



# RESEARCH ANNUAL REPORTS

## FY 2000 - FY 2002

- Management
- Construction
- Pavement Design
- Pavement Performance
- Bridges
- Materials

Projects Developed and Managed by:

the Testing and Research Section  
Construction and Technology Support Area

March 31, 2003

## **FOREWARD**

This report has been compiled by Sudhakar Kulkarni and Nancy Crider. The report is a summary of three years of the Michigan Department of Transportation (MDOT)'s research program, which includes fifty completed projects at a cost of approximately \$4,038,000. Thanks are due to the project managers for providing this information.

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Jon W. Reincke  
Engineer of Testing and Research

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## Research Program Highlights FY 2000

During fiscal year 2000, the Testing and Research Section of MDOT completed ten projects at a cost of \$649,132.11. The projects can be broadly classified into the following areas:

TYPE	NUMBER OF PROJECTS/ CONTRACTS	TOTAL EXPENDITURES FOR PROJECT/ CONTRACT	TOTAL EXPENDITURES IN PERCENT
Management	3	\$80,685.53	12.5
Construction	1	\$39,092.39	6.0
Pavement Design	1	\$125,068.43	19.3
Pavement Performance	4	\$362,055.78	55.8
Bridges	1	\$42,229.98	6.4
Materials	0	0.00	0.0
<b>TOTALS</b>	<b>10</b>	<b>\$649,132.11</b>	<b>100.00</b>

The implemented items or products received are in the Summaries Section for each area in bold letters for your quick review. Benefits of these items or products must be documented for future reference.

## Research Program Highlights FY 2001

During fiscal year 2001, the Testing and Research Section of the MDOT completed 13 research projects at a cost of \$1,004,251.83. The projects are classified as follows:

TYPE	NUMBER OF PROJECTS/ CONTRACTS	TOTAL EXPENDITURES FOR PROJECT/ CONTRACT	TOTAL EXPENDITURES IN PERCENT
Management	3	\$65,855.07	6.6
Construction	0	0.00	0.0
Pavement Design	3	\$45,976.96	4.6
Pavement Performance	1	\$59,652.64	5.9
Bridges	5	\$771,397.16	76.8
Materials	1	\$61,370.00	6.1
<b>TOTALS</b>	<b>13</b>	<b>\$1,004,251.83</b>	<b>100.0</b>

The implemented items or products received are in the Summaries Section for each area in bold letters for your quick review. Benefits of these items or products must be documented for future reference.

## Research Program Highlights FY 2002

During fiscal year 2002, the Testing and Research Section of the MDOT completed 27 research projects at a cost of \$2,152,248.13. The projects are classified as follows:

TYPE	NUMBER OF PROJECTS/ CONTRACTS	TOTAL EXPENDITURES FOR PROJECT/ CONTRACT	TOTAL EXPENDITURES IN PERCENT
Management	4	\$161,965.98	7.5
Construction	2	\$154,801.37	7.2
Construction (Non SPR funds)	1	\$101,119.96	4.7
Pavement Design	3	\$375,027.01	17.4
Pavement Performance	4	\$581,853.23	27.0
Bridges	6	\$397,629.59	18.5
Materials	4	\$379,850.99	17.7
<b>TOTALS</b>	<b>24</b>	<b>\$2,152,248.13</b>	<b>100</b>

The implemented items or products received are in the Summaries Section for each area in bold letters for your quick review. Benefits of these items or products must be documented for future reference.

## PROJECTS/CONTRACTS CLOSED FY 2000

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
00-MTU-1	Jon Reincke	Publication of Research Record	\$30,998.79	09/30/00	Management
00-MTU-2	Jon Reincke	Operation and Coordination of the Transportation Materials Research Center (TMRC)	\$33,130.08	09/30/00	Management
MSU 00-6-2	Jon Reincke	Coordination and Management of the Pavement Research Center of Excellence (PRCE)	\$16,556.66	09/30/00	Management
99-MTU-5	John LaVoy	Construction Project Scheduling at the MDOT	\$39,092.39	08/23/00	Construction
MSU 96-1-0	Tom Hynes	Improvement of MichPave and MichBack	\$125,068.43	09/20/00	Pavement Design
MSU 97-7-1	John Staton	Factors Affecting Shear Capacity of Transverse Cracks in Jointed Pavement	\$128,021.28	06/19/00	Pavement Performance



## PROJECTS/CONTRACTS CLOSED FY 2000

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
MSU 98-2-1	Mike Frankhouse	Detecting and Quantifying Segregation in Bituminous Pavements and Relating Its Effect to Condition	\$141,980.27	07/13/00	Pavement Performance
MSU 99-3-3	Dave Smiley	Comparison of Concrete Pavement Performance Utilizing Different Types of Coarse Aggregate	\$7,835.77	06/30/01	Pavement Performance
MSU 99-4-3	Vern Barnhart	Identify Causes for Under-Performing Rubbilized Concrete Pavement Projects Phase I	\$84,218.46	09/05/00	Pavement Performance
UM 98-1219	Roger Till	Development of a Guide for the Evaluation of Existing Bridges - Phase 2	\$42,229.98	11/15/99	Bridge
<b>TOTAL</b>			<b>\$649,132.11</b>		

## PROJECTS CLOSED FY 2001

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
01-MTU-2	Jon Reincke	Operation and Coordination of the Transportation Materials Research Center (TMRC)	\$31,619.93	10/31/01	Management
01-MTU-4	Roger Till	Administrative Operations for the Center for Structural Durability (CSD) at WSU/MTU Joint Venture	\$20,000.00	10/31/01	Management
01-MTU-7	Jon Reincke	Publication of the Research Record	\$14,235.14	10/31/01	Management
98-MTU-1	Dave Smiley	Modernization of the Illi-Slab Finite Element Analysis Program for Concrete Pavements	\$40,012.00	12/14/00	Pavement Design
00-MTU-8	Dave Smiley	Feasibility Evaluation for Enhancing Michigan's Procedures for Pavement Design and Selection	\$679.44	09/21/01	Pavement Design

## PROJECTS CLOSED FY 2001

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
MSU 00-5-1	Dave Smiley	Feasibility Evaluation for Enhancing Michigan's Procedure for Pavement Design and Selection	\$5,285.52	07/02/01	Pavement Design
MSU 00-2-1	Mike Eacker	Evaluation of Alignment Tolerances for Dowel Bars and Their Effects on Joint Performance	\$59,652.64	07/16/01	Pavement Performance
UM 96-1067	Roger Till	Repair and Strengthening of Reinforced and Prestressed Concrete Beams Using CFRP Glued-On Plates	\$149,670.00	01/25/01	Bridge
MSU 96-1068	Dave Juntunen	Non-Metallic Reinforcement of Concrete Bridge Deck	\$262,221.03	03/21/01	Bridge
MSU 96-1069	Roger Till	Polymer Composite Jackets for Column Repair	\$194,497.03	01/25/01	Bridge

## PROJECTS CLOSED FY 2001

PROJECT/CONTRACT		TITLE	TOTAL PROJECT/CONTRACT EXPENDITURES	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
UM 98-1303	Dave Juntunen	Research Study to Determine Procedures for Efficient Evaluation of Bridge Decks	\$61,359.10	06/26/01	Bridge
UM 00-0341	Roger Till	Verification of Girder Distribution Factors for Steel Girder Bridges	\$103,650.00	07/09/01	Bridge
00-MTU-3	John Staton	Aggregate Absorption as Related to Anti-Icing for Elastomeric Concrete Bridge Deck Overlays	\$61,370.00	04/12/01	Materials
<b>TOTAL</b>			<b>\$1,004,251.83</b>		

## PROJECTS/CONTRACTS CLOSED FY 2002

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
02-MTU-1	Jon Reincke	Operation & Coordination of the Transportation Materials Research Center (TMRC) for FY 2002	\$103,223.00	09/30/02	Management
02-MTU-2	Roger Till	Administrative Operations for the Center for Structural Durability (CSD) at WSU & MTU	\$20,340.00	09/30/02	Management
02-MTU-3	Jon Reincke	Publication of the Research Record for FY 2002	\$24,740.98	09/30/02	Management
MSU 26	Jon Reincke	Coordination & Management of the Pavement Research Center of Excellence (PRCE) for FY 2002	\$13,662.00	09/30/02	Management

## PROJECTS/CONTRACTS CLOSED FY 2002

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
01-MTU-5	John LaVoy	Work Item Production Rates for MDOT Projects	\$74,801.37	09/30/02	Construction
01-MTU-6	John LaVoy	Comparison of MDOT Schedules as a Result of Special Provision for Progress Schedule, FUSP102G	\$80,000.00	09/30/02	Construction
WSU 00-0781	Jeff Grossklaus	Effectiveness of the Lane Merge Traffic Control System at Construction/Work Zones	\$101,119.96 (Non SPR monies)	12/31/01	Construction
00-MTU-4	Al Robords	Analysis of Bituminous Pavement Surface Characteristics & Their Effects on Friction Properties	\$198,990.08	09/30/02	Pavement Design
00-MTU-6	John Barak	Synthesis & Review of Superpave Implementation	\$37,850.91	04/02/02	Pavement Design

## PROJECTS/CONTRACTS CLOSED FY 2002

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
MSU 00-1-1	Tom Hynes	Development of a Computer Program for Dynamic Backcalculation of Flexible Pavement Layer Moduli	\$138,186.02	09/30/02	Pavement Design
MSU 99-2-1	Dave Smiley	Development of a Roughness Threshold for the Preventive Maintenance of Pavements Based on Dynamic Loading Considerations and Damage Analysis	\$175,819.06	11/01/01	Pavement Performance
UM 00-4-1	Dave Smiley	Investigation of Early Cracking on Selected JPCP Projects	\$28,000.00	01/14/02	Pavement Performance
UM 98-8-1	John Staton	Transverse Crack Propagation of JPCP as Related to PCC Toughness	\$217,301.95	01/29/02	Pavement Performance

## PROJECTS/CONTRACTS CLOSED FY 2002

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
MSU 00-3-1	Vern Barnhart	Identify Causes for Under Performing Rubblized Concrete Pavement Phase II	\$160,732.22	09/30/02	Pavement Performance
01-MTU-1	Steve Kahl	Development Length of Stainless Steel Reinforcing Bars	\$64,149.75	02/07/02	Bridges
01-MTU-8	Roger Till	Forecast & Resolve Deterioration problems With the Ends of PC Beams-Causes & Cures of PC Bridge Beam End Deterioration - Joint Venture	\$68,931.00	05/31/02	Bridges
01-MTU-9	Roger Till	Investigation of Current Bridge Loading vs Design Loading	\$44,934.00	07/03/02	Bridges



## PROJECTS/CONTRACTS CLOSED FY 2002

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
WSU 01-0339	John Staton	Criteria & Benefits of Penetrating Sealants for Bridge Decks	\$86,640.84	6/30/02	Bridges
WSU 01-0363	Roger Till	Investigation of Current Bridge Loading vs Design Loading - Joint Venture	\$33,098.00	07/03/02	Bridges
WSU 01-0364	Roger Till	Forecast & Resolve Deterioration Problems With the Ends of PC Beams-Causes & Cures of PC Bridge Beam End Deterioration Joint Venture	\$99,876.00	05/31/02	Bridges

## PROJECTS/CONTRACTS CLOSED FY 2002

PROJECT/CONTRACT		TITLE	TOTAL EXPENDITURES FOR PROJECT/CONTRACT	CLOSED DATE	PROJECT/CONTRACT TYPE
NUMBER	MANAGER				
99-MTU-3	Bob Muethel	A Study of Materials-Related Distress (MRD) in Michigan's PCC Pavements	\$295,503.99	05/31/02	Materials
01-MTU-3	John Staton	Field Performance of Polymer Concrete Bridge Deck Overlays in Michigan	\$65,391.00	10/31/01	Materials
02-MTU-4	Frank Spica	Road Temperature Sensor Project for FY 2001/2002	\$15,000.00	09/30/02	Materials
02-MTU-6	Dick Endres	Mechanical Properties of Rock Cores	\$3,956.00	09/30/02	Materials
<b>TOTAL</b>			<b>\$2,152,248.13</b>		

## SUMMARY OF COMPLETED PROJECTS BY UNIVERSITY

FY 2000		
University	Number of Projects	Expenditures
Michigan Technological	3	\$103,221.26
Michigan State	6	\$503,680.87
University of Michigan	1	\$42,229.98
Wayne State	0	
Lawrence Technological	0	
<b>SUBTOTAL</b>	<b>10</b>	<b>\$649,132.11</b>
FY 2001		
University	Number of Projects	Expenditures
Michigan Technological	6	\$167,916.51
Michigan State	4	\$521,656.22
University of Michigan	3	\$314,679.10
Wayne State	0	
Lawrence Technological	0	
<b>SUBTOTAL</b>	<b>13</b>	<b>\$1,004,251.83</b>
FY 2002		
University	Number of Projects	Expenditures
Michigan Technological	14	\$1,097,812.08
Michigan State	4	\$488,399.30
University of Michigan	2	\$245,301.95
Wayne State	4	\$320,734.80
Lawrence Technological	0	
<b>SUBTOTAL</b>	<b>24</b>	<b>\$2,152,248.13</b>
<b>TOTAL</b>	<b>47</b>	<b>\$3,805,632.07</b>

# Summaries - Management Projects FY 2000

**00-MTU-1      Publication of Research Record**

Project Manager:            Jon Reincke  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$43,447.00  
Total Amount Spent:        \$30,998.79  
FY 2000 Expenditures:     \$30,998.79  
Completion Date:           9/30/00

**00-MTU-2      Operation and Coordination of the Transportation  
Materials Research Center (TMRC)**

Project Manager:            Jon Reincke  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$36,202.00  
Total Amount Spent:        \$33,130.08  
FY 2000 Expenditures:     \$33,130.08  
Completion Date:           9/30/00

**00-6-2      Coordination and Management of the Pavement Research  
Center of Excellence (PRCE)**

Project Manager:            Jon Reincke  
Contractor:                 Michigan State University  
Total Project Cost:         \$22,879.00  
Total Amount Spent:        \$16,556.66  
FY 2000 Expenditures:     \$16,556.66  
Completion Date:           9/30/00

# Summaries - Construction Projects FY 2000

## **99-MTU-5      Construction Project Scheduling at MDOT**

Project Manager:	John LaVoy
Contractor:	Michigan Technological University
Total Project Cost:	\$40,543.00
Total Amount Spent:	\$39,092.39
FY 1999 Expenditures:	\$21,983.92
FY 2000 Expenditures:	\$17,108.47
Completion Date:	8/23/00

The purpose of the research was to review current MDOT requirements for contractor-submitted schedules, identify the purpose, capabilities, or problems related to the process, along with associated recommendations for change including new scheduling techniques.

Research included collecting information from surrounding states relating to their methods of scheduling, conducting numerous interviews with contractors and MDOT personnel and an analysis of three test projects with various scheduling techniques such as Critical Path Method Scheduling, Bar Charts, and Linear Scheduling

Findings, as a result of the above, confirmed that MDOT's current (pre-1999) requirements for contractor progress schedules reflected the potential for a level of inaccuracy. The typical Contractor did actually take the time to develop a reasonable plan for constructing the project, but the means for measuring progress throughout the duration of the project and using the submitted schedule to document evidence for justification of decisions relative to impacts to the schedule was not evident under the existing process. Suggested changes as a result of the study included introducing requirements that allow more accurate schedule submission, a review of the system MDOT uses to establish contract time, reevaluating of the need to require schedules on small projects, making the initial schedule on projects optional with the contractor assuming all risk, the submission of more than the minimal information on projects, and the use of sophisticated scheduling techniques on high impact projects.

**In conjunction with this study and other MDOT initiatives, several changes in the requirements for contractor-submitted work schedules have now been developed and are currently the standards in projects. Contractors' schedules now have the potential to be more realistic and reflective of reality on MDOT projects.**

# Summaries - Pavement Design Projects FY 2000



## 96-1-0 Improvement of MichPave and MichBack

Project Manager:	Tom Hynes
Contractor:	Michigan State University
Total Project Cost:	\$125,069.00
Total Amount Spent:	\$125,068.43
FY 1996 Expenditures:	\$11,233.76
FY 1997 Expenditures:	\$16,709.87
FY 1998 Expenditures:	\$62,586.21
FY 1999 Expenditures:	\$34,538.59
Completion Date:	9/20/00

This research project, undertaken by Michigan State University (MSU), provided enhancements to the mechanistic pavement analysis program Michpave and the deflection back calculation program Michback. It incorporated enhanced mathematical models that were developed under a companion project into the software. The two programs were converted from a DOS format operate in a Windows environment. **The two programs, in addition to a computerized version of the current AASHTO pavement design method, were combined into one interactive computer program called the Michigan Flexible Pavement Design System (MFPDS).**

**If it is decided to implement mechanistic pavement design in Michigan, MFPDS will be implemented by MSU-sponsored training programs for region pavement designers.** Potential benefits include more cost effective pavement designs and a better prediction of pavement life.

Summaries - Pavement  
Performance Projects  
FY 2000

## 97-7-1 Factors Affecting Shear Capacity of Transverse Cracks in Jointed Pavement

Project Manager: John Staton  
Contractor: Michigan State University  
Project Period: 10/1/96 to 9/30/99  
Total Project Cost: \$150,172.39  
Total Amount Spent: \$128,021.28  
FY 1997 Expenditures: \$17,075.96  
FY 1998 Expenditures: \$37,818.92  
FY 1999 Expenditures: \$55,841.12  
FY 2000 Expenditures: \$17,285.28  
Closed Date: 6/19/00

Environmental and/or traffic related stresses can lead to the development of transverse cracking in jointed concrete pavements (JCPs). Deterioration of transverse cracks over time can result in loss of serviceability and loss of structural capacity in such pavements. An understanding of the factors affecting transverse cracking in JCPs and the ability to assess when and how to repair pavements with this distress are, therefore, two issues of importance to transportation agencies. Addressing these issues, the primary objectives of this research were to study the effects of various factors on transverse cracking in JCPs and to demonstrate methods for evaluating these cracked pavements. Field data collected from in-service JCPs located throughout southern Michigan was used to accomplish these objectives. **Joint spacing, concrete coarse aggregate type, and shoulder type were found to have significant effects on transverse crack development and/or performance.** Three analysis procedures that are based on the use of falling weight deflectometer (FWD) data - back calculation of pavement support and stiffness parameters, determination of crack performance parameters, and assessment of void potential near cracks were demonstrated using data from this study and allow for evaluation of cracked JCPs. Results from these FWD analyses were used to develop threshold limits necessary for performing evaluations with these procedures.

In conjunction with the field testing, a laboratory study of large-scale concrete slabs was performed. This involved the collection and analysis of load transfer data from a variety of concrete slabs with different coarse aggregate types and blends. **This laboratory study verified findings from the field study in a controlled environment.**

## **98-2-1 Detecting and Quantifying Segregation in Bituminous Pavements and Relating Its Effect to Condition**

Project Manager: Mike Frankhouse  
Contractor: Michigan State University  
Project Period: 10/1/97 to 9/30/00  
Total Project Cost: \$200,328.00  
Total Amount Spent: \$141,980.27  
FY 1998 Expenditures: \$44,444.41  
FY 1999 Expenditures: \$74,635.06  
FY 2000 Expenditures: \$22,900.80  
Closed Date: 7/13/00

The final report for this study was a collaborative effort between MDOT and Michigan State University.

The project was the **second phase of a segregation study**, which started in 1995. Both phases had the objective of developing an expedient field test to verify and quantify segregation in hot mixed asphalt (HMA) pavements. This report defines three degrees of segregation: light, medium, and heavy. It is shown that nuclear density testing can form the basis of an expedient field quality-control test to verify and quantify the existence of medium and heavy degrees of segregation. Statistical differences in nuclear density values are shown to be good predictors of actual aggregate gradation differences and are correlated to visual observations of medium and heavy degrees of segregation.

**The focus of the study involved 20 test sites.** At each site, a joint MDOT and MSU team mapped pavement segregation in detail for data gathering and evaluation purposes. The locations were chosen to reflect consistent descriptions of the various degrees of segregation, as well as non-segregated “control” areas.

The results of the study provided extensive and insightful information regarding density variations in pavements. An important finding of the study is as follows:

Statistical comparisons of nuclear density values provide a good indication of segregation, when (a) areas of medium or heavy segregation are visually identified, and (b) areas of non-segregation are visually selected from the same truck load during construction and at the same distance from the pavement edge as the segregated area.

**As a result of this study, a special provision has been implemented on all surfacing projects that measures HMA surface uniformity, including a software program mbitseg.xls, to facilitate statistical calculations in the field and provide directions for resolving segregation problems in the field.**

In addition, during the two-year study, it was found that heavy segregation causes a minimum of 50 percent reduction in pavement service life for the affected areas.

### **99-3-3 Comparison of Concrete Pavement Performance Utilizing Different Types of Coarse Aggregate**

Project Manager: Dave Smiley  
Contractor: Michigan State University  
Project Period: 10/1/97 to 9/30/99  
Total Project Cost: \$8,000.00  
Total Amount Spent: \$7,835.77  
FY 2000 Expenditures: \$7,835.77  
Closed Date: 6/30/00

This project was established to obtain student help in data analysis. **No report was required. No followup is needed.**

### **99-4-3 Identify Causes for Under-Performing Rubblized Concrete Pavement Projects Phase I - (See 00-3-1 for Phase II)**

Project Manager: Vern Barnhart  
Contractor: Michigan State University  
Project Period: 4/1/99 to 12/31/99  
Total Project Cost: \$91,549.79  
Total Amount Spent: \$84,218.46  
FY 1999 Expenditures: \$11,117.03  
FY 2000 Expenditures: \$73,101.45  
Completion Date: 9/5/00

The Report for Phase I of this project is an interim report. The items that have been brought out in this report that can be implemented at this time are as follows:

- More preliminary engineering is needed to assure that the project selected to be rubblized is well suited to be rubblized.
- Take cores through the concrete (driving lane) to determine the condition of the concrete.
- Check the condition of the base, subbase, and subgrade under the concrete.

- Read, follow, and enforce the current Special Provision for Rubbilizing Concrete Pavements that is being placed in proposals.

# Summaries - Bridge Projects FY 2000

## **98-1219                    Development of a Guide for the Evaluation of Existing Bridges - Phase II**

Project Manager:                    Roger Till  
Contractor:                            University of Michigan  
Total Project Cost:                 \$42,230  
Total Amount Spent:                \$42,229.98  
FY 1999 Expenditures:             \$42,229.98  
Completion Date:                    11/15/99

Report RC-1378. The objective of this report is to present the results of the field test carried out in 1999 by the team at the University of Michigan. The field tests were performed to determine the load distribution factors needed to evaluation of bridges. The test program was a continuation of the field tests carried out in 1997-98. The previous study focused on shorter spans (10-18m), and the present study covered spans from 20 to 30m. Six bridges were tested, all located in the Southern part of Michigan. Steel girders with a concrete deck slab were considered. The tests were performed using fully loaded 11 axle trucks (up to the legal limit). Strains were measured for a single truck and for two trucks side-by-side. Girder distribution factors (GDF) were calculated using the measured strains. The obtained GDFs were compared with the code specified GDFs. The tests confirmed previous observations that the code specified girder distribution factors are conservative. However, for the spans considered in this study (20-30m), the safety margin is smaller than for shorter spans. The tests also included measurement of dynamic loads and proof load testing. The dynamic load factor (DLF) for two fully loaded trucks side-by-side is practically less than 0.10. For a single truck, DLF is less than 0.20. Proof load tests were carried out using two M-1 tanks, each weighing about 62 tons, and two fully loaded 11-axle trucks. The bridge response (strains) was within linear elastic limits, even though the deflection exceeded 40mm. The results are summarized in the final chapter of this report. **Girder distribution factor results included in revised Bridge Analysis Guide.**



# Summaries - Materials Projects FY 2000

# Summaries - Management Projects FY 2001

**01-MTU-2      Operation and Coordination of the Transportation  
Materials Research Center (TMRC)**

Project Manager:            Jon Reincke  
Contractor:                Michigan Technological University  
Total Project Cost:        \$36,499.00  
Total Amount Spent:       \$31,619.93  
FY 2001 Expenditures:    \$31,619.93  
Completion Date:          10/31/01

**01-MTU-4      Administrative Operations for the Center for  
Structural Durability (CSD) at WSU/MTU Joint  
Venture**

Project Manager:            Roger Till  
Contractor:                Michigan Technological University  
Total Project Cost:        \$20,000.00  
Total Amount Spent:       \$20,000.00  
FY 2001 Expenditures:    \$20,000.00  
Completion Date:          10/31/01

**01-MTU-7      Publication of the Research Record**

Project Manager:            Jon Reincke  
Contractor:                Michigan Technological University  
Total Project Cost:        \$34,000.00  
Total Amount Spent:       \$14,235.14  
FY 2001 Expenditures:    \$14,235.14  
Completion Date:          10/31/01

# Summaries - Construction Projects FY 2001

# Summaries - Pavement Design Projects FY 2001

**98-MTU-1            Modernization of the Illi-Slab Finite Element  
Analysis Program for Concrete Pavements**

Project Manager:            Dave Smiley  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$40,012.00  
Total Amount Spent:        \$40,012.00  
FY 1998 Expenditures:     \$11,325.07  
FY 1999 Expenditures:     \$28,686.93  
Completion Date:            12/14/00

This was a pooled-fund project with Minnesota Department of Transportation. Michigan Technology University acted as our technical advisor/representative. **The only deliverable was the new software program, which we now have.** Before implementation can take place, there is a need for assessment of the new software for Michigan designs/conditions. Also, there is a need for a user's operation manual. These items will be done as part of a followup project for fiscal year 2000 with Michigan Technological University and Michigan State University. The proposal is now underway.

**00-MTU-8            Feasibility Evaluation for Enhancing Michigan's  
Procedures for Pavement Design and Selection**

Project Manager:            Dave Smiley  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$1,500.00  
Total Amount Spent:        \$679.44  
FY 2001 Expenditures:     \$679.44  
Completion Date:            9/21/01

This project was established **to fund support for advisory consulting**, when required, from Michigan State University principal investigators for development of a work plan per the project title. The department is responsible for the work plan, which is incomplete.

**00-5-1      Feasibility Evaluation for Enhancing Michigan's  
Procedure for Pavement Design and Selection**

Project Manager:            Dave Smiley  
Contractor:                 Michigan State University  
Total Project Cost:         \$5,500.00  
Total Amount Spent:        \$5,285.52  
FY 2000 Expenditures:     \$5,033.82  
FY 2001 Expenditures:     \$251.70  
Completion Date:            7/2/01

This project was established **to fund support for advisory consulting**, when required, from Michigan State University principal investigators for development of a work plan per the project title. The department is responsible for the work plan, which is incomplete.

Summaries - Pavement  
Performance Projects  
FY 2001



## **00-2-1 Evaluation of Alignment Tolerances for Dowel Bars and Their Effects on Joint Performance**

Project Manager:	Mike Eacker
Contractor:	Michigan State University
Total Project Cost:	\$61,130.00
Total Amount Spent:	\$59,652.64
FY 2000 Expenditures:	\$106.88
FY 2001 Expenditures:	\$56,563.13
FY 2002 Expenditures:	\$2,982.63
Completion Date:	7/16/01

Report RC-1395 available on compact disk. Dowel bars are placed at pavement mid-depth, and care is taken to minimize the detrimental effects of misalignment. Dowel bars at contraction joints should be exactly parallel to the surface and centerline of the hardened slab. If they deviate from the desired position, they are said to be misaligned. Misalignment may result from misplacement (initially placing the dowels in an incorrect position), displacement (movement during the paving operation), or both.

The objective of this study is to develop justifiable tolerance levels that ensure that doweled joints do not cause high levels of stresses due to misaligned dowels. This may lead to a possible construction cost savings without jeopardizing pavement performance. The first stage of this project involves the development of finite element models capable of analyzing PCC stress due to dowel misalignment. The study reported herein included the development of several finite element models using a commercial finite element package - ABAQUS. **A comprehensive PCC-dowel interaction model was developed and calibrated/validated using the results of a pullout test.**

The second stage of the project will include laboratory testing using various modified pullout tests to verify the stage one findings and misalignment tolerances will be recommended.

# Summaries - Bridge Projects FY 2001

## **96-1067            Repair and Strengthening of Reinforced and Prestressed Concrete Beams Using CFRP Glued-On Plates**

Project Manager:	Roger Till
Contractor:	University of Michigan
Total Project Cost:	\$149,670.00
Total Amount Spent:	\$149,670.00
FY 1997 Expenditures:	\$41,046.76
FY 1998 Expenditures:	\$61,649.83
FY 1999 Expenditures:	\$29,102.54
FY 2000 Expenditures:	\$14,878.05
FY 2001 Expenditures:	\$2,992.82
Completion Date:	1/25/01

Report RC-1372 and RC-1388. Repair and strengthening techniques using adhesive bonded carbon fiber reinforced plastic or polymeric (CFRP) laminates (also called sheets, tow sheets, and thin plates) form the basis of a new technology being increasingly used for bridges and highway superstructures. The study described in this report (Volumes 1 to 7) focused on the use of carbon fiber reinforced plastic (CFRO) laminates for repair and strengthening of reinforced concrete beams. Its primary objectives are as follows: (1) to ascertain the applicability of CFRP adhesive bonded laminates for repair and strengthening of reinforced concrete beams; (2) to synthesize existing knowledge and develop procedures for implementation in the field; (3) to identify key parameters for successful design and implementation; and (4) to adapt this technique to the specific conditions encountered in the State of Michigan.

### **Volume 1 - Summary Report**

This volume summarizes the main findings of the project. Since the adhesive-bonded plate repair and strengthening technique applies to plain, reinforced and prestressed concrete structures, as well as steel and timber structures, the experience gained during this project and the technology transfer developed covered a wide range of future applications.

### **Volume 2 - Literature Review**

This volume provides a review of existing literature on the repair and strengthening of reinforced concrete beams using external glued-on Fiber Reinforced Plastic (FRP) sheets, particularly Carbon Fiber Reinforced Plastic (CFRP) sheets. A special emphasis is placed at synthesizing the information so as to allow the reader to first comprehend the material, and then make rational decisions about its use. Useful sources of information and contact persons throughout the US are also gathered. First, the mechanical properties of different FRP sheets, made with different types of fibers such as Carbon, Glass, and Aramid, are compared to the properties of steel plates. A summary of the technical data of the commercial CFRP sheets is then presented. Information about the epoxy necessary to glue the CFRP sheets to the structural element is provided as obtained from different suppliers. Different application procedures of CFRP sheets glued-on to

the surface of concrete beams are documented. Specific information concerning surface preparation, mixing of adhesives, application of the CFRP sheet to the structure, and additional limitations and safety precautions are presented for each procedure. The results of an extensive survey of a large number of research projects and field applications of glued-on FRP sheets for repair and strengthening of concrete structures in the US are summarized. Whenever possible a summary of projects (research or field applications) that are deemed relevant to the current investigation, is presented. An analysis of the structural behavior of concrete beams externally strengthened by CFRP sheets is provided. Issues related to durability, which is of concern to the current study, are addressed. A summary of the recommendations for the current study based on what was learned from the literature review is presented, and an extensive list of references classified by source is provided.

#### Volume 3 - Behavior of Beams Strengthened for Bending

The part of the investigation dealing with reinforced concrete beams strengthened in bending is described in this volume, where the results are also analyzed, compared, and discussed. The experimental program comprised fourteen reinforced concrete T-beams. The test parameters included two levels of steel reinforcement ratios before strengthening, and up to four strengthening levels. Two commercially available strengthening systems were tested, the Sika CFRP plate system (CarboDur), and the Tonen CFRP sheet system. Other selective parameters investigated included two different concrete covers; two conditions of cover preparation, three different end anchorage systems of the glued-on sheets, and pre-loading pre-yielding of the beam prior to strengthening. Conclusions are drawn and some recommendations for design are suggested.

#### Volume 4 - Behavior of Beams Strengthened for Shear

The parts of the investigation dealing with reinforced concrete beams strengthened in shear is described in this volume, where the results are also analyzed, compared, and discussed. The experimental program comprised three rectangular concrete beams and three T-beams. The test parameters included two different shear-span ratios. Two commercially available strengthening systems were tested, the Sika CFRP plate system (CarboDur), and the Tonen CFRP sheet system. Both systems were used for shear strengthening and for two specimens they were also used for shear and bending strengthening. Other selective parameters investigated included two levels of longitudinal steel reinforcement ratio before strengthening and two steel shear reinforcement levels. Conclusions are drawn and some recommendations for design are suggested.

#### Volume 5 - Behavior of beams Under Cyclic Loading at Low Temperature

The part of the investigation dealing with the tests in bending and shear of strengthened beams under low temperature (-29°C) and high amplitude cyclic loading is the subject of this volume. Results are also analyzed, compared, and discussed. Four reinforced concrete beams strengthened with CFRP sheets were designed, prepared and tested under low temperature conditions (-29°C). Two beams were tested mono tonically to failure and the other two were tested under high amplitude cyclic load (fatigue loads). Parameters investigated were: Low temperature and loading conditions. The four beams were tested under low temperature conditions (-29°C). Two beams were tested under a four-point load configuration, one mono

tonically and one in cyclic fatigue. These beams considered to fail in bending were strengthened with the Sika system. The remaining two beams were tested under a three-point load configuration, also one mono tonically and one in cyclic fatigue. These beams considered to fail in shear were retrofitted with the Tonen system. The amplitude of the cyclic fatigue load was taken as 10 to 80 percent of the failure load from the monotonic test. Conclusions are drawn and some recommendations for design are suggested.

#### Volume 6 - Behavior of Beams Subjected to Freeze-Thaw Cycles

The part of the investigation dealing with the flexural testing of reinforced concrete beams with glued-on CFRP plates subjected to different numbers of freeze-thaw cycles is the subject of this volume. Results are also analyzed, compared, and discussed. The experimental program comprised forty-eight reinforced concrete beams. The specimens were subjected to up to 300 freeze-thaw cycles according to ASTM C666. For every parameter, three beams were tested in bending at 0, 100, 200, and 300 cycles. Parameters investigated were two different adhesive systems, the Tonen CFRP sheet system (Mbrace), and the Sika CFRP system (Carbodur); and a cracking stage where a precracked condition simulates cracking conditions in the field prior to strengthening. Control specimens (RC beams with no CFRP laminate externally glued-on) were also subjected to 0, 100, 200, and 300 cycles freeze-thaw cycles. Conclusions are drawn and some recommendations for design are suggested.

#### Volume 7 - Technical Specifications

Volume 7 provides technical specifications based on information provided by the manufacturers of the two CFRP strengthening systems used and augmented by the experience accrued during the course of this investigation. Since the adhesive-bonded plate repair and strengthening technique applies to plain, reinforced, and prestressed concrete structures, as well as steel and timber structures, the experience gained during this project and the technology transfer developed covered a wide range of future applications.

#### **Special provision for CFRP sheets written. One construction project and one CFRP sheet demonstration project were completed in 2000.**

The load tests performed on Bridge ID #B02-19031, carrying old US-27 over Holden Creek, in Clinton County is documented by report RC-1388. The objective of the load test was to verify the effect of a strengthening with carbon fibers on the behavior of a reinforced concrete deck slab. The tests were carried out prior to strengthening, on July 7, 2000, and after application of carbon fibers, on August 22, 2000. Carbon fiber-reinforced polymer (CFRP) sheets were glued at the bottom of the deck slab to strengthen concrete in tension. The strains at the bottom of the slab and deflections were measured to find the effect of strengthening.

## 96-1068 Non-Metallic Reinforcement of Concrete Bridge Deck

Project Manager: Dave Juntunen  
Contractor: Michigan State University  
Total Project Cost: \$262,226.00  
Total Amount Spent: \$262,221.03  
FY 1997 Expenditures: \$21,842.49  
FY 1998 Expenditures: \$78,861.13  
FY 1999 Expenditures: \$91,865.85  
FY 2000 Expenditures: \$3,374.73  
FY 2001 Expenditures: \$66,276.83  
Completion Date: 3/20/01

Report RC-1392. A field demonstration project comprising a concrete bridge deck reinforced with an Aramid Fiber composite bar was implemented and is subjected of long-term monitoring. A field demonstration project (M-15 over Goodings Creek) was built using Aramid Fiber reinforcement, and it is being monitored. Building durable bridge decks using non-metallic reinforcement is feasible; however, at present, the cost and availability of the products are prohibitive. However, **the experience provided by this research has set the ground work for researchers and manufacturers of non-metallic reinforcement to develop second and third generation products that will be more competitive to steel reinforcement.**

## 96-1069 Polymer Composite Jackets for Column Repair

Project Manager: Roger Till  
Contractor: Michigan State University  
Total Project Cost: \$194,981.00  
Total Amount Spent: \$194,497.03  
FY 1997 Expenditures: \$17,759.59  
FY 1998 Expenditures: \$83,582.09  
FY 1999 Expenditures: \$52,193.81  
FY 2000 Expenditures: \$40,961.54  
Completion Date: 1/25/01

Report RC-1386. Experiments were conducted to assess the effects of using fiber-reinforced polymer (FRP) wraps with fibers oriented in the hoop direction for rehabilitating corrosion-damaged columns. Issues that were explored are: (1) freeze-thaw durability of concrete square and cylindrical specimens wrapped with glass and carbon FRP and subjected to an internal expansive force; (2) effect of wrapping on the rate of corrosion in an accelerated corrosion test; Freeze-thaw and we-dry conditioning had no detrimental effect on carbon FRP panels other than a 28 to 36 percent reduction, respectively, in the ultimate strain. Glass FRP panels showed 21 and 20 percent reductions in ultimate strength and ultimate strain due to freeze-thaw conditioning, and 18 and 20 percent reductions in ultimate strength and ultimate strain due to

wet-dry conditioning. The results of tension tests on carbon panels were somewhat unreliable. Better grip fixtures should be used for future testing.

Both glass and carbon FRP panels did not display any significant damage due to the impact test.

At temperatures in excess of 200°C the epoxy in the FRPs burn and evaporate and the individual plies of wraps unravel. Hence the wraps become ineffective at such high temperatures unless effective insulation is provided.

It is evident from the experimental study conducted that both carbon and glass wrap systems are sufficiently resistant to free-thaw cycles and reduce the corrosion rate by about the same rate. Therefore, three layers of glass wrap or two layers of carbon wrap may be used to repair Michigan bridge columns. **Special provision and use criteria for column wrapping written.** Use criteria to be included in the Bridge Design Manual according to Bridge Committee Minutes of May 10, 2001. **One column wrapping demonstration project completed in 1999.**

### **98-1303                      Research Study to Determine Procedures for Efficient Evaluation of Bridge Decks**

Project Manager:	Dave Juntunen
Contractor:	University of Michigan
Total Project Cost:	\$61,446.00
Total Amount Spent:	\$61,359.10
FY 1999 Expenditures:	\$43,340.56
FY 2000 Expenditures:	\$14,365.39
FY 2001 Expenditures:	\$3,122.36
FY 2002 Expenditures:	\$530.79
Completion Date:	6/26/01

Report RC-1389. Objective of this project was to provide a guide for evaluating bridge decks. The report is to be used as a supportive document to the many guidelines and specifications either developed or recognized by MDOT. The guide was distributed to Regional Bridge Engineers and Bridge Inspectors. Upon receiving feedback from the users of the Guide, it can be updated to best meet their needs, and as Department procedures regarding bridge decks change, the Guide can be updated to stay current. The Guide will be distributed in electronic format (.pdf) for fast and economical distribution.

**00-0341                      Verification of Girder Distribution Factors for Steel  
Girder Bridges**

Project Manager:                      Roger Till  
Contractor:                              University of Michigan  
Total Project Cost:                    \$103,650.00  
Total Amount Spent:                   \$103,650.00  
FY 2000 Expenditures:               \$1,257.06  
FY 2001 Expenditures:               \$88,403.65  
FY 2002 Expenditures:               \$13,989.29  
Completion Date:                       7/9/01

Report RC-1393. The report documents the field testing and finite element analysis of steel girder bridges with spans from 10 to 45 m. A total of six bridges were instrumented and loaded with heavy 11-axle trucks. In addition, a truck survey was carried out to determine the frequency of simultaneous occurrence of two trucks in-lane and side-by-side. The field tests confirmed that the code specified GDF's, for a single lane and for two-lane traffic, are conservative. An advanced finite element (FEM) analysis was performed using ABAQUS. The actual behavior was modeled by assuming a partial fixity of the supports (fixed hinges and restrained rotation). For the design of new bridges, it is recommended to use AASHTO LRFD (1998) GDF's. For evaluation of existing steel girder bridges, it is recommended to use AASHTO LRFD (1998) GDF's specified for a single lane even for two lane structures, because of a reduced probability of a simultaneous occurrence of two heavy trucks side-by-side. The field study also confirmed previous findings related to the dynamic load factors (DLF). Therefore, for evaluation of existing steel girder bridges it is recommended to use  $DLF = 0.10$  for two-lane loading, and  $DLF = 0.20$  for a single truck load case. **Girder distribution factor results included in revised Bridge Analysis Guide.**



# Summaries - Materials Projects FY 2001

## **00-MTU-3      Aggregate Absorption as Related to Anti-Icing for Elastomeric Concrete Bridge Deck Overlays**

Project Manager:            John Staton  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$61,370.00  
Total Amount Spent:        \$61,370.00  
FY 2000 Expenditures:     \$48,612.37  
FY 2001 Expenditures:     \$12,757.63  
Completion Date:            4/12/01

**The use of freezing point depressants to remove hard packed snow and ice from pavements has been a common practice by highway maintenance crews for decades.** The search for lower impacts on the environment has facilitated the search for methods to decrease volumes applied as well as alternative chemicals to be used in environmentally sensitive areas such as near lakes and streams. Each new chemical that is brought into the market has its own unique set of properties. Some are thicker than others, are more concentrated, have an unpleasant odor, work only at warm temperatures, and so on. In some cases more is needed to achieve the same melting ability. The property that is of highest interest to this study is the tendency for “residual effect.”

Residual effect can be explained as the characteristic of a chemical that allows it to keep working for an extended period of time during a single storm event, and also has the potential to remain on the pavement for subsequent storms. This was a study of combinations of chemicals and aggregates that have the potential to greatly increase residual effect at the pavement surface.

**Testing within the scope of this research project clearly shows that certain combinations of aggregate and deicing chemical can drastically reduce the formation of frost on pavements, as well as minimizing the bond potential between ice and the pavement.** A limited number of combinations of aggregate and chemical were tested under this project, but good results were obtained.

Frost growth tests show that in some cases, the occurrence of frozen water vapor precipitation (hoar frost or rime ice deposit) is nearly eliminated. Some limestones in combination with freezing point depressants show no freezing even after numerous washes. This has the potential for coating areas such as bridge decks that are highly susceptible to frost, and keeping the deck ice free through numerous storm events. In contrast, testing on low absorptive samples show rapid re-freezing after only a few washes. Tests with NaCl show that it will inhibit frost growth, but at a temperature slightly higher than the other three chemicals.

**The same potential holds true for the reduction of bond strength with a single chemical application.** In general, the same scenarios work well for residual effect for bond reduction as do frost mitigation. In both cases, the limestones with medium absorptions perform well with all chemicals tested under this scope. **The CMA and NaCl appear to perform slightly better**

**than the other two chemicals in all cases, but the difference is small enough to probably be insignificant.**

In general, several different conclusions can be made from this testing. For both the frost and bond reduction testing, the tile samples were chosen to simulate a non-absorptive pavement. This would be a pavement (i.e., bridge decks) consistently having frost and icing problems for nearly every frost or freezing event even after chemicals were applied on the previous event. Any chemical that was applied has been washed off and there is little or no residual effect left. Considering the results for the tile samples, this is a good assumption. First, frost grows on these samples after the first set of washes. For the bond reduction the bond strength rises to a level comparable to the “no chemical” state after only a few washes. This is shown graphically by the trend given by the linear regression of the data. These regression lines show how rapidly a combination returns to the “no chemical” state after application of chemical. A steep line depicts a poor tendency for residual effect with a flat slope showing good chemical retention.

Keeping the tile results in mind, and assuming that the tile samples simulate a surface that exhibits “poor” anti-icing attributes, what do the other combinations show? In contrast to tile, **Figures 23 and 25 (of the report) show combinations resulting in excellent residual reduction in bond strength. These are the TS-E limestones with CMA and NaCl. Both of these show bond strengths well below the baseline values even after 16 washes.** This means that the pavement simulated by the tile samples could be coated with one of these aggregate/chemical combinations and the residual bonding could be drastically reduced. Further investigation of the frost results narrows this down even further. The CMA can eliminate frost down to 20° F on this aggregate while the NaCl is good to only about 23° F. This may not be a bad result, however, since frost events normally occur in the range of 30° F or warmer. In any case, both of these and several other combinations tested showed that a much safer pavement can be obtained by coating pavements that exhibit “poor” residual effect with “anti-icing” smart aggregate/chemical combinations.

**The next step that is anticipated from this research is to use some of these concepts in the field.** It is hoped that the aggregate types, and possibly others, can be crushed and graded, and used as broadcast aggregates with elastomeric coatings. One scenario may be to set up short test lanes of various combinations on a straight section of highway and monitor them through the winter. Some further laboratory studies could also be conducted. There are still some questions as to the setup for these trials, but it is hoped that they can be answered with this proposed further testing.

# Summaries - Management Projects FY 2002

**02-MTU-1      Operation and Coordination of the Transportation  
Materials Research Center (TMRC)**

Project Manager:            Jon Reincke  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$103,848.00  
Total Amount Spent:        \$103,223.00  
FY 2002 Expenditures:     \$103,223.00  
Completion Date:            09/30/02

**02-MTU-2      Administrative Operations for the Center for  
Structural Durability (CSD) at WSU/MTU Joint  
Venture - See 01-0366**

Project Manager:            Roger Till  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$20,340.00  
Total Amount Spent:        \$20,340.00  
FY 2002 Expenditures:     \$20,340.00  
Completion Date:            09/30/02

**02-MTU-3      Publication of the Research Record**

Project Manager:            Jon Reincke  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$45,672.00  
Total Amount Spent:        \$24,740.98  
FY 2002 Expenditures:     \$24,740.98  
Completion Date:            09/30/02

**26                Coordination & Management of the Pavement  
Research Center of Excellence (PRCE)**

Project Manager:            Jon Reincke  
Contractor:                 Michigan State University  
Total Project Cost:         \$13,662.00  
Total Amount Spent:        \$13,662.00  
FY 2002 Expenditures:     \$13,662.00  
Completion Date:            09/30/02

# Summaries - Construction Projects FY 2002

## **01-MTU-5      Work Item Production Rates for MDOT Projects**

Project Manager:            John LaVoy  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$75,000.00  
Total Amount Spent:        \$74,801.37  
FY 2001 Expenditures:     \$38,082.79  
FY 2002 Expenditures:    \$36,718.58  
Completion Date:           06/30/02

MDOT utilizes production rates from the MDOT Construction Manual to estimate overall contract time duration on new construction projects. Production rate data was found to be available from the FieldManager construction inspection records. A practical procedure was developed for MDOT to create and maintain a database of historical production rates. Testing the production rates developed against a completed MDOT project revealed a problem with the accuracy of applying the production rates to determining contract durations. It is believed that recording additional work item time data in FieldManager will improve production rate accuracy.

## **01-MTU-6      Comparison of MDOT Schedules as a Result of Special Provision for Progress Schedule, FUSP102G**

Project Manager:            John LaVoy  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$80,000.00  
Total Amount Spent:        \$80,000.00  
FY 2001 Expenditures:     \$38,852.94  
FY 2002 Expenditures:    \$41,147.06  
Completion Date:           09/30/02

During the 2000 construction season, MDOT allowed contractors to submit a Progress Schedule with overlapping or concurrent controlling operations if an explanation in writing as to why the operations are overlapping is provided. The comparison revealed that in three of the four cases, the accuracy of Progress Schedules increased with the allowance of concurrent controlling activities. **Additionally, the twenty-two crush and shape and passing relief lane projects revealed that the accuracy of Progress Schedules varied considerably over the three construction seasons.**

**00-0781                      Effectiveness of Lane Merge Traffic Control System  
at Construction/Work Zones**

Project Manager:                      Jeff Grossklaus  
Contractor:                              Wayne State University  
Total Project Cost:                      \$101,755.00  
Total Amount Spent:                      \$101,119.96  
FY 2000 Expenditures:                      \$8,092.70  
FY 2001 Expenditures:                      \$73,440.57  
FY 2002 Expenditures:                      \$19,586.69  
Completion Date:                      12/31/01

The Michigan Dynamic Lane Merge System consists of traditional work zone control devices along with a system of dynamic “DO NOT PASS/WHEN FLASHING” signs, to create a no-passing zone to minimize late lane merges, to minimize aggressive driver behavior, and delay at the taper area. With the system implemented in advance of the taper section of the work zone compared to before it was implemented, the following was found:

- The average travel speed based on the peak period, travel time increased
- The average peak period travel time delay decreased
- The average number of stops in the work zone decreased
- The number of aggressive driver maneuvers during peak hours reduced dramatically.

Results of tests were presented to the MDOT Executive Operations Committee (EOC) for implementation. **The EOC endorsed the use of the Dynamic Lane Merge System as a “work zone tool.” It can be used anywhere the specific criteria of traffic volumes and peaks are met. Potential benefits include smoother transition into a work zone, less aggressive driving behavior, and less delay at the taper areas.**



# Summaries - Pavement Design Projects FY 2002

**00-MTU-4      Analysis of Bituminous Pavement Surface  
Characteristics & Their Effects on Friction  
Properties**

Project Manager:            Al Robords  
Contractor:                Michigan Technological University  
Total Project Cost:        \$201,135.70  
Total Amount Spent:      \$198,990.08  
FY 2000 Expenditures:    \$99,970.14  
FY 2001 Expenditures:    \$65,277.56  
FY 2002 Expenditures:    \$33,742.38  
Completion Date:         09/30/02

Report no available as of this printing.

**00-MTU-6      Synthesis & Review of Superpave Implementation**

Project Manager:            John Barak  
Contractor:                Michigan Technological University  
Total Project Cost:        \$38,153.00  
Total Amount Spent:      \$37,850.91  
FY 2000 Expenditures:    \$3,229.91  
FY 2001 Expenditures:    \$34,621.00  
Completion Date:         04/02/02

The purpose of this project is to **facilitate the review and exchange of new technologies and practices being undertaken across the United States in the asphalt materials area for the MDOT**. The focus areas were on hot mix asphalt constituent materials: asphalt binder and aggregate, as well as hot mix asphalt. The information gained were from three primary areas: (1) new technology, (2) implementation of Superpave, and (3) areas that needed research. The information was transferred to MDOT through periodic meetings with presentations and quarterly reports. The final report acts as a final summary for the project.

**00-1-1      Development of a Computer Program for Dynamic  
Backcalculation of Flexible Pavement Layer Moduli**

Project Manager:            Tom Hynes  
Contractor:                Michigan State University  
Total Project Cost:        \$138,939.00  
Total Amount Spent:      \$138,253.84  
FY 00 Expenditures:     \$20,927.04  
FY 01 Expenditures:     \$69,869.04  
FY 02 Expenditures:     \$47,457.76  
Completion Date:         9/30/02

Report not available as of this printing.

Summaries - Pavement  
Performance Projects  
FY 2002

## **99-2-1 Development of a Roughness Threshold for the Preventive Maintenance of Pavements Based on Dynamic Loading Considerations and Damage Analysis**

Project Manager: Dave Smiley  
Contractor: Michigan State University  
Total Project Cost: \$217,665.00  
Total Amount Spent: \$175,819.06  
FY 1999 Expenditures: \$68,158.27  
FY 2000 Expenditures: \$88,777.73  
FY 2001 Expenditures: \$18,883.06  
Completion Date: 11/01/01

The objective of this study was to investigate the interaction between surface roughness, dynamic truck loading and pavement damage for the purpose of determining roughness thresholds. The research was successful at validating the above hypothesis by: (1) Identifying empirical relationships between roughness and distress using current indices from in-service pavements. (2) Developing similar relationships between surface roughness and theoretical pavement damage using the mechanistic approach. Consequently, a new roughness index, called the Dynamic Load Index (DLI), was developed for the purpose of identifying “unfriendly” pavement profiles from a dynamic truck loading aspect. The new index was used to develop tables showing the predicted life extension that would be achieved by smoothing a pavement section with a given remaining service life (RSL) for different DLI levels. These tables can be used to decide when smoothing action needs to be taken in order to get a desired life extension for a particular project. **Comparison with RSL-values derived using actual distress growth over time from in-service pavements allowed for determining the optimal range of DLI-values that would lead to the desired life extension upon smoothing the pavement surface. The results showed that such preventive maintenance smoothing action is best suited for rigid pavements.**

## **00-4-1 Investigation of Early Cracking on Selected JPCP Projects**

Project Manager: Dave Smiley  
Contractor: University of Michigan  
Total Project Cost: \$28,000.00  
Total Amount Spent: \$28,000.00  
FY 2000 Expenditures: \$21,653.60  
FY 2001 Expenditures: \$6,346.40  
Completion Date: 01/14/02

Report not available as of this printing.

## **98-8-1      Transverse Crack Propagation of JPCP as Related to PCC Toughness**

Project Manager:	John Staton
Contractor:	University of Michigan
Total Project Cost:	\$244,347.00
Total Amount Spent:	\$217,301.95
FY 1998 Expenditures:	\$49,155.27
FY 1999 Expenditures:	\$38,046.45
FY 2000 Expenditures:	\$110,439.16
FY 2001 Expenditures:	\$19,661.07
Completion Date:	01/29/02

**This study determined the effects of coarse aggregate type and size on crack resistance (toughness) and propagation of the crack after it occurs.** The coarse aggregate types were limestone, gravel and blast-furnace slag. Findings showed that there is a significant gain in load transfer when the aggregate is a larger size and tough. The projects results repeated previous research findings that aggregate quality features do have a significant affect on concrete pavement performance. **Generally, these results support the need to maintain a high level of aggregate quality for the P1-mod concrete specification. They also add to the mounting evidence that selective, higher quality materials should also be used in standard specification applications.**

## **00-3-1 Identify Causes for Under Performing Rubblized Concrete Pavement Phase II**

Project Manager: Vern Barnhart  
Contractor: Michigan State University  
Total project Cost: \$162,111.04  
Total Amount Spent: \$160,732.22  
FY 2000 Expenditures: \$8,636.23  
FY 2001 Expenditures: \$74,874.45  
FY 2002 Expenditures: \$77,221.54  
Completion Date: 06/30/02

**It is strongly recommended that the following steps be adopted for immediate implementation: (1) Revise the acceptance criteria of the MDOT special provision for rubblizing concrete pavements. (2) Strictly enforce the MDOT special provision for rubblizing concrete pavements and quality control measures. (3) Provide the Regions and the Transportation Service Centers a list of deteriorated concrete pavements that should not be selected for rubblization. (5) Implement the layer coefficients and/or modulus values of rubblized materials.** As an alternative to method specifications, the following performance measures are highly recommended for inclusion in a five-year warranty period: (1) No longitudinal and/or transverse top-down cracks. (2) No reflective or regular transverse or longitudinal cracks. (3) No faulting (differential elevation) between two adjacent lanes. (4) No shear failure. (5) No raveling. (6) Less than 0.25-inch rut depth.

**Implementation of the recommendations will be delayed until a new Pavement Selection Review Committee is formed in January of 2003.** When the committee is formed, the report will be submitted to determine the best way to implement the recommendations.

# Summaries - Bridge Projects FY 2002



## **01-MTU-1      Reinforcement - Allowable Lap Lengths, Development Length & Concrete Covers**

Project Manager:	Steve Kahl
Contractor:	Michigan Technological University
Total Project Cost:	\$64,150.00
Total Amount Spent:	\$64,149.75
FY 2001 Expenditures:	\$45,010.75
FY 2002 Expenditures:	\$19,139.00
Completion Date:	02/07/02

Concrete bridge decks in corrosive environments have utilized several methods to prevent corrosion of the reinforcing steel including the use of stainless steel as reinforcement. While proven for corrosion resistance, very little information is available about the bond strength of stainless reinforcement. The bond strength of stainless steel reinforcement in concrete compared to conventional carbon steel reinforcement was studied in working stress ranges between 34 and 100 percent of yield. One hundred and ninety-one bond tests were performed with beam-end specimens similar to the ASTM A944 (1995) specimen. Bar types used in the bond tests were conventional A615 Gr. 60 carbon steel reinforcement, 316LN stainless steel reinforcement, and 2205 Duplex stainless steel reinforcement. Bonded lengths of 4-inch to 10-inch were used for the No. 4 bars, and 5.5 inches to 12-inches for the No. 6 bars. Concrete clear cover for all tests was 1 ½-inch to conduce cracking bond failure. No transverse reinforcement was present in the tests. Comparisons of stainless reinforcement test results to predicted values revealed that there was no reason to believe the bond strength of stainless reinforcing bars, independent of bar type studied, was less than predicted. No. 4 reinforcing bar comparisons involving stainless steel reinforcement to carbon steel reinforcement showed that there was no reason to believe that the stainless steel bond strength was different from the carbon steel bond strength. The comparison of No. 6 stainless steel reinforcement bond tests to carbon steel bond tests revealed a weaker bond for some stainless bars. However, the conservatism of the AASHTO development length relationship (as well as other comparative relationships including OJB, ACI, and Darwin) predicted lower bond strengths than observed at all bonded lengths for all bar types. Therefore, no modifications are suggested when determining the development length of stainless reinforcement on a one-to-one replacement of stainless steel 316LN or Duplex 2205 for Gr. 60 A615 reinforcement, No. 4 to No. 6 bars.

**The study was forwarded to bridge design unit managers. It is hoped that when using stainless for bridge decks, the development/lap lengths specified will be as listed in bridge design guides for uncoated reinforcement. This will reduce the amount of steel needed in bridge decks, thus lower costing.**

We are planning to add these projects to the previous report. Thus, we will have three years of research projects summarized in this report. A copy of this report will be given to all the project managers.

**01-MTU-8 Forecast & Resolve Deterioration Problems with the Ends of PC Beams - Causes & Cures of PC Bridge Beam End Deterioration Joint Venture See 01-0364**

Project Manager: Roger Till  
Contractor: Michigan Technological University  
Total Project Cost: \$68,931.00  
Total Amount Spent: \$68,931.00  
FY 2001 Expenditures: \$44,187.62  
FY 2002 Expenditures: \$24,743.38  
Completion Date: 09/30/02

**Prestressed concrete (PC) for highway bridges was first introduced in Michigan in the 1950s. In 2000, Michigan had more than 1,700 prestressed box beam and 700 prestressed I-beam structures.** A recent study on the condition of Michigan's PC bridges revealed that while most were in fair or better than fair condition, older bridges are showing signs of deterioration, particularly in the ends of I-beam structures. End deterioration needs to be addressed through various inspection and repair techniques for these structures. The specific goals of this research were to (a) develop an inspection procedure for prestressed concrete I-beam bridges that will clearly distinguish distress severity and disclose potential problems, (b) identify preventive maintenance strategies to extend the service life of prestressed concrete I-beam ends, and (c) evaluate repair techniques for I-beam ends to avoid performing complete beam replacement.

The information presented begins with field survey inspection data and results of a multi-state survey to determine nationwide practices for inspection and repair of prestressed concrete I-beam ends. Analytical studies incorporated extensive field inspection data and showed beam-end deterioration to significantly influence the load path through the member to the bearing. An experimental investigation of shrinkage/cracking and adhesion of vertically patched shallow and deep repairs was conducted. Three repair materials were used in patches and specimens were thermally cycled. **All repair materials showed cracking larger than 6 mils and no material met the minimum bond performance criteria of 400 psi. A master listing of suggested preventive maintenance and repair techniques is provided.**

## **01-MTU-9 Investigation of Current Bridge Loading vs Design Loading - Joint Venture See 01-0363**

Project Manager:	Roger Till
Contractor:	Michigan Technological University
Total Project Cost:	\$44,934.00
Total Amount Spent:	\$44,934.00
FY 2001 Expenditures:	\$19,939.65
FY 2002 Expenditures:	\$24,994.35
Completion Date:	09/10/02

This report presents the process and results of a joint research effort between Michigan Technological University and Wayne State University to examine the adequacy of current vehicles loads used to design bridges in the State of Michigan. The target reliability index used in the AASHTO LRFD Bridge Design Specifications was used here as the criterion for evaluating the adequacy. Reliability indices were calculated for twenty different bridges selected randomly from the Michigan inventory of new bridges. The bridge suite included five bridges from each of four major types in Michigan: steel girder, prestressed I-beam, prestressed adjacent box girder, and prestressed spread box girder bridges. Existing weigh-in-motion data was processed to statistically characterize the truck load effect, i.e., moment, shear, and wheel loads. For moment and shear in girders, two strengths were used in the reliability analyses for: (1) strength as designed according to construction plans termed herein as as-designed; and (2) strength required by the current design code as the sum of factored design dead load and live load (HS25) termed herein as design-minimum. For wheel loads, punching shear capacities were used. The two different girder resistances resulted in different reliability levels for comparison. The reliability indices were calculated for each of those cases: (1) entire State of Michigan, and (2) Metro Region (Region 7). To cover the variation of truck traffic volume, two values of truck traffic were used in these analyses: 50<sup>th</sup> and 90<sup>th</sup> percentiles for several functional classes of roads.

The reliability indices were found to vary from bridge type to bridge type. The following conclusions are drawn based on the calculated reliability indices: (1) The 50<sup>th</sup> and 90<sup>th</sup> percentiles of traffic volume do not noticeably influence the reliability indices. (2) This also leads to an observation that the reliability indices for the entire state and for the metro Region (Region 7) do not show significant differences. This is because both cases used the same VIM data collected from around the Metro Region. **(3) The current design load, HS25, could be modified to achieve, on average, a reliability index of 3.5, which was used as the target index for the AASHTO LRFD Bridge Design Specifications. (4) The deck design load of HS 20 is adequate for reinforced concrete decks. It is recommended that a new design load level be considered for bridge beam design in the Metro Region.**

## **01-0339                      Criteria & Benefits of Penetrating Sealants for Bridge Decks**

Project Manager:                      John Staton  
Contractor:                              Wayne State University  
Total Project Cost:                      \$87,059.00  
Total Amount Spent:                      \$86,640.84  
FY 2001 Expenditures:                      \$47,059.61  
FY 2002 Expenditures:                      \$39,581.23  
Completion Date:                      06/30/02

The study presented in the report evaluates the potential durability gained by the use of penetrating sealants on concrete bridge decks. The goal of the study was to evaluate the potential durability gained by the use of penetrating sealants on concrete bridge decks. The study did not endorse the use of sealants for bridge deck protection prior to reviewing controlled field implementations as well as the development and testing of QC/QA procedures. However, this study does conclude that sealants can provide effective deck protection if used once either for decks placed in the fall or at regular maintenance cycles. It is very obvious that the repeated use protocols may have a low benefit/cost when operational costs are considered.

**The following recommendations are provided if the sealant use is adopted for deck protection:**

- 1.        Minimum sealant penetration depth of 0.25-inch is required to provide effective sealing layer for concrete bridge decks.**
- 2.        Neat silane can provide the required durability for bridge decks.**
- 3.        A single sealing cycle is sufficient for late construction if regular preventive maintenance cycles are not required. Otherwise, four to five-year sealing cycles are required.**
- 4.        Moisture is needed for sealant reaction, but it inhibits the sealant penetration. Therefore, the deck surface at least should be dry when the sealant is applied.**
- 5.        Deck cracks should be sealed. If the maximum crack width is less than 0.002-inches, silane sealers are adequate to seal the deck. When the crack width is less than 0.08-inches, silane and HMWM sealers can be applied provided adequate drying period is maintained between silane and HMWM applications.**

**01-0364 Forecast & Resolve Deterioration Problems with the Ends of PC Beams - Causes & Cures of PC Bridge Beam End Deterioration Joint Venture See 01-MTU-8**

Project Manager: Roger Till  
Contractor: Wayne State University  
Total project Cost: \$99,876.00  
Total Amount Spent: \$99,876.00  
FY 2001 Expenditures: \$46,004.14  
FY 2002 Expenditures: \$53,871.86  
Completion Date: 05/31/02

Prestressed concrete (PC) for highway bridges was first introduced in Michigan in the 1950s. **In 2000, Michigan had more than 1,700 prestressed box beam and 700 prestressed I-beam structures.** A recent study on the condition of Michigan's PC bridges revealed that while most were in fair or better than fair condition, **older bridges are showing signs of deterioration, particularly in the ends of I-beam structures.** End deterioration needs to be addressed through various inspection and repair techniques for these structures. The specific goals of this research were to (a) develop an inspection procedure for prestressed concrete I-beam bridges that will clearly distinguish distress severity and disclose potential problems, (b) identify preventive maintenance strategies to extend the service life of prestressed concrete I-beam ends, and (c) evaluate repair techniques for I-beam ends to avoid performing complete beam replacement.

The information presented begins with field survey inspection data and results of multi-state survey to determine nationwide practices for inspection and repair of prestressed concrete I-beam ends. Analytical studies incorporated extensive field inspection data and showed beam-end deterioration to significantly influence the load path through the member to the bearing. An experimental investigation of shrinkage/cracking and adhesion of vertically patched shallow and deep repairs was conducted. **Three repair materials were used in patches and specimens were thermally cycled. All repair materials showed cracking larger than 6 mils and no material met the minimum bond performance criteria of 400 psi. A master listing of suggested preventive maintenance and repair techniques is provided.**

# Summaries - Materials Projects FY 2002

## **99-MTU-3      A Study of Materials - Related Distress (MRD) in Michigan's PCC Pavements**

Project Manager:	Bob Muethel
Contractor:	Michigan Technological University
Total Project Cost:	\$295,504.00
Total Amount Spent:	\$295,503.99
FY 1999 Expenditures:	\$29,642.26
FY 2000 Expenditures:	\$162,917.40
FY 2001 Expenditures:	\$61,110.10
FY 2002 Expenditures:	\$41,834.23
Completion Date:	09/30/02

Materials-related distress (MRD) is of concern to MDOT, potentially affecting all concrete transportation structures including pavements, bridges, retaining walls, barriers, and abutments. MRD is a direct result of a component breakdown within the concrete matrix due to the interaction between the concrete and its surrounding environment. The specific MRD mechanism and extent varies with location due to differences in local environmental factors, concrete constituent materials, construction practices, deicer applications, and traffic. MRD can occur even in properly constructed PCC pavements having adequate structural capacity, resulting in costly, premature concrete deterioration and eventual failure. This study investigated the occurrence of MRD in Michigan's concrete pavements, using a variety of investigative techniques, including visual assessment, nondestructive deflection testing, strength and permeability testing, microstructural characterization, and chemical methods to determine the causes of observed distress. Based on this investigation, specific recommendations were made regarding treatment of distressed pavements and approaches to avoid the occurrence of these distresses in future concrete pavement construction.

Specifically, it was observed that MDOT's current emphasis on screening aggregates using MTM 115 has been effective in preventing aggregate freeze-thaw deterioration in newly constructed pavements. But it was also found that in some cases the air-void system purposely entrained in the concrete to protect it against freeze-thaw damage was inadequate, making the concrete susceptible to freeze-thaw damage. Further, the air contents of mixtures made with blast furnace slag coarse aggregate were higher than desired indicating that some difficulties exist in controlling the air content of such concrete. Alkali-silica reactivity (ASR) was observed in over half the test sites evaluated. In recent projects, the ASR is predominately isolated to the chert constituents in the fin aggregate in concrete made with blast furnace slag coarse aggregate. No definitive conclusions can be drawn at this time regarding the interactions leading to this observation, but the evidence clearly indicates that some type of interaction exists. **It was also observed that in concrete made with blast furnace slag coarse aggregate, there is strong microscopic evidence of calcium sulfide dissolutions near the contact zone with the hydrated cement paste, a preponderance of calcium hydroxide in the hydrated cement paste, and secondary ettringite filling adjacent voids and cracks. Further investigations need to be conducted to confirm whether this is resulting in a type of internal sulfate**

**attack. But mixtures containing Class F fly ash were observed to have markedly better durability, indicating the beneficial nature of this cement supplement/replacement.**

### **01-MTU-3      Field Performance of Polymer Concrete Bridge Deck Overlays in Michigan**

Project Manager:            John Staton  
Contractor:                Michigan Technological University  
Total Project Cost:        \$65,391.00  
Total Amount Spent:      \$65,391.00  
FY 2001 Expenditures:    \$54,180.59  
FY 2002 Expenditures:    \$11,210.41  
Completion Date:         10/31/01

**This study covered a large range of efforts pertaining to the use of sealers on bridge decks.** One of the most important observations of all of the studies performed during this scope, is that research in this area over the past 15 or more years has progressed the development of these systems to a point where they are highly durable and will last long periods of time. Overall, these systems are quite useful for increased friction as well as prolonging the life of a pavement by sealing out unwanted moisture and chlorides. Service life will need to be monitored over the next few years since new materials addressing the needs of proper bridge overlaying have only been on the decks for five or so years. **Looking at some of the most recent projects and the limited wear on those, it is not hard to envision a 15-year or longer service life.**

### **02-MTU-4      Road Temperature Sensor Project for FY 2002**

Project Manager:            Frank Spica  
Contractor:                Michigan Technological University  
Total Project Cost:        \$15,000.00  
Total Amount Spent:      \$15,000.00  
FY 2002 Expenditures:    \$15,000.00  
Completion Date:         09/30/02

This project was not completed to the point it could be installed. It will be continued for the next fiscal year. **Upon completion of the project, frost tubes would be replaced by sensors that will allow remote reading of the temperature under the roadway at various depths.**



## 02-MTU-6      **Mechanical Properties of Rock Cores**

Project Manager:            Dick Endres  
Contractor:                 Michigan Technological University  
Total Project Cost:         \$5,000.00  
Total Amount Spent:        \$3,956.00  
FY 2002 Expenditures:     \$3,956.00  
Completion Date:            09/30/02

A bridge structure over the Sturgeon River is to be built on US-2 in Dickinson County. **For the pier foundations, drilled shafts will be advanced thru cobbles and boulders and socketed into the underlying bedrock. A rock core retrieved from the pier location was studied to gain knowledge of engineering properties.** It was determined that the drilled shaft sockets will be cut into the Curry Iron-Bearing member of the Vulcan Iron Formation. Samples of the rock core were tested for point load strength and correlated to uniaxial compressive strength using empirical formula. The uniaxial compressive strength of the rock is estimated between 30000 and 40000 psi with a Youngs Modulus of  $9.5 \times 10^6$  psi and a Shear Modulus of  $3.6 \times 10^6$  psi. The Mohs hardness of the iron ore was found to vary between 6.5 and 7.5 while the absolute density was  $3.31 \text{ g/cm}^3$ .

The research report is a contract document that was distributed to construction companies at a mandatory pre-bid meeting. **This information will make contractors aware of the site conditions and aid in the selection of equipment for drilling the rock sockets.**

## PROJECTS APPROVED FOR FY 2002/2003

TITLE	PROJECT NUMBER	PROJECT MANAGER
Development and Implementation of Asphalt Binder Characterization and Hot-Mix Asphalt Design Certification Classes	568590	John Barak
Repair of Box Beam Ends	568420	Roger Till
Post-Tensioned Spliced Prestressed Concrete Beams	568440	Roger Till
Bridge Deck Barrier Cracking - Alternate 2	56847	John Staton
Effects of Michigan Multi-Axle Trucks on Accelerating Pavement Distress	568660	Tom Hynes
Development of a Remaining Service Life for Ride Quality	568670	Steve Bower
Guidelines for the Utilization of Recycled Materials in Portland Cement Concrete Pavements	568680	Dave Smiley
The Ability to Quantify Moisture Damage in Hot-Mix Asphalt Using Superpave Gyrotory Compacted Specimens	568690	Gary Mayes
The Use of Roughness Profiles as a Diagnosis Tool for PCC Pavement Distresses	568700	Tom Hynes
Calibration of the MDOT Pavement Management System Distress Points	568710	Steve Bower
Acceptance Specification for Permeability of PCC Pavements	568720	John Staton
Crack Propagation in JPCP On-Grade Subjected to Fatigue Loading	56873	Dave Smiley
Joint Spalling in JPCP from the Dynamic Mechanical Effects of Heavy Vehicle Loading	568750	Mike Eacker
Improved Design and Construction Modules for JPCP and JRPC for Michigan Climate and Heavy Truck Loading	568760	Curtis Bleech
A Laboratory Evaluation of Alignment Tolerances for Dowel Bars and Their Effects on Joint Performance	568830	Mike Eacker

# NOTES:

# NOTES: