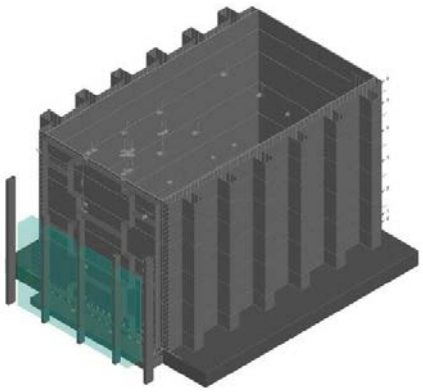
Background

Mechanically stabilized earth (MSE) walls are structures comprising layers of compacted backfill and soil reinforcement behind concrete facing. MSE walls can support heavy loads, like traffic, and prevent earth from shifting or spilling out onto roads or rights-of-way. The stability of MSE walls may be compromised in undrained conditions such as during heavy rain, flooding or rapid drawdown. For MSE walls subject to inundation, such as those located adjacent to rivers, canals, detention basins or retention basins, understanding pore pressure evolution during infiltration and drainage of the backfill soils and the corresponding implications to wall stability is essential. The objective of this research was to quantify how infiltration and drainage correspond with the stability of MSE walls subject to flooding and rapid drawdown.

Methodology

Two full-scale MSE walls were constructed at an indoor geostructure testing facility located at the Royal Military College of Canada. Both walls had the same dimensions, facing material, reinforcement (spacing and material) and boundary conditions; however, one wall had sand backfill, and the other wall had sand with gravel backfill. Instrumentation was installed to measure pore pressure distribution; moisture content distribution; strain in the reinforcement layers; connection loads; wall deflections; horizontal and vertical toe loads; and earth pressures during flooding and rapid drawdown.

The research team also conducted numerical simulations using model geometry and material properties calibrated to match the full-scale physical test results. Stability factor of safety during infiltration and drawdown was analyzed, and parametric studies were conducted to examine how backfill hydraulic conductivity, flood height and length of the backfill affect time to backfill saturation and wall stability during flooding and drawdown.



Full-scale MSE wall with water reservoir to simulate flooding and rapid drawdown. Model dimensions are 3.6m H X 3.4m W X 6m L.

"This project provides an analysis method for evaluating MSE walls under flooding and drawdown conditions, which can be used in designing MSE walls near fluctuating bodies of water."
– Jeffery Horsfall, WisDOT

Interested in finding out more?

Final report is available at:
WisDOT Research website

Results

The stability factor of safety increased immediately after flooding and gradually decreased to the value before flooding as the backfill was saturated. However, it decreased immediately after rapid drawdown and gradually increased to the value before rapid drawdown as pore water pressure dissipated from the backfill. The relative increase and decrease in the stability factor of safety after flooding and rapid drawdown correlated with the water pressure head in front of the walls relative to the height of the walls. Results showed the stability factor of safety can increase by up to 105 percent immediately after flooding and decrease by up to 25 percent after rapid drawdown when the ratio of the pressure head to wall height increases to one.

The percent rise or drop in the stability factor of safety presented are extreme values that reflect sudden rise or drawdown of reservoir water levels. The gradual rise or drawdown that would allow some level of hydrostatic pressure balance during flooding or pore pressure dissipation during rapid drawdown in the backfill would result in less change in the stability factor of safety. Increasing the reinforcement tensile strength increased the stability factor of safety for both flooding and rapid drawdown. The increase of backfill friction angle from 30 to 35 degrees increased the stability factor of safety by about 20 percent for both flooding and rapid drawdown conditions.

Recommendations for implementation

The research team produced a series of generalized charts for estimating the extent and timing of infiltration or drainage from flooding and drawdown and corresponding impacts to wall stability. For the wall type examined in this research, the team recommended the following procedure:

1. Calculate the stability factor of safety during steady-state seepage based on the backfill strength properties, geometry and reinforcement layout and strength properties.
2. Select the appropriate graph for factor of safety at a given time for backfill hydraulic conductivity, applied pressure head ratio and hydraulic gradient.
3. In the selected graph, choose or interpolate the change in the factor of safety at a given time.
4. Compare the new factor of safety with the minimum design factor of safety.

Unique models should be developed for walls with different reinforcement layout, slope and backfill material types.

This brief summarizes Project 0092-18-07,
"Mechanically Stabilized Earth (MSE) Wall Backfill Water Infiltration"
Wisconsin Highway Research Program

Recycled Asphalt Binder Study

Research Objectives

- Investigate how the quantity and quality of recycled asphalt materials affects the performance of resultant binders
- Validate resultant binder test results using mixture performance testing
- Develop procedure for evaluating the quality of recycled asphalt materials and virgin asphalt binder blends used in Wisconsin

Research Benefits

- Developed a step-by-step guide to evaluate the quality of asphalt blends with high recycled asphalt materials content
- Developed guidance on using recycling agents to balance rutting and cracking performance of recycled asphalt mixtures

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Background

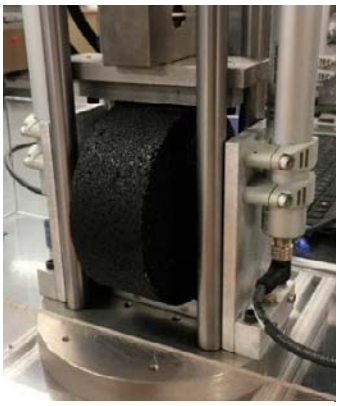
The use of recycled asphalt materials (RAM), including reclaimed asphalt pavements (RAP) and recycled asphalt shingles (RAS), has significant economic and environmental benefits that include cost savings, conservation of natural resources and reduction in energy consumption and emissions. Increasing the amount of RAM in asphalt mixtures typically increases rutting resistance but can also increase susceptibility to cracking and durability issues.

Current Wisconsin Department of Transportation (WisDOT) specifications limit the quantity of RAM that can be included in new pavement. WisDOT allows up to 40 percent of virgin asphalt binder to be replaced with RAM binder in lower pavement layers and 25 percent in upper layers. The objective of this research was to evaluate how the quantity and quality of RAM affects the performance of binder blends and to determine if a higher binder replacement contents could be allowed without sacrificing pavement performance.

Methodology

The research team conducted rheological and chemical tests on asphalt blends with various RAM contents to investigate the effect of RAP/RAS binders on the properties of the blends. In addition, blends containing recycling agents (RAs) were tested to assess the ability of the RAs to improve the properties of the blends. These tests included performance grading (PG), multiple stress creep recovery (MSCR), linear amplitude sweep (LAS), Fourier transform infrared spectroscopy (FTIR) and gel permeation chromatography (GPC).

Binder results were validated with performance testing of mixtures. Mixtures were tested for rutting resistance (Hamburg Wheel Tracking Test [HWTT]) after being subjected to short-term oven aging (STOA), and cracking resistance at intermediate temperature (Indirect Tensile Asphalt Cracking Test [IDEAL-CT]), and low temperature (Disc-Shaped Compact Tension Test [DCT]) after being subjected to STOA plus long-term oven aging (LTOA).In addition, dynamic modulus (|E*|) testing was conducted after STOA and LTOA to assess the stiffness and aging resistance of the mixtures.



IDEAL-CT measuring resistance to cracking at intermediate temperatures.

"Deliverables from NCAT will enable WisDOT to approve use of highly recycled asphalt mixture designs without sacrificing quality."
– Erik Lyngdal, WisDOT

Interested in finding out more?

Final report is available at:
WisDOT Research website

Results

The addition of RAM to virgin binders significantly increased the stiffness of the resultant recycled binder blends, which improved rutting resistance but decreased fatigue resistance, thermal cracking resistance and stress relaxation properties. These effects tend to be more pronounced as RAM content increased. However, the degree to which material properties changed depended on RAM source and use of recycled agents.

|E*| testing showed mixed results for rejuvenated mixtures after STOA and LTOA when compared to the control mixtures (with unmodified and modified binders). Some of the rejuvenated mixtures showed higher stiffnesses while others showed lower stiffness at different frequencies and temperatures.

HWTT and DCT testing of mixtures with RAM and RAs exceeded the preliminary test thresholds for Wisconsin mixtures recommended in Wisconsin Highway Research Program (WHRP) *Balanced Mixture Design Implementation Support* project, while the IDEAL-CT results showed that some of the recycled mixtures with RAs narrowly failed the preliminary IDEAL-CT index criteria.

Recommendations for implementation

The results of this research were used to develop a step-by-step guide to evaluate the quality of asphalt blends with high RAM contents, and to guide the use of RAs to produce recycled asphalt mixtures with balanced rutting and cracking performance. The design steps are summarized as follows:

1. Determine the high-temperature and low-temperature performance grade (PG) of the component materials to be used for blending.
2. Determine the RA dosage by targeting the low-temperature PG and ΔTc (relaxation properties) for the recycled binder blends after being subjected to rolling thin-film oven aging (RTFO) and 40 hours in a pressure aging vessel (PAV).
3. Perform the rheological characterization of the recycled binder blend with RA at the dosage selected in step 2, using standard test methods (AASHTO M320, AASHTO M332) and data analysis.
4. Conduct mixture performance tests to ensure compliance with the BMD performance criteria.

The complete step-by step guide can be found in the final report.

This brief summarizes Project 0092-19-04,
"Recycled Asphalt Binder Study"
Wisconsin Highway Research Program

Research Brief

Wisconsin Highway Research Program
Project 0092-19-05
February 2021

Ground Tire Rubber (GTR) Asphalt Study

Research Objectives

- Develop specifications and testing parameters for GTR-modified asphalt mixtures
- Perform cost-benefit estimates of incorporating GTR in WisDOT pavements
- Identify challenges of incorporating rubber modified mixtures into practice

Research Benefits

- Determined that each tested GTR mixture offers improved performance over the control mixture
- Affirmed economic benefit of incorporating GTR into asphalt pavements
- Recommended Wisconsin-specific GTR mixture specifications and testing parameters

Background

The push for state transportation agencies to recycle ground tire rubber (GTR) into asphalt pavements originated as a strategy for disposing of scrap tires. The practice continues in states that have found the benefits to extend beyond waste reduction to improved performance and service life of pavements. Rubber slows oxidative aging and therefore the brittleness of asphalt cement that generally increases over time. Performance benefits include increases in rutting resistance, skid resistance, ride quality and pavement service life and decreases moisture susceptibility, cracking potential and noise levels. WisDOT has not yet specified or placed GTR mixtures. The main objective of this research was to develop mixture specifications and testing parameters for incorporating GTR in Wisconsin pavements.

Methodology

A special provision (SPV) was drafted outlining mixture design guidance for terminal and dry process GTR. The SPV included Hamburg Wheel Tracking, Disk-Shaped Compact Tension (DCT) and Illinois Flexibility Index (I-FIT) performance tests. Short- and long-term aging was performed on DCT and I-FIT samples to determine long-term performance. Test strips were constructed on USH 51 consisting of control, terminal blend (TB), terminal blend hybrid (TBH) and dry process (DP) sections. A preliminary pavement distress survey was performed to quantify pavement distresses before construction of the overlay test sections. Another pavement distress survey was performed approximately one year after construction. A cost-benefit analysis was performed comparing bid prices with improved performance compared to the control.

Dry crumb rubber addition system at plant

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"This project advances WisDOT's efforts to successfully implement ground tire rubber in hot mix asphalt mixtures."
– Dan Kopacz, WisDOT

Interested in finding out more?

Final report is available at:
WisDOT Research website

Results

All GTR mixtures improved pavement performance to varying degrees. TBH and TB mixtures met or exceeded the performance of the control in both cold- and intermediate-temperature cracking resistance and rutting resistance. The TBH mixture was the most economical in terms of performance per dollar spent when compared to the control. The biggest challenge in working with GTR mixtures was swelling. While the DP mixture costs less per ton than the control mixture, it was more difficult to work with and exhibited far more variability in testing.

Any long-term pavement performance issues will likely appear after five- and ten-year time periods and offer a better perspective on which process of the rubber-modification performs best.

Recommendations for implementation

The research team advises WisDOT to specify TB or TBH mixtures, as they both offer significant improvements in every metric at an economical cost. The TBH, however, may be the most economical, since it offers improved rutting resistance; substantially better low-temperature cracking performance; and a similar flexibility index in the short and long term for only $3.59 more per ton than the control. Additional condition surveys of the test sections should be taken after five and 10 years in service to better track and understand long-term performance of these mixtures.

WisDOT specifications consider "modifiers" separate from "additives." Both are inclusions in an asphalt mixture; the former changes binder performance grade (PG), and the latter does not. Depending on the blend, GTR could be considered either a modifier or additive. If WisDOT chooses to use PG grade as the specification equivalency standard, TB processes are recommended substitutes for any type of mixture. DP is recommended for stone matrix asphalt mixtures only. Specifying by a performance testing equivalency would enable WisDOT to allow contractors either TB or DP, as long as they meet the required performance parameters. This type of specification allows the most options for contractors and, in turn, could provide more competitive bid prices.

The research team also advises WisDOT update its specifications on GTR material quality, plant modifications, mix design procedures, verification mix testing and performance test methods.

This brief summarizes Project 0092-19-05,
"Rubber Asphalt Study for Wisconsin"
Wisconsin Highway Research Program

Research Brief

Wisconsin Highway Research Program
Project 0092-19-06
September 2021

Comparison of ASTM Standards for the Evaluation of Geogrid Strength

Research Objectives

- Assess and compare test methods ASTM D4595, ASTM D6637 and ASTM D7737 for determining geogrid tensile strength
- Determine minimum standard guidelines based on ASTM D6637 and ASTM D7737
- Provide recommendations to WisDOT on geogrid tension strength values for implementation in geogrid specifications

Research Benefits

- Concluded ASTM D6637 more accurately and consistently represents the tension strength of geogrid materials than ASTM D4595.
- Recommended average minimum tension strength for accepting geogrids in WisDOT projects
- Recommended sampling from both edges and center of geogrid rolls to reduce variability in testing

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Background

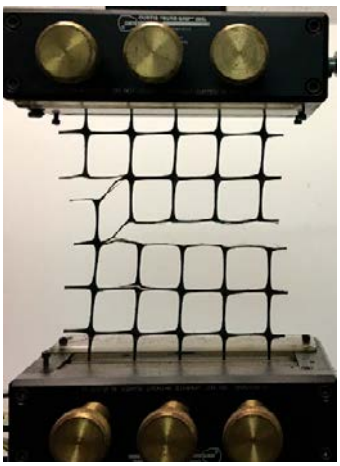
Geogrids are grid-patterned geosynthetic materials used to reinforce soils, retaining walls and other structures. Geogrids interlock with soil, providing stabilization through tension in the ribs and junctions.

Geogrid material and aperture shapes vary by manufacturer, and there are multiple test methods for determining strength. WisDOT currently uses ASTM D4595, which was originally developed for geotextiles, a different type of geosynthetic. ASTM D6637 Method B has gained popularity, as agencies and producers have found it more representative of geogrid structure and observed load redistribution. The objective of this study was to assess and compare test methods ASTM D4595, ASTM D6637 and ASTM D7737 for determining geogrid tensile strength.

Methodology

The research team investigated the application of ASTM D4595, ASTM D6637 (methods A and B) and ASTM D7737 on 987 geogrids specimens taken from 31 geogrid rolls from nine manufacturers supplying WisDOT projects. Specimens were primarily biaxial types, but also included uniaxial and triaxial types.

Specimens for the ASTM D4595 are eight inches tall and at least eight inches wide; this method does not take into account the number of ribs per specimen. ASTM D6637 – Method A measures six single-rib specimens at least eight inches long from junction to junction. ASTM D6637 – Method B is a multi-rib test, where specimens must have five parallel ribs eight inches or greater in length in the direction in which the specimen is going to be tested. ASTM D7737 tests a single junction in isolation from the ribs. In each test, tensile loads are applied until rupture to determine strength.



A biaxial geogrid ruptures during ASTM D6637 Method B testing.

"This research will allow WisDOT to transition to testing geogrids via method ASTM 6637 and revise our specifications accordingly."
– Andrew Zimmer, WisDOT

Interested in finding out more?

Final report is available at:
WisDOT Research website

Results

Current WisDOT specifications based on ASTM D4595 standard procedure require geogrid tension strength at five percent elongation to achieve a minimum average of 450 lb/ft for both machine and cross machine direction. Based on statistical analysis results, 3.6 percent of geogrid specimens will not pass the current WisDOT tension strength specifications (based on ASTM D6637), and 2.77 percent of geogrid specimens will not pass the corresponding tension strength threshold based on ASTM D6637 Method B.

Results show ASTM D6637 results in less scatter in tension strength compared to ASTM D4595, with the strength at five percent elongation yielding consistent results and accounting for the material nonlinearity. ASTM D6637 Method A tracks the results with ASTM D6637 Method B when ultimate strengths are used, but not when using five percent elongation, which complicates correlation between the two methods. Method A also does not capture variability in aperture sizes.

Statistical analysis conducted on biaxial tension strength test results at five percent elongation, including the use of Monte Carlo simulations based on ASTM D4595 and D6637 Method A and Method B, exhibit a lognormal distribution. A simulation using 10,000 geogrid tension tests showed consistency between lognormal distribution, based on the actual test results and simulated test results for both methods.

Junction strength from ASTM D7737 showed consistently favorable junction strength compared to rib tension strength ASTM D6637 in all test specimens examined.

Recommendations for implementation

The research team concluded that ASTM D6637 more accurately and consistently represents the tension strength of geogrid materials, with less variability and more accuracy across the roll, than ASTM D4595. The team recommends an average minimum tension strength of 500 lb/ft for biaxial geogrid in both machine and cross machine directions based on ASTM D6637 Method B for accepting geogrid in WisDOT projects for subgrade improvement and stabilization and base reinforcement.

Variability in tension strength of a geogrid roll can be captured by sampling from both edges and center of the roll. While weight per unit area of the geogrid can be correlated to the tension strength, it is not recommended that the weight per unit area be used as a criterion for geogrid material selection to indicate tension strength. Variability in machine and cross-machine direction showed the importance of testing both directions.

This brief summarizes Project 0092-19-06,
"Comparison of ASTM Standards for the Evaluation of Geogrid Strength"
Wisconsin Highway Research Program

Research Brief

Wisconsin Highway Research Program
Project 0092-19-01
January 2022

Textured Epoxy Coated and Galvanized Reinforcement to Control Cracking in Concrete Bridges

Research Objectives

- Evaluate the influence of different reinforcing bar surface coatings on crack control performance
- Provide specs and guidelines for improving crack-control performance

Research Benefits

- Develop an understanding of the crack control performance advantages and disadvantages of reinforcement surface texture
- Develop specifications for the potential use of textured reinforcement on Wisconsin Projects

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Background

Bridge owners have searched for ways to control cracking of concrete bridge decks and components to slow deterioration. While some degree of cracking is generally expected and accepted, it is desirable to minimize the cracking to reduce the intrusion of water and deicing chemicals into the concrete. This project evaluated the influence of different reinforcing bar surface coatings on crack control performance.

Methodology

Five different reinforcing bar coatings were considered: black (uncoated), conventional (smooth) epoxy, textured epoxy, hot-dipped galvanized and continuously galvanized coatings.

Five different series of laboratory tests were conducted to evaluate the impact of coatings on bar-concrete bond, static flexural cracking, cyclic flexural cracking and shrinkage cracking.

Two field studies were conducted. The same bridge construction project was used for both studies, with the first study focusing on the cast-in-place concrete bridge deck and the second focusing on the precast-pretensioned concrete girders. Half of the concrete deck was reinforced with textured epoxy-coated bars and the other half was reinforced with hot-dipped galvanized bars.

In the second field study, smooth epoxy, textured epoxy, and hot-dipped galvanized bars were alternately used as confinement reinforcement in the girders' bottom flanges. End region cracks were compared in the days following prestress transfer.

Bridge Deck Reinforcement (Hot-Dipped Galvanized / Textured Epoxy Coated)

"This research gives WisDOT a better understanding of the influence reinforcement surface texture has on controlling cracks in concrete. This project also developed a specification for future implementation of textured epoxy-coated bars."
– James Luebke, WisDOT

Interested in finding out more?

Final report is available at:
WisDOT Research website

Results

Table 1 – Summary of crack control performance of bar types. Percentages are relative to the average performance of all bar types in comparable tests.

Bar Type	Performance in Load Cracking Tests	Performance in Shrinkage Cracking Tests
Black (uncoated)	10% better	2% worse
Textured epoxy-coated	15% better	15% better
Smooth epoxy-coated	27% worse	8% worse
Hot-dipped galvanized	Not tested	5% better
Continuously galvanized	3% worse	8% worse

Recommendations for implementation

Based on the results of the project, the research team makes the following recommendations:

- Textured epoxy and hot-dipped galvanized bars provided superior crack control performance in laboratory tests relative to the smooth epoxy bars. Textured epoxy and hot-dipped galvanized bars are recommended as alternatives for reinforcement in concrete bridge decks.
- Continuously galvanized bars performed the same as or better than the smooth epoxy bars in lab tests. Continuously galvanized bars should receive consideration as an alternative reinforcement for concrete bridge decks.
- Laboratory and field tests should be conducted to compare alternative bar coatings' corrosion mitigation effects and life-cycle costs. These topics are beyond the scope of the current project; however, they are essential criteria for selecting reinforcement coatings.
- The use of textured epoxy-coated and hot-dipped galvanized bars as confinement reinforcement in precast concrete girders is neither encouraged nor discouraged. These alternative bars did not provide consistent advantages or disadvantages in the field study.
- Future visits should be made to the case study bridge to evaluate the long-term performance of the textured-epoxy and hot-dipped galvanized reinforcement. Such visits should evaluate crack control and the extent of and rebar corrosion.

This brief summarizes Project 0092-19-01,
"Textured Epoxy Coated and Galvanized Reinforcement to Reduce Cracking in Concrete Bridge Decks and Components"
Wisconsin Highway Research Program

Research Brief

Wisconsin Highway Research Program
Project 0092-20-04
November 2021

Balanced Mixture Design Implementation Support

Research Objectives

- Evaluate performance-based methodologies for asphalt mixture design
- Develop preliminary balanced mixture design (BMD) specifications

Research Benefits

- Recommended BMD specifications for stone matrix asphalt and low-, medium- and high-traffic mixtures
- Identified several successful mixture design modification strategies
- Highlighted opportunities for asphalt industry innovation

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Background

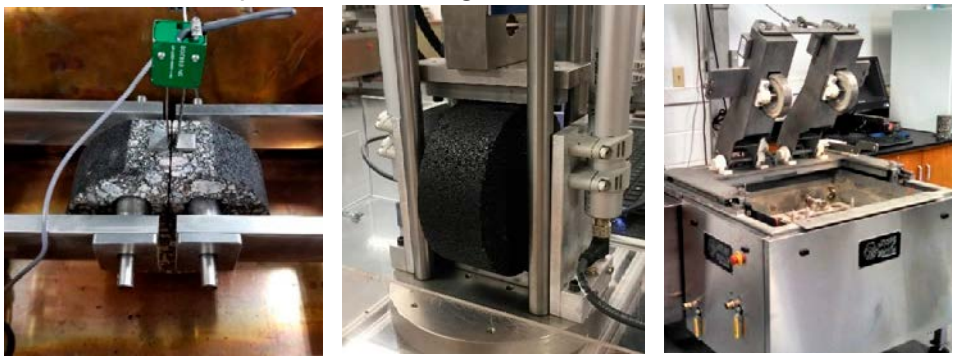
The Superpave system is the most commonly used asphalt mixture design system in the United States. WisDOT and several other state transportation agencies share concerns of asphalt durability and cracking issues associated with the system. To address these issues, WisDOT started implementing the regressed air voids approach in 2017, which was proved effective in improving cracking resistance without compromising rutting resistance in Wisconsin Highway Research Program (WHRP) project 0092-16-06 *Regressing Air Voids for Balanced HMA Mix Design Study.* This modified Superpave approach still has significant limitations that hinder innovations and lead to an unacceptable range of field performance for current asphalt pavements.

WisDOT has interest in implementing performance tests for balanced mixture design (BMD) that will better assess resistance to common distresses and enable designers to better utilize sustainable and innovative materials. The objective of this research project was to evaluate performance-based methodologies for asphalt mixture design with the intent of developing a preliminary implementable BMD specification for WisDOT projects.

Methodology

The research team interviewed Wisconsin mixture designers, conducted a BMD workshop, benchmarked existing WisDOT designs, modified selected designs for improved performance and conducted a cost analysis of design modifications.

Mixture resistance to common distresses was assessed using Hamburg Wheel Tracking Testing (HWTT) to evaluate rutting and moisture resistance; the Indirect Tensile Asphalt Cracking Testing (IDEAL-CT) to evaluate intermediate-temperature cracking resistance; and the Disc-shaped Compact Tension (DCT) testing to evaluate low-temperature cracking resistance.



Specimen testing with (from left to right) DCT, IDEAL-CT and HWTT.

"This research identifies important aspects of performance testing benchmarking and specification development that Wisconsin will need to move toward implementation of Balanced Mix Designs."
– Steven Hefel, WisDOT

Interested in finding out more?

Final report is available at:
WisDOT Research website

Results

The interviews of mixture designers revealed no consensus on which of the current Superpave volumetric criteria should be relaxed or eliminated for BMD. Although designers recognized the benefits of implementing BMD, they also expressed concerns about the selection of performance tests and criteria; changes to the current practice with design and quality assurance; and several other implementation challenges.

The BMD optimization experiments affirmed that fixing one performance issue can create another performance issue elsewhere in the design modification process, highlighting the need for multiple performance tests to ensure a balance between rutting, cracking and moisture damage resistance. Several successful design modification strategies were identified through performance testing, such as using a rejuvenator and increasing the asphalt content to improve IDEAL-CT results. In another case, eliminating recycled asphalt shingles was found to be less cost effective than increasing the asphalt content for improving cracking resistance.

Recommendations for implementation

The research team recommends WisDOT continue using its current specifications with the regressed air voids approach for the design of low-traffic mixtures. For medium-traffic, high-traffic and stone matrix asphalt (SMA) mixtures, the researchers recommended the BMD approach referred to as performance-modified volumetric mix design and provided preliminary criteria of the HWTT, IDEAL-CT, and DCT. This BMD approach will help ensure satisfactory rutting and cracking resistance while providing designers opportunity to innovate to meet performance test requirements.

Cost analysis of the design modifications indicated that material costs could increase by approximately eight to 22 percent to meet proposed criteria. For asphalt contractors to remain competitive in a low-bid environment, there is need to explore different design modification strategies to determine the most cost-effective options for materials.

This brief summarizes Project 0092-20-04,
"Balanced Mixture Design Implementation Support"
Wisconsin Highway Research Program

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