WisDOT RESEARCH PROGRAM

WISCONSIN DEPARTMENT OF TRANSPORTATION

Annual 2017 Report

Foreword

I am pleased to present the Wisconsin Department of Transportation (WisDOT) 2017 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." The department's MAPSS Performance Improvement program, which focuses on five core goals areas—**M**obility, **A**ccountability, **P**reservation, **S**afety and **S**ervice—guides the department in achieving its mission to support a culture of data-driven decision making that implements promising policies, materials and technologies and shows accountability to the public.

WisDOT's award-winning, $3.88 million research program completed eight projects through the Wisconsin Highway Research Program (WHRP) and Policy Research Program, and participated in 33 Transportation Pooled Fund (TPF) Program projects, three as the lead state. The American Association of State Highway Transportation Officials (AASHTO) recognized the WisDOT-led *Recycled Materials Resource Center (RMRC) Third Generation* TPF and WHRP's *Evaluation of Thin Polymer Deck Overlays and Deck Sealers* as two of the nation's highest-value research projects in its annual Research Makes the Difference "Sweet 16" publication and supplementary brochure on innovative maintenance research.

The department 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. WisDOT hosted the 2016 Mid-Continent Transportation Research Symposium, a two-day event that saw 180 transportation officials gather to share cutting-edge research practices and findings. Research and Library staff completed one synthesis report and 31 literature searches; responded to 767 customer inquiries; and circulated 2,559 items.

I am proud to recognize these accomplishments and would like to thank the 115 staff that serve in at least one role on nearly 250 research committees and panels at the national and state levels. Their expertise and guidance are critical to the success and implementation of research, and I look forward to what they can achieve in 2018 and beyond.

Dave Ross
Secretary
Wisconsin Department of Transportation

Contents

This is a report of research and technology transfer activities carried out by the Wisconsin Department of Transportation through the Part 2 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 2017, covering October 1, 2016 through September 30, 2017.

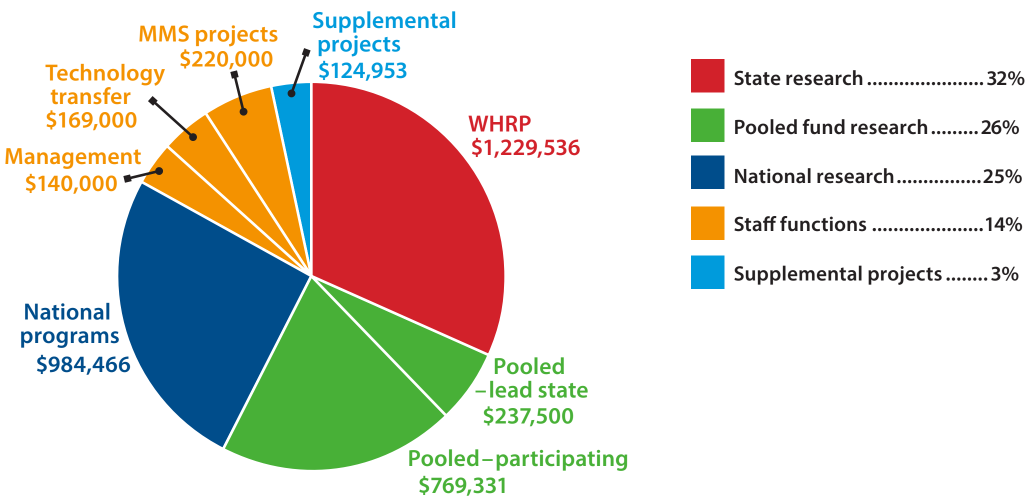
Common acronyms used in this document

AASHTO	American Association of State Highway and Transportation Officials
DOT	U.S. Department of Transportation
DBM	(WisDOT) Division of Business Management
DMV	(WisDOT) Division of Motor Vehicles
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
MAPSS	**M**obility, **A**ccountability, **P**reservation, **S**afety and **S**ervice
NCHRP	National Cooperative Highway Research Program
OPFI	Office of Policy, Finance and Improvement
SHRP2	The Second Strategic 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 $3.88 million program for research, library and technology transfer services during federal fiscal year (FFY) 2017. The State Planning and Research Part 2 (SPR2) federal program funded 90 percent ($3.5 million) of the program, while state funds covered the remaining 10 percent ($.38 million).

Research program funding



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. It focuses on geotechnics, structures and flexible and rigid pavements. Policy research addresses non-engineering issues such as planning, operations and safety. See pages 8 – 10 for all completed and in progress projects.

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 2017, WisDOT research led three pooled fund projects and provided support for 30 others. These projects range in scope and include advances in engineering methods and materials; safety; and performance management. For a full list of pooled fund projects, see pages 11 – 12.

Supplemental projects

WisDOT partners with the University of Wisconsin - Madison to further transportation research through the Construction and Materials Support Center (CMSC), Traffic Operations and Safety (TOPS) Laboratory and University Transportation Center (UTC).

National research

The department helps sustain national research initiatives on topics of broad interest through the Transportation Research Board (TRB), the National Cooperative Highway Research Program (NCHRP) and Strategic Highway Research Program 2 (SHRP2). Approximately 115 WisDOT staff play at least one role in over 250 research committees including: 88 positions on WHRP and WisDOT policy project and technical oversight committees; 82 positions on national research committees through TRB and AASHTO; 39 positions on transportation pooled funds (as technical representatives for the research); and 31 positions on national research project panels through the Cooperative Research Program, AASHTO and other national initiatives.

Staff functions

Efficient management of the transportation knowledge and research findings contributes to continuous performance improvement. The research program funds technology transfer activities and library services to coordinate dissemination of research recommendations to enhance operations within the department. Funds for WisDOT's Materials Management Section (MMS) projects are also included in the research program.

Featured research

MAPSS
Performance
Improvement

The Department's MAPSS Performance Improvement program focuses on the five core goal areas of: **M**obility, **A**ccountability, **P**reservation, **S**afety and **S**ervice. Examples of research that contribute to achieving the department's strategic mission are listed below. The realized or anticipated impact to the state of practice is included for each project, to reaffirm the department's commitment to support data-driven decision making through agile implementation of applied research recommendations.

Mobility

MAPSS goal: To deliver transportation choices that result in efficient trips and no unexpected delays.

0092-15-08

Better Concrete Mixes for Rapid Repair in Wisconsin

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

Rapid-repair strategies such as precast and cast-in-place (CIP) concrete patches help reduce the number and duration of traffic disruptions. The goal of this research was to identify strategies to recommended mixture improvements to alleviate construction difficulties and reduce life-cycle costs.

The researchers confirmed that Wisconsin's current CIP rapid-repair concretes perform adequately, and that durability issues more likely occur due to construction or mix procedure difficulties, rather than WisDOT specifications.

Increasing the durability of rapid repair concretes could cut facility maintenance and rehabilitation costs by nearly 50 percent over standard eight-year service life repairs; however, given current constraints with field concrete, precast repairs may stand as the more efficient method.

Accountability

MAPSS goal: To use public dollars in the most efficient and cost-effective way.

0092-15-03

Self-Consolidating Concrete for Prestressed Bridge Girders

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

Self-consolidating concrete (SCC) is a high strength, highly workable mixture that can save time and money flowing through dense reinforcement to fill formwork and achieve minimal segregation without the assistance of vibration mechanisms. The goal of this research was to develop a mix design that can overcome the difficulty Wisconsin producers have had maintaining uniformity.

The mixture used in the one fully-constructed girder showed adequate structural performance and compressive strength.

The results of this project reaffirm the cost-saving and time-saving potential of SCC use in bridge girders. If supplemental cementitious materials can be incorporated into SCC mix design, SCC projects will become even more feasible for local producers to perform.

Featured research *(continued)*

Preservation

MAPSS goal: To protect, maintain and operate Wisconsin's transportation system efficiently by making sound investments that preserve and extend the life of our infrastructure, while protecting our natural environment.

0092-14-01
Reflective Cracking between Precast Prestressed Box Girders

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

Adjacent precast prestressed concrete box-beams are easy to construct, aesthetically appealing and have favorable span-to-depth ratios and high torsional stiffness; however, they often suffer from longitudinal deck cracking at shear key locations, resulting in persisting durability and performance issues. The goal of this project was to develop practical construction recommendations to minimize cracking.

The three bridges constructed following new methods showed improved performance, but did not entirely eliminate the issue. Results showed that negative temperature gradient and concrete shrinkage are the leading causes of deck cracking.

Employing crack-resistant overlays to further mitigate negative temperature gradient and shrinkage could extend the life of these bridges even further. This would reduce the cost and frequency of maintenance.

Safety

MAPSS goal: To move towards minimizing the number of deaths, injuries and crashes on our roadways.

0092-12-07
Predicting Scour of Bedrock in Wisconsin

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

To ensure the safety of a bridge, hydraulic and geotechnical engineers must account for the depth to which rock around its foundation will erode over the lifetime of the structure. The research team evaluated scour prediction models and explored improvements to WisDOT's bridge manual.

Hydraulic modeling and analysis estimated that the annual scour depths of the rock on the riverbed foundations and around bridge piers are typically small to negligible. Reducing the depth at which foundations are laid would lower costs without compromising the integrity of the bridge.

Calibrating the model for predicting scour will provide WisDOT with a more comprehensive, accurate and cost-effective approach for assessing and addressing bridge site scour across Wisconsin's geologically-diverse waterways.

MAPSS Performance Improvement

Featured research *(continued)*

Service

MAPSS goal: To be a professional and proactive workforce that delivers high-quality and accurate products and services in a timely fashion.

Technology transfer

The Office of Policy, Finance and Improvement (OPFI), Research and Library Services Unit provides information services for WisDOT staff and supports implementation of research results. Services provided in FFY 2017 include:

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. One synthesis report was completed in FFY 2017 on the topic of inventory and removal of Americans with Disabilities Act barriers.

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. Thirty-one literature searches were completed in FFY 2017. Topics included: J-turn design; cold-in-place recycling practices; transportation resiliency to climate change; sinusoidal "mumble" strips; and OWI recidivism.

WisDOT library services

Library staff handled 767 customer inquiries, circulated 2,559 items (books, reports, periodicals and articles) and added 1,031 records (558 print and 473 digital) to the library database.

Mid-Continent Transportation Research Symposium

WisDOT hosted the 2016 Mid-Continent Transportation Research Symposium, an annual gathering of transportation professionals to discuss critical research topics their agencies face. 75 presenters shared their experience and advancements of transportation research at the conference themed "Where the Rubber Hits the Road: Moving from Research to Implementation." 180 professionals attended sessions organized around the MAPSS themes of Mobility, Accountability, Preservation, Safety and Service. WisDOT policy makers met after the conference to discuss the implementation of new ideas brought forward at the two-day event. Presentations from the symposium are available on the Mid-Con website.

MAPSS
Performance
Improvement

Completed research projects

Program	Project ID	Performing organization	Principal investigator	Project budget	WisDOT project manager	Project title	Completion date
WHRP – Geotech	0092-12-07	UW-Milwaukee	Hani Titi	$94,989	Daniel Reid	Predicting Scour of Bedrock in Wisconsin	5/4/2017
WHRP – Structures	0092-13-05	UW-Milwaukee	Al Ghorbanpoor	$120,000	William Dreher	Aesthetic Coatings for Concrete Bridge Components	3/20/2017
WHRP – Structures	0092-14-01	Western Michigan University	Upul Attanayake	$84,999	Bill Oliva	Reflective Cracking between Precast Prestressed Box Girders	8/21/2017
WHRP – Flexible Pavement	0092-14-06	Advanced Asphalt Technologies, L.L.C	Ramon Bonaquist	$224,992	Carl Johnson	Critical Factors Affecting Asphalt Concrete Durability	11/28/2016
Policy	0092-14-14	WisDOT	Matt Rauch	$14,425	Matt Rauch	Copper Naphthenate Treatment Usage in Wood Sign Posts	9/15/2017
WHRP – Structures	0092-15-03	South Dakota State University	Junwon Seo	$74,876	Steve Doocy	Self-Consolidating Concrete for Prestressed Bridge Girders	8/31/2017
WHRP – Flexible Pavement	0092-15-04	UW-Milwuakee	Hussain Bahia	$247,528	Dan Kopacz	Analysis and Feasibility of Asphalt Pavement Performance-Based Testing Specifications for the WisDOT	3/20/2017
WHRP – Geotech	0092-15-07	UW-Milwaukee	Hani Titi	$59,945	Andy Zimmer	Correlation of ASTM D4833 and D6241 Geotextile Puncture Test Methods and Results for Use on WisDOT Projects	5/19/2017
WHRP – Rigid Pavement	0092-15-08	UW-Madison	Steven Cramer	$120,000	Jim Parry	Better Concrete Mixes for Rapid Repair in Wisconsin	5/25/2017
WHRP – Flexible Pavement	0092-15-09	Behnke Materials Engineering, L.L.C.	Signe Reichelt	$99,899	Barry Paye	WisDOT Asphaltic Mixture New Specifications Implementation- Field Compaction and Density Validation	11/22/2016
WHRP – Rigid Pavement	0092-15-10	UW-Milwaukee	Konstantin Sobolev	$49,990	Andrea Breen	Class F Fly Ash Assessment for Use in Concrete Pavement	3/31/2017
Policy	0092-16-10	Behnke Materials Engineering, L.L.C.	Signe Reichelt	$127,969	Emily Kuntz	Materials Laboratory Design Guidelines	6/30/2017

Ongoing research projects

Program	Project ID	Performing organization	Principal investigator	Project budget	WisDOT project manager	Project title
WHRP – Rigid Pavement	0092-14-05	UW-Madison	Steven Cramer	$249,918	Kevin McMullen	Comparison of Fresh Concrete Air Content Test Methods & Analysis of Hardened Air Content in Wisconsin Pavements - Phase I and Phase II
WHRP – Flexible Pavement	0092-15-05	Temple University	Ahmed Faheem	$100,000	Erv Dukatz	Evaluation of WisDOT Quality Management Program (QMP) Activities and Impacts on Pavement Performance
WHRP – Geotech	0092-15-06	UW-Milwaukee	Hani Titi	$119,997	Andy Zimmer	Evaluation of the Long-Term Degradation and Strength Characteristics of In-situ Wisconsin Virgin Base Aggregates under HMA Pavements
Policy	0092-15-11	UW-Madison	Andrea Bill	$77,000	Sarah Buzzell	Motorcycle Licensing and Safety
WHRP – Rigid Pavement	0092-16-01	Marquette University	James Crovetti	$149,979	Myungook Kang	Joint Sawing Practices and Effects on Durability
WHRP – Flexible Pavement	0092-16-02	University of Auburn	Carolina Rodezno	$150,000	Andrew Hanz	Asphalt Binder Extraction Protocol for Determining Amount & PG Characteristics of Asphaltic Mixtures
WHRP – Geotech	0092-16-03	Clemson University	Amir Pourasee	$149,938	Jeff Horsfall	Evaluation of H-pile Corrosion Rates for WI Bridges Located in Aggressive Subsurface Environments
WHRP – Structures	0092-16-04	UW-Madison	Gustavo Parra-Montesinos	$140,000	Bill Oliva	On time Staged Concrete Bridge Deck & Overlay Pours Adjacent to Live Traffic
WHRP – Structures	0092-16-05	University of Buffalo	Pinar Okumus	$150,000	Philip Meinel	Design & Performance of Highly Skewed Deck Girder Bridges
WHRP – Flexible Pavement	0092-16-06	University of Auburn	Randy West	$150,000	Steve Hefel	Regressing Air Voids for Balanced HMA Mix Design Study
WHRP – Geotech	0092-16-07	University of Missouri	Andrew Boeckmann	$110,000	Andy Zimmer	Thermal Integrity Profiling for Detecting Flaws in Drilled Shafts
Policy	0092-16-11	UW-Milwaukee	Xiao Qin	$100,000	Evan Moorman	Identifying Highly Correlated Variables Relating to the Potential Causes of Reportable Wisconsin Traffic Crashes

Ongoing research projects *(continued)*

Program	Project ID	Performing organization	Principal investigator	Project budget	WisDOT project manager	Project title
WHRP – Geotech	0092-17-01	UW-Milwaukee	Hani Titi	$99,990	Andy Zimmer	Evaluation of Recycled Base Aggregates
WHRP – Structures	0092-17-02	UW-Milwaukee	Habib Tabatabai	$167,218	Aaron Bonk	Strength & Serviceability of Damaged Prestressed Girders
WHRP – Rigid Pavement	0092-17-03	UW-Platteville	Danny Xiao	$60,000	Chad Hayes	Evaluation of the Effects of Deicers on Concrete Durability
WHRP – Flexible Pavement	0092-17-04	UW-Madison	Hussain Bahia	$150,000	Stacy Glidden	Field Aging and Moisture Sensitivity Study
WHRP – Structures	0092-17-05	Simpson Grumpertz & Heger	Jesse Beaver	$100,000	Matt Allie	Performance and Policy Related to Aluminum Box Culverts and Pipe Culverts in Wisconsin
WHRP – Flexible Pavement	0092-17-06	UW-Madison	Hussain Bahia	$100,000	Steve Hefel	Investigation of Tack Coat Materials on Tracking Performance
WHRP – Rigid Pavement	0092-17-07	Behnke Materials Engineering, L.L.C.	Signe Reichelt	$124,962	Chad Hayes	Evaluation of Current WI Mixes Using Performance Engineered Mixtures (PEM) Testing Protocols
WHRP – Geotech	0092-17-08	GeoComp Corporation	W. Allen Marr	$149,971	Andy Zimmer	Monitoring of Lateral Earth Pressure and Movements of Cut Retaining Walls

Pooled fund participation

Project number	Title	FFY 2017 funding amount	WisDOT technical representative	Lead agency/ state
TPF-5(176)	Traffic Analysis and Simulation	$35,000	Vicki Haskell – DTSD	FHWA
TPF-5(183)	Improving the Foundation Layers for Concrete Pavements	N/A	Jeffrey Horsfall – DTSD	Iowa
TPF-5(193)	Midwest States Pooled Fund Crash Test Program	$66,000	Erik Emerson – DTSD	Nebraska
TPF-5(206)	Research Program to Support the Research, Development, and Deployment of System Operations Applications of Vehicle Infrastructure Integration	$50,000	Anne Reshadi – DTSD	Virginia
TPF-5(219)	Structural Health Monitoring System	N/A	Scot Becker – DTSD	Minnesota
TPF-5(253)	Member-level Redundancy in Built-up Steel Members	N/A	Alex Pence – DTSD	Indiana
TPF-5(255)	Highway Safety Manual Implementation	N/A	Brian Porter – DTSD	FHWA
TPF-5(264)	Passive Forced Displacement Relationships for Skewed Abutments	N/A	James Luebke – DTSD	Utah
TPF-5(267)	Accelerated Performance Testing for the NCAT Pavement Test Track	N/A	Steve Krebs, Barry Paye – DTSD	Alabama
TPF-5(272)	Evaluation of Lateral Pile Resistance Near MSE Walls at a Dedicated Wall Site	N/A	Jeffrey Horsfall – DTSD	Utah
TPF-5(281)	Center for the Aging Infrastructure: Steel Bridge Research, Inspection, Training and Education	N/A	Scot Becker – DTSD	Indiana
TPF-5(283)	The Influence of Vehicular Live Loads on Bridge Performance	$50,000	Alex Pence – DTSD	FHWA
TPF-5(290)	Aurora Program	$25,000	Mike Adams – DTSD	Iowa
TPF-5(295)	Smart Work Zone Deployment Initiative	$50,000	Travis Feltes – DTSD	Iowa
TPF-5(297)	Improving Specification to Resist Frost Damage in Modern Concrete Mixtures	$17,500	Chad Hayes – DTSD	Oklahoma
TPF-5(302)	PG+/Modified Binder Quality Control Criteria	$25,000	Barry Paye – DTSD	WisDOT
TPF-5(305)	Regional and National Implementation and Coordination of ME Design	$10,000	Laura Fenley – DTSD	FHWA
TPF-5(308)	The Use of Bridge Management Software in the Network Analysis of Big Bridges	N/A	Josh Dietsche – DTSD	Michigan

Pooled fund participation *(continued)*

Project number	Title	FFY 2017 funding amount	WisDOT technical representative	Lead agency/ state
TPF-5(313)	Technology Transfer Concrete Consortium	$8,000	Chad Hayes – DTSD	Iowa
TPF-5(316)	Traffic Control Device (TCD) Consortium	$20,000	Travis Feltes – DTSD	FHWA
TPF-5(317)	Evaluation of Low Cost Safety Improvements	$5,000	Brian Porter – DTSD	FHWA
TPF-5(319)	Transportation Management Center Pooled Fund Study	$50,000	Paul Keltner – DTSD	FHWA
TPF-5(326)	Develop and Support Transportation Performance Management Capacity Development Needs for State DOTs	$10,000	Lynn Hanus – OPFI	Rhode Island
TPF-5(330)	No Boundaries Roadway Maintenance Practices	$10,000	Scott Bush – DTSD	Ohio
TPF-5(335)	2016 through 2020 Biennial Asset Management Conference and Training on Implementation Strategies	N/A	Scot Becker – DTSD, Justin Shell – DTIM	Iowa
TPF-5(340)	Axle and Length Classification Factor Analysis and Effects on Annual Average Daily Traffic (AADT)	N/A	Russell Lewis – DTIM	WisDOT
TPF-5(341)	National Road Research Alliance (NRRA)	N/A	Steve Krebs – DTSD	Minnesota
TPF-5(346)	Regional Roadside Turfgrass Performance Testing	$20,000	Leif Hubbard – DTSD	Minnesota
TPF-5(351)	Self De-Icing LED Signals	$20,000	Don Schell – DTSD	Kansas
TPF-5(352)	Recycled Materials Resource Center	$40,000	Steve Krebs, Barry Paye – DTSD	WisDOT
TPF-5(353)	Clear Roads Phase II	$25,000	Mike Sproul – DTSD	Minnesota
TPF-5(354)	Improving the Quality of Highway Profile Measurement	$20,000	Mike Wolf – DTIM	South Dakota
TPF-5(368)	Performance Engineered Concrete Paving Mixtures	$15,000	Chad Hayes – DTSD	Iowa

Note: N/A indicates that the pooled fund is ongoing, but no additional funds were required by participating agencies for FFY 2017.

Wisconsin Highway Research Program* (WHRP)

WHRP Steering Committee

Diane Gurtner, Chair (Interim)
WisDOT, EXEC, OPFI

Jack Arseneau
Wisconsin Earth Movers Association

Joe Balice
FHWA – Wisconsin

Scot Becker
WisDOT, DTSD, Bureau of Structures

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Christopher Foley
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Kevin McMullen
Wisconsin Concrete Pavement Association

Brandon Strand
Wisconsin Asphalt Pavement Association

WHRP technical support staff

Dante Fratta
Co-Principal Investigator, UW-Madison

David Noyce
Principal Investigator, UW-Madison

WHRP Technical Oversight Committee chairs

FLEXIBLE PAVEMENTS

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WisDOT, DTSD, Bureau of Technical Services

GEOTECHNICS

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RIGID PAVEMENTS

Myungook Kang
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STRUCTURES

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Wisconsin Department of Transportation* (WisDOT)

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Lynn Hanus
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Heidi Noble
Contracts Specialist–Senior

**Rosters and staff as of June 1, 2017.*
The FFY 2017 Annual Report will provide updated rosters and reflect staffing updates after this date.

Wisconsin Highway Research Program
Project 0092-12-07
October 2017

Research Brief

Predicting Scour of Bedrock in Wisconsin

Research Objectives

- Assess the ability of the newly developed methods described in NCHRP Report 717 "Scour at Bridge Foundations on Rock" to characterize the scour potential for various types of Wisconsin bedrock
- Recommend updates to the WisDOT Bridge Manual to better suit structures built on Wisconsin's geologically diverse waterways

Research Benefits

- Determined that scour is typically small to negligible for bridges built on rock types capable of bearing a bridge's weight
- Confirmed that the bedrock at bridge sites representative of Wisconsin are within the durable rock range
- Recommended reductions in future foundation depth that will lower cost of construction without compromising bridge integrity or users' safety
- Provided WisDOT with more comprehensive scour estimation methods

Principal Investigator

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Background

Bridge scour, the erosion or removal of sediment due to flowing water around piers or abutments, is a major cause of highway bridge failure in the United States. After the collapse of New York's Schoharie Creek Bridge during a flood in 1987, the Federal Highway Administration (FHWA) issued a technical advisory that required evaluation of all bridges to determine vulnerability to scour.

Before laying the foundations for bridges, hydraulic and geotechnical engineers must estimate the depth of scour that will occur in erodible rock over the lifetime of the structure. The current method for determining foundation scour depth is based on the assumption that foundations are built over sand, which can lead to overly-conservative estimates and higher costs for bridge-construction projects. The National Cooperative Highway Research Program (NCHRP) Report 717, "Scour at Bridge Foundations on Rock," recommends assessing hydraulic behavior over the anticipated life of a structure differently when foundations are laid in bedrock rather than sand. The goal of this research was to test the NCHRP methods and recommend updates to the Wisconsin Department of Transportation (WisDOT) Bridge Manual that better suit the diverse geology of Wisconsin's waterways.

Methodology

Drilling in granite on the Eau Claire River.

The project oversight committee and the research team selected 10 bridges, the majority of which rest on spread footings or shallow foundations. The bridge sites were chosen for their higher rate of water flow and representation of bedrock types common to Wisconsin, such as sandstone, limestone/dolostone, gneiss and granite.

The research team conducted comprehensive geological evaluations of the bedrock and visited sites to collect core and hand-picked rock samples and to perform hydrographic field surveys of the channel bottoms. The core and hand samples were subjected to modified slake durability (continuous abrasion) testing as described in NCHRP Report 717. Test results were used to determine the equivalent hourly scour depth and the equivalent hourly stream power, and to estimate the geotechnical scour number (GSN) and

"This research will provide WisDOT with a more comprehensive, accurate and cost effective approach for assessing bedrock scour at many bridge sites across Wisconsin."

– Dan Reid, WisDOT

Interested in finding out more?

Final report is available at: WisDOT Research website.

the abrasion number (β). Hydraulic modeling analysis was conducted to estimate the annual average scour depth at the river bed and near the bridge piers using the daily stream flow data, and the long-term scour depths were predicted based on the flood frequency analysis.

Results

Sandstone samples subjected to the modified slake test exhibited significant mass loss. Sandstone's GSN and β were higher than those of limestone/dolostone, gneiss and granite, indicating that, under high stream powers, sandstone is more susceptible to higher scour rates than the other rock types investigated.

Bridge abutment on sandstone on WIS 13 in Wisconsin Dells.

Hydraulic modeling and analysis estimated that the annual scour depths of the rock on the riverbed foundations and around bridge piers are typically small to negligible. The two exceptions to this finding were the bridge sites on the Wisconsin River and the Black River, which had significant scouring.

Recommendations for Implementation

Results indicate that some bridge foundations may be laid deeper than necessary, and that reducing the depth would lower costs without compromising the integrity of the bridge. Rock types susceptible to high scour may indicate locations where deep foundations could be more cost effective and preferable to spread footings. WisDOT's Bureau of Structures will consider adding language and guidance relating to the qualitative conclusions of this research and placing foundations on rock. The model for predicting scour will be calibrated as field inspections and measurements are conducted and more data is collected. Typical geotechnical investigation needed for conventional bridge scour analysis, along with the collection of bedrock samples, should be sufficient for supporting these procedures.

The researchers identified limitations of the slake durability test. For instance, the test does not capture the degradability of rotten granite, a highly degradable rock. The test indicates very little loss in mass because the sample fragments are too large to be lost through the mesh of the testing apparatus.

This brief summarizes Project 0092-12-07,
"Predicting Scour of Bedrock in Wisconsin"
Wisconsin Highway Research Program

Research Brief

Wisconsin Highway Research Program
Project 0092-14-01
August 2017

Reflective Cracking between Precast Prestressed Box Girders

Research Objectives

- Determine the major causes of longitudinal deck cracking in adjacent precast prestressed box-beam bridges in Wisconsin
- Recommend modifying current details, specifications and methods used in bridge construction and maintenance to decrease deck cracking and extend service life

Research Benefits

- Determined that negative temperature gradient and concrete shrinkage are the leading causes of deck cracking
- Recommended changes to current overlay, abutment and grouting practices that can improve the lifespans of Wisconsin's bridge decks

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Background

Ease of construction, favorable span-to-depth ratios, aesthetic appeal and high torsional stiffness make adjacent precast prestressed concrete box-beams a popular option for short-to-medium span bridges. However, persisting durability and performance issues resulting from longitudinal deck cracking at shear key locations threaten its favorability. Deck cracking is the primary trigger of deterioration and distresses of these bridges. The goal of this project was to develop practical recommendations for modifications to current details, specifications and methods used in the construction of adjacent precast prestressed concrete box-beam bridges in Wisconsin to minimize the potential for developing longitudinal deck cracking over shear keys.

Methodology

The research team surveyed bridge maintenance engineers, industry fabricators and other state departments of transportation regarding the extent and consistency of deck cracking problems, and reviewed Wisconsin bridges that applied adjacent precast prestressed concrete box-beams. Recommendations for improved policies, design detailing, specifications and construction inspection practices were made based on the findings. Additionally, the impact of using various wearing surface types on adjacent box-beam bridge superstructure durability performance was evaluated using National Bridge Inventory data. The revised details and specifications were implemented on three bridges, one with traditional abutments and a six inch thick cast-in-place concrete slab, and the other two with Geosynthetic Reinforced Soil (GRS) abutments and two inch thick masonry overlays.

Deck cracking over the shear keys was documented shortly after construction and after five months. Refined finite element analysis was conducted by incorporating user subroutines to simulate concrete strength and shrinkage development with time. The temperature gradient effect was also investigated.

Moisture ingress through cracks and shear keys.

“The researchers’ recommendations, including revised shear key geometry, hold significant potential to improve the performance and economy of precast box section bridges” – Project Manager Bill Oliva, WisDOT

Interested in finding out more?

Final report is available at: [WisDOT Research website].

Results

The bridges showed improved performance but did not eliminate the longitudinal reflective cracking. All three bridge decks developed longitudinal cracking over the shear keys, with the longest cracks of each bridge ranging from 28 to 144 inches. These cracks originated at the edge of the deck over the abutments and travelled toward the mid span. Each deck also developed a large number of randomly dispersed hairline cracks, a common occurrence for overlays of that mix design.

Analysis revealed that the stresses of shrinkage and thermal gradient loads are high enough to initiate cracking in typical concrete mixes. These effects are especially prominent over supports, where maximum principal stress direction is perpendicular to the direction of traffic. The effect of shrinkage was 205 pounds per square inch (psi) for the six inch overlay and 274 psi for the two inch overlay. Combined with the thermal gradient effect, this is adequate to develop cracking over the abutments.

The bridges with GRS abutments had unrelated drainage issues, cracking at the approach pavement-bridge deck joint, and significant impact from live load.

Recommendations for Implementation

Despite the adequate overall performance of new bridges, their life-spans can be improved by employing more crack-resistant overlays, rather than the portland cement mixes currently used in six inch cast-in-place concrete slabs and two inch thick overlays. These overlays will mitigate the damaging effects of shrinkage and temperature gradient loads and prolong the life of the deck. Asphalt overlays with waterproofing membranes may also serve as an adequate alternative or complement to concrete overlays or slabs.

The researchers also offered recommendations on improving grouting practices and GRS abutments. Use of impermeable membranes is needed to abate drainage issues with GRS abutments.

This brief summarizes Project 0092-14-01,
“Reflective Cracking between Precast Prestressed Box Girders”
Wisconsin Highway Research Program

Research Brief

Wisconsin Highway Research Program
Project 0092-15-03
August 2017

Self-Consolidating Concrete for Prestressed Bridge Girders

Research Objectives

- To examine effects of various SCC mixture constituents on the material characteristics and performance.
- To develop mix design guidelines for the use of SCC in PSC girders on WisDOT bridge projects.
- To investigate structural behavior of a full-scale prestressed SCC girder.

Research Benefits

- Developed an SCC mixture design for use in PSC bridges.
- Recommended specifications for fabrication and implementation of prestressed SCC girders.
- Reaffirmed the cost- and time-saving potential of SCC use in bridge girders.

Principal Investigator

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Background

Self-consolidating concrete (SCC) is commonly used as an alternative to conventional concrete (CC) in precast, prestressed concrete (PSC) bridge girders. The high strength, highly workable mixture can flow through dense reinforcement to fill formwork and achieve minimal segregation without the assistance of vibration mechanisms, saving time and money. Several state departments of transportation have found success in using SCC in precast PSC bridge girders; however, producers in Wisconsin have struggled to maintain uniformity in terms of mixture properties with low segregation, as well as transporting and placing the girder for bridge construction. The objective of this project was to examine effects of various SCC mixture constituents on the material characteristics in order to develop a uniform mixture design that achieves consistent, desired performance.

Methodology

Local materials from three Wisconsin precastors were used to develop SCC trial mixtures for testing fresh and hardened material properties. For designing the mixtures, the research team investigated the effects of cement content and type; aggregate size and type; sand-to-aggregate ratio; and water-to-cement ratio. The mixtures were evaluated in a fresh state using slump flow, visual stability index (VSI), T20, J-ring and column segregation testing. They were then tested in a hardened state for compressive strength at transfer after 18 hours and 28 days.

Five mixtures were selected for further testing under the mixing, curing and quality control procedures of the three precastors, and the specimens' creep and shrinkage were examined for 280 days. One mixture was selected for casting a full-scale prestressed SCC girder to monitor structural performance, and a conventional concrete (CC) girder with similar target compressive strength was fabricated as a control specimen. Prestress losses and camber for both the SCC and CC girders were then monitored in the precast yard for 161 days, and their transfer lengths were measured for 28 days.

Camber was measured early in the morning to mitigate thermal effects.

"The results of this study show that WisDOT can incorporate the use of SCC in bridge girders with confidence. With the data from this research, we have created a special provision and are investigating potential pilot projects for implementation. We look forward to examining other components in our structures that may benefit from the use of SCC."

– Steve Doocy, WisDOT

Interested in finding out more?

Final report is available at: WisDOT Research website.

Results

For the SCC and CC girders, respectively, elastic shortening was 9.07 and 10.61 kilopounds per square inch (ksi); final prestress losses were 8.53 and 6.42 ksi; construction losses were 2.22 and 1.90 ksi; and the total prestress losses were 16.89 and 17.03 ksi. The prestress losses continued to climb until day 161, when the girders were shipped and placed on site; the losses then slowly declined until final recording on day 287.

Transfer length immediately after release was 19.0 inches for the SCC girder and 24.0 inches for the CC girder. At 28 days, the transfer length increased by 1 inch, to 20.0 inches, for the SCC girder and 0.5 inches, to 24.5 inches, for the CC girder. The American Association of State Highway and Transportation Officials (AASHTO) and the American Concrete Institute (ACI) specify transfer lengths of 36.0 and 30.0 inches, respectively, suggesting that their formulas for determining transfer length are conservative.

The variation in camber was 1.63 inches for the SCC girder and 1.38 inches for the CC girder. Each girder reached a peak camber of 4.5 inches, but the SCC girder peaked faster, at 91 days, than the CC girder, at 126 days.

Recommendations for Implementation

Implementation of prestressed SCC bridge girders could save the Wisconsin Department of Transportation (WisDOT) time and money on its construction projects; however, since only one mixture was tested as a fully constructed girder, there is need to validate any other mixture before permitting its use in girder production. This project provides recommendations for performance requirements for the fabrication and quality control of SCC bridge girders. Larger, full-scale SCC girders should be monitored to gather information on long-term structural behavior.

The researchers also recommend investigating the implementation of supplemental cementitious materials to reduce the costs of SCC mixtures to make them more feasible for local producers.

This brief summarizes Project 0092-15-03,
"Self-Consolidating Concrete for Prestressed Bridge Girders"
Wisconsin Highway Research Program

Wisconsin Highway Research Program
Project 0092-15-08
July 2017

Research Brief

Better Concrete Mixes for Rapid Repair in Wisconsin

Research Objectives

- Evaluate performance of rapid-repair concrete in Wisconsin
- Identify high-quality concrete rapid-repair mixtures with long service lives and high performance in Wisconsin's wet freeze-thaw climate
- Analyze life-cycle costs of CIP rapid repair for the laboratory tested mixtures
- Recommend improved mixtures in comparison with precast concrete pavement

Research Benefits

- Confirmed that Wisconsin's current CIP rapid-repair concretes perform adequately
- Recommended mixture improvements to alleviate construction difficulties
- Determined that increasing the durability of rapid repair concretes could cut maintenance and rehabilitation costs by nearly 50 percent over standard eight-year service life repairs

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Background

Increasing demands on Wisconsin's highway system impact the lifespan of roadways, resulting in more frequent lane closures for maintenance and repairs, creating additional user-delay. Rapid-repair strategies such as precast and cast-in-place (CIP) concrete patches aim to minimize the duration of traffic disruptions and lower costs.

The Wisconsin Department of Transportation (WisDOT) uses high early strength (HES) portland cement concrete in its rapid-repair CIP operations. The mix has a high cement content, accelerators, superplasticizers, air entraining admixtures and other mixture constituents that give it high strength gain and a fast curing time but also makes it more susceptible to high shrinkage and inadequate air void systems. This repair strategy costs less up front than precast patches but has a potentially shorter service life if the CIP is not optimal. The goal of this research was to identify strategies to reduce life-cycle costs by evaluating the performance of existing rapid-repair pavements and identifying mixtures with longer service lives capable of withstanding Wisconsin's punishing freeze-thaw climate.

Methodology

Wisconsin concrete suppliers were surveyed to obtain information on rapid-repair mix designs, challenges and approaches. A field review of 12 recent rapid-repair pavement projects in Wisconsin evaluated field performance. Based on information from the field reviews and informal survey, 13 rapid-repair mixture candidates were proposed, made and tested in the lab.

Sets of three 4x8-inch cylinder samples were cured in a wet room at 73° F then strength tested at four, six, eight, 10, 12, 24 and 36 hours and 28 days after mixing according to AASHTO T 22. Air-dry shrinkage testing was conducted on sets of three 4x4x10-inch prisms according to ASTM C 157. Twelve-inch diameter, three-inch thick cylindrical samples were cured for 28 days before being submitted to 60 freeze-thaw cycles according to ASTM C 672.

Rapid-repair patches were visually inspected in the field.

Results

The field review showed significant durability issues in only one project, where severe scaling occurred. Durability issues that occur in rapid-repair pavements are more likely due to difficulties associated with construction or mix procedures than with WisDOT's specifications.

The cohesiveness of tested mixes was satisfactory with no segregation issues. In mixes using two percent calcium chloride, workability was lost very quickly, and it became difficult to consolidate cylinders by hand-rodding within 40 minutes of mixing the cement with water.

The average strengths of the concretes after eight hours ranged from 837 to 4,763 psi. Only the mixes using calcium chloride and a water-cement ratio of 0.32 met WisDOT's average strength requirement for special HES concrete of 3,000 psi within eight hours. The average strengths after 28 days ranged between 7,463 and 10,845 psi.

Shrinkage values of mixes not containing calcium chloride were between 600 and 700 x 10^{-6} after 28 days. Most of the mixes containing calcium chloride had shrinkage values between 800 and 1,000 x 10^{-6} after 28 days.

Assuming an acceptance limit of 500 g/m^2 after 60 cycles, all the mixes in this research performed satisfactorily except for the samples cured with the poly-alpha-methylstyrene curing compound.

"Adjusting WisDOT concrete mix specifications to allow dry flake calcium chloride as an alternative to liquid calcium chloride solutions will yield workable, high quality concrete with lower shrinkage potential than mixes with higher water-cement ratios."

– James Parry, WisDOT

Interested in finding out more?

Final report is available at: WisDOT Research website.

Recommendations for Implementation

Durability issues occurring in rapid-repair pavements are more likely due to construction or mix procedure difficulties than to WisDOT specifications. Dry calcium chloride has the potential to ease these difficulties, if it can be mixed uniformly with the concrete to control slump, or if upper slump limits are raised to six inches. Concrete using portland cement with calcium chloride accelerator can surpass the WisDOT compressive strength requirement of 3,000 psi within eight hours of construction and have satisfactory scaling resistance. If the strength requirement of 3,000 psi can be extended to within 10 hours of construction, a non-chloride accelerator may be a preferable alternative, as it has excellent scaling resistance and only slightly higher shrinkage than non-accelerator concrete.

Increasing the durability of rapid repair concretes could cut facility maintenance and rehabilitation costs by nearly 50 percent over standard eight-year service life repairs; however, given current constraints with field concrete, precast repairs may stand as the more efficient method.

This brief summarizes Project 0092-15-08,
"Better Concrete Mixes for Rapid Repair in Wisconsin"
Wisconsin Highway Research Program

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