Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements

Annual Report (Phase I)
September 2004

Study TPF-5(066)
Transportation Pooled Fund Program
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CENTER FOR
PORTLAND CEMENT CONCRETE
PAVEMENT TECHNOLOGY

IOWA STATE UNIVERSITY

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The Center for Portland Cement Concrete Pavement Technology (PCC Center) is housed and administered at the Center for Transportation Research and Education, Iowa State University.

The mission of the PCC Center is to advance the state of the art of portland cement concrete pavement technology. The center focuses on improving design, materials science, construction, and maintenance in order to produce a durable, cost-effective, sustainable pavement.

Table of Contents

INTRODUCTION

Problem Statement

The chemistry of today's concrete mixture designs is complicated by many variables, including multiple sources of aggregate and cements and a plethora of sometimes incompatible mineral and chemical admixtures. Concrete paving has undergone significant changes in recent years as new materials have been introduced into concrete mixtures. Supplementary cementitious materials such as fly ash and ground granulated blast furnace slag are now regularly used. In addition, many new admixtures that were not even available a few years ago now have widespread usage. Adding to the complexity are construction variables such as weather, mix delivery times, finishing practices, and pavement opening schedules.

Mixture materials, mix design, and pavement construction are not isolated steps in the concrete paving process. Each affects and is affected by the other in ways that determine overall pavement quality and long-term performance.

Equipment and procedures commonly used to test concrete materials and concrete pavements have not changed in decades, leaving serious gaps in our ability to understand and control the factors that determine concrete durability. The concrete paving community needs tests that will adequately characterize the materials, predict interactions, and monitor the properties of the concrete.

Project Background

The Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements (MCO) project was initiated to investigate available and new testing procedures for evaluating concrete materials, mix designs, and construction practices.

In August 1998, the Federal Highway Administration (FHWA) demonstration project 119, Implementing PCC Excellence in the Highway Project, was discontinued due to lack of funding; however, the urgent need for better testing was still present. The ten states that make up the Midwest Concrete Consortium (MC^2) recognized this shortcoming and the advantages of pooling their research resources. At their April 18, 2001 meeting, MC^2 members voted to support the pooled fund concept for research to meet these needs. With their input, the Center for Portland Cement Concrete Pavement Technology (PCC Center) at Iowa State University developed a research plan for the five-year MCO pooled fund project.

Pooled Fund Partnership

The MCO project solicitation was posted on the FHWA transportation pooled fund website, ultimately resulting in a research partnership of 16 states, FHWA, and the concrete paving industry (see Figure 1).

Figure 1. Map of States Participating in the MCO Project

The 16 participating state highway agencies are as follows:

- Georgia DOT
- Indiana DOT
- Iowa DOT (lead state)
- Kansas DOT
- Louisiana DOT
- Michigan DOT
- Minnesota DOT
- Missouri DOT
- Nebraska Department of Roads
- New York DOT
- North Carolina DOT
- North Dakota DOT
- Ohio DOT
- South Dakota DOT
- Texas DOT
- Wisconsin DOT

The industry is represented by the American Concrete Paving Association (ACPA) and 13 state/regional paving associations:

- Indiana Chapter ACPA
- Iowa Concrete Paving Association
- Concrete & Aggregates Association of Louisiana
- Michigan Concrete Paving Association
- Concrete Paving Association of Minnesota
- Missouri/Kansas Chapter ACPA
- Nebraska Concrete Paving Association
- North Dakota Chapter ACPA
- Northeast Chapter ACPA
- Ohio Concrete Construction Association
- South Dakota Chapter ACPA
- Southeast Chapter ACPA
- Wisconsin Concrete Pavement Association

Project Objectives

- Evaluate conventional and new technologies and procedures for testing concrete and concrete materials to prevent material and construction problems that could lead to premature concrete pavement distress.
- Develop a suite of tests that provides a comprehensive method of ensuring long-term pavement performance.

Project Phases

The five-year MCO project is divided into three major phases.

Phase I

The objective in Phase I (2003–2004) was to compile practical, easy-to-use testing procedures for identification and monitoring of material and concrete properties to ensure durable pavement.

Phase I involved a literature search and a survey of participating agencies and others in the portland cement concrete (PCC) paving community to gather information about best practices and solutions to common problems. Phase I also included developing standard test procedures for tests that may not have national standards and developing new tests as needed.

Phase II

Phase II (2004–2006) will demonstrate, evaluate, and refine best practices and lab and field tests proposed in the Phase I suite of tests. The research team will work with participating states to demonstrate and evaluate newly proposed practices and tests on a current paving project in each state. SWAT teams will help states evaluate problems that arise on PCC paving projects. A field-oriented manual that includes a description of recommended tests and troubleshooting guidance will be prepared.

Phase III

Phase III (2006–2007) will refine and finalize lab and field tests based on shadow project test data. Training on new procedures and tests will be conducted. A final report including a summary of all findings will be produced.

Coordinated Research

The MCO project research team is closely monitoring ongoing related research and incorporating findings when possible. The following projects are examples of complementary research.

FHWA Task 64

The purpose of FHWA Task 64, Software to Identify Rapid Optimization of Available Inputs, is to create computer-based guidelines for optimization of paving concrete. Task 64 involves the development of a computerized knowledge base that will be populated by data from numerous sources. The result will be a comprehensive software package that can assist in the optimization of paving concrete. The MCO project research team is working closely with those preparing the FHWA Task 64 study in order to coordinate efforts and incorporate those results into the project.

FHWA Task 4

The purpose of FHWA Task 4 is to evaluate incompatibility issues related to hydraulic cements in combination with other common admixtures and identify combinations of materials that lead to premature deterioration in concrete pavements.

Blended Cements

This Iowa State University research was conducted to facilitate a better understanding of the behavior of concrete made with supplementary cementitious materials under different weather conditions.

Material and Mix Uniformity

This Iowa State University project consists of a field study and a lab study. The purpose of the field study is to document the uniformity of raw materials delivered to a construction site and the uniformity of fresh concrete that is produced under normal field conditions. The purpose of the lab study is to evaluate new mix control technology and to evaluate mix problems that may occur when using supplementary cementitious materials.

PROJECT ORGANIZATION

The MCO project is organized by the following model: a state highway agency leading other participating states; a university research center serving as the central research team; the FHWA acting as a primary technical and administrative advisor; a technical advisory committee (TAC) composed of representatives from participating states and industry; and an executive committee providing close guidance and monitoring of the project.

Iowa Department of Transportation (Lead State)

The Iowa DOT serves as the lead state for the project. The Iowa DOT has selected the PCC Center at Iowa State University to administer the day-to-day workings of the project.

PCC Center, Iowa State University

The PCC Center is a research coordination center at Iowa State University. The PCC Center, under the direction of the TAC, is responsible for the management and execution of the project. These responsibilities include the following:

- Administration of the Federal appropriation and industry financial contributions
- Completion of the work tasks
- Communication with the TAC and executive committee regarding ongoing research and problems or potential problems
- Preparation of progress, interim, and final reports

The PCC Center manages a website for the project. Copies of meeting minutes, committee member rosters, project updates, etc., can be found at http://www.pcccenter.iastate.edu/mco/.

Federal Highway Administration

The FHWA provides a significant contribution to the project. The FHWA–Iowa Division is active as both a technical and administrative liaison on the project TAC and executive committee. The FHWA Office of Pavement Technology also participates in the project's TAC.

Technical Advisory Committee

Each agency participating in the pooled fund study may provide two individuals to serve on the TAC that will provide direction to the project. Along with the state representatives, the committee also has members from industry participants as represented by an ACPA representative and two ACPA chapter representatives. The FHWA participates in the TAC with a representative from the Office of Pavement Technology in Washington and one from the Iowa Division office.

The TAC is responsible for the following:

- Overall direction to the project
- Formalizing the specifics of the cooperative work tasks
- Review of work in progress

- Approval of interim and final reports and other project deliverables

TAC meetings are held twice a year and in conjunction with MC^2 meetings when possible. The first TAC meeting was held in Chicago on April 9, 2003, with subsequent meetings in Ames, Iowa, on October 14, 2003, and in Madison, Wisconsin, on April 13, 2004.

Executive Committee

At the first TAC meeting, an executive committee was appointed to function as the board of directors for the project. The executive committee's responsibilities include the following:

- Implement the recommendations of the TAC
- Define and approve work tasks
- Monitor progress of the project
- Track financial expenditures

A monthly conference call updates the executive committee and allows for their input on issues that might arise. See Appendix A for a list of executive committee members.

PHASE I

Phase I Tasks

1. Data Collection
   a. Review existing relevant literature
   b. Conduct current practices survey
   c. Compile database from past projects
   d. Field monitor and review current projects
2. Test Development
   a. Identify material and concrete tests that characterize properties of durable concrete
   b. Further develop existing tests
   c. Research new tests
3. Pilot Project
   a. Conduct field project evaluation of preliminary suite of tests in Iowa
   b. Refine suite of tests accordingly
   c. Recommend necessary testing equipment for a mobile lab facility
4. Technology Transfer
   a. Produce initial guidelines of known solutions
   b. Communicate progress and interim findings to sponsors and peers through events, brochures, and the project website

Research Focus and Framework

In order to focus this project on the most critical research needs, experts from the concrete paving community were brought in at an early stage to help develop the scope for this research. An initial focus group meeting included industry participants (Gordon Smith, Iowa Concrete Paving Association; Jim Thompson, Ash Grove; Rob Rasmussen, Transtec; Tom VanDam, Michigan Technological University), Iowa DOT representatives (Sandra Larson, Jim Grove), and Iowa State University researchers (Jim Cable, Tom Cackler, Halil Ceylan, Dale Harrington, Bob Guinn). The group drafted a proposal to develop a suite of laboratory and field tests so that concrete mixes can be designed and field controlled for the parameters that relate to performance and constructability.

The focus group limited the scope of the research to concrete and its materials in order for the work to be focused and limited to what could feasibly be accomplished within a reasonable timeframe and budget. Construction aspects that affect concrete performance were also included. The group prioritized the properties of concrete, establishing workability, strength development, air system, permeability, and shrinkage as the five focal areas that were felt to be the most critical to the long life and durability of concrete pavements.

Another primary consideration was the point in the construction process when the tests needed to be performed. The project will focus on three critical stages in the construction process:

1. The first stage is during mix design development. Mix design is usually a laboratory procedure performed either before the letting or before construction.

The materials used may or may not be exactly what will be used on the job site.

2. The second stage is just prior to construction or on the first day of paving. This stage was labeled as mix verification because the mix design is verified with actual project materials and plant-produced concrete.
3. The third stage is the quality control stage during the construction itself.

On April 9, 2003, this approach was presented to the MCO project TAC for discussion, and the draft was approved as the guiding framework for the MCO pooled fund study.

Administrative Procedures Plan

An administrative procedures plan was developed to identify the project's procedures and roles of participants. This document is a supplement to the FHWA's "Transportation Pooled Fund Program Procedures" guide available on the FHWA website. The project administrative procedures plan was needed to define the administration of the project due to the complexity and length of the project, multiple funding sources involved, coordination with other related ongoing research, and the need to be responsive to the research findings throughout the project. The intent is that the plan will be a working document; it will be kept up-to-date as the work progresses.

Data Collection

Three specific types of information were gathered:

1. Published and Unpublished Research Literature. The first research task included a thorough literature search for existing information on concrete material and concrete pavement tests. Because of the common goals with FHWA Task 64 research (Task 64 will develop a computer-based mix optimization program), this task was completed jointly with Transtec, the lead researchers for Task 64. Transtec searched national and international databases for this information. MCO project researchers contacted and visited each participating state to gather published and unpublished research documentation related to concrete materials and concrete pavement testing (the state visit requested information form is included in Appendix B). Great effort was also made to find simple, practical research that state highway agencies conduct but that doesn't usually get reported. Emphasis was placed on research related to concrete material properties and concrete paving construction practices. A summary compilation of the state research is included in Appendix C.

2. State Practices. A detailed inventory of participating states' technologies and procedures for mix design, materials control, concrete testing, and field control was gathered (see Appendix B for data collection form). This information provided a baseline for proposed testing recommendations and helped identify practices with potential for success in other states. A summary compilation of the state practices is included in Appendix D.
3. Problem Projects. Problem project data from participating states were collected through a web-based information reporting form (see Appendix E). Participating states identified past projects exhibiting some form of early pavement deterioration. Details about these projects provided researchers with specific, real-world examples of problems and the opportunity to assess the causes of concrete pavement distress to ensure that the proposed testing identifies the problems. The survey gathered information on problem projects in the last 15 years and what solutions were used. The survey was intended to gather representative examples of common problems from a maximum of a half dozen projects from each state. Appendix F is a compilation of the responses.

Visits to Participating States

The project monitor visited each of the participating states between fall 2003 and summer 2004. A half-day meeting was held with each participating state's personnel involved with research, materials, and construction. Representatives from the FHWA division office and state/regional concrete paving association were also invited. Table 1 summarizes the meeting dates and attendance.

The visits served the following purposes:

- Present an overview and update of the project to the participating states.
- Solicit details on past projects exhibiting premature pavement distress.
- Collect information on current state technologies and practices for materials and construction testing.
- Gather related state research, especially unpublished research.

In addition, several state visits involved a field trip to a nearby project. The meeting and site visits provided the research team with critical information and insights into the concerns and priorities of each state.

Table 1. Meetings with Participating States

Participating State	Meeting Date	Meeting Attendance				
		DOT	FHWA	CPA*	Other	Total
South Dakota	September 30, 2003	7	2	0	0	9
Nebraska	October 1, 2003	7	0	0	0	7
Wisconsin	October 7, 2003	5	0	0	0	5
Minnesota	October 8, 2003	4	1	2	0	7
North Dakota	October 9, 2003	12	0	1	0	13
Missouri	October 28, 2003	7	1	0	0	8
Kansas	October 29, 2003	6	0	0	0	6
Michigan	December 10, 2003	10	1	10	1	22
New York	January 9, 2004	10	0	0	0	10
Texas	January 27, 2004	8	1	0	1	10
Louisiana	January 29, 2004	17	1	0	2	20
Georgia	March 2, 2004	6	0	1	0	7
North Carolina	March 19, 2004	5	1	1	0	7
Indiana	June 8, 2004	4	0	1	0	5
Ohio	June 9, 2004	4	1	2	0	7
Iowa	August 26, 2004	9	1	1	0	11
Total						**154**

* Concrete paving association.

Suite of Tests

A preliminary suite of tests to ensure long-term pavement performance was developed. The goal was to include tests that provide useful information and results that are easy to interpret, and that can be reasonably performed routinely in terms of time, expertise, training, and cost.

The tests examine concrete pavement properties in five focal areas: (1) workability, (2) strength development, (3) air system, (4) permeability, and (5) shrinkage. For each of these areas, tests were identified as existent and adequate, existent but needing further development, or nonexistent and needing to be developed. The tests were considered for relevance at three stages in the concrete paving process: mix design, preconstruction verification, and construction quality control. See Table 2.

Table 2. Tests of Concrete Properties in Five Focal Areas at Three Stages

	Mix Design	Preconstruction Mix Verification	Construction Quality Control
Workability			
Strength development			
Air system			
Permeability			
Shrinkage			

The list of tests in the suite was narrowed to approximately 40 (see Appendix G). Each test was described in detail, including what the test will tell, test procedures, training needed before running the test, and how the test relates to the "big picture" in the suite of tests. Model tests were performed to determine day-to-day variation and establish a standard for testing frequency.

A pilot project in Iowa was used to evaluate the suite of tests in late August to early October 2003. This served as a trial run for evaluating the tests and helped the research team refine the suite of tests to a feasible number and scope.

The tests selected for the suite will be evaluated and further refined at construction sites in states participating in the project.

Shadow Projects

As the scope of the project was developed, it became clear that the key to the research's success was the implementation of the results by the participating states. In order for the states to see what the tests could do for them, it seemed logical that performing the tests in each state on a local project would be the best way to demonstrate the benefits of the tests, at the same time evaluating the effectiveness of the tests themselves. Shadow construction projects in each state would help researchers examine material compatibility, delineate mixture troubleshooting, identify quality procedures, and define implementable specifications in order for states to realize the full potential of available materials, better tools, and new procedures.

In the next phase of the research, the new Mobile Concrete Research Lab (see below) will visit each of the states, and their shadow projects will be used to showcase and evaluate procedures and tests proposed by the study. The research team will be on-site to demonstrate mix design procedures, material tests, quality control tests, and construction practices. As the shadow projects are conducted, the suite of tests will be further refined or enhanced.

Mobile Concrete Research Lab

The complex logistics of the shadow project research led the research team to realize a mobile testing lab would be necessary. In order for testing to be timely and effective, the researchers would need an on-site lab to both conduct the research and demonstrate new procedures. The industry partners involved in the project also recognized the need for a mobile concrete research lab to facilitate this and other PCC research on a national level. Such a lab would bridge the gap between the lab and field, bringing high-tech laboratory equipment right the construction site.

The ACPA, state/regional concrete paving associations, and Iowa State University all contributed funding toward the purchase and equipping of a trailer to be use as a mobile concrete lab. The MCO project is the first of many PCC Center research projects that will benefit from the new PCC Center Mobile Concrete Research Lab.

Many meetings were held to discuss the specifications of the mobile lab based on the suite of tests for the MCO project, as well as likely future needs. The pilot project in Iowa helped in understanding the space required for the tests so appropriate room could be incorporated into the mobile lab design.

All stakeholder input and revisions culminated in the final custom design. The 44-foot Featherlite trailer is suitable for towing by a medium-duty truck with a flat bed. The trailer's gooseneck style makes it more maneuverable than a semi and less costly to own and operate, with the additional advantage of having the pull vehicle available to transport material around the construction site.

The mobile lab is fully outfitted with equipment capable of performing the identified suite of tests:

- Unit weight balance
- Sieves stored in custom-built cabinets to determine coarse and fine aggregate gradations
- Penetrometer to test mortar set time (ASTM C 403, ASTM C 359 / C 359 Modified)
- Calorimeters (heat signature drums) to determine the heat signature of mortar and concrete
- Slump cone
- 250,000-lb-capacity compression tester to measure compressive and flexural strength development, also adapted to perform flow table tests
- Microwave oven to determine water-to-cement (w/c) ratios
- Concrete core drill and saw
- Curing tank
- Air void analyzer (AVA) to measure the volume and size distribution of the concrete air void system
- Air meter
- Weather station
- Computer with HIPERPAVE software
- Global positioning system (GPS)

The AVA and weather station make the mobile lab a unique testing facility capable of gathering a much more comprehensive and useful set of data than previously possible.

Air Void Analyzer

A good air system is critical to ensuring durable concrete in regions that experience freeze/thaw conditions. Until recently, the only method to evaluate the air system was petrographically from a concrete sample of the pavement. A new testing device, the air void analyzer, has recently become available. The AVA allows evaluation of plastic concrete.

The AVA is a very sensitive machine that has been considered only usable in permanent buildings, thus limiting its use in field control. Because any vibration, such as that caused by wind, can dramatically skew the AVA's results, the trailer was designed with a trapdoor in the floor to accommodate the AVA. When the lab is parked, the base of the AVA will rest on the ground through the hole so that it is protected by the trailer but not touching the trailer. This will allow accurate use in the field.

Weather Station

Weather data will be recorded using the lab's weather station and GPS capabilities from the beginning of testing at a project site until the testing is complete.

See Figure 2.

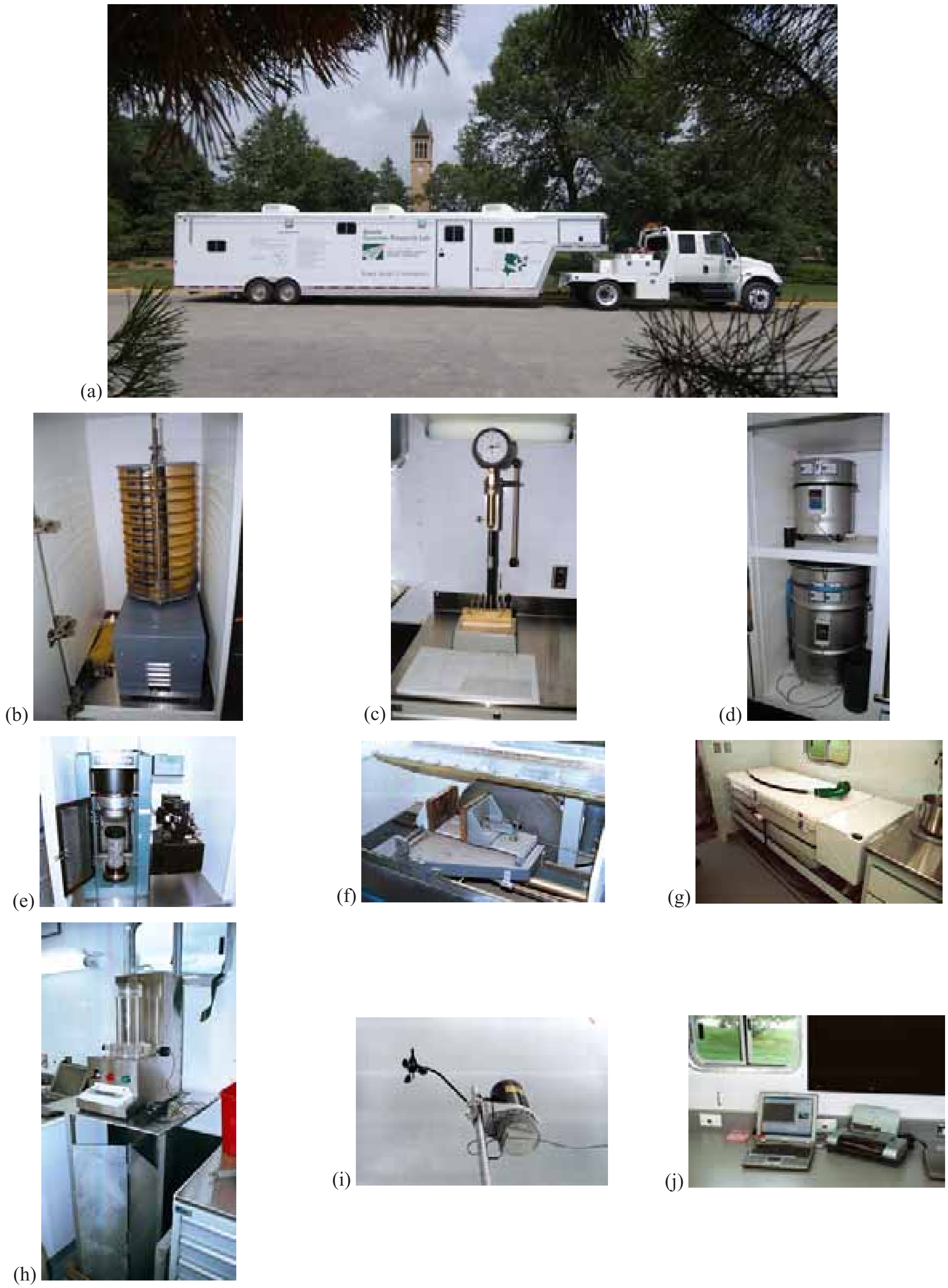

Figure 2. (a) Mobile Concrete Research Lab; (b) Sieves; (c) Penetrometer; (d) Calorimeters; (e) Compression Tester; (f) Concrete Core Saw; (g) Curing Tank; (h) AVA; (i) Weather Station; (j) Computer with GPS

TECHNOLOGY TRANSFER

Technology transfer is of paramount importance to this project. MCO project interim findings have been communicated with a variety of audiences through numerous events and publications. The MCO project continues to make ongoing contributions toward merging concrete science with concrete practice by reporting research findings in effective ways.

Technology Transfer Events

The MCO project has been the subject of many presentations at a variety of meetings and outreach events. Interest in the project has brought requests for information and presentations to be made at a number of states' paving workshops. The following Microsoft PowerPoint presentation slides are available on the MCO project website (http://www.pcccenter.iastate.edu/mco/):

- "Computer-Based Guidelines for Job-Specific Optimization of Paving Concrete," April 2004
- "Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements: Tests Development," Technical Advisory Committee Meeting, April 2004
- "Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements: Tests Development," Technical Advisory Committee Meeting, October 2003
- "Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements: Project Overview," Technical Advisory Committee Meeting, April 2003
- "Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements: Research Objectives," November 2002

The researchers hope continued interest in the project will result in additional states joining the pooled fund study.

Project Brochures

Several brochures communicating the project's objectives and progress have been published and distributed at workshops, conferences, and other events:

- "Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC Pavements: Project Overview" (January 2003)
- "Material and Construction Optimization for Prevention of Premature Distress in PCC Pavements: Suite of Tests" (March 2003)
- "Material and Construction Optimization for Prevention of Premature Pavement Distress in PCC

Pavements: Project Summary" (February 2004)

These brochures are available on the project website (http://www.pcccenter.iastate.edu/mco/).

Website

A website was developed for the research project and is maintained by the Center for Transportation Research and Education at Iowa State University. Presentations, brochures, meeting minutes, quarterly reports, and other information are made available to participating states and others through this mode of communication. The web address is http://www.pcccenter.iastate.edu/mco/.

State Reports

The shadow projects will involve technology transfer throughout the process of testing at each site. The personnel from each state will be involved with the researchers as the tests are run and evaluations are completed. The research team's intention is to document the data from the tests and the results of the evaluations in each state and present this information to each state after their shadow project is completed.

Integrating Materials and Construction Practices Manual

The results of the MCO project are being compiled in a user-friendly field manual, the Integrating Materials and Construction Practices (IMCP) Manual. The target audience includes agency inspectors, contractor superintendents, engineers, technicians, and other field practitioners.

The manual will describe concrete pavement construction as an integrated system in which materials selection, mix design, and construction practices all affect each other in many ways. The focal properties of PCC materials that predict overall quality of the final product will be identified.

The manual will present integrated guidelines about the technologies, test procedures, and practices that, when more widely used, will optimize materials selection, mix design, and construction practices. In addition, it will explain *how* as well as *why* to implement these technologies, tests, and practices. A detailed, easy-to-use decision tree or matrix for using recommended technologies, tests, and practices will be provided.

The following will be included:

- An understanding of the physical and chemical interactions of different materials used in concrete
- Control techniques for concrete mixtures when supplementary cementitious materials and other admixtures are used
- Identification of the potential of known compatibility problems associated with given materials and mixture proportions
- Aids on how to adjust concrete mixes under various weather conditions
- Troubleshooting for field placement problems

- Best practice techniques for long-term performance

Development of this manual is being funded outside the TPF-5(066) pooled fund. It is funded under the PCC Center's cooperative agreement with the FHWA as DTFH61-01-X-0042 Project 10, Manual for Optimizing Materials and Construction Practices.

The technical advisory committee for this manual is the MCO project executive committee with a technical advisory subcommittee reviewing the technical material. A request for proposals for a technical editor for the manual was developed, and the editor has been determined.

The goal of the research team is to have this manual ready for distribution in the spring of 2005.

Educational/Technology Transfer Modules

Tech transfer of the MCO project will also include development of training modules designed to improve the quality of concrete and concrete products. Educational/technology transfer modules will communicate the best material and construction practices and research results to practicing engineers, technicians, quality assurance/quality control personnel, contractor superintendents, trade persons, and producers. Each module will include a state-of-the-practice review, innovative techniques that have been used successfully, and case histories of successful applications of the module subjects.

APPENDIX A. MCO PROJECT CONTACTS

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- Dan DeGraaf, Michigan Concrete Paving Association, ddegraaf@miconcpave.com, 616-361-9810

- Doug Schwartz, Minnesota DOT, doug.schwartz@dot.state.mn.us, 651-779-5576
- George Woolstrum, Nebraska Department of Roads, gwoolstr@dor.state.ne.us, 402-479-4791
- John Volker, Wisconsin DOT, john.volker@dot.state.wi.us, 608-246-7930
- Max Grogg, FHWA–Iowa Division (ex officio member), max.grogg@fhwa.dot.gov, 515-233-7306

APPENDIX B. STATE VISIT REQUESTED INFORMATION FORM

STATE VISIT REQUESTED INFORMATION

MATERIAL AND CONSTRUCTION OPTIMIZATION

FOR PREVENTION OF PREMATURE PAVEMENT DISTRESS IN PCC PAVEMENTS

State Procedures

- ❑ **Concrete Mix Design**

  - o Who provides the mix design?

    - ❑ State
    - ❑ Contractor/Supplier

  - o What procedure is used to develop the mix design?

    - ❑ ACI 211.1
    - ❑ A state specific procedure
    - ❑ Past experience
    - ❑ Another procedure

  - o What concrete properties are specified (hardened or fresh) in contract documents? For example, is concrete strength, slump, etc. specified?

Mark the properties that are commonly specified:

Specified?		
	Workability / Slump	Fresh Concrete Properties
	Bleeding	
	Segregation	
	Set	
	w/cm (water-to-cementitious materials ratio)	
	Plastic Shrinkage Cracking	
	Strength at Opening	Hardened Concrete Properties
	Strength at 28 days	
	Coefficient of Thermal Expansion (CTE)	
	Drying Shrinkage	
	Permeability	
	Resistance to freezing and thawing	Concrete Durability
	Resistance to sulfate attack	
	Resistance to ASR	
	Abrasion Resistance	
	Corrosion Resistance	
	Other (specify)?	

- In addition to the specified properties, what properties are targeted (desired), but are not specified? Fresh ones are targeted for the best possible placement / construction? Hardened ones for increased concrete durability?

Of the properties that are not specified, rank their importance with <u>1</u> the most important:

Rank		
	Workability	Fresh Concrete Properties
	Bleeding	
	Segregation	
	Set	
	Plastic Shrinkage Cracking	
	Strength / Stiffness	Hardened Concrete Properties
	Coefficient of Thermal Expansion (CTE)	
	Drying Shrinkage	
	Permeability	
	Resistance to freezing and thawing	Concrete Durability
	Resistance to sulfate attack	
	Resistance to ASR	
	Abrasion Resistance	
	Corrosion	
	Other (specify)?	

- What are the typical values of the following mix design parameters for paving concrete? Please denote the method of construction, *i.e.* slip-formed (SF), formed paving (FP), or other.
  - w/c

    Min._________, Max. _________, Typical_________
  - Slump (in)

    Min._________, Max. _________, Typical_________

    Method of Construction: ________________________

    Min._________, Max. _________, Typical_________

    Method of Construction: ________________________

- Air content (%)

  ___ ± ___% to ___ ± ___% Application: ____________________

  ___ ± ___% to ___ ± ___% Application: ____________________

  ___ ± ___% to ___ ± ___% Application: ____________________

  ___ ± ___% to ___ ± ___% Application: ____________________

- Water content (lb/cu.yd)

  ____ to ____ lb/cu.yd Application:________________

  ____ to ____ lb/cu.yd Application: ________________

  ____ to ____ lb/cu.yd Application: ________________

- Cement content (lb/cu.yd)

  ____ to ____ lb/cu.yd Application:________________

  ____ to ____ lb/cu.yd Application:________________

  ____ to ____ lb/cu.yd Application:________________

- Maximum size of coarse aggregate (in)

  ☐ 3/8 ☐ 1 ☐ 3

  ☐ ½ ☐ 1½ ☐ 6

  ☐ ¾ ☐ 2 ☐ 6+

- Coarse aggregate (lb/cu.yd)

  ____ to ____ lb/cu.yd Application:________________

  ____ to ____ lb/cu.yd Application: _______________

- Fine aggregate (lb/cu.yd)

  ____ to ____ lb/cu.yd Application:________________

  ____ to ____ lb/cu.yd Application:________________

- Which of these SCMs are commonly used in your concrete mix design? (Check all that apply)
  - ❑ Class F Fly Ash Application: ________________
  - ❑ Class C Fly Ash Application: ________________
  - ❑ GGBFS Slag Application: ________________
  - ❑ Silica Fume Application: ________________
  - ❑ Metakaolin Application: ________________
  - ❑ Volcanic Ash/Pumicite Application: ________________
  - ❑ Calcinated Shale Application: ________________
  - ❑ Opaline Shale Application: ________________
  - ❑ Calcinated Clay Application: ________________
  - ❑ Diatomaceous Earth Application: ________________
  - ❑ Other (describe) Application: ________________

- Which of these chemical admixtures are commonly used in your concrete mix design? (Check all that apply)
  - ❑ Air entraining admixtures Application: ________________
  - ❑ Conventional water reducer Application: ________________
  - ❑ Mid-range water reducer Application: ________________
  - ❑ High-range water reducer Application: ________________
  - ❑ Accelerator Application: ________________
  - ❑ Retarder Application: ________________
  - ❑ Corrosion inhibitor Application: ________________
  - ❑ Shrinkage reducer Application: ________________
  - ❑ ASR inhibitors (*i.e.* Lithium) Application: ________________
  - ❑ Hydration control admixtures Application: ________________
  - ❑ Other (describe) Application: ________________

- What combinations of cement type + SCM (supplementary cementitious materials) + chemical admixtures are ***most commonly used*** in your paving mixes?

Please provide the types and dosages.
Cement: Type I/II, Type III, Type IP, Type IS, or other cement.
SCMs: Fly Ash Class F or C, Silica Fume, Slag, Metakaolin.
Chemical admixture: water reducer (WR), mid-range water reducer (MRWR), high range water reducer (HRWR), accelerator, retarder, air entraining admixture (AEA) or other.

Cement Type (lb/cu yd)	SCM (lb/cu yd)	Chemical Admixture (fl oz / cwt)

Comments:

- Have you experienced compatibility problems between mix components like SCM's and chemical admixtures?
  "Symptoms" 1 to 4 such as,
  - ☐ Less than expected water reduction (1)
  - ☐ Rapid loss of slump (2)
  - ☐ Fast set (3)
  - ☐ Abnormally retarded setting (4)
  - ☐ Other ______________________(5)
  - ☐ Other ______________________(6)

- What were the *complete* mix designs (lb)/ dosages (floz/cwt)? How was the problem corrected?

	Symptom #__	Symptom #__	Symptom #_
Water	____	____	____
Portland Cement	____	____	____
Fly Ash Class C	____	____	____
Fly Ash Class F	____	____	____
Slag	____	____	____
Silica Fume	____	____	____
WR	____	____	____
MRWR	____	____	____
HRWR	____	____	____
AEA	____	____	____
Acclerator	____	____	____
Retarder	____	____	____
Other ___________	____	____	____

Correction for Symptom #__:

Correction for Symptom #__:

Correction for Symptom #__:

- o Do you require a combined aggregate gradation design/analysis procedure? If yes, what one or ones?

- Do you have an aggregate sources approval system? If yes, explain.

- Do you require testing of the cementitious materials, beyond normal certification testing? If yes, what tests?

- What fresh concrete tests are required? Please cite name/number of specification/test procedure.

    - Slump Test Method: __________________
    - Air Content Test Method: __________________
    - Unit Weight Test Method: __________________
    - Time of Setting Test Method: __________________
    - Plastic shrinkage cracking susceptibility Test Method: __________________
    - Heat of hydration Test Method: __________________

- What hardened concrete tests are required? Please cite name/number of specification/test procedure.

    - Resistance to freezing and thawing?
      Test Method: __________________

    - Strength, What is the typical design strength?
      Test Method: __________________

    - Permeability?
      Test Method: __________________

- Shrinkage – restrained or free?

  Test Method: ________________

- Creep?

  Test Method: ________________

- Have you ever used fibers in a paving mix? Yes ☐ No ☐
  - If so, which fiber type?
    - ☐ Steel
    - ☐ Polypropylene
    - ☐ Polyester
    - ☐ Polyolefin
    - ☐ Nylon
    - ☐ Carbon
    - ☐ Other (describe)
  - How was the mix design adjusted for the fibers?

    Was there a change in the water content?

    Were chemical admixtures used?

    Some other method?

Comments:

- Please rank the primary concerns about concrete durability in your state?

  (1 – not a concern, 2 – rarely a concern, 3 – sometimes, 4 – often, 5 - always)

	Rank
☐ Freeze-thaw resistance / Scaling resistance	___
☐ DEF susceptibility	___
☐ ASR susceptibility	___
☐ Chemical attack	___
☐ Abrasion resistance	___
☐ Fatigue cracking	___
☐ Other (describe)	___

If possible, please attach some of the typical mix designs used by your state for paving concrete.

	Mix #1	Mix #2	Mix #3
Water			
Portland Cement			
Fly Ash Class C			
Fly Ash Class F			
Slag			
Silica Fume			
WR			
MRWR			
HRWR			
AEA			
Acclerator			
Retarder			
Other ___________			

Comments:

- **Project testing**
  - Do you require field trial-batch testing?
    - If yes, what tests are required?
  - Do you require tests on field materials prior to paving?
    - If yes, what tests are required?

QC/QA

- What concrete tests are required? And what test is performed?

  - Air? ☐ Yes ☐ No
    Test Method:

  - Slump? Yes ☐ No ☐
    Test Method:

  - Strength? ☐ Yes ☐ No

  - Maturity?

  - Beams? Center point or third point?

  - Compression?

  - Split tensile?

  - Other? (describe)

Research

- ❑ What research, especially local/in-house research, have you, or others in your state, conducted that relates to the five concrete properties focused on in this study?
  - o Workability
  - o Strength development
  - o Air content
  - o Permeability
  - o Shrinkage

This should include materials tests, concrete tests, and any other research that would be relevant to this project.

- ❑ Please provide reports, write-ups, or data for these research efforts if available.

APPENDIX C. SUMMARY COMPILATION OF STATE RESEARCH

Georgia

King, W. M. Design and Construction of a Bonded Fiber Concrete Overlay of CRCP (Louisiana, Interstate Route 10, August 1990). Report No. FHWA/LA-92/266. Louisiana Transportation Research Center, Baton Rouge, January 1992.

Memo from Geoff Chapman (the Concrete Co.) to Jay Page, Office of Materials & Research, Georgia Department of Transportation, Jan 2004.

Attached are copies of the mix design data as performed in the lab of the Concrete Co. The Concrete Company proposed to use Class 3 Pavement mix designs for reconstruction of ramps on I-75. It included data from 7 and 28-day test results.

Memo from G. M. Geary to L. E. Dent, Materials & Research, Georgia Department of Transportation, March 2002.

This memo pertains to concrete mix designs (Portland Cement Concrete Pavement). Attached are Four Class I Portland cement concrete pavement designs. Mix proportions approved for use on this project provided the concrete delivered to the roadway meets all applicable acceptance tests. Mix 1 is not approved for the stated project.

Special Provision, Section 440 Roller Compacted Concrete Shoulder Pavement. Georgia Department of Transportation, Jan. 2004.

The information attached is a replacement for Section 440. It includes the headings; general description, materials, construction requirements, measurement, and payment.

Standard Operating Procedure (SOP) 1 – Monitoring the Quality of Coarse and Fine Aggregates. Office of Materials and Research, Georgia Department of Transportation, Rev. Oct. 2003.

These procedures include sections on general information, fine and coarse aggregate source lists, source evaluations, source approval procedures (qualified products), establishing and maintaining an acceptable quality assurance program, policy for departmental testing, acceptance, and use of certified aggregates, removal and reinstatement to qualified products list, assistance to producers, monthly samples for complete analysis, and department of transportation materials producer files.

Standard Operating Procedure (SOP) 5 – Quality Control of Portland Cement and Blended Hydraulic Cements and Quality Control of Fly Ash and Granulated Blast-Furnace Slag. Office of Materials and Research, Georgia Department of Transportation, July. 2003.

These procedures include sections on general information, documentation and use of materials, requirements for approved sources, list of approved sources, inspection, sampling and testing, and distribution points.

GDT 27. http://tomcat2.dot.state.ga.us/thesource/pdf/auxdata/gdt/gdt027.html, accessed March 1, 2004.

This includes information on the scope, apparatus, sample size and preparation, procedures, calculations, and report. Also, attached is a schematic drawing of the testing apparatus.

GDT 28. http://tomcat2.dot.state.ga.us/thesource/pdf/auxdata/gdt/gdt028.html, accessed March 1, 2004.

This includes information on the scope, apparatus, sample size and preparation, procedures, calculations, and report.

GDT 26. http://tomcat2.dot.state.ga.us/thesource/pdf/auxdata/gdt/gdt026.html, accessed March 1, 2004.
This includes information on the scope, apparatus, sample size and preparation, procedures, calculations, and report. Also, attached is a schematic drawing of the testing apparatus.

Iowa

***1992-1997 Core Investigation and 2003 Conclusions*. Iowa Department of Transportation, Ames, IA.**
In 1996 new specifications (lowering SO_3 and alkali contents of PC, increasing plastic air content, limiting vibration) were implemented in order to prevent the premature deterioration of concrete pavements. An investigation was carried out on concrete cores obtained from the pavements constructed in 1992 and 1997. The study showed that the new specifications imposed in 1996 resulted in better concrete pavement performance. In addition, use of GGBFS or fly ash improves the pavement resistance against deterioration.

***Investigation on Use of Higher Volume Class C Fly Ash*. Iowa Department of Transportation, Ames, IA.**
In the study, performance of higher volume Class C fly ash in ternary mixes (portland cement, GGBFS, and fly ash) was investigated. It was intended to evaluate the performance of various combinations of fly ash and Portland cement in terms of workability, finishability, strength, maturity, permeability, air void distribution, and durability (F/T). Test sections were cast with different combinations of Type I/II cement, Type I(SM), and Class C fly ash (15 and 20% replacements). The results obtained from the test section on US 34 showed that 5% increase in fly ash replacement resulted in no significant difference in strength, permeability, and hardened air characteristics.

***Iowa Barrier Rail Mix Design Development*. Iowa Department of Transportation, Ames, IA.**
In 1998, the Iowa DOT made an investigation into slip formed median barrier rail in order to improve the Iowa Class D-57 mix design. The major problem was the difficulty of air entrainment which in turn results in poor durability. It was decided to use of well graded aggregates (Shilstone principles applied) together with a reduced cement paste content. The new mix design, named as BR, achieved better results compared to D-57: better workability, higher air content with less amount of AEA, higher strength, lower permeability, and less cracking. Later, further changes such as use of slag (up to 20%) and fly ash (up to 15%) were done in barrier rail. The Shilstone method of well graded aggregate mix design was also applied to QMC for pavements in 2000 and is in practice now.

Summary of Other Related Iowa DOT Research

Proj.	No.	Title	End	PIs
HR	506	Recycled Portland Cement Concrete Pavement in Iowa (NEEP 22)	5/1/82	V. Marks
HR	513	PC Concrete Overlay - Pottawattamie County	12/1/84	J. Lane, D. Smith
HR	520	Thin Bonded PCC Overlay	10/1/89	J. Lane
HR	527	Crack and Seat PCC Paving Prior to ACC Resurfacing (saw and seal ACC Joints)	12/1/91	J. Smythe
HR	528	Nongrouted Bonded PCC Overlay - City of Oskaloosa	1/1/92	V. Marks
HR	531	"Fast Track" PCC Overlay	12/1/89	J. Lane
HR	537	Evaluation of Bonded PCC Using Infrared Thermography (Inc HR-1045)	12/1/89	R. Dankbar
HR	538	Bettendorf Spruce Hills Drive Fast Track Paving	12/1/90	R. Holland, R. Merritt

Proj.	No.	Title	End	PIs
HR	539	Automated Pavement Data Collection Equipment (Demo 960)	10/1/86	J. Cable, K. Jeyapalan
HR	541	Scott Co. Load Transfer Retrofitting (See HR-2033)		--
HR	544	Accelerated Rigid Paving Techniques (FHWA 201)	12/1/92	J. Bergren, V. Marks
HR	546	Field Evaluation of Variations of Fast Track Concrete (MLR-88-15)		J. Grove
HR	559	Ultra Thin PCC Overlays	7/31/00	J. Grove, J. Cable
HR	561	Bonded Overlay Grout Evaluation	1/1/95	J. Cable
HR	563	Improved Gradation of PCC Mixtures	10/1/96	T. Hanson
HR	1004	Corrosion of Steel in CRC Pavement		S. E. Roberts
HR	1006	Use of Low Slump, Dense Concrete for Brdge Deck Protection and Restoration	1/1/77	J. Bergren
HR	1009	Bonded Thin Lift, Nonreinforced PCC Resurfacing and Patching (MLR-77-2)		J. Bergren
HR	1010	Recycled Portland Cement Concrete Pavements	3/1/78	V. Marks
HR	1015	Evaluation of Darex Corrosion Inhibitor		P. McGuffin
HR	1021	High Range Water Reducers in PCC Made With D-Crack Susceptible Coarse Aggregate		S. Moussalli
HR	1024	Thin Bonded Portland Cement Concrete Resurfacing (film)	11/1/80	V. Marks
HR	1031	Fly Ash (Demo 59)	6/1/87	K. Isenberger
HR	1038	PC Paving Open House	10/1/83	J. Lane
HR	1045	Evaluation of Bond Retainage in PCC Overlays	2/1/88	R. Dankbar
HR	1061	Evaluation of Concrete Mix Characteristics Using a Total Gradation Design		
HR	1063	Pooled Fund Study for Premature Rigid Pavement Deterioration	1/1/97	D. Gress
HR	1065	Durability of Highway Concrete Pavements (PCA 50%)	12/1/99	J. Clifton
HR	1066	Evaluation of Mixing Time vs Concrete Consistency & Consolidation	8/1/97	J. Cable
HR	1068	Evaluation of Paver Vibrator Frequency Monitoring & Concrete Consolidation (ACPA $86,616)	6/1/98	Jim Cable
HR	1069	Field Evaluation of Alternative PCC Pavement Reinforcement Materials		--
HR	1074	Development of a Short Course in Concrete Mixture Design & Proportioning	11/30/01	K. Hover
HR	1079	Two Stage Mixing of Portland Cement Concrete		R. Steffes
HR	1080	Synthesis of Dowel Bar Research	8/15/02	M. Porter
HR	1081	Development of In-Situ Detection Methods for Material Related Distress (MRD) in Concrete Pavements, Phase II Extension	12/31/04	S. Schlorholtz/K. Wang
HR	2012	Fly Ash Pavement Sections		T. Cackler
HR	2015	Portland Cement Concrete over Broken Pavement		--
HR	2022	Iowa Pore Index Test		W. Dubberke
HR	2037	ERES "Performance/Rehabilitation of Rigid Pavements"		M.I. Dater
HR	2057	Early Strengths of PCC on US 20 Near Ft. Dodge		--
HR	2064	Retarder Overdose on IA 83 Pottawattamie County Bridge		--
HR	2065	Structural Contribution of Geogrids - Bridge Approach		C. Anderson
HR	2069	Transverse Crack Maintenance on US 71 South of Atlantic		----
HR	2072	Field Evaluation of Ash Grove Type IP Cement (I-29 in Pottawattamie Co.)	6/1/99	J. Grove
HR	2074	A Different Perspective for Investigation of PCC Pave Deterioration		V. Marks
HR	2076	Tine Impressions From PCC With RTV Rubber Molds	5/1/96	R. Steffes
HR	2077	I-80 Jasper PCC Test Sections	7/1/95	J. Lane
HR	2078	Soff-Cut Centerline Joint and Potential Cracking Problem	6/1/95	R. Steffes
HR	2092	Hot Poured Joint Sealant Bubbles		R. Steffes
HR/TR	9	Performance of Various Thicknesses of Portland Cement Concrete Pavement		C. A. Elliott
HR/TR	10	Durability of Portland Cement Concrete	6/1/69	B. Brown

Proj.	No.	Title	End	PIs
HR/TR	34	Thin Concrete Resurfacing	12/1/60	B. Myers
HR/TR	40	Steam Curing of Concrete at Atmospheric Pressure	1/1/59	S. Roberts
HR/TR	86	Relationship of Carbonate Aggregate to Serviceability of PCC	6/1/65	J. Lemish
HR/TR	92	Use of Sucrose and Dextrose in Portland Cement Concrete Paving	1/1/64	S. Roberts
HR/TR	118	Carbonate Aggregates for Portland Cement Concretes	11/1/67	J. Lemish
HR/TR	120	Concrete Popouts	2/1/67	R. Handy
HR/TR	136	Creep & Shrinkage Properties of Lightweight Aggregate Concrete Used in Iowa	9/1/70	D. Branson, B. Meyers
HR/TR	141	Deterioration of PCC Pavements	5/1/73	J. Lane
HR/TR	146	Preliminary Studies of Remedial Measures for Prevention of Bridge Deck Deterioration	3/1/70	H. Ellery, F. Klaiber
HR/TR	165	Experimental Steel Fiber Reinforced Concrete Overlay -1		V. Marks, R. Betterton
HR/TR	165	Experimental Steel Fiber Reinforced Concrete Overlay -2	3/1/89	V. Marks, R. Betterton
HR/TR	183	Fatigue Behavior of High Air Content Concrete	7/1/77	D. Y. Lee, F. Klaiber
HR/TR	191	Bonded Thin-Lift Non-Reinforced Portland Cement Concrete Resurfacing	6/1/80	M. Johnston
HR/TR	192	An Evaluation of Dense Bridge Floor Concretes	9/1/82	J. Pratt
HR/TR	197	Fatigue Behavior of High Air Content Concrete, Phase II	1/1/79	D. Y. Lee, F. Klaiber
HR/TR	200	Fly Ash in Portland Cement Concrete Pavement - Monona Co.	1/1/80	O. Ives
HR/TR	201	Fly Ash in Portland Cement Concrete Pavement - Woodbury Co.		C.E. Leonard
HR/TR	206	Cement Produced From Fly Ash and Lime	5/1/80	W. Rippie
HR/TR	209	Pavement Surface on Macadam Base - Adair County	12/1/83	D. Lynam
HR/TR	225	Characterization of Fly Ash for Use in Concrete	10/1/83	T. Demirel, J. Pitt
HR/TR	244	Detection of Concrete Delamination by Infrared Thermography	11/1/82	B. Brown
HR/TR	250	A Non-Destructive Method for Determining the Thickness of Sound Concrete on Older Pavements	11/1/82	V. Marks
HR/TR	258	Frost Action in Rocks and Concrete	4/1/86	T. Demirel
HR/TR	266	The Relationship of Ferroan Dolomite Aggregate to Rapid Concrete Deterioration	11/1/86	W. Dubberke
HR/TR	270	Development of Training Aids and Demonstration of PCC Pavement Rehabilitation (Demo 69)	9/1/88	R. Given, M.J. Knutson
HR/TR	271	Effects of Deicing Salt Compounds on Deterioration of PC Concrete	11/1/85	J. M. Pitt
HR/TR	272	Development of a Conductometric Test for Frost Resistance of Concrete	1/1/88	T. Demirel, B. Enustun
HR/TR	277	Cracking and Seating PCC Pavement Prior to Resurfacing to Retard Reflective Cracking	7/1/96	W. Smith, R. Munn
HR/TR	279	Cracking and Seating PCC Pavement Prior to Resurfacing to Retard Reflective Cracking - Fremont County	7/1/96	D. Miller
HR/TR	286	Development of a Rational Characterization Method for Iowa Fly Ash	11/30/88	T. Demirel
HR/TR	288	Field Evaluation of Bonded Concrete Resurfacing	10/31/86	Shiraz Tayabji
HR/TR	291	Performance of Nongrouted Thin Bonded PCC Overlay	10/1/90	J. Lane, W. Folkerts
HR/TR	299	Control of PCC Deterioration Due to Trace Compounds in Deicers (Ph 1, 2, & 3)	10/31/91	J. Pitt
HR/TR	300	Iowa Development of Roller Compacted Concrete	12/1/87	J. Lane, M. Callahan
HR/TR	301	Iowa Development of Roller Compacted Concrete - Mills Co. (ABORTED 88/02)	5/1/92	J. Lane, M.Callahan, J. Hare
HR/TR	315	Iowa Development of Rubblized Concrete - Mills Co.	12/31/94	J. Ebmeier, M. Callahan
HR/TR	318	Evaluation of Preformed Neoprene Joint Seals	4/1/94	R. Steffes
HR/TR	327	Evaluation of the Chemical Durability of Iowa Fly Ash Concretes	3/31/93	K. Bergeson
HR/TR	329	Hydrodemolition Preparation for Dense Concrete Bridge Overlays (TERMINATED)	12/1/94	V. Marks
HR/TR	336	Thermogravimetric Analysis of Carbonate Aggregate to Predict Concrete Durability	3/1/93	W. Dubberke

Proj.	No.	Title	End	PIs
HR/TR	337	Investigation of Rapid Thermal Analysis Procedures for Prediction of the Service Life of PCCP Carbonate Coarse Aggregate	6/30/93	S. Schlorholtz, K. Bergeson
HR/TR	341	Bond Enhancement Techniques for PCC Whitetopping	9/30/96	G. Harris/B. Skinner
HR/TR	343	Non-corrosive Tie Reinforcing and Dowel Bars for Highway Pavement Slabs	11/30/93	M. Porter
HR/TR	355	The Role of Magnesium in Concrete Deterioration (+Executive Summary)	10/31/94	R. Cody, P. Spry, A. Cody
HR/TR	358	Evaluation of Microcracking and Chemical Deterioration in Concrete Pavements	10/31/95	S. Schlorholtz, J. Amensen
HR/TR	380	Maturity & Pulse Velocity Measuremts for PCC Traffic Opening Decisions	3/31/98	J. Cable
HR/TR	384	Expansive Mineral Growth and Concrete Deterioration	8/31/97	R. Cody
HR/TR	396	Image Analysis for Evaluating Air Void Parameters of Concrete	2/28/98	S. Schlorholtz
HR/TR	403	Development of A Comprehensive Quality Incentive Program for PCC Paving	6/14/98	J. Cable
HR/TR	406	Determine Initial Cause for Current Premature PCC Pave Deterioration	11/30/00	S. Schlorholtz
HR/TR	408	Glass Fiber Composite Dowel Bars for Highway Pavement	5/31/01	M. Porter
HR/TR	409	Evaluation of Photoacoustic Spectroscopy for Quality Control of Cement	12/31/97	G. Norton
HR/TR	420	Field Evaluation of Alternative Load Transf Device Location in Low Traffic Volume Pavements	12/31/03	J. Cable/C. Greenfield
HR/TR	432	Ultrathin PCC Overlay Extended Evaluation	12/31/04	J. Cable
HR/TR	451	Investigation Into Improved Pavement Curing Materials and Techniques - Phase I & II	9/30/02	K. Wang/J. Cable
HR/TR	466	Evaluation of Unbonded Ultrathin Whitetopping of Brick Streets	6/30/06	J. Cable
HR/TR	469	Reduction of Concrete Deterioration by Ettringite Using Crystal Growth Inhibition Techniques-Part II-Field Eval of Inhibitor Effectiveness	5/30/04	P. Spry/R. Cody
HR/TR	473	Rehabilitation of Concrete Pavements Utilizing Rubblization and Crack and Seat Methods	12/31/04	Brian Coree
HR/TR	478	Evaluation of Composite Pavement Unbonded Overlays (Installation and Maintenance of Weigh In Motion Detection System on Iowa Hwy 13 in Delaware Co.)	6/30/06	P. Meraz/J. Cable
HR/TR	479	Investigation Into Improved Pavement Curing Materials and Techniques: Part II (Phase III)	4/30/03	J. Cable
HR/TR	480	Investigation of the Long Term Effects of Concentrated Salt Solutions on Portland Cement Concrete	7/14/04	
HR/TR	484	Materials and Mix Optimization Procedures for PCC Pavements	12/31/04	S. Schlorholtz/K. Wang
HR/TR	490	Stringless Portland Cement Concrete Paving	2/28/04	J. Cable
HR/TR	505	Improving PCC Mix Consistency & Production by Mixing Improvements	9/30/05	V. Schaefer
HR/TR	510	Laboratory Study of Structural Behavior of Alternative Dowel Bars	10/31/05	M. Porter - J. Cable - F. Fanous - B. Coree
HR/TR	511	Design and Construction Procedures for Concrete Overlay and Widening of Existing Pavements	9/30/05	J. Cable - H. Ceylan - F. Fanous
HR/TR	512	Measuring Pavement Profile at the Slipform Paver	12/31/04	J. Cable
HR/TR	520	Evaluation of Dowel Bar Retrofits for Local Road Pavements	7/31/08	J. Cable/M. Porter
IR	710	Recycled PCC in Base Shoulder and Fillet Construction		
IR	717	PCC Over ACC (9 mi.)	8/1/77	
IR	730	Joint Sealing - Without Backer Rope, Sta. 1060-1070		R. DeBok
IR	731	Blank Band Tining Over Transverse Joints		T. Brady
MLR	6901	Lightweight Aggregate Use in Structural Concrete	4/1/69	G. Calvert
MLR	7101	An Investigation of the Chemical Method of Determining the Air Content of Hardened Concrete	3/1/71	M. Sheeler
MLR	7102	A Study of the Relative Durability and Drying Shrinkage of Concrete Using Various Retarders	7/1/71	S. Carey
MLR	7103	Durability Study of Type II Cements	6/1/71	S. Carey

Proj.	No.	Title	End	PIs
MLR	7201	A Study of the Reliability of the ASTM C-666 Freeze-Thaw Test	9/1/72	V. Marks
MLR	7301	Method to Increase Durability of Reactive ("D" Cracking) Coarse Aggregate in PCC	8/1/73	R. Less
MLR	7502	Evaluation of Argentine Nondestructive Test for Determining Concrete Compressive Strength	2/1/75	R. Less
MLR	7504	An Investigation of Concrete Setting Time	4/1/75	G. Calvert
MLR	7702	Bonded, Thin-Lift, Non-Reinforced PCC Resurfacing	5/1/77	Bergren, Britson, Schroeder
MLR	7703	PCC Utilizing Recycled Pavement	1/1/77	J. Bergren, R. Britson
MLR	7705	Chloride Penetration into LSDC (IA System) Resurfacing Mixes	4/1/77	G. Calvert
MLR	7706	Recycling of Portland Cement Concrete Roads in Iowa		
MLR	8001	Bonded PCC Resurfacing	11/1/80	J. Bergren
MLR	8105	Evaluation of the Concrete Admixture Gla-zit	3/1/83	B. Brown
MLR	8106	Fly Ash Concrete Compressive Strength & Freeze-Thaw Durability	6/1/81	K. Isenberger
MLR	8301	Bonding Agents for PCC and Mortar	8/1/83	B. Brown
MLR	8302	An Investigation of the I-80 Rutting in Adair Co. Note: under HR-2028	10/1/83	V. Marks
MLR	8304	Effect of Grooved Concrete on Curing Efficiency	7/1/83	J. Roland
MLR	8401	Curing Compound Efficiency on Grooved Concrete	5/1/84	M. Sheeler
MLR	8404	Durability of Concrete With Additives	7/1/85	J. Lane, S. Moussalli
MLR	8406	Strength-Temperature Study of Fly Ash Concrete	8/1/84	B. Brown
MLR	8407	Evaluation of Fly Ash in Water Reduced Paving Mixtures	6/1/85	B. Brown
MLR	8408	Reduction of D-Cracking Deterioration by Increasing Density of Concrete		S. Moussalli
MLR	8502	Fly Ash Effects on Alkali-Aggregate Reactivity		R. Allenstein
MLR	8503	Fly Ash in PCC Base Mixes	8/1/86	S. Moussalli
MLR	8505	Air Entrainment and PCC Durability		--
MLR	8508	Durability of Fly Ash Concrete Containing Class II Durability Aggregates	7/1/86	S. Moussalli, J. Myers
MLR	8509	Length Change of PC Concrete Due to Moisture Content	3/1/87	V. Marks
MLR	8601	Fly Ash in PCC Base	8/1/86	S. Moussalli
MLR	8602	Early Bond Str. Determined by 007 Bond Test & Direct Shear		O. J. Lane
MLR	8606	Roller Compacted Concrete	9/1/88	G. Calvert
MLR	8611	Rapid Determination of Permeability of PCC by AASHTO T277-83	9/1/87	J. Nash
MLR	8612	Determination of Tension Crack Development in Plastic PCC with Retarding Admixture	9/1/87	K. Jones, O.J. Lane
MLR	8703	Field Evaluation of Class A Subbase Using Fly Ash	10/1/88	T. Parham
MLR	8704	Special Cements for Fast Track Concrete (Phase I)	6/1/88	K. Jones
MLR	8706	Evaulation of Type I Cement Fast Track Concrete	10/1/88	K. Jones
MLR	8707	Early Strength of Class B, C & F Portland Cement Concrete	11/1/87	J. Grove
MLR	8801	Pavement Evaluation of Iowa 44 in Audubon & Guthrie Counties (D-Cracking)		K. Jones & J. Nash
MLR	8806	Fine Sand for Use in PC Concrete	3/1/89	K. Jones
MLR	8812	Admixtures for Use as Retarders/Water Reducers in C-WR Mixes		--
MLR	8813	Fast Track Mixes for IA 100, Linn County		J. Grove
MLR	8815	Field Evaluations of Variations of Fast Track Concrete (Transferred to HR-546)	12/1/88	J. Grove, K. Jones
MLR	8902	Pavement Evaluation Using the Road Rater(TM) Deflection Dish	12/1/89	C. Potter
MLR	8904	Evaluation of Precast & Prestressed Mix Design Using Fly Ash for		C. Narotam, K. Jones
MLR	8905	Drying Shrinkage in PC Concrete	3/1/90	K. Jones
MLR	8906	Field Evaluation of Accelerated Cure Modified C-Mix Concrete	5/1/89	J. Grove

Proj.	No.	Title	End	PIs
MLR	8911	Precision & Accuracy Determination for PCC Core Testing - SHRP	2/1/90	K. Bharil
MLR	8914	Hydraulic Cement Grout Testing	8/1/90	K. Bharil
MLR	9001	Evaluation of Test Method to Measure Response of Aggregate Cement-Fly Ash Combinations to D		--
MLR	9101	Evaluation fo Deterioration on US 20 in Webster County	12/1/91	--
MLR	9203	Affect of Fly Ash on Concrete Compressive Strength		C. Narotam
MLR	9207	Correlation of Air Content of Concrete		C. Narotam
MLR	9303	Effect of Cement & Sand Components on Expansion in ASTM P-214 Test		C. Narotam
MLR	9306	Concrete Prism Testing		C. Narotam
MLR	9307	Evaluation of Concrete Patching Mixes & Opening Time Using Maturity Concept		--
MLR	9405	Laboratory Testing of SHRP SPS-2 PCC Mixes	4/1/95	J. Grove
MLR	9406	Evaluation of Various Cements in Combination With Ground Slag or Class F FlyAsh	10/1/94	S. Gent
MLR	9408	Coarse Aggregate Gradations for PCC	4/1/95	C. Ouyang
MLR	9409	Durability of Concrete Pavents Using Cements With Different Alkali Contents	5/1/97	C. Ouyang
MLR	9503	An Investigation of Concrete Maturity	6/1/95	C. Ouyang
MLR	9504	Vibration Study For Consolidation of Portland Cement Concrete	1/1/97	S. Tymkowicz, R. Steffes
MLR	9505	Freeze/Thaw Durability Testing of Oversanded Bridge Floor Concrete	5/1/95	C. Ouyang
MLR	9510	Instrumentation of Paver Vibrators	1/1/99	R. Steffes
MLR	9512	Ground Granula Blast Furnace Slag Concrete Resistance to Salt Scale		C. Ouyang/T. Hanson
MLR	9513	Freeze/Thaw Resistance of Cement With Excess Free Lime		T. Hanson
MLR	9601	Maturity of Concrete: Field Implementation	4/1/96	C. Ouyang
MLR	9602	Determination of Concrete Workability		R. Steffes
MLR	9604	Laboratory Study of the Leachate From Crushed PCC Base Materials		B. Steffes
MLR	9701	Mini Slump Cone Test Procedures and Precision	11/00	T. Hanson
MLR	9702	Vibratory Effects in Reinforced PCC Pavement	5/1/97	B. Steffes
MLR	9703	Field Evaluation of QMC Strength Variability	7/98	S. Tymkowicz
MLR	9704	Concrete Whiteness for Barrier Rails	9/1/97	J. Lane
MLR	9705	Soffcut Sawed PCCJoint Ends		B. Steffes
MLR	9708	The Effect of Cement and Water Reducers on Concrete Durability	7/00	T. Hanson
MLR	9802	Effect of Waterproofing Admixture Ipanex on Concrete Durability	3/99	T. Hanson
MLR	9804	Core Analysis of Slip Formed Barriers	9/99	T. Hanson/B. Steffes
MLR	9805	High Performance Concrete for Bridge Decks		C. Ouyang
MLR	9901	Evaluation of Performance Based Specifications for Blended Cements (ASTM C1157)		T. Hanson/C. Ouyang
MLR	9903	Plastic Air Versus Hardened Air by High Pressure Air Meter		T. Hanson/J. Hart
MLR	9905	Field Evaluation of Water Reducers With Type I (sm) Cement		J. Grove/T. Hanson
MLR00-03	200003	Evaluation of Long Term Durability of PCC Using Intermediate Sized Gravels to Optimize Mix Gradations		J. Hart
MLR00-04	200004	Study of Chloride Intrusion into PCC Pavements		B. Gossman/K. Jones
MLR00-05	200005	Longitudinal Joint Forming In PCC Pavements		R. Steffes
MLR00-05	200005	(MLR-00-05A) Patent for Joint Former for Plastic Concrete		R. Steffes
MLR02-01	200201	Evaluating Properties of Blended Cements for Concrete Pavements	12/31/02	K. Wang
MLR02-03	200203	PCC Curing Compound Performance - Phase I & II		R. Steffes
MLR03-01	200301	Transverse Joint Forming in PCC Pavements	6/1/08	R. Steffes

Kansas

Introducing the Air Void Analyzer – AVA **(CD-ROM and Brochure). AASHTO Technology Implementation Group.**

The air void analyzer is an apparatus for rapid measurement of the air-void characteristics of fresh concrete. It is useful for verifying and controlling the air-void system before and during production. The size and distribution of the air voids determine the durability of the concrete. Concrete with an adequate air-void system has better freeze-thaw durability, sulfate resistance and scaling resistance. The AVA measures the size of the voids and their distribution, not just the total air content like the roll-o-meter and pressure meter tests measure. Vibrating a wire cage into fresh concrete using a percussion drill collects AVA specimens. The mortar fills the cage and a syringe captures a mortar sample. This sample is then tested in a viscous liquid where air bubble rise to the top and the buoyancy is measured. The time rate of air loss and Stoke's Law is used to determine results. Entrained air content, spacing factor and specific surface are reported. Testing can be done almost anywhere and results are immediate.

A Kansas case history is discussed where pavement less than 10 years old was cracked and deteriorating at joints even though the aggregate was sound and met specifications. Poor spacing factors were to blame. For distress prevention strategy, AVA was used for monitoring concrete paving projects. When contractors were given immediate results they were able to make immediate improvements in the concrete air systems of on-going projects and experience future cost savings.

Fresh Concrete Air Void Analyzer (from CD-ROM). AASHTO TIG.

The mechanisms causing freezing and thawing damage are fairly well understood. The air-void system in concrete is commonly singled out as being the most significant factor in freeze-thaw resistant concrete. Researchers believe that the pressure developed by water as it expands during freezing depends upon the distance the water must travel to the nearest air void. The voids must be spaced close enough to relieve the pressure. Thus, smaller, closely spaced voids provide better protection than larger, more distant void spacing.

Commonly used field test methods are only capable of measuring the volume of air voids, not the size or spacing of the voids. In an effort to address this problem, researchers in Europe developed the Air Void Analyzer (AVA) in the late '80's to characterize the air-void structure of fresh concrete. The clear advantage of the AVA is its ability to obtain air-void structure information on fresh concrete in less than 30 minutes. With this information, adjustments can be made in the production process to rectify any problems with the air-void system during concrete placement.

The AVA clearly provides information that characterizes the air-void system in fresh concrete in real time. Commonly used test methods monitor only the total air volume in fresh concrete, and provide no information about the size and spacing of the air-void system. Only the fresh concrete Air Void analyzer, (AVA) can provides that information in during placement.

In order to improve the durability of concrete used in transportation structures, the AASHTO TIG strongly encourages State DOT's to specify air-void system characteristics, and adopt the use of the AVA for quality control.

***Special Provision to the Standard Specifications 1990 Edition*. Section 402, Concrete. Kansas Department of Transportation.**

These specifications are for the *Concrete* section and includes details on materials, mix design, mortar, commercial grade concrete, certified concrete, requirements for combined materials, mixing, delivery, and placement limitations, inspection and testing, and air-entrained concrete for pavement.

***Special Provision to the Standard Specifications 1990 Edition*. Section 1102, Aggregates for Concrete. Kansas Department of Transportation.**

These specifications are for the *Aggregates for Concrete* section and includes details on requirements, test methods, prequalification, and basis of acceptance. Included under the details section is information pertain got coarse, fine, mixed, and miscellaneous aggregates.

Special Provision to the Standard Specifications 1990 Edition. **Division 500, Portland Cement Concrete Pavement (Quality Control/Quality Assurance (QC/QA)). Kansas Department of Transportation.**

These specifications are for the *Portland Cement* Concrete *Pavement* division and includes details on Contractor Quality Control Requirements, Materials, Construction Requirements, and Measurement and Payment. Under the Contractor Quality Control Requirements section is information regarding quality control organization, Certified Technicians required duties, testing facilities, testing requirements, documentation, corrective action, non-conforming materials, and quality control plan.

Table of Contents, Section 5.16. Kansas Department of Transportation.

A copy of the table of contents showing the section titles and revision dates of sections 5.16.00 through 5.16.59.

Construction Using Quality Control/Quality Assurance Specifications. Appendix B, Sampling and Testing Frequency Chart for Kansas Department of Transportation, February 2002.

Information included are the tests required, test method, quality control by contractor, and verification by KDOT for concrete pavement. The categories of concrete pavement are individual aggregate, combined aggregates, and concrete including Class I &/or II aggregate.

Construction Using Non Quality Control/Quality Assurance Specifications. Appendix A, Sampling and Testing Frequency Chart for Kansas Department of Transportation, February 2002.

Information included are the tests required, test method, CMS, verification samples and tests, and acceptance samples & tests for concrete pavement.

Various concrete mix designs, Kansas Department of Transportation.

Included are four mix designs from different dates, two from June 7, 2002, one from January 24, 2003 and one from July 22 2003. A materials distribution chart is included with each one.

Wojakowski, J. *High Performance Concrete Pavement*. Report FHWA-KS-98/2. Kansas Department of Transportation, April 1998.

Portland Cement concrete pavements of especially high quality became an area of interest in the early 1900s and precipitated a tour by representatives of industry and government to observe European construction practices. Following the tour the FHWA developed a research program to encourage and aid states in constructing High Performance Concrete Pavement (HPCP). Important criteria for research projects were service life and costs, innovative design and materials, and construction productivity and quality. This Kansas HPCP research project was facilitated greatly by the FHWA funding and was conceived to address most of the criteria enumerated above. Specific test sections generally one half to one kilometer in length were built with the following special features and materials: 1) Single saw cuts w/o sealing the joint, 2) fiberglass dowels, 3) and X frame load transfer device, 4) early cut saws, 5) polyolefin fibers, 6) longitudinal tining, 7) high solids curing compound, 8) two-lift construction, 9) recycled asphalt pavement millings as intermediate size aggregate in PCCP in bottom lift, 10) lower water-cement ratio concrete, 11) hard, igneous coarse aggregate in PCCP in top lift with a pozzolan, and 12) random transverse tining. Laboratory testing was done on innovative materials and mixtures. Fatigue testing of the various dowels and load transfer devices was performed. Most materials and test sections performed as expected with the exception that interpanel cracking occurred between the 18.3-meter (60 foot) joints of the polyolefin fiber section. The cost increase for the two-lift construction was significant even though the first lift was placed using only a spreader. Evaluation and monitoring of the test sections will be carried out for the next five years.

Clowers, K. A. *Seventy-five Years of Aggregate Research in Kansas*. Report FHWA-KS-99/1. Kansas Department of Transportation, March 1999.

The Kansas Department of Transportation (KDOT) has a long history of aggregate research directed towards finding the most reliable and durable aggregate for highway construction. Beginning with a study on freeze thaw durability in 1928, this paper summarizes the historical development of aggregate research conducted over the last 75 years. Research studies have focused predominantly on freeze-thaw damage (D-cracking) and alkali-silica reaction (ASR). This research has contributed significantly towards the development of current specifications. Today KDOT pavements are relatively free of ASR and D-cracking. Current test methods and concrete aggregate specifications have been included in the Appendix.

Louisiana

New Flexural Strength Requirements for Portland Cement Concrete Pavements (PCCP).

Current designs for PCC pavements have increased in thickness compared to those in the past. Thirty years ago, it was common for PCCP to be 8 to 10 inches in thickness based on then current traffic data and growth projections. At this time, it is now known that these projections were underestimated especially concerning heavy commercial traffic. A considerable number of these pavements are still performing satisfactorily passed their anticipated design life. Taking today's increased traffic into account, there is a call to increase the pavement thickness to as much as 15 inches. These increases in pavements have caused a concern both in economic feasibility and constructability.

To alleviate this substantial increase in pavements thickness, the strength of the pavements must increase. Due to increasing the design flexural strength of the concrete, in order to minimize the thickness, it becomes important that new testing standards and procedures are put in place. What follows are the initial provisions for PCCP flexural testing.

Uniform Aggregate Gradation Specifications (Pavement Types B & D).

The combined aggregates for the proposed PCCP mix, both fine and coarse, shall be evaluated on a percent-retained chart, as shown on the following two charts; Combined Aggregate Gradation 5-20 Band: Grade B and Combined Aggregate Gradation 5-20 Band: Grade D. The charts note that no two adjacent sieve sizes shall account for less than 14% of the total gradation within the #30 and ¾" boundary.

Photos attached showing the LA DOTD; Louisiana Transportation Research Center, Pavement Research Facility.

King, W. M. Design and Construction of a Bonded Fiber Concrete Overlay of CRCP (Louisiana, Interstate Route 10, August 1990). Report No. FHWA/LA-92/266. Louisiana Transportation Research Center, Baton Rouge, January 1992.

The purpose of this study was to evaluate a bonded steel fiber reinforced concrete overlay on an existing 8-inch CRC pavement on Interstate 10 south of Baton Rouge, LA. The project objectives were to provide an overlay with a high probability for long term success by using a concrete mix with high cement content, internal reinforcement, and with good bonding characteristics.

The existing 16-year-old CRC pavement had carried twice its design load and contained only a few edge punch-out failures per mile. A 4-inch concrete overly was designed for a 20-year service life. An additional level of reinforcement bonding was provided which utilized curb type reinforcement bars epoxied into the existing slab. The primary purpose in the additional reinforcement was to provide positive bonding at the slab edges where thin overlays have a tendency to debond due to curling and/or warping. A 9-inch tied concrete shoulder was added to increase the pavements structural capacity.

The overall Serviceability Index of the pavement increased from 3.4 to 4.4 with measured Profile Index levels typically below the 5-inch per mile specification. Test revealed excellent bond strengths, and reduced edge deflections by 60% under a 22,000 pound moving single axle loading. Cores taken over transverse cracks in the overlay indicated reflection cracking from the transverse cracks in the original pavements. The final results reveal an estimated 35% of these cracks have reflected through and debonding has not occurred at he pavement edges. Anticipation of reflective cracking was one consideration in using the steel fibers, which provide three-dimensional reinforcement.

Michigan

Concrete Analysis and Deterioration. In *Transportation Research Record 853,* TRB, National Research Council, Washington, D.C., 1982.

Four articles below included.

Girard, R.J., E. W. Myers, G.D. Manchester, and W.L. Trimm. D-Cracking: Pavement Design and Construction Variables. In *Transportation Research Record 853*, TRB, National Research Council, Washington, D.C., 1982.

Reported map cracking and D-cracking problems observed on Portland cement concrete (PCC) pavements in Missouri from the late 1930's to 1981 are briefly discussed. Investigations involving studies in the laboratory and constructed pavements have contributed significantly to a better understanding of the deterioration process and its cause. Type, characteristics, and maximum size of coarse aggregate; source of cement; design of concrete mix; and type of base have been or are being studied in the field or laboratory to determine their influence to frost susceptibility of concrete. Missouri has increased the service life of its PCC pavements. This has been accomplished by (a) not using river and glacial gravels in construction of PCC pavements and (b) subjecting limestones that have a known history of D-cracking problems to increased quality restrictions, which have resulted in some ledges and entire quarries and formations being eliminated. However, D-cracking remains and, in terms of required maintenance and service life, is still a problem.

Traylor, M. L. Efforts to Eliminate D-Cracking in Illinois. In *Transportation Research Record 853*, TRB, National Research Council, Washington, D.C., 1982.

Severe D-Cracking on Interstate pavements prompted the Illinois Department of Transportation to initiate a program to identify and eliminate the use of D-cracking aggregate. More than 200 crushed-stone and gravel sources were evaluated by using both the Iowa pore index and ASTM C-666 freeze-thaw tests. Shortcomings in the Iowa pore index test have resulted in its use being limited to a screening test. The results of the freeze-thaw program have formed the basis for a specification that the state believes will guarantee the durability of future pavements.

Halverson, A. D. Recycling Portland Cement Concrete Pavement. In *Transportation Research Record 853*, TRB, National Research Council, Washington, D.C., 1982.

Quality aggregates for highway construction are in short supply in many parts of Minnesota. Although the current total supply is adequate, the distribution of sources results in localized shortages. It is sometimes necessary to import high-quality aggregate from distant locations. Haul distances can increase aggregate prices substantially, add to the overall project cost, and require the expenditure of sizable amounts of energy. One available source of aggregate is existing Portland cement concrete (PCC) pavement currently in need of reconstruction. Reusing this aggregate would result in cost savings in aggregate-short areas, conserve natural resources, and conserve energy in the form of fuel savings when aggregates must be acquired from distant sources. A research study is described that was undertaken to determine the feasibility of recycling PCC pavement, evaluate the new recycled pavement, determine the cost-effectiveness of recycling versus conventional paving, and determine the amount of energy consumed and natural resources conserved. Economic and engineering factors led to the selection of a 16-mile segment of US-59 form Worthington to Fulda in southwestern Minnesota for the study. The in-place roadway, which was constructed in1955 and consisted of 9-, 7-, 9-in-thick, 24-ft-wide, nonreinforced, D-cracked concrete pavement with soil shoulders, was broken, salvaged, and crushed. Material passing the no. 4 sieve was used for base stabilization and shoulder aggregate, and material retained on the no. 4 sieve but passing the 0.75-in sieve was used as the coarse aggregate for concrete paving. The project results are evaluated based on pavement performance and energy and cost comparisons.

Paxton, J. T. Ohio Aggregate and Concrete Testing to Determine D-Cracking Susceptibility. In *Transportation Research Record 853*, TRB, National Research Council, Washington, D.C., 1982.

Several laboratory test methods were analyzed to determine their capability of indicating the D-cracking susceptibility of coarse aggregates. Two methods were modified versions of ASTM C666 A and B, two were unconfined freeze-thaw tests of the aggregate, and the remaining to were standard sodium and magnesium soundness tests. The major modification of the ASTM C666 test methods was to determine the elongation of the test specimens versus routine weight-loss determinations and/or sonic modulus determinations. Results are evaluated by plotting the percentage of expansion versus the number of cycles completed and calculating the area under the curve generated. Although 10 specimens are used in the testing, the 2 high and 2 low test results are removed before final analysis. The correlation of this test method with service records of various aggregates was found to be good; however, when the same coarse aggregates were tested in sodium sulfate, magnesium sulfate, or unconfined freeze and thaw, the results did not correlate well with the service records.

Arnold, C. J. *Pressure Induced Failures in Jointed Concrete Pavements and a Machine for Installation of Pressure Relief Joints*. Research Report No. R-949. Testing and Research Division, Michigan Department of Transportation, December 1974.

This report considers only jointed reinforced concrete pavements. Continuously reinforced concrete pavements behave afar differently, and require special consideration not covered here. Joint failures in concrete pavements have caused traffic hazards and maintenance problems for many years. When an expansive force exceeds the strength of a deteriorated joint, a blow-up or localized crushing occurs. Problems of this nature usually begin when the pavement is 10-15 years old. Pressure relief joints have been installed at several locations. The same type of joint fillers has been used in conjunction with repairs. Although the foam seems to provide an effective joint seal when the joint closes upon it, opening of he joint allows penetration of water into the base. It became evident that the filler should be placed with some initial compression, so that the opening of the joint can be accommodated, the seal maintained and the sealer kept in place.

Arnold, C. J. *The Relationship of Aggregate Durability to Concrete Pavement Performance, and the Associated Effects of Base Drainability*. Research Report No. R-1158. Testing and Research Division, Michigan Department of Transportation, January 1981.

It is evident that Michigan has problem aggregates in many localities since D-cracking is appearing on many projects of 10 years or more of age and even at 3 ½ to 4 years on the US 10 Clare experimental pavements of this study.

The early results of the experimental installation at Clare show the deleterious effects of poor base drainage on concrete pavement performance. Improved drainability for all future base course construction should be pursued.

All effort should be put into identifying and evaluating sources and specifying corrective size changes or material substitution where warranted. Also, serious consideration should be given to raising the minimum acceptable durability rating by application of the latest principles to adjust the gradation of the coarse aggregate along with other appropriate mix design changes to obtain all practically attainable improvements in longevity of performance. It is also recommended that durability requirements be increased for the more critical applications. Some significant benefits should result from such procedures.

Additional data are needed to separate the better performing aggregates from those that cause earlier deterioration. Also, any test that could be developed to identify D-cracking aggregates in less time than the long-term freeze thaw test would be a boon to this endeavor.

Arnold, C. J., M. A. Chiunti, and K. S. Bancroft. ***A Five-Year Evaluation of Preventative Maintenance Concepts on Jointed Concrete Pavement*****. Research Report No. R-1185. Testing and Research Division, Michigan Department of Transportation, February 1982**.

Experimental jointed concrete pavement preventive maintenance procedures were used on 270 lane miles of I 75 and I 696 during the summer of 1975. These procedures included an objective rating on the condition of the joints, selection of the worst joints for replacement and the use of pressure relief joints at structures and at least every 850 ft, in pavement sections where repairs were not made.

The conclusions were that pressure relief joints are effective in delaying joint blow-ups in the 99-ft slab reinforced pavements with base plates and poured joint sealants. Also, preventative maintenance concepts have accomplished the intended goal of delaying emergency-type repairs for five years for more.

Arnold, C. J., M. A. Chiunti, and K. S. Bancroft. ***Jointed Concrete Pavements Design, Performance and Repair*****. Research Report No. R-1169. Testing and Research Division, Michigan Department of Transportation, May 1981**.

Background information is presented concerning the performance and problems related to postwar pavements with the 99 ft. reinforced slabs, load transfer, and base plates under the joints. Newer pavements have been designed with successively shorter slab lengths and still use load transfer and reinforcement. An experimental installation having extreme variations in drainability is discussed and the effects of base drainage on the performance of the concrete pavement as well as the inter-relationships with aggregate quality are demonstrated. Highly variable performance with changes in course aggregate source is shown as well. Pavement joints faulting due to rearrangement if fine base materials is shown. The effects of pressure build up in older pavements is discussed, along with strategies for pressure relief, experimental pressure relief projects, preventative maintenance, and the development of the techniques for locating pressure relief joints and installing joint filer.

Baladi, G. and T. Svasdisant. ***Causes of Under Performance of Rubblized Concrete Pavements.*** **Research Report RC-1416. Pavement Research Center of Excellence, Michigan State University, East Lansing, August 2002.**

When an asphalt concrete is placed on top of an existing concrete pavement, within a relatively short time period (3 to 5 years depending of the thickness of the AC overlay and the pre-overlay repairs of the original concrete pavement), the resulting composite pavement would typically exhibit reflective cracking from the underlying concrete pavement. Since 1986, the Michigan Department of Transportation (MDOT) and other State Highway Agencies are rubblizing concrete pavements to prevent reflective cracking through the bituminous surfaces. Over time, special provisions for rubblizing concrete pavements have evolved. However, some rubblized pavement projects are very successful and are expected to last their intended design life. Others are underperforming and have shown a reduced service life. The underperforming pavement sections have shown various types of distress including cracking, rutting and raveling. The overall objective of this study is to determine the causes of under performance of rubblized concrete pavements.

Rubblization of deteriorated concrete pavements is a viable rehabilitation option that requires more detailed quality control measures than conventional asphalt pavements. It is strongly recommended that quality control measures be revisited, tightened and strictly enforced.

Barnhart, V. T. ***Field Evaluation of Experimental Fabrics to Prevent Reflective Cracking in Bituminous Resurfacing*****. Research Report No. R-1300. Materials and Technology Division, Michigan Department of Transportation, July 1989**.

This study involved the installation of six different types of commercially available fabric strips as reinforcement over conventionally repaired joints and cracks on a 0.9 mile section for concrete pavement being prepared for asphalt resurfacing. The purpose of the study was to compare the performance of fabric-treated and untreated repaired joints and cracks in the overlay.

The field results from these projects indicate that the use of the experimental fabrics as overly reinforcement to reduce reflective cracking did to some extent extend the length of time for reflective cracking to show through the bituminous overlay. While there is some evidence that the experimental fabrics do perform as crack resistant material, none of them have met the manufacturers claims that they will either greatly reduce or completely prevent reflective cracking.

Barnhart, V. T. ***Inspection of Pavement Problems on I-275 and on I-75 from the Ohio Line Northerly to the Huron River*****. Research Report R-1390. Construction and Technology Division, Michigan Department of Transportation, February 2001.**

The purpose of this study was to verify the conclusions reached in previous reports (1, 2, 3, 4, 5, 6) regarding poor drainage and filter problems on both I-275 and I-75 and with the Open-Graded Drainage Course (OGDC) on I-75. Also, to verify the conclusion reached in the placements of the continuously reinforced concrete (CRC) reinforcement and longitudinal cracking on I-275 (1, 2, 3, 4, 5).

I-275 Project Findings: Pavement surveys, conducted in 1977, indicated some longitudinal cracking and punch-out failures on three of the projects. The cause of this early distress was immediately investigated and resulted in three report (1, 2, 3). The conclusions reached in the previous reports regarding the causes for the longitudinal cracking are still valid. Since the studies ere done in the late 1970's and early 1980's, questions have been raised regarding the relative location (depth, bar spacing, alignment) of CRC reinforcement bars, and whether or not the longitudinal cracking in the CRC pavement follows the bars. The longitudinal cracking in the CRC pavement followed the longitudinal reinforcement bars.

I-75 Project Findings: In 1980, a study was conducted to determine the cause of performance problems in the roadway constructed between 1955 and 1957 and widened between 1973 and 1974. The conclusions reached in Part 1 of the 1980 study could not be confirmed as the concrete pavement was completely removed and recycled during reconstruction between 1984 and 1990. The conclusion reached in Part 2 of the 1980 study regarding the problems with the subbase is still valid. However, the conclusions made regarding the dense-graded aggregate base are not valid, as the base was removed during reconstruction.

Barnhart, V. T. ***Inspection and Performance Evaluation of Prefabricated Drainage System (PDS) in Cooperation with Monsanto Company*****. Research Report R-1341. Construction and Technology Division, Michigan Department of Transportation, October 1998.**

This study involved the investigation of geocomposite drains (Prefabricated Drainage Systems (PDS)) that were installed on construction projects that included crack and seat, break and set, rubblizing, recycling PCC, concrete overlays and reconstruction, as underdrains, to evaluate the performance of the PDS.

The study concluded that the PDS is performing well. While there was some evidence of J-ing of the bottom and occasional bending over of the top of the PDS, these factors did not appears to obstruct the flow of water through the system. In general, the filter fabric and core were clean except for some insignificant staining of the fabric and core. There was no evidence of calcium carbonate precipitate found in the core or on the filter fabric of the PDS on the project sites where the concrete pavement had been rubblized or where untreated crushed concrete or asphalt treated crushed concrete was used as the open-graded drainage course.

Further investigation research should continue to determine the long-term performance of all underdrains where the Open-Graded Drainage Course (OGDC) is used in conjunction with a dense-graded aggregate or geotextile separator.

Branch, D. E. *Concrete Pavement Restoration*, *Final Report*. Research Report R-1327. Materials and Technology Division, Michigan Department of Transportation, January 1995.

For the past 25 years, the MDOT Research Laboratory has conducted several studies to develop effective maintenance procedures for concrete pavement. The procedures were developed for daylight closures to minimize the inconvenience and hazard to motorists caused by maintenance operations. By 1982 (following evaluation of cast-in-place repairs, with and without dowelled joints), the department used dowelled repairs as a standard procedure. The dowels are loose fitting in holes drilled in the adjacent slabs. The restoration work described in this report uses repair techniques previously developed in addition to new ones. The pavement selected for restoration was a 20 year-old, 9 in reinforced concrete slab with 71 ft joint spacings, and joints sealed with preformed neoprene seals. Deteriorated joints were repaired using full depth repairs having dowelled joints with the dowels grouted-in-place using an epoxy grout. Some mid-slab failures were repaired by tying the new concrete to the existing slab using grouted-in-place No. 10 deformed bars. The deteriorated intersections of the longitudinal and transverse joints were restored using –ft by 4-ft full depth repairs tied in place with grout-in No. 5 deformed bars. Spalls along the joint grooves were repaired partial-depth with fast-set premixed mortar; the neoprene seals were replaced with silicone sealant; the longitudinal joints were resealed using a low-modulus hot-poured sealant; and surface pop-outs were fixed using fast-set premixed mortar. The performance of the various restoration techniques were evaluated for a five-year period.

Bruinsma, J. E., Z.I. Raja, M.B. Snyder, and J.M. Vandenbossche. *Factors Affecting the Deterioration of Transverse Cracks in JCRP.* Final Report MDOT Contract 90-0973. Department of Civil and Environmental Engineering, Michigan State University, Lansing, March 1995.

Joint Reinforced Concrete Pavement (JRCP) develops transverse cracks as the drying and thermal shrinkage of the concrete is resisted by friction with the supporting layers. These cracks deteriorate with time and traffic due to loss of aggregate interlock load transfer capacity. However, unusually rapid deterioration of these cracks has even observed on some recently constructed projects in Michigan. This rapid crack deterioration leads to accelerated maintenance requirements and shortened service lives. This research report describes the development, conduct and results of a laboratory investigation to determine the relative effects of selected factors on the deterioration of transverse cracks in JRCP.

Based on the results of these tests, it is recommended that pavement made with concrete derived from recycled concrete aggregate or slag should feature structural designs that minimize reliance on aggregate interlock in any area of the design (i.e., at joints or cracks). The use of blended aggregates (recycle concrete or slag combined with suitable natural aggregates) may be useful to provide additional design reliability, but is probably not necessary for the types of designs described above.

Transverse crack deterioration appeared to be strongly correlated with concrete strength (presumable due to reductions in pavement stiffness and abrasion resistance that probably accompany the use of weak concrete). Thus, pavement made with concrete that includes relatively weak aggregate particles, such as slag and recycled concrete, should: a) use mix designs that provide concrete strengths that are comparable to those of concrete made with virgin aggregates; b) use structural designs that reduce pavement stresses to levels that are appropriate for the strength that will be obtained; or c) do both.

Buch, N., M.A. Frabizzio, and J.E. Hiller. *Factors Affecting Shear Capacity of Transverse Cracks in Jointed Concrete Pavements (JCP).* Report RC-1385. Pavement Research Center of Excellence, Michigan State University, East Lansing, May 2000.

Environmental and/or traffic related stresses can lead to the development of transverse cracking in jointed concrete pavements (JCP's). 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 JCP's 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 JCP's and to demonstrate methods of evaluating these cracked pavements. Field data collected from in-service JCP's 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 calculations 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 JCP's. Results form theses 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.

Buch, N., L. Khazanovich, and A. Gotlif. *Evaluation of Alignment Tolerances for Dowel Bars and Their Effects on Joint Performance* (CD-ROM), Final Report. Pavement Research Center of Excellence, Michigan State University, East Lansing, June 2001.

The Michigan Department of Transportation (MDOT) uses dowel bars to assure that adequate load transfer takes place across transverse joints in rigid pavements. Dowel bars are placed at pavement mid-depth, and care is taken to minimize the detrimental effects of misalignment.

Several major pavement performance studies (Yu et al. 1997, Khazanovich et al. 1998, Hoerner et al. 2000) demonstrated that properly placed dowels significantly reduce transverse joint faulting and corner cracking.

The dowel bar's performance is a key factor that directly affects the service life of the joint. The objective of this study is to develop justifiable tolerance levels that ensure that doweled joints do not cause high levels of stress and damage due to misaligned dowels.

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 analysis of misaligned dowels showed that uniform vertical misalignment did not cause significant resistance to joint horizontal movements. At the same time, non-uniform misalignment may cause joint lock-up and premature pavement failure.

Although the magnitude and uniformity of dowel misalignment are significant factors affecting joint performance, its interaction with other factors should be considered

In this study, several comprehensive finite element models were developed for a single dowel misaligned vertically or horizontally. Those models provide accurate modeling of joints with all dowels misaligned uniformly or joints with adjacent dowels misaligned by the same magnitude but in different directions. The model developed in this study will be crucial for the development of dowel misalignment tolerance levels for automatic dowel bar inserters.

The finite element model for multi-slab analysis clearly demonstrates that the presence of dowel misalignment can significantly affect joint opening and the subsequent stress development. However, the model assumes that all joints have been properly formed. It is recommended to develop a finite element model of joint formation that accounts for the presence of misaligned dowels. Such a model permits accurate evaluation of the magnitude of dowel misalignment, which prevents joints from proper formation.

To verify the finite element models developed in this study and to provide proper inputs to them, the following laboratory tests are recommended:

1. Modified pullout test - *It is recommended to conduct this test for dowel diameters of 1.25 and 1.5 inches.*
2. Combined pullout/bending test – *It is recommended to conduct this test for 1.25-inch dowels and three vertical-to-horizontal displacement ratios: 0, .05, and 0.1 inch.*
3. Generalized pullout test

Chatti, K., D. Lee, and G. Y. Baladi. *Development of Roughness Thresholds for the Preventive Maintenance of Pavements based on Dynamic Loading Considerations and Damage Analysis.* Research Report RC-1396. Pavement Research Center of Excellence, Michigan State University, East Lansing, June 2001.

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 threshold. This threshold would be used in the pavement management system as an early warning for preventive maintenance action. This was done by testing the hypothesis that there is a certain level of roughness (roughness-threshold values) at which a sharp increase in dynamic load occurs, thus causing an acceleration in pavement damage accumulation.

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.

The above relationships allowed for determining critical ranges of RQI, at which distress and theoretical pavement damage accelerate. Reasonable agreement was obtained between theoretically derived and empirically derived ranges. However, these RQI were too wide to be adopted at the project level. It was therefore concluded that the RQI was not suitable for predicting dynamic truckloads at the project level, i.e., for a specific pavement profile.

Consequently, a new roughness index, called the Dynamic Load Indices (DLI), was developed for the purpose of identifying 'unfriendly' pavement profiles form 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.

Chiunti, M. A. *Experimental Short Slab Pavements; Construction Report*. Research Report No. R-1016. Testing and Research Division, Michigan Department of Transportation, August 1976.

This report describes the pavement construction on an experimental portion of freeway on relocated US 10 northwest of Claire, MI. The project was constructed to evaluate the performance of short slab, unreinforced pavement placed on conventional base, on a porous bituminous drainage blanket, and on a bituminous stabilized base.

There have been some difficulties in constructing continuously reinforced pavements with slipform equipment, and there are indications of rebar corrosion in this type of pavement built with slag aggregate. Although exiting pavement of this type have performed well, the above mentioned problems have led to reconsideration of rigid pavement design for areas of relatively light commercial traffic. Concrete pavements that require less steel and/or those that can be built at lower costs are to be evaluated. The purpose of this study is to obtain relative performance information on several alternate pavement designs.

***Durability of "Early-Opening-to-Traffic" Portland Cement Concrete for Pavement Rehabilitation*. NCHRP 18-04B Working Plan. Michigan Technological University, Houghton, April 11, 2000**.

The study objective is to develop guidelines for materials, mixtures, and construction techniques to obtain long-term durability of early-opening-to-traffic Portland cement concrete for pavement rehabilitation. The study is to focus on two types of EOT PCC mixtures: Those that are suited for opening to traffic within 6 to 8 hours after placement and those that can be opened to traffic within 20 to 24 hours of placement. Further, the study is limited to full-depth rehabilitation that includes full-depth repair and slab replacement.

Eacker, M. J. *Whitetopping Project on M-46 Between Carsonville and Port Sanilac.* Research Report No. R-1387. Construction and Technology Division, Michigan Department of Transportation, October 2000.

Adjacent to the whitetopping (from Carsonville to the whitetopping) a bituminous project was built, which consisted of three standard fixes: milling and resurfacing; overlay only; and a crush and shape with overlay. The performances of these fixes will be compared to the whitetopping project to judge long term cost effectiveness.

This report summarizes the construction of both projects of thin and ultra-thin concrete overlays (a.k.a. whitetopping) on M-46 between Carsonville and Port Sanilac. This is the first whitetopping project constructed in Michigan by the Michigan DOT. The purpose of this trial project is to study whitetopping as an alternative to our standard bituminous fixes for rehabilitating deteriorated bituminous pavements. A project to the west of the whitetopping project was constructed using several of MDOT's standard bituminous methods.

Construction went per plan with no significant changes to report for either fix type. The only deviation fro plan was thickness of the whitetopping sections. The 150 mm proposed sections were paved at 203 mm (average of 15 cores), and the proposed 75 mm inlay was paved at 106 mm (average of 3 cores). The increase was due to necessary grade and crown correction.

Eacker, M. J., and A. R. Bennett. *Evaluation of Various Concrete Pavement Joint Sealants.* Research Report No. R-1376. Construction and Technology Division, Michigan Department of Transportation, May 2000.

A test section of pourable sealants was placed on reconstructed I-94 between Watervliet and Hartford in the fall of 1994. Five sealants, Dow 888 and 890SL, Sikaflex 15LM and 1CSL, and Crafco Roadsaver SL, were each used to seal 60 contraction joints. Preformed neoprene, Michigan's standard sealant, was used on the remainder of the job. The sealants were visually evaluated and rated twice a year for three and a half years. Sikaflex 1CSL performed the best of the pourable sealants. It had the best sealing rating after 44 months and the failures it did have were small. It was followed by Dow890SL, which also had small failures but more than Sikaflex 1CSL, and Sikaflex 15LM. Crafco Roadsaver SL and Dow 888 both performed poorly. Crafco Roadsaver SL had a mixture of small to moderate failures about half of which were cohesive. Dow 888 had many large failures including a handful of joints where the sealant is completely missing. The Preformed Neoprene performed better than any of the pourable sealants. It is in the same condition as when it was first placed. Weathering is not a problem with any of the sealants. Debris intrusion is a function of the sealing. With more sealant failures more debris can enter the joint reservoir.

Preformed neoprene should remain the standard sealant when sealing contraction joints in new concrete pavements. Silicones and polyurethanes should not be used as a joint sealant for new pavements

Felter, R. L. Concrete Pavement Cracking, Interim Report. (Memorandum) Research Report No. R-1198. Michigan Department of Transportation, June 29, 1982.

This project was established in 1978 to evaluate the effectiveness of cracking concrete pavement, prior to placing a bituminous overlay, to reduce reelection cracking in the overlay. An inspection party visited the three US 2 projects in March of 1982. Most cracking started near an outside edge of a pavement lane and proceeded across the pavement in one direction and across the adjacent shoulder in the other. The existing aggregate shoulders and 3 ft bituminous ribbon were left in place along one side during construction. It was felt that the crack in the shoulder material extending out from the joints was instrumental in initiating the reflection cracks. A bituminous acceleration ramp was left in place in one location with the existing cracks initiating reflection cracks in the overlay. It was also felt that the reinforcing steel in these projects may be encouraging the slabs to remain intact and diminishing the effectiveness of the pavement cracking.

Hansen, W., A. Definis, E. A. Jensen, P. H. Mohr, C.R.Byrum, G. Grove, T.J. Van Dam, and M. Wachholz. *Investigation of Transverse Cracking on Michigan PCC Pavements over Open-Graded Drainage Courses*. Research Report RC-1401. University of Michigan, Ann Arbor, November 1998.

Some OGDC projects have developed premature transverse cracking with associated spalling and faulting. The objective of this project was to investigate these projects to determine the cause(s) of the cracking and the relationships, if any, the cracking may have with the OGDC base layer.

Field measurements were used to quantify the amounts of transverse cracking and spalling for each project. The results were plotted vs. pavement age. In general, both distress types follow unexpected trends over time with very little, if any, spalling development during the first ten years. These results corroborate MDOT findings using PMS performance data that indicates there is no premature deterioration of OGDC pavements compared to pavements constructed on dense-graded bases. However some pavements have developed severe spalling and faulting after 13 years. The most plausible reasons for the associated distress were trapped water in the subbases/subgrade and clogged outlet drains. No evidence was found that indicates the OGDC by itself was a major contributor to the observed severe distress.

The results from this study suggest that improvements in both construction and in the concrete mix are needed. Given that MDOT is moving towards JPCP as it's standard pavement type, premature mid-slab cracking and spalling must be avoided. High PCC placement temperatures (>80 degrees), especially during morning hours on hot summer days, should be avoided as premature transverse cracking can be expected. Nighttime paving would help reduce this problem.

Hansen, W. and E.A. Jensen. *Transverse Crack Propagation of JPCP as Related to PCC Toughness.* Research Report RC-1404. University of Michigan, Ann Arbor, August 2001.

The Main purpose of this project was to improve the aggregate interlock k property in jointed plain concrete pavement (JPCP) containing a midslab transverse crack, and to improve concrete resistance to cracking from mechanical loading effects. The aggregate interlock property of a transverse crack was studied using large-scale test frame supporting 3.0 m long by 1.8 m wide by 250 mm thick JPCP slab resisting on a typical MDOT highway foundation. A total of 7 JPCP slabs, 96 large beams, and 243 cylinders were tested I this study. The different slab concretes were supplied from ready-mix plants using MDOT mix proportions. Seven concrete mixes containing different coarse aggregate types and sizes were tested at different ages to evaluate their resistance to cracking.

Major findings:

- Aggregate interlock properties of a cracked PCC slab can be greatly improved if the concrete contains strong coarse aggregate, which provide a rough-textured crack surface that provides a "ball and socket" effect due to the may protruding and intact aggregates.
- Strong coarse aggregates also provide a greater resistance to crack propagation. Improvements of about 35% were gained for concretes with similar strength, but containing different coarse aggregate types.
- Concrete slabs, irrespective of aggregate type, were found to be crack sensitive, which is in accordance with established factory theory. Once partially cracked the remaining tensile resistance was s far below that expected from strength theory using remaining cross-sectional area. It is therefore important to repair cracked slabs, as the fatigue life is expected to be reduced.

Hansen, W., and T. J. Van Dam. ***Premature Deterioration in Michigan Jointed Concrete Pavements on Open Graded Drainage Courses*****. University of Michigan, Ann Arbor and Michigan Technological University, Houghton, November 11, 1997**.

Approximately 10% of the projects that have been constructed with the new OGDC materials have been developing various distresses at relatively high rates over time. The distresses observe have typically consisted of premature transverse cracking, and slightly accelerated faulting and spalling. This premature development of distress has related in the initiation of this study to investigate the factors that may be causing them.

Holbrook, L.F., and W.H. Kuo. ***General Evaluation of Current Concrete Pavement Performance in Michigan; Jointed Concrete Pavement Deterioration Considered as a Probability Process.*** **Research Report No. R-905. Testing and Research Division, Michigan Department of Transportation, March 1974.**

A large variety of techniques were used to measure and predict jointed concrete pavement structural performance for 128 projects with up to 15 years of performance history. Factor analyses, a statistical method designed to group correlated performance variables such as spalls, cracks, corner breaks, etc., into a smaller number of clusters thereby simplifying analyses, reduced 19 field survey performance variables to 14. This reduction was not considered sufficient to warrant further analysis with casual variables, nor to provide a generalized measure of pavement performance. Thus, the expectation that survey variables could be combined into one or two indices of performance was abandoned.

It was decided to explore pavement performance with selected performance variables found to have a high frequency of occurrence in the pavement condition surveys. Transverse cracking was chosen as the subject of five pilot performance models that were designed to predict crack incidence probability for any point in time up to 15 years of service. The Markov chain approach gave the best correlations with field data and thus was generalized into a form suitable not only for transverse cracking, but joint performance as well.

Because blowups are a serious hazard and maintenance problem, this state of joint deterioration was singled out for special analysis. In particular, 5 and 10-year survey data, together with crude information on coarse aggregate composition , were used to predict future blowup occurrence.

We recommend that the 5-year condition survey be eliminated in favor of a 7, 8, or even 10-year survey. Also, careful attention should be given to acceptance testing programs designed for coarse aggregate pits known to contain gravel-lime-stone mixes in roughly a 50/50 proportion. Early survey information should be used to estimate future joint performance. If this is facilitated with models developed in this report, good estimates can be made of 15-year performance. This same performance estimation program is used to focus attention on problem projects so that additional condition surveys can be made. Future research on pavement performance takes account of our favorable findings with the continuous time Markov chain. Future research with this model should make use of more than four states; perhaps 10 states, including a zero-percent deterioration state.

Karaca, H., I. O. Yaman, and H. Aktan. ***Evaluation of Concrete Permeability by Ultrasonic Testing Techniques, Phase III, Final Report.*** **Repot No. RC-1403. Civil Engineering Department, Wayne State University, Detroit, MI, May 2000.**

The development and verification of a non-destructive test for early age assessment of concrete bridge deck durability is described. The test is based on ultrasonic pulse velocity (UPV) of longitudinal waves measured on field concrete and compared to measurements made on standard specimens. The basis of the test is the theoretical relationship established between UPV and concrete permeability. The theoretical relationship was confirmed by developing and empirical relationship between UPV and permeability obtained from absorption, air permeability, and rapid chloride permeability measurements conducted on specimens made from a series of concrete grades. The test has potential implementation in the quality control and quality assurances (QC/QA) specifications level II field tests for measurements of performance parameters. The test is also being promoted for intelligent health monitoring of infrastructure concrete, for example, in timing the positive maintenance interventions. The intelligent monitoring procedure is quantified by a parameter called paste quality loss (PQL), where the standard concrete specimens made from field concrete mixture are utilized as reference measures. The verification tests are conducted on six 1000mm x 1500 mm x 230 mm lab-deck specimens representing portions of a R/C bridge deck. The measurements on the lab deck specimens indicated that the PQL parameter computed from the UPV measurements as early as the 28th day is a good predictor of soundness. The UPV measurements are also performed on the 7th, 14th, and 90th days. The UPV measurements made at increasing age of concrete very clearly document the rapid loss of soundness of improperly cured concrete decks. Moreover, tests are also performed on two actual bridge decks to test the efficiency of the UPV measurement procedure.

The methods and procedures developed during this research are specifically calibrated for concrete bridge deck durability assessment starting at an early age. Potential uses for these techniques are, first in the QC/QA specification level II field tests of performance parameters and, second in timing the positive maintenance interventions for intelligent health monitoring. Future research should deal with developing relations between UPV and concrete performance.

Khazanovich, L., N. Buch, and A. Gotlif. *Evaluation of Alignment Tolerances for Dowel Bars and Their Effects on Joint Performance.* Research Report RC-1395. Pavement Research Center of Excellence, Michigan State University, East Lansing. June 2001.

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 both 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-level 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.

To verify the finite element models developed in this study and to provide proper inputs to them, the following laboratory test are recommended:

1. Modified pullout test
2. Combined pullout/bending test
3. 3Generalized pullout test

Muethel, R. W. *Calcium Carbonate Precipitate from Crushed Concrete.* Research Report No. R-1297. Materials and Technology Division, Michigan Department of Transportation, March 1989.

Inspections of geotextile-wrapped drainage system installations have revealed that geotextile filters can become coated with a calcium carbonate precipitate which has been found to occur when leachable calcium compounds are present in the drainage course aggregates. Laboratory tests for calcium carbonate precipitation have identified crushed Portland cement concrete as an aggregate that will produce heavy calcium carbonate deposits when crushed to fine aggregate size. Tests for calcium carbonate precipitation have indicated that aggregates such as gravel, crushed stone, and blast furnace slag do not produce heavy calcium carbonate deposits when crushed to fine aggregate size.

This investigation was established to determine the comparative amount of calcium carbonate precipitate, which would be produced by crushed concrete 5G open-graded drainage coarse, an aggregate which contains predominantly coarse sized particles. In addition to the crushed concrete, samples of gravel, crushed stone, and blast furnace slag were tested as control aggregates representing three major types of material available for drainage courses.

The calcium carbonate precipitation tests and pH measurements indicated that crushed concrete fines passing No. 4 can produce heavy calcium carbonate precipitates, and that coarser material has the potential for producing continued calcium carbonate deposition. The leaching tests produced calcium carbonate precipitation on the larger crushed concrete particles but considerably less precipitation of discreet calcium carbonate deposits in the leachates during the three-week test periods. No calcium carbonate precipitation resulted form the soak tests conducted on the gravel and crushed stone control aggregates. A negligible amount of calcium carbonate precipitation was formed by the blast furnace slag control aggregate.

Leaching of the calcium hydroxide component of concrete may be a significant contributor to the deterioration of pavements at joints. This process has received little attention and should be investigated.

Recommendations:

1. Due to the high potential for heavy calcium carbonate precipitation, crushed concrete fines passing the No. 4 sieve should not be used in conjunction with drainage systems containing geotextile filter fabrics.
2. The use of crushed concrete for 5G open-graded drainage course should be limited to installations where drainage gradients are adequate to prevent stagnant water conditions that would promote long-term calcium carbonate build-up on perforated conduits resulting in the progressive impairment of drainage.
3. The process of calcium hydroxide depletion due to long-term acid leaching should be investigated as a contributor to the deterioration of pavements at joints and cracks where continued chemical activity is likely to occur.

Muethel, R. W. *Development of Test for Calcium Carbonate Precipitation in Aggregate.* Research Report No. R-1286. Materials and Technology Division, Michigan Department of Transportation, October 1987.

Inspections of prefabricated drainage system (PDS) installations have revealed calcium carbonate deposits plugging geotextile filters. The deposits have occurred in systems using steel furnace slag as open graded drainage course (OGDC). The findings resulted in a Departmental moratorium on the use of steel furnace slag in PDS installations. This project was established to develop a laboratory test to identify aggregates that would produce carbonate deposits in drainage installations.

Selected aggregates including steel furnace slag, blast furnace slag, crushed Portland cement concrete (PCC), crushed limestone, and crushed dolomite were tested using the laboratory procedure. The steel furnace slag and crushed concrete aggregates produced heavy carbonate deposits. No deposits formed from the blast furnace slags, limestone, or dolomite.

Muethel, R. W. *Freeze-Thaw Evaluation of Selected Rock Types From a Composite Sample of Michigan Gravel.* Research Report No. R-1301. Materials and Technology Division, Michigan Department of Transportation, August 1989.

The glacial gravels of Michigan contain a mixture of durable and non-durable rock types. Twenty-four rock types sorted from glacial gravel obtained from 49 selected sources were subjected to the standard MDOT Laboratory acceptance tests for aggregates, including those for freeze-thaw durability, abrasion loss, and sulfate soundness loss. Additional information was obtained form specific gravity, absorption, and Iowa Pore Index determinations.

Results of the laboratory tests supported the MDOT classification. The deleterious rock types showed low freeze-thaw durability in concrete; the durable rock types showed high durability. The durable rock types exhibited no ill effects form vacuum saturation pre-treatment for freeze-thaw testing. Most of the deleterious rock types displayed undesirable pore characteristics similar to the D-cracking carbonates investigated in Iowa. The deleterious rock types also recorded lower specific gravities and higher absorptions that the durable rock types indicating that heavy media separation can remove most of the deleterious rock types from Michigan glacial gravels. The carbonate rock constituents including possible D-cracking particles were not evaluated, but will be investigated in a separate study.

Novak, E. C. Jr. *Infiltration of Subbase Sand Into Open Graded Drainage Course (OGDC) Bases.* Research Report R-1211. Testing and Research Division, Michigan Department of Transportation, April 1983.

This abbreviated study was conducted to determine if open graded drainage course material (OGDC) bases could be expected to perform satisfactorily when placed directly on sand subbase and to evaluate the effectiveness of filter fabric for improving performance when placed between OGDC base and subbase layers. Both rigid and flexible pavements were to be considered in the study. However, much of the information obtained is not specific enough to offer definite conclusions at this time. Also, the effect that a subbase frost action might have on settlement of the pavement surface could not be established.

The results of this study show that unless a filter fabric separates base and subbase layers, sand will infiltrate into voids of OGDC bases. The degree to which sand infiltration takes place will govern the performance of OGDC bases and ultimately influence pavement surface performance. Based on results of this study and presumed environmental effects, the following conclusions regarding the performance of OGDC bases appear to be warranted. On rigid pavements, a layer of filter fabric between OGDC and subbase layers should ensure good performance of OGDC bases under any subbase condition. OGDC bases should perform satisfactorily when placed directly on a sand subbase when the subgrade permeability is equal to or greater than the subbase. OGDC bases may or may not perform satisfactorily when placed on a sand subbase layer subject to a loss of density.

Oehler, L. T. Salt Degradation Study (Memorandum). Research Report R-1100. Michigan Department of Transportation, November 29, 1978.

This report contains some statistics obtained from data sent to the MDOT in November 1978. The average salt gradations of 30 samples of variance program was used to analyze the data. A table lists the analyses of the thirty samples that were taken from a salt shipment.

Opland, W.H., and V.T. Barnhart. *Evaluation of the URETEK Method for Pavement Understanding.* Research Report No. R-1340. Materials and Technology Division, Michigan Department of Transportation, August 1995.

This project was initiated in 1993 to evaluate the use of URETEK 486 high density polyurethane as a method of raising and undersealing concrete pavement slabs. Three sites were selected on I-75 (truck lane) in Monroe County for test and control sections. The pavement consists of 10-11 in. reinforced concrete on an open-graded base.

The URETEK method is a patented process that was originally developed in Europe. In 1975, the URETEK Company developed special high-density polyurethane for its undersealing compound, which distinguishes it form typical grouting mixtures used in mud-jacking operations.

The URETEK method improved the base support where the pavement was severely cracked. However, where the cracks were either hairline or open1/8 in. or less, there was little improvement in the base support. Where the pavement was severely faulted, the URETEK did raise the pavement and provided a temporary increase in base stability. The URTEK method had some insulating effect of the base that caused differential frost heaving when the adjacent lane was not similarly undersealed. As expected, the depth of the penetration of the URETEK into open graded drainage course (OGDC) was dependent on the gradation (porosity) of the OGDC. There was no intrusion of the URETEK into any portion of the open-graded underdrained system. While base support was initially improved, the base support decreased somewhat during the one-year trial period. Therefore, more evaluation is needed to determine if URETEK is an effective method of undersealing and raising pavements supported on open-graded drainage courses.

It is recommended that URETEK not be used as a substitute for mud jacking for pavements with open-graded bases. However, additional limited testing is warranted to gain further experience and knowledge about the materials limitations and capabilities. At this time, URETEK should only be considered as an alternate to mud jacking on pavements with dense-graded aggregate bases.

Peterson, K. R., T. Van Dam, and L. L. Sutter. ***Assessment of the Cause of Deterioration on US-23 South of Flint, Michigan*****. Draft Technical Report. Michigan Tech Transportation Institute, Michigan Tech Civil & Environmental Engineering Department, January 7, 2002.**

Sections of US-23 south of Flint are suffering extensive map cracking and joint deterioration in spite of the fact that they were constructed only nine and a half years ago in 1992. An adjacent section constructed the following year using comparable design features and materials remained in good condition with little sign of visual distress. Eighteen cores were taken, nine from the mix design used in 1992 and nine from 1993. Based on the results of this study the following conclusions can be drawn. Most of the concrete initially had an air-void system that was adequate to protect the paste against freeze-thaw damage. Since construction, the air-voids have been filling with secondary mineral sulfate deposits, which may be compromising the air-void efficiency. Also, the chert particles in the fine aggregate are undergoing a deleterious alkali-silica reaction in all of the “poor” pavement sections. The total alkalis measured were in excess of that recommended for mild alkali-silica reactivity protection. The poorest performing section had a sulfate content that was 30% in excess of what would be expected based on the mixture design alone. Two hypotheses have emerged that can partially explain the deterioration. The first centers on the alkali-silica reactivity of the chert particles in the fine aggregate, which is aggravated by the high total alkalinity and mitigated by the presence of Class F fly ash. The second focuses on the dissolution of the calcium sulfide and the formation of sulfate-bearing mineral, which results in a type of internal sulfate attack.

The permeability of concrete made with slag concrete needs to be conclusively and authoritatively documented. Also, a well-designed factorial experiment needs to be conducted to evaluate both the ASR and Calcium sulfide dissolution issues, and the interaction between the two.

Portland Cement Concrete Pavement Mixture for I-75 Demonstration Project; Special Provision. Michigan Department of Transportation, May 9, 2003.

This special provision sets forth requirements for furnishing Portland cement concrete mixtures for mainline, shoulder, and misc. pavement applications. The Contractor does not have the option of using other concrete Grades or Types in lieu of the concrete mixtures described in this special provision. The prescribed materials include aggregates, cementitious materials, and concrete mixture requirements. Construction methods and measurement and payment are also discussed.

Portland Cement Concrete Grade P1 (Modified); Special Provision. Michigan Department of Transportation, August 27, 2003.

This special provision sets forth requirements for furnishing Portland cement concrete mixtures for mainline, shoulder, and misc. pavement applications. The Contractor does not have the option of using other concrete Grades or Types in lieu of the concrete mixtures described in this special provision. The prescribed materials include aggregates, cementitious materials, and concrete mixture requirements. Construction methods and measurement and payment are also discussed.

Simonsen, J. E., and A. W. Price. ***Improved Joint Sealant Materials for Concrete Pavements; Construction Report*****. Research Report No. R-1259. Testing and Research Division, Michigan Department of Transportation, February 1985**.

This initial evaluation report contains general project and cost information concerning a low-modulus silicone sealant (Dow Corning Silicone 888) and a preformed neoprene sealant used in mainline joints on two new concrete pavement projects in I 69 west of Port Huron. An evaluation plan, cross sections of the two joint types, location sketch, and special provisions covering the silicone sealant are included.

Simonsen, J. E., and A. W. Price. ***PCC Pavement Joint Restoration and Rehabilitation; Final Report*****. Research Report No. R-1298. Materials and Technology Division, Michigan Department of Transportation, June 1989**.

The objective of this project was to develop a joint repair detail that would function properly for a 10-year period. It was required that the repair be opened to traffic within eight hours and its construction would be adaptable to mass production techniques. Laboratory studies were conducted that led to the development of mechanized drilling of horizontal holes in the end faces of the existing slab. To obtain adequate 8-hour concrete strength a nine-sack concrete mix accelerated with calcium chloride was used. The developed techniques and materials were field-tested. The experimental repairs utilizing step-cut tied joints proved successful. Ten loose fitting dowels were used in repair joints, which had performed satisfactorily in the past. The experimental repairs using step-cut tied end joints performed well, but those installed under contract did not. The failures occurred in the epoxy-grouted portion of the tie bars. The performance of loose fitting doweled joints depends on good base support, properly sized dowel holes, exact matching of the new concrete surface to the elevation of the existing pavements, and good durability and abrasion characteristics of the aggregate used in the concrete pavement to be repaired.

It is concluded that when properly constructed, loose fitting doweled joints will provide several years of service without excessive faulting. They should only be used on pavements 15 years old or older. On newer pavements and pavement with low abrasion value aggregates, the use of epoxy grout for fastening the dowel is recommended.

Simonsen, J. E., and A. W. Price. ***Performance Evaluation of Concrete Pavement Overlays; Construction Report*****. Research Report No. R-1262. Materials and Technology Division, Michigan Department of Transportation, May 1985**.

With a large portion of the concrete highway system in need of major rehabilitation work, a renewed interest in concrete overlays has surfaced as a possible alternate to recycling the existing pavement. During 1984, the Department constructed two concrete overlays for the purpose of evaluating their performance compared to recycled pavement and to compare the long-term cost effectiveness of the two rehabilitation systems. Also, the use of a thin sand-asphalt layer as a bond-breaker between the existing concrete surface and the new overlay would be evaluated with respect to controlling reflective cracking in the concrete overlay.

Simonsen, J. E., and A. W. Price. ***Performance Evaluation of Concrete Pavement Overlays; Final Report*****. Research Report No. R-1303. Materials and Technology Division, Michigan Department of Transportation, December 1989.**

Concrete overlays were a common method used by the MDOT to rehabilitate deteriorated roads. 21 overlays, from 4 – 6 inches, were placed between 1932 to 1954. All of these were of the unbonded type with a bituminous coat used as the separation medium. One overlay is still in service after 35 years. Now with the Interstate and other routes needing rehabilitation or reconstruction, the concrete overlay has again emerged as an alternative to total reconstruction. The newer overlays are thicker, 6 –13 inches and normally of the unbonded type. Two 7 inch reinforced, unbonded, and dowelled concrete overlays were constructed in 1984.

Observations, measurements, and examinations of cores, and load tests indicate that the overall performance of the 1984 overlays to date have been satisfactory. It is estimated that using an overly instead of recycling will result in at least a $35,000 savings per mile of two-lane pavement. Field and laboratory data indicate that overlays will have a favorable life cycle cost compared to recycled pavements. Based on the performance of the two overlays, it is concluded that concrete overlays are a viable alternative to recycling when the existing facility can accommodate the extra overlay thickness.

It is recommended that careful consideration be given during the design process to the condition of the existing pavement and to the volume of commercial traffic the overlay will carry. It is also recommended that severely deteriorated and patched areas in the existing pavement be repaired to minimize failure in the overlay at these locations. It is recommended that consideration be given to improve the effectiveness of the debonding layer.

Simonsen, J. E., and A. W. Price. ***Restoration and Preventive Maintenance of Concrete Pavements.*** **Research Report R-1267. Materials and Technology Division, Michigan Department of Transportation, October 1985.**

In 1976 the MDOT began a study aimed at developing a preventive maintenance program for reinforced concrete pavements having neoprene sealed transverse joints. The developed procedures were to be such that traffic could be maintained throughout the repair are and compatibles with daylight lane closures. The procedures applied involved the use of five fast-set patching materials for joint groove spall repairs, removing damaged or malfunctioning contraction joint seals and resealing with new neoprene seals, and removing tight and frayed neoprene expansion joint seals, resawing the joint groove, and resealing the joint with either a liquid sealant or a neoprene seal. Early cracking and bond failure in repairs during the first few months service appear to be related to errors in proportioning and placing the material rather than to traffic load.

It is concluded that restoring concrete pavements using the techniques employed is feasible provided the pavement contains high quality aggregates and major base problems are not present. Recommendations for future restoration projects suggest that the possibility of overnight lane closures be considered as a means of reducing cost and to allow use of patching materials less sensitive to construction problems than the current fast set materials. It is also recommended that the MDOT adopt the restoration techniques and a standard preventive maintenance program for our new concrete pavements as well as recycled and overlaid ones.

Simonsen, J. E., and E. C. Novak, Jr. ***Concrete Pavement Performance Problems and Foundation Investigation of I 75 from the Ohio Line Northerly to the Huron River.*** **Research Report No. R-1171. Testing and Research Division, Michigan Department of Transportation, June 1981**

These data indicate that the installation for subbase underdrains may be beneficial in removing gravity drainable water from subbase and side slope areas in those cases where the subbase materials contain gravity drainable water. Such drains could also serve to reduce the tie required for subbase consolidation. However these benefits may not significantly improve the pavements performance for two reasons: 1) the add-on lane is already heavily transverse cracks; 2) faulting is caused by pumping of the base which should be largely unaffected by the presence of a subbase underdrain.

The results of this investigation adds to growing evidence that rigid pavement foundations are not free draining. The foundation on I 75 was found to be deficient in tow critical respects: the base permeability and frost susceptibility is similar to that of silts; and the subbbase has a high water-holding capacity. In the case of rigid pavements, such foundation deficiencies can be minimized by using a greater thickness of concrete than would be used for a non-deficient foundation and buy using reinforcing steel and load transfer devices.

It is recommended that a ‘plowed in’ retrofit subbase underdrain be installed to improve foundation drainage conditions. The repair of distressed areas should be made after placement of retrofit underdrains and within two weeks after the pavement had been sawed into removable slabs.

Simonsen, J. E., F. J. Bashore, and A. W. Price. ***PCC Pavement Joint Restoration and Rehabilitation; Construction Report*****. Research Report No. R-1179. Testing and Research Division, Michigan Department of Transportation, August 1981.**

The objective of this project is to develop a tied joint for use between existing and new concrete pavement slabs that can be constructed rapidly without extensive hand labor, which when used in conjunction with a dowelled joint in the repair center will provide necessary load transfer and eliminate faulting.

On the basis of this study, it is concluded that the use of tied joints constructed by grouting tie bars into drilled holes in the existing concrete is a practical way of preventing faulting of repair slabs. The time required to drill the holes is less than half the time it takes two men to save the steel for tying into an existing slab. It is estimated that the tied joints should give satisfactory performance for at least ten years. And will add slightly to the cost of the lane repair.

Simonsen, J. E., F. J. Bashore and A. W. Price. *PCC Pavement Joints Restoration and Rehabilitation.* Research Report R-1235. Testing and Research Division, Michigan Department of Transportation, November 1983.

In 1968, the MDOT initiated an experimental project to develop repairs for concrete pavements that could be opened to traffic the same day they were placed and also maintain their structural integrity for a number of years. The result was the use of precast concrete slabs as a standard repair method during 1972 and most of 1973. From 1974 until 1982, cast-in-place repairs using undoweled joints were used on all repair projects during this period. Doweled joints were not used because they were labor intensive and time consuming to place. The use of undoweled repairs was intended as an interim method to maintain the pavements until overlaying or reconstruction. However, overlaying was postponed so many of the undoweled repairs have served well beyond their intended life and some of the slabs had tilted.

Better repair methods were needed to lengthen service life of concrete pavements. In 1979, the MDOT began testing of constructing a non-tilting joint between new and old concrete. The process of constructing the repair joint would need to be mechanized. It was determined that horizontal dowel holes could be machine drilled into the hardened concrete slab quickly. Several other tied joints, utilizing deformed bars, mortared into the drilled holes with epoxy were tested. The most promising of these were the results of field tests indicated that tied joints could be constructed without much difficulty. Repairs constructed by installing dowels in drilled holes and those having tied end joints with a doweled expansion joint in the center were done. Tied joints performed satisfactorily, but failures developed which were determined to be caused by misproportioning of the epoxy binder. The MDOT is now using doweled joints exclusively. Ten dowels, 1-5/16-in. diameter, are inserted in 1-3/8-in. machine drilled holes. Expansion joints are constructed by placing a compressible filler material over the dowels and against the existing concrete end face.

Smiley, D. L. *First Year Performance of the European Concrete Pavement on Northbound I-75 – Detroit, Michigan*. Research Report R-1338. Materials and Technology Division, Michigan Department of Transportation, February 1995.

This report describes the performance of the I-75 European concrete pavement reconstruction project approximately one year after construction. The experimental features of the pavement design were assimilated from designs used in Germany and Austria.

The objective of this project is to determine whether innovative features of typical rigid pavement designs used in European countries can be applied cost effectively to conventional designs and construction methods used for rigid pavement in the United States. Two concerns that currently prohibit their use in American designs are: (1) their relatively high initial costs and (2) their unknown effect of life cycle costs over the pavement's service life.

European pavement appears to be performing as expected, except for the disappointing results pertaining to the exposed aggregate surface as a means to reduce traffic noise levels. Specific points of interest about the project are summarized as follows: No surface distress features have developed on the European pavement. The EPDM joint seals art performing satisfactorily. The exposed aggregate surface appears to have lost macro-texture in the two inner lanes of northbound I-75. Surface friction numbers increased and the exposed aggregate surface provides only a slight reduction in exterior Leq noise levels.

Staton, J. F. *Construction and Performance Monitoring of Hinged Joint Pavement, I-94.* Research Project No. 95 TI-1790. Materials and Technology Division Project Assignment Form, October 1995.

The objective of this technical investigation was to monitor the long-term performance of the hinged-joint pavement test section on eastbound I-94, south of Benton Harbor, constructed in 1995.

Several cycles of field monitoring were performed, including crack survey and joint movement measurements.

This project indicates that the overall performance of the pavement test section is not associated with the particular joint detail exhibited by the hinge-joint. Any localized failures found within the test section were also found in areas outside of the test section. These distresses were determined to be related to excessive plastic and drying shrinkage cracks in the concrete as a result of the highly absorptive blast-furnace slag aggregate.

Staton, J. F. Investigation of Low 28-Day Strength of Portland Cement Concrete (PCC) (Memorandum). Michigan Department of Transportation, December 13, 1995.

The subject research project was established to investigate reports as to the causes of low 28-day compressive strengths of PCC for construction projects from the 1994 and 1995 construction season. The problems related to low compressive strength appear to be a result of variability in quality control during the cement manufacturing process. The outcome of several discussion with industry was that high levels of quality control during manufacturing, along with continuous improvements in the consistency of raw materials, has minimized the probability that the product is responsible for the strength deficiencies of the concrete. The MDOT staff is not thoroughly convinced of that fact, however.

Staton, J. F. Investigation of PCC Pavement Using Ground Granulated Blast Furnace Slag (Memorandum). Michigan Department of Transportation, September 18, 1995.

The subject technical investigation was established to conduct a short-term study regarding incorporation of ground granulated blast furnace slag (GGBFS) as a partial substitute for Type I Portland cement in concrete pavements. It was determined that this pozzolanic material may provide beneficial properties related to long term performance of PCC pavements, such as an overall decrease in the permeability of the concrete. Also, less initial heat is developed in the concrete reducing early age internal concrete stresses due to excessive heat. Our study indicates that 40% substitution by weight of Type I Portland cement with grade 100 minimum GGBFS would be optimum for application for PCC pavements. The predominant lack of usage of GGBFS has been due to economic deficiencies in shipping and storage, resulting in excessive material handling expense.

Staton, J. F. and A. R Bennett. *Performance Evaluation of Concrete Pavement Overlays to Reduce Reflective Cracking*. Research Project 90 F-168. Michigan Department of Transportation, 1990.

Two methods that were being studied at the time of inception of this research project were 1) recycling the existing slab and 2) overlaying the existing concrete with bituminous concrete. The initial cost of recycling a pavement is relatively high and has since been discontinued as an alternative for reconstruction in Michigan due to its suspected poor performance. Overlaying with bituminous concrete has not been totally satisfactory due to reflective cracking in the overlay.

Two types of PCC overlays were constructed on this project. One overly was a bonded type placed directly over the existing PCC pavement after rubblizing. The second PCC overlay was constructed as an unbonded type by placing a bituminous-sand mix layer on the existing PCC pavement surface before overlaying with the PCC. The rubblized and unbonded overlay area were subdivided into three sections incorporating different subbase drainage techniques to study effects of drainage on pavement performance.

Staton, J. F., and J. D. Anderson. *Laboratory Evaluation of High Durability Pavement (HDP) Concrete Mix Design*. Research Project 94TI-1736. Michigan Department of Transportation, June 1996.

During early 1995, The Materials Research Group embarked on a mission to develop a Portland cement concrete mix design for use in high durability pavements (HDP). Pavement concretes of this type may be used for applications where high anticipated future traffic volumes warrant special pavement design considerations. The expected payoff by taking this foresight approach would be reduced long-term maintenance costs, reflecting lower life-cycle costs represented by actual costs attributed to repairs, as well as additional indirect savings in terms of user delay costs.

This laboratory investigation shows that utilizing the largest practical top-size coarse aggregate in a Portland cement concrete mixture is an important component for producing a highly durable cost efficient concrete pavement. The HDP mix design included in this study show that utilizing a 50.0 mm (2-inch) top-size coarse aggregate does enhance the strength characteristics of the concrete. This study also shows that high quality, larger top-size coarse aggregate in the concrete mixture should produce greater aggregate interlock across a pavement crack interface.

Udegbunam, O., I. O. Yaman, and H. Aktan. *Evaluation of Concrete Permeability by Ultrasonic Testing Techniques, Phase I, Final Report.* Report No. RC-1403. Wayne State University, Detroit, MI, March 1998.

The overall goal of this research is to provide a measure for the durability of concrete bridge decks. Quantification of concrete durability is essential if durability requirements are to be included in quality assurance and quality control (QA/QC) specifications. A significant parameter of concrete deck durability is related to its permeability.

Selected literature regarding concrete pore structure characteristics, specifically porosity and pore size, is reviewed. The influence of these characteristics on the elastic properties of concrete is also reviewed. An expression that relates permeability and ultrasonic pulse velocity (UPV) is formulated. An experimental program is established and conducted to verify the relation between concrete permeability and UPV. Five groups of specimens corresponding to different water-cement ratios (w/c) were cast and were tested for permeability and UPV at the age of 28 days. The permeability tests were made in accordance with AASHTO T 277, “Rapid Test for Permeability to Chloride Ions,” and AASHTO T 259, “Chloride Ion Penetration.” The relationship between permeability and UPV is defined and the statistical significance is shown. The results show a measurable relationship between permeability and UPV in the range of w/c tested.

Van Dam, T., N. Buch, K.R. Peterson, and L.L. Sutter. *A Study of Materials-Related Distress (MRD) in Michigan’s PCC Pavements – Phase 2.* Research Report RC-1425. Michigan Technological University, Houghton, December 2002.

Materials-related distress (MRD) is of concern to the Michigan Department of Transportation, 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.

The hypothesis regarding the dissolution of calcium sulfide should be tested. It is recommended that a controlled laboratory study be initiated to investigate the following: The dissolution process and how it is effected by cement properties and total alkalinity. The relationship between ASR in the chert constituent of the fine aggregate and the presence of slag coarse aggregate. The ability of fly ash and GBFS to mitigate the effects of calcium sulfide dissolution and ASR in the fine aggregate.

The densified paste region characterized by unhydrated cement grains adjacent to the slag particles should be studied to determine its effect, if any, on the observed deterioration. A parametric study of all slag concrete pavements should be conducted using mix design and construction data as well as field inspections. This limited study has found that Class F fly ash might offer a way to improve the durability of concrete made with slag coarse aggregates, whereas Class C fly ash has had an apparently negative impact. A more detailed large-scale study should be implemented to confirm this finding and determine if other variable are also instrumental.

Weinfurter, J. A., D. L. Smiley, and R. D. Till. ***Construction of European Concrete Pavement on Northbound I-75 - Detroit, Michigan*****. Research Report No. R-1333. Materials and Technology Division, Michigan Department of Transportation, September 1994.**

This report describes the design and construction of the experimental pavement reconstruction project on I-75 (Chrysler Freeway) in downtown Detroit, between I-375 and I-94 (Edsel Ford Freeway). The experimental features were assimilated from European pavement designs and incorporated into the plans and specifications of Federal Project IM 75-1(420), Michigan Project IM 82251/30613A. The European pavement was constructed for the purpose of comparing the European with American pavement designs to demonstrate the applicability of certain European concepts to the United States highway system.

The initial saw depth for the longitudinal and transverse joints in the two-layer pavement should be revised. German research has shown that forming plane of weakness joints in the lean concrete base by notching is just as effective as sawing. The notching action pushed aggregate particles to either side to form the plane-of-weakness. The variable spacing of dowel bars in a basket assembly should be oriented such that the spacing between bars actually represents a standard uniform spacing, but with missing bars. This will reduce the fabrication costs for the baskets.

Yaman, I. O., H. Karaca, and H. Aktan. ***Evaluation of Concrete Permeability by Ultrasonic Testing Techniques, Phase IV, Final Report.*** **Report No. RC-1403. Civil Engineering Department, Wayne State University, Detroit, MI, January 2001**

The nondestructive test procedure for the quantification of bridge deck concrete's future durability is based on the fundamental relationship between ultrasonic pulse velocity (UPV) and permeability of an elastic medium. An experimental study using standard concrete cylindrical specimens documented adequate sensitivity between UPV and permeability. The test procedure utilizes a parameter directly proportional to increase in field concrete permeability and called paste quality loss (PQL). The PQL is computed from UPV measurements on standard concrete specimens made from field concrete mixture and measurements of field concrete. Deck replacement projects on three NHS bridges are used as demo sites to implement the test procedure. The respective 56-day PQLs are calculated as 15%, 28% and 9% demonstrating a significant variability in the permeability of the three bridge decks. Field permeability tests are also conducted by Figg's apparatus for comparison purposes. PQL evaluation from post construction measurements proved to be an effective and reliable means of testing the bridge deck's future durability.

The PQL measure developed in this research will be a very useful feedback tool for evaluating the impact of an isolated parameter on durability. Potential use of the durability measure may be for health monitoring of bridge decks for the timing of preventive maintenance procedures. In this implementation, the bridge deck UPV will be measured intermittently. Changes will be documented with the rate of change in UPV, which can be correlated to the deck deterioration rate. A clear model between the UPV changes and deck deterioration can be developed by testing of multiple decks at different levels of deterioration.

Yaman, I. O., O. Udegbunam, and H. Aktan. ***Evaluation of Concrete Permeability by Ultrasonic Testing Techniques, Phase II, Final Report.*** **Department of Civil and Environmental Engineering, Wayne State University, Detroit, MI, May 1999.** The goal of the research presented in this report is to develop a rapid non-destructive permeability test method that can be performed during the early ages of concrete. The proposed test procedure is based on ultrasonic pulse velocity (UPV) methods.

The research is based o the hypotheses that there is a measurable relationship between UPV and permeability. The objectives of this phase are in two categories. One category is the evaluation of the effects of aggregate type, entrained air, and water reducing admixtures on UPV and permeability. The other is the review and resolution of some of the anticipated field implementation problems.

The first proposed study should deal with developing the paste efficiency relation for high performance concrete (HPC) mixtures. The second study should develop guidelines for the utilization of UPV of determining concrete permeability in a manner similar to 7 or 28-day compressive strength of concrete. In that case, both on concrete strength and durability can be documented. A final study should include the development of deterministic mechanistic models for life-cycle cost of concrete bridge decks.

Minnesota

Plan Sheets, General Layout. Project S.P. 3412-60 (T.H. 71), Sheets 2 – 4 of 53. Minnesota Department of Transportation, March 13, 1998.

Plans showing areas of unbonded concrete overlay sections and bituminous overlay sections.

Embacher, R. A., and M. B. Snyder. Refinement and Validation of the Hydraulic Fracture Test. In *Transportation Research Record 1837*, Paper No. 03-4058. TRB, National Research Council, Washington, D.C.

This study was undertaken to improve the Minnesota Department of Transportation's (MnDOT) ability to rapidly evaluate the potential freeze-thaw durability of coarse aggregate sources intended for use in Portland cement concrete (PCC) pavement applications. This was to be accomplished by refining the hydraulic fracture tests (HFT) and validating that apparatus and procedures using Minnesota aggregates. [It is believed that he hydraulic fracture test is now ready for more broad based validation testing and eventual widespread acceptance and implementation as an accurate screening tool for concrete aggregate freeze-thaw durability].

The following conclusions can be drawn from this study: The hydraulic fracture test and data analysis procedure appear to be well correlated with concrete specimen dilation measurements obtained from freeze-thaw testing. This suggests that the modified hydraulic fracture test offers a reliable, relatively rapid alternative to predicting the D-cracking potential of coarse aggregate on properly air-entrained concrete. There is a strong correlation between hydraulic fractures tests outputs and concrete test specimen dilation data obtained from rapid freezing and thawing tests. This links coarse aggregate top size to freeze-thaw durability for potentially non-durable aggregate sources.

More freeze-thaw and hydraulic fracture tests should be performed using the small test chamber on additional aggregate sources. Additional hydraulic fracture testing should be performed using the modified large hydraulic fracture test chamber. Additional tests and research should be performed to verify and determine the nature of the outlier hydraulic fracture test results. Also, additional test and research should be performed to verify and determine the nature of the differences in hydraulic fracture test results obtained using the small and large chambers. Future development research should investigate the way that carbonate aggregate pore properties relate to HFT and freeze-thaw test results.

Materials Performance System; COPES Data. Minnesota Department of Transportation, June 25, 2003.

Shown is data on route 71 from beginning MP 126.26 to End MP 129.32 in Kandiyohi County in Minnesota. The current surface is unbonded overlay-JPCP with a previous surface of JPCP. The joint system, dowels, mix design, drainage, and many other items are detailed.

Rettner, D. L. State of Minnesota Office Memorandum To Roger Skogen from the Office of Materials and Research, Minnesota Department of Transportation, July 21, 1992.

The subject of this memo is concrete mix design test sections on S.P. 5507-47. There was a high rate of low core strength in their concrete pavement. The Concrete Engineering Unit tried two different modified mix designs with different fly ash substitution rates. The test sections were one-mile long sections of each mix design separated with one-mile control section of the standard mix design. Four additional control beams per test section were required so that the concrete strength gain could be better determined.

Attached is the Fly Ash study SP 5507-47, several weekly concrete information reports, concrete test beam data, test reports on concrete cylinders, estimated composition of concrete mixes, concrete batching reports, and plan sheets.

Missouri

Advanced Research of an Image Analysis System for Hardened Concrete. Research Investigation 98-006. Research Development and Technology, Missouri Department of Transportation, March 2003.

Analysis has been routinely conducted for research purposes or to verify the quality of concrete placed in a structure or pavement. The characteristics of the air-void system in concrete, such as void size and spacing, serve as valuable tools in assessing the resistance of concrete to freezing and thawing. Knowledge of the air-void system characteristics can help determine concrete durability and long-term performances.

With testing methods, a human operator must participate to distinguish among the various concrete constituents (air, paste, aggregate). Several researchers have proposed completely automated systems using image analyses to replace the human operator. Though they have several disadvantages, it is felt that the human operator is still needed for the best results. Developing an automated system that would produce results as accurate as human based ones would have great impact for concrete testing and research.

A national pooled fund study is underway for developing and validating an image analyses system for determining the parameters of the air-void system in hardened concrete. MoDOT and NNSA-KCP has developed a prototype image analysis system with a baseline capability of analyzing hardened concrete and determining its air void characteristics. The goal of the pooled fund study is to develop an image analysis system that produces results of equivalent accuracy to a human based linear transverse.

MoDOT Application of Maturity Technology. Research Investigation 93-007. Research Development and Technology, Missouri Department of Transportation, July 2003.

In December 2002, inspectors looked to the concrete maturity method to facilitate reconstruction operations of a structure's northern bents, which was severely impacted in a tractor-trailer accident. The maturity method is recognized as a more reliable and timely method as opposed to testing conventional 6"x12" compressive strength cylinders. Application of the maturity method allowed earlier form removal and completion of the bridge repairs than if concrete cylinders had been used for strength determination. As a result, the bridge was opened to traffic earlier than if conventional methods had been used.

Application of maturity technology can provide an ideal, non-destructive means of facilitation construction operations including sawing pavement joints, coring pavement, opening pavement to traffic, removing formwork, cold and hot-weather concreting, and others. While maturity method is a valuable tool, it does have some limitations. But it has demonstrated itself as a desirable and reliable means of indicating in-situ compressive strength and facilitating construction operations.

Optimized Mix with Chips. James Cape and Sons Company, July 29, 2003.

This was a reference sheet showing weights per cubic yard (saturated, surface dry) of several ingredients of a contractor's optimized PCC mix which was tested on July 25, 2003.

Standard Missouri state mix.

Four different reference sheets are showing the standard PCC mix.

Missouri Department of Transportation. ***Bonded Concrete Overlay (Fast Track) – Route I-70, Cooper County, Final Summary of Performance*****. Report No. RDT 00-002B. MoDOT, March 2000.**

This bonded concrete overlay project was constructed on Route I-70, Cooper County during the summer of 1991 using "Fast Track" high early strength paving mixture. The high early strength concrete bonded overly was constructed with Type III cement to obtain a minimum compressive strength for 3500 psi in no more than 18 hours. The original pavement was prepared by coldmilling, shotblasting, and airblasting before overlaying. A neat grout, made of Type I cement and water, was sprayed directly on the pavement.

Several problems arose during the paving of the overlay. An average of two transverse cracks was observed within two days of paving. The remaining concrete overlay was saw cut at 20 feet intervals to help control random cracking. The pavement continued to have random cracking. The mixer unit had problems with buildup of hardened concrete in the drum. The overlay had mud pockets and segregated concrete having a raw unmixed sand layer or a weak sandy layer after paving. Since construction, the transverse cracking, longitudinal cracking, debonding and map cracking in the concrete bonded overlay has continued to show a large increase of deterioration, especially at the locations of original pavement repairs.

The poor performance of the high early strength mix used on this project observed during construction and in performance to date, indicated that the mix may be the source of some of the pavement distresses noted. When using a high early strength mix, strict quality control should be recommended to prevent concrete mixture, placing and curing problems. Further research should be pursued to closely evaluate the concrete bonded overlay mix used on this project.

Chojnacki, T. ***Evaluation of Fiber-Reinforced Unbonded Overlay.*** **Report No. RDT 00-015. Missouri Department of Transportation, December 2000.**

Fiber-reinforced concrete (FRC) is a composite material consisting of Portland cement concrete (PCC) and discontinuous natural, steel or plastic fibers. The inclusion of fibers in concrete results in improved energy absorbing characteristics of the concrete. Energy absorption is directly or indirectly related to properties such as crack propagation resistance, ductility, impact resistance, fatigue performance and durability.

A concrete unbonded overlay was constructed on I-29 in Atchison County. Eight test sections were established in the unbonded overlay. Three of the test sections were reinforced with steel fibers, three of the test sections were reinforced with polyolefin fibers and two of the test sections were non-reinforced PCC. There were fiber-reinforced test sections 9", 6" and 5" thick for each type of fiber reinforcement. Transverse joint paving varied in the fiber-reinforced sections from 15' to 200'. The two non-reinforced PCC test sections were 9" and 11" and all transverse joints were spaced 15'.

The overlay was diamond ground at least 21 days after construction to provide the finished texture. The profilograph readings of the finished pavement measured less than 11 in./mile with a zero blanking band. The International Roughness Index (IRI) averaged 67. Both of these measures are indicative of very smooth pavement. The compressive and flexural strength of polyolefin fiber-reinforced samples were slightly lower than the non-reinforced concrete. The compressive and flexural strength of the steel fiber-reinforced concrete were comparable to the non-reinforced concrete.

Some transverse cracking has appeared in the fiber-reinforced sections of the unbonded overlay. In general, more cracking has developed in the steel fiber-reinforced sections that the polyolefin fiber-reinforced sections. Thinner sections exhibited more cracking than the thicker sections and longer panels exhibited more cracking than shorter panels.

Portland Cement Concrete, Field Section 501. Materials Engineering, Missouri Department of Transportation.

This section contains specifications on concrete mix design. The instructions contained are intended to supplement those contained in the Construction Manual Sec. 500.

General Construction Manual, Section Document. Section 500, Portland Cement Concrete Plant and Pavement. Missouri Department of Transportation, April 23, 1996.
This section, 501.6, contains specifications on concrete mix design with field proportions.

Nebraska

Tuan, C. *Durability of PCC* – Research in progress, ASR P547 with Supplement 1, University of Nebraska and Nebraska Department of Roads, completion date June 30, 2004. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.
A consensus has been reached among NDOR material engineers, aggregate suppliers, cement suppliers, suppliers of pozzolanic materials and concrete producers, that there is a need to quantify the reactivity levels of the aggregates from the various sources frequently used in Nebraska. And to find simple means to mitigate the unwanted expansion and deterioration of concrete. Similar efforts have been carried out in the States of Texas [1] and New Mexico [2].
Alkali-silica reaction (ASR) takes place between certain reactive siliceous aggregates (e.g., opal and chalcedony) and the alkali from Portland cement paste and external sources. A reaction product gel forms that, in the presence of moisture, expands and may cause cracking of mortar and concrete. These surface cracks are aggravated by freeze-thaw action, leading to shallow delamination, rebar corrosion, potholes, and other serious problems including structural failure.
Concrete prism tests in accordance with ASTM C1293 can be conducted to measure the length change due to ASR of concrete. The duration of this test is fifty-two (52) weeks. The fine or coarse aggregates in question and 1.25 percent Na2O-equivalent cement is used for making 3” 3” 11-1/4” prisms with a water-cement ratio of 0.42 to 0.45. Measurements are taken at 7, 28, and 56 days, and 3, 6, 9, and 12 months. The tests are conducted under 100 percent relative humidity and 100oF. Potentially deleterious behavior is indicated if the one-year expansion is greater than or equal to 0.04 percent. An accelerated version of this test may also be conducted. If a particular concrete mix design passes the screening test, strength and durability tests according to the ASTM Standards may also be conducted to further determine the concrete’s acceptability.
This proposal is for phase one of a possible two-phase project. In Phase One, a comprehensive test matrix along with a program plan will be developed. The test matrix will consist of each selected aggregate with varying amounts of cements, fly ashes (Class C and F), granular blast furnace slag and calcined clay. The test matrix will also list which tests and evaluations should be conducted in phase two. Phase Two involves the execution of the test matrix involving an extensive testing program and data analysis. Based on the findings, specifications for the use of various aggregates, cements, and pozzolans will be drafted and circulated for adoption by NDOR.
The objective of the Phase One project is to develop a detailed testing program involving ASTM C 1260 and C 1293 tests to evaluate the reactivity levels and the ASR potential of the various Nebraska aggregates in combination with various amounts of cements, fly ashes (Class C and F), granular blast furnace slag and calcined clay.
Phase one will develop a comprehensive test matrix and program plan. The development of the matrix and plan will be the result of input from interested parties in the concrete industry. The results of the phase one test matrix and program plan will take the guesswork out of which tests to conduct in phase two of this project.

***Kansas Accelerated Testing Facility*, Research in progress, SPR-3(047). Nebraska Department of Roads. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.**

As part of a national effort to improve pavement performance in the United States, Departments of Transportation in Iowa, Kansas, Missouri and Nebraska are designing a number of new pavement mixes and structures. To learn more about the performance of these new designs and products before they are put on the road, large scale testing is necessary in an experimental setup that represents actual road conditions and real world situations.

An Accelerated Testing Facility was built in Kansas. The facility has a 40K loading capacity using a standard 2-axle 8-tire bogey or a "thumper" (servo-hydraulic loading to a plate placed on the pavement). Pit dimensions are 20x20x6 feet and 20x12x6 feet, the later having subgrade environmental controls. Heat can be applied to the surface using infrared heaters on either pit and subgrade moisture can be varied on the larger pit.

The testing is being conducted under actual road conditions that include exposure to both highway traffic (repetitive loading) and adverse environmental effects (temperature and moisture variations). The goal is to provide DOTs with data about pavement performance in a test environment, thus allowing for analysis and possible adjustments before undergoing the expense of paving on construction projects.

The benefits from eliminating mistakes in the laboratory instead of on the road and the large reduction in time for evaluation and verification could represent hundreds of thousands of dollars in saving to the state DOTs on just a few projects. The long-term potential benefits are high with respect to the research/testing investment. This directly translates into time saving and reduction in maintenance and production costs and fewer accidents or hazardous situations on the road in work zones during road repairs.

Tuan, C. *Lithium Field Implementation Trials*– Research in progress, RDT-QX5(1), University of Nebraska and Nebraska Department of Roads, completion date June 30, 2005. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.

This research opportunity is provided by FHWA to implement lithium-based technology in field projects through FHWA division offices.

Alkali-silica reaction (ASR) takes place between certain reactive aggregates (e.g., those dredged from the Platte River) and the highly alkaline pore fluids in the Portland cement paste. A reaction product gel forms that, in the presence of water, expands and may cause cracking of mortar and concrete. These surface cracks are aggravated by freeze-thaw action, leading to shallow delamination, rebar corrosion, potholes, and other serious problems including structural failure. Recent studies have shown that adding lithium compounds to concrete in the plastic state to be effective in the control of ASR. However, lithium-based technology has not been applied to existing and aged concrete bridge decks and pavement. The development of materials and application procedures is urgently needed for field implementation of using lithium compounds in arresting ASR in existing concrete pavements.

This project is proposed to be a joint effort of NDOR, the U.S. Army Corps of Engineers, Omaha District(USACE), and the University of Nebraska-Lincoln(UNL), in that the test structures will be selected by NDOR, petrographic analyses of lithium-treated and untreated concrete samples will be performed by USACE, and the lithium treatment procedures will be jointly developed by the USACE and UNL researchers.

The objective of this research is to develop materials and application procedures to stabilize or reduce the ASR distress mechanism in existing and aged concrete using lithium saturation and pressure injection treatment.

Expected results from the proposed research include reduced ASR-related deterioration, improved concrete durability, improved life-cycle performance, and reduced maintenance costs. The lithium treatment should produce a revitalized, ASR-stable concrete pavement without the cost and downtime of traditional concrete repair or replacement operations.

Traynowicz, M. *Early Concrete Pavement Deterioration*, Research in progress, R-02-07. Nebraska Department of Roads, completion date August 1, 2008. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.

The Nebraska Department of Roads has experienced some early deterioration in concrete pavements. Determination needs to be made on the types of deterioration occurring, and how it can be slowed down or stopped. The objective of this research is to produce longer lasting concrete pavements by determining the causes of early deterioration and learning how to prevent it. As a result of this research, we expect to gain familiarity with potential problems we will face with certain mixes, and how we can retard or prevent those problems from occurring. By learning more about what causes the concrete deteriorations, we can minimize or slow those reactions and produce a better, longer lasting surface.

Jensen, W. *Pavement Quality Indicators*. Research in progress – P563. University of Nebraska and Nebraska Department of Roads, Completion date June 30, 2004. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.

Several innovative pavement technologies have been introduced in the Nebraska road system by NDOR during the past decade. These include retrofitting of dowel bars into pavement joints, continuous "daylighting" of granular subbases material, lime and fly ash modified subbgrades, longitudinal tining, PCC overlays for asphalt concrete, crumb rubber overlays and many others. No studies have been undertaken to determine if these new technologies produce pavements that are in any way superior to the preceding technologies.

The proposed research will evaluate a specified number of pavement sections where innovative technologies have been used and compare these sections to nearby conventional pavement sections. Analyses will include annual maintenance cost(s), cracking indices, faulting indices, international roughness indices, decibel measurements, faulting, shoulder rating, spalling at joints and other selected criteria.

This research can be used to evaluate annual maintenance costs for specific innovative pavement sections versus annual maintenance costs for more conventional pavement systems. Research will also allow comparison of various pavements quality indicators from conventional pavements versus those same indicators for the more innovative pavement systems.

Woolstrum, G. *Utilizing the Maturity Method* – Research in progress – R-01-04. Nebraska Department of Roads, completion date August 1, 2005. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.

The maturity method for determining concrete strength is being conducted on several projects in Nebraska. This method relates temperature of concrete, and time to a predetermined strength curve to estimate strength of the pavement slab. This method eliminates the need to have samples brought to the lab in order to determine when to open the project to traffic. By inserting thermocouples into the freshly poured pavement, curing tie can be monitored throughout the day.

Abdelrahman, M. *Assess Current Pavement Designs* – in progress, P545. Nebraska Department of Roads and University of Nebraska, completion date June 30, 2003 with Supp 1 completion date April 30, 2004. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.

Roads and highways are a huge asset to the state of Nebraska, and a major portion of the Department of Roads annual budget goes toward constructing, improving, and maintaining these facilities. Much thought and effort goes into pavement selection and design to try to use the best strategies and elements in new and rehabilitated pavements. While to the best of our knowledge, the best and most cost effective designs are being used, there may be other factors affecting the life of the new and rehabilitated pavements. Such as construction techniques, material selection, and integration of various design features. Many factors need to be taken into account when selecting and specifying new pavement strategies. Research is needed to systematically select and design the best and most cost effective pavements in Nebraska.

The objective of this project is to assess the current and existing pavement design strategies in Nebraska and develop a comprehensive program to enhance the quality of new, rehabilitated and maintained pavements.

Expected benefits will include setting up guidelines for how to select the best and most cost effective strategies, designs, and techniques for new, rehabilitated, and maintained pavement facilities in Nebraska. This will result in a total cost savings for the Department of Roads and the state of Nebraska.

The Assessment Project (P545) has progressed with providing information on the condition of pavement sections and the effectiveness of maintenance and rehabilitation (M&R) strategies in Nebraska. Figure 1 shows an example of the assessment of pavement condition in Nebraska detailing acceptable rutting per district for the past few years. Figure 2 provides an example of the effectiveness of M&R strategies, doweled PCC.

There are two main objectives for extending the Assessment project:

- Assess the effectiveness of specific M&R applications, as determined by NDOR personnel. This analysis will be conducted using additional data that was not considered during the original tasks of the project. The assessment will be based on performance indicators currently in use by NDOR.
- Develop software that will update the results of the current project based on the yearly visual assessment of NDOR pavement sections and/or sources of updated information.

The extension of the Assessment Project will provide updates on the condition of pavement sections and the effectiveness of M&R activities in Nebraska. This information will help in:

- Evaluating and comparing the effectiveness of M&R alternatives.
- Optimizing the selection process of M&R techniques.
- Developing new M&R strategies considering performance and condition of current applications

Woolstrum, G. *Concrete Overlay-White Topping* – in progress, R-02-02. Nebraska Department of Roads, completion date August 1, 2006. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.

NDOR currently uses asphalt overlays, however these overlays cannot prevent the reoccurrence of rutting and reflective cracking. In general using a concrete overlay can prevent or rehabilitate these types of deterioration.

The ultimate goal of the research project is to evaluate the white-topping treatment. Is this something that NDOR would like to do more of? Is it cost efficient? When should we white-top versus using and asphalt overlay?

From this research we expect to determine the usefulness of white-topping. Historically Asphalt State highways require asphalt resurfacing an average of 8-12 years. Concrete overlays could be expected to last to 20-25 years or more without major rehabilitation.

Rea, R. ***New Pavement Design* – in progress, R-01-05. Nebraska Department of Roads, completion date August 1, 2005. http://ndorapp01.dor.state.ne.us/research/rpms.nsf/.**

The NDOR has a number of new features on concrete paving projects. The first is a widened pavement section called the 30' top. This provides a pavement section with reduced edge stresses, greater load transfer, resistance to shoulder depressions from wandering trucks, and improved safety with installed rumble strips. We are also using dowel bars for load transfer on concrete pavements to eliminate faulting. And lastly, we are longitudinally tining the pavements. This provides a quieter, more enjoyable ride while providing a friction texture.

47B Concrete Pavements and 47BD Concrete for Bridges, Nebraska.

Discusses the amendments to Section 1002 in the 1997 Standard Specifications and Supplemental Specifications. A table shows the alternates for the proportioning used for 47BD concrete used in bridge decks, approach slabs, bridge rails, and barriers.

Section 1 – Portland Cement Concrete, Nebraska.

The brands and types of cement that are accepted are shown in a table, as well as the accepted fly ash, pozzolanic, silica fume admixtures, air-entraining admixtures, water-reducing, retarding, and accelerating admixtures, and finishing aids/evaporation reducers.

Section 1033 – Aggregates, Nebraska.

A description of mineral aggregates including material characteristics, general aggregate properties, and Portland cement concrete aggregate are included. Tables showing coarse aggregate for concrete gradation limits, aggregate classes and uses, sampling and testing procedures, and fine aggregate for concrete gradation limits are included.

Project No. RD-33-6(1014). Diamond Grinding and Texturing Concrete Pavement, Nebraska.

Discusses the work on 8" plain concrete pavement constructed in 1955. It consists of diamond grinding and texturing mainline concrete pavement surface for profile improvement. Project information is detailed, as well as equipment, diamond grindings, methods of measurement, and basis of payment.

New York

Plan sheets. New York State Department of Transportation, October 16, 2000.

Plan sheets showing Typical Plan, Cross Section, and Joint Layout, Longitudinal Joints, Joint Ties, Joint Sawing and Sealing, Transverse Joints, Joint Sawing and Sealing, Utility Isolation and Joint Layout General Notes and Guidelines, Telescoping Manhole Casting Layout, Non-Telescoping Manhole Casting Isolation, Shallow Structure Isolation, Drainage Structure Isolation and Isolation Near Manhole Castings, Multiple Utilities Isolation, and Telescoping Manhole Casting and Ring.

Freezing and Thawing, Portland Cement Concrete Cores, Test Method. Materials Bureau, New York State Department of Transportation, April 1986.

The resistance of Portland cement cores when exposed to alternate freezing and thawing is determined with this method. The test method using appropriate apparatus, procedure, and results are discussed.

Section 500 - Portland Cement Concrete, Standard Specifications. New York State Department of Transportation, January 2, 2002.

Section 501 – Portland Cement Concrete – General information. Sections 501-1 through 501-5 are included. These sections offer details on description, materials (composition of materials, material requirements, concrete batching facility requirements, concrete mixer and delivery unit requirements), construction details (proportioning, handling, measuring, and batching materials, concrete mixing, transporting, and discharging), method of measurement, and basis of payment.

Materials Method 9.1M: Plant Inspection of Portland Cement Concrete (Metric). Materials Bureau, New York State Department of Transportation, January 2002.

Materials Method 9.1M describes Department practices involved in the plant inspection of Portland cement concrete mixes. Full conformance with Materials Method 9.1 M will provide uniform inspection procedures at the plant, in an effort to minimize the chance of unacceptable concrete being incorporated into Department projects. A secondary purpose is to provide proper documentation of the acceptability of the concrete as it leaves the plant.

Materials Method 9.1M consists of four Sections and Appendices. Sections 1 through 3 contain procedures that the Plant Inspector should use while inspecting and documenting the production of concrete. Section 4 describes the inspection approval procedures performed normally by either the Regional Materials Engineer and his staff or by representatives of the Materials Bureaus as indicated.

Materials Method 9.2: Field Inspection of Portland Cement Concrete (Metric). Materials Bureau, New York State Department of Transportation, April 2002.

This Materials Method describes specific procedures for inspecting, sampling, and testing Portland cement concrete to insure conformance with Department Specifications.

Material Method 9.2 consists of eight sections (A through H) discussing sampling procedures, temperature, slump test, air content test procedure, unit weight and yield test procedure, concrete cylinder fabrication, and uniformity test procedure.

Ohio

Abdulshafi, O., H. Mukhtar, and B. Kedzierski. Reliability of AASHTO Design Equation for Predicting Performance of Flexible and Rigid Pavements in Ohio. Report No. FHWA/OH/95/006. CTL Engineering, Columbus, OH, Nov. 5, 1994.

The AASHTO pavement design procedures were developed as a result of AASHO Road Test conducted in the late 50's and early 60's. The developed design methods are empirical and relate pavement performance measurements and the loss of serviceability directly to the traffic volume and loading characteristics, the modulus of subgrade reaction, layer coefficients, and environmental factors that were present at the road site. The resulting design equations have been generalized to make them applicable to broader sets of design variables. In the 1986 AASHTO design guide, the equations were enhanced to included design reliability, the resilient modulus of the subgrade soil, material variability and drainabilty, and construction quality. Further, the design guide permits the user to use overall standard deviations applicable to the local conditions. These values of standard deviation are used to determine the reliability design factors. Large values of Standard deviation result in pavement designed at a higher level of reliability than supposed. Therefore, any uncertainty in standard deviation will result in uncertainty in the reliability level. Since the Ohio Department of Transportation (ODOT) has adopted the AASHTO design equations for new pavement design, it was considered needful to conduct a research study that would determine the deviations in traffic and performance prediction parameters and the overall standard deviations applicable to Ohio conditions. Pavement test sites were selected to represent the state wide distribution of pavement designs in Ohio, characterized by such factors as material type, functional classification, and different climatic and soil regions. Continuous traffic data collection was accomplished by the use of Weigh-in-motion devices. Pavement serviceability index (PSI) was measured by Ohio non-contact profilometer. Core samples were obtained and several laboratory tests were conducted to determine the as-constructed material properties and variability of the design input parameters. Comparison of predicted and observed performances based on approximately four years of data indicated that AASHTO equation does not predict the performance of flexible pavements in Ohio. The predicted and the observed performance for rigid pavement sites were essentially the same that is no change in the observed and the predicted PSI, however, these observations were based on short term performance data. The overall variance estimates for flexible and rigid pavements were, however, not obtained due to lack in the change of performance data for most sections.

Chapin. L. T., and J. B. Dryden. An Evaluation of the Cost Effectiveness of D-Cracking Preventive Measures. Report No. FHWA/OH-2002/05. Bowling Green State University, Bowling Green, OH, Sep. 2001.

D-cracking has long been a serious problem in the deterioration of concrete pavements in severe weather climates. After much research, the mechanics and variables involved in the destructive forces of concrete D-cracking are becoming known. This study focuses on these variables that include analysis of the cost effectiveness in using certain preventive measures to reduce premature deterioration of concrete pavement due to D-cracking. These variables will include aggregate source, cement source, joints, types of pavement, vapor barrier, cure, and subbase.

A test road located on State Road (SR) 2 near Vermilion, Ohio was built in 1974 and 1975 with specific sections to investigate the role of subbase drainage systems, pavement joint design, subbase materials, joint sealant, different aggregate sources and size, different cements, types of cure, and joint spacing. In 1998 this field study was done on the Vermilion project to evaluate many of the factors that were initiated on the pavement.

Cook, J. P., I. Minkarah, and J. F. McDonough. Determination of Importance of Various Parameters on Performance of Rigid Pavement Joints. Report No. FHWA/OH-81/006. Ohio Department of Transportation, August 1981.

The objective of the present study was to evaluate the effects of various parameters on an experimental concrete pavement in Ross County, Ohio. Variables included in the pavement were (1) joint spacing, (2) sub-base stabilization, (3) coating of dowel bars, and (4) configuration of the saw cut and (5) the use of skewed joints.

Both long term and short term horizontal movements caused by temperature and vertical movement of slab ends under known axle loads were measured.

A record of cracking and spalling of the pavement is also included.

A statistical analysis of both long and short term movement was conducted and recommendations for joint design are included.

Cook, J., F. Weisgerber, and I. Minkarah. Development of a Rational Approach to the Evaluation of Pavement Joint and Crack Sealing Materials. Report No. FHWA/OH-91-007. University of Cincinnati, Jan. 1990.

This study included interviews, field evaluations, measurements of gap motions, laboratory testing and stress analysis relating to highway pavement crack and joint seals. Both asphalt and concrete pavements were included. This report provides extensive comparative data on the behavior of a wide variety of sealant material and seal configurations. Successful sealing practices, such as using the "saw and seal" technique for asphalt overlays, and wide-spread problems, such as maintaining an effective bond to concrete, have been documented fully. The primary results, conclusions and recommendations are summarized in three sets of guidelines provided in Appendices. These are guidelines for:

a) predicting the potential of materials for use as sealants;
b) selecting seal materials and configurations; and
c) evaluating sealants in place

Cool, J. P. and I. Minkarah. Development of an Improved Contraction Joint of Portland Cement Concrete Pavements. Report No. OHIO-HWY-19-73. University of Cincinnati, August 1973.

This report deals with the contraction joints in portland cement concrete pavement. The variables studied which affect joint behavior are 1) Joint spacing, 2) Sub-base stabilization, 3) Coating of dowel bars, 4) Configuration of the sawcut, and 5) Use of skewed joints.

Hand gage readings, taken monthly, give the yearly curve of joint movement. Electronic instrumentation is used to give a continuous record of the daily slab movements. Electronic instrumentation is used to measure pavement deflection under known axle loads.

A condition report of the pavement after one year's use is included and tentative recommendations are made for an improved contraction joint.

Dudley, S. W. Evaluation of Concrete Pavement Restoration Techniques. Ohio Department of Transportation, November 1983.

The objective of this demonstration project is to evaluate concrete pavement restoration (CPR) of a rigid pavement that remains in good condition except for limited areas of deterioration and loss of riding comfort due to problems at joints and cracks. The steps involved in this technique are: under seal to fill voids; patch full and partial-depth; diamond-grind faults and bumps; saw and seal joints; repair and seal isolated random cracks; and install new-type load-transfer devices in transverse joints and random cracks. A seventh step, not demonstrated, is to provide concrete sills or shoulders to better support the roadway and minimize water infiltration. Field evaluations will be made annually to determine the cost-effectiveness of the CPR system.

Early Age Evaluation of a High Performance Concrete Pavement. Ohio Research Institute for Transportation and the Environment.

High Performance Concrete (HPC) pavement has recently attracted great interest because of potentially longer service lives and reduced life-cycle costs. General design criteria have been established for these pavements by various federal and state transportation agencies. Ground granulated blast furnace slag (GGBFS) is one material used in the construction of HPC pavements.

The purpose of this technical note is to discuss the effects of GGBFS on the curing and early performance of HPC pavement on one project in Ohio. Field measurements included slab temperature and slab curvature. Maturity functions were used to determine the effect of GGBFS on strength gain in the concrete.

During this study, environmental strain was monitored with gauges mounted in a few slabs at the time of construction, and dynamic deflection was measured later on the hardened slabs with a Dynatest Falling Weight Deflectometer.

Evaluation of Base Materials under PCC Pavement. Ohio Research Institute for Transportation and the Environment.

In 1990, a distressed portion of SR 2 in Erie and Lorain Counties near Vermilion, Ohio was replaced with test sections designed to investigate the effects of base type on D-cracking, slab length on transverse slab cracking, and natural versus manufactured sand on skid resistance. Twelve sections constructed for the study of base type on D-cracking were located in the westbound lanes of SR 2 between Station 1835+10 in Erie County and Station 90+23 in Lorain County. While no evidence of D-cracking is apparent to date in these sections, numerous transverse slab cracks observed in sections with Ohio 307NJ and cement-treated free draining base suggest these materials should not be used as a base directly under PCC pavement. This technical note provides a review of the performance of these test sections.

Evaluation of HPC Pavements in Nelsonville, Ohio. Ohio University, Athens, OH. TRB research in progress.

The objective of this study is to apply the concrete mix used by Dr. Clelik Ozyildirim in “Evaluation of HPC Pavement in Newport News, Virginia” to the reconstruction of U.S. Route 33 in Nelsonville, Ohio. Three test sections, each consisting of 1000 feet, will be constructed as part of the U.S. 33 reconstruction. In each test section, 500 feet will be cured with membranes; the other 500 feet will be cured with burlap. The following parameters will be monitored during the concrete curing, service, and non-destructive testing (NDT): (1) Temperature profile during curing with thermocouples; (2) Temperature as a function of time for the maturity test; (3) Shape of the slab with Dipstick and stationary profilers; (4) Shape of the slab using ODOT profilers; (4) Joint movement of the slabs; and (5) Deflection during non-destructive testing.

Gupta, J. D. and W. A. Kneller. Precipitate Potential of Highway Subbase Aggregates. Report No. FHWA/OH-94/004. The University of Toledo, Nov. 1993.

Tufaceous material has been observed clogging pavement drains along highways in northeastern Ohio. Previous studies suggest that the free lime (CaO) present in subbase material is the source for the deposition of the tufa. Nine slag samples which consisted of air cooled blast furnace (ACBF), open hearth (OH), basic oxygen furnace (BOF), and electric arc furnace (EAF) and two recycled portland cement concrete (RPCC) were evaluated for the tufa precipitate research.

An X-ray, SEM and physicochemical test were conducted on these samples. In addition, leachate study and surface area measurements were performed to characterize the precipitate potential of these samples. The results of these tests indicted that all of the slags, except the ACBF slag, are prone to produce tufa.

The solution of CaO in hot ethylene glycol (‘sugar’ test) revealed that the ACBF slag does not contain any residual feel lime. The results of the X-ray diffraction and thermogravimetric (TG) analyses confirmed that ACBF slag does not contain either portlandite or calcium carbonate. X-ray diffraction analysis for both the OH and the BOF slags shows that these slags contain portlandite Ca(OH)2 and calcium carbonate.

ODOT requires six months aging of slags before they are used. The ‘sugar’ test results shows that the aging of slags for six months or more, does not decrease the free lime content enough to prevent the formation of tufa deposits.

TG analyses and the results of the ‘sugar’ test permit the determination of original percentage free lime. Five groups, according to the calculated total percent free lime are recognized: 1) 0%; 2) 3.5 – 5 %; 3)8 -9%; 4) 10-12%; and 5) 24-25%. The thermogravimetric and ‘sugar’ test methods used are excellent and economical ways to characterize the original free lime in slags and the susceptibility of the slags to precipitate CaCO3 in subdrains of highways.

The RPCC samples contain both portlandite and calcium carbonate.

X-ray diffraction and SEM analyses indicate that one RPCC sample does not contain free lime. The leachate study shows that both samples produce tufa. Therefore, presence of free lime or portlandite in the cement paste of the concrete can result in tufa precipitation.

Gupta, J. Magnitude Assessment of Free and Hydrated Limes Present in RPCC Aggregates. Report No. FHWA/OH-2002/014. The University of Toledo, Toledo, OH, Feb. 2002.

The tendency of tufa to block pavement drains in northeastern Ohio can be associated with the total calcium content of the aggregate materials. In the present project, recycled Portland Cement Concrete (RPCC) aggregates are examined when leached with acidic water formed by carbon dioxide dissolved in water. The RPCC aggregates were supplied by the Ohio department of Transportation (ODOT) from various sections of the interstate highways in the state of Ohio. The locations of sample and a summary of the components in terms of course aggregate, fine aggregate, and cement are quoted in the study of D-cracking report. All the RPCC aggregates were around 30 years old. X-ray power diffraction (XRD) data and thermal analysis (thermogravimetry, TG and differential thermal analysis, DTA) data established the portlandite, dolomite, and calcium carbonite content of the RPCC aggregates. The presence of quartz is established from the DTA plots and its relative abundance established for the XRD data. The ethylene glycol test indicated that the free calcium oxide content has been reduced in most samples to around 0.5% due to carbonation over 30 years. All the samples were subjected to leaching test in the presence of acidic water (CO2 in water) and the concentration of Ca2 and Mg2 ions established using Inductively Coupled Plasma-Atomic Emission Spectroscopy (ICP-AES). A ratio of Mg/Ca ions>0.60 indicates that he aggregates have higher concentration of Ca2 ions and may result in the precipitation of calcium carbonate or tufa. In laboratory studies, the ambient temperature of pouring concrete (below 50 deg F) has shown a higher incidence of tufa precipitation. It may be due to incomplete hydration. The study recommends establishing Mg/Ca ratio before using RPCC aggregates as base/subbase course. Also it is recommended to limit the use of RPCC aggregates to coarse size only.

Ioannides, A. and I. Minkarah. Ohio Route 50 Joint Sealant Experiment. Report No. FHWA/OH-2002/019. University if Cincinnati, Cincinnati, OH, April 2002.

This research project entailed the construction and evaluation to date of a four-lane highway near Athens, Ohio. The main purpose of this project has been to evaluate concrete pavement performance in connection with various sealant types and joint configurations in the Wet-Freeze climatic zone. Fifteen different material-joint configuration combinations have been used. The new pavement consists of a 250-mm (10-in.) jointed reinforced concrete slab with 21-ft joint spacing, placed over a 100-mm (4-in) free-

drainage base layer, constructed over a 150-mm (6-in) crushed aggregate subbase, resting over the predominantly silty clay local subgrade. The highway has a twenty year design period, with design traffic level of 11 million ESALs. The eastbound lanes were constructed first and have been open to traffic since Spring 1998, whereas the westbound lanes have been serving traffic only since Spring 1999. Three joint sealant, profilometer and pavement performance surveys are described in this Report. These evaluations were conducted in October 2000, June 2001, and October 2001 in accordance with an evaluation plan developed by the University of Cincinnati research team based on statistical principles. Sealant effectiveness values are calculated and treatments are ranked according to a rating scheme that describes each sealant type very good, good, fair, poor, or very poor. Results from these evaluations are analyzed and compared to those from earlier inspections to delineate the major trends exhibited by the test pavement. During the March 2000 evaluation, a significant flooding event was witnessed. The Hocking River, which runs along the highway, could not handle the amount of water from the storm. Several fields adjacent to the roadway were flooded and the drainage ditches overflowed. Following the flooding several transverse cracks were noticed in the pavement. Both the development of structural distresses and the drainage features of the pavement system are also examined in this Report. It is reported that significant mid-slab cracking has been observed in the test pavement, but that this distress appears unrelated to the performance of the sealant treatments. It is anticipated that pavement and sealant performance monitoring will continue for several years. Several recommendations for future investigations are formulated.

Ioannides, A. M. and I. A. Minkarah. Mechanistic-Empirical Performance of U.S. 50 Joint Sealant Test Pavement (Fall 1999 to Fall 2000). University of Cincinnati, Cincinnati, OH, Jan. 2002.

Ioannides, A. M. and I. A. Minkarah. Ohio Route 50 Joint Sealant Experiment Construction Report (Phases 1 and 2) and Performance to Date (1997-99). University of Cincinnati, Cincinnati, OH, Sept. 1999.

Klieger, P., G. Monfore, D. Stark, and W. Teske. D-Cracking of Concrete Pavements in Ohio. Report No. OHIO-DOT-11-74. Portland Cement Association, Skokie, IL, Oct. 1974.
A three phase program was undertaken to determine the extent and severity of D-cracking in Ohio, and to determine the role of drainage and materials properties in its development. A rating system was established to evaluate the performance of materials, in particular, coarse aggregate, in existing pavements. Data from these surveys have been processed for storage in a computerized retrieval system. Laboratory freeze-thaw testing has identified the importance of source of coarse aggregate in the development of distress and has provided strong evidence that reducing the maximum particle size of the aggregates may reduce or eliminate the development of D-cracking. A test procedure has been recommended for identifying coarse aggregate sources and gradations vulnerable to freeze-thaw failure in pavements. Source of cement was found, in laboratory tests, to be of minor importance while level of air entrainment within the existing specified range was found to be of essentially no importance in this problem. The presence of bulk water or only capillary held water in granular subbases was found to have little differential effect on the degree of saturation of certain coarse aggregate materials in simulated pavements exposures. A test road has been designed to verify the importance of certain materials factors in the development of D-cracking, and a gage has been developed to measure moisture changes in subbases and pavement slabs.

Larger Sized Coarse Aggregate in Portland Cement Concrete Pavement and Structures. University of Cincinnati, Cincinnati, OH, TRB research in progress.
Given that the efficiency of an optimum concrete mix is controlled by the amount of cement employed and that the paste is usually responsible for most of the durability and cracking problems encountered, the goal of this research will be to see if the cement efficiency of standard ODOT mixes can be improved through the use of larger aggregate. The project will seek to develop and validate

mechanistic-based correlations to assess and quantify the influence of aggregate size on strength, chloride resistance, abrasion resistance, freeze thaw resistance, creep and shrinkage. The effect of aggregate size on curling, warping, cracking and load transfer will also be considered.

Liang, R. Polishing and Friction Characteristics of Aggregates Produced in Ohio. Report No. FHWA/OH-2000/001. The University of Akron, Akron, OH, Jan. 2000.

A research project has been carried out to investigate the specific causes of rapid polishing behavior of aggregates produced in Ohio and to develop practical testing procedures for evaluating the ability of aggregates to provide adequate skid resistance over the intended service time periods. The properties investigated include the polish number of each aggregate, the petrographic and mineralogical properties, the acid insoluble residue (AIR), chemical analysis and the soundness properties. Aggregates collected for 20 different quarries and those extracted for cores taken for two pavement sections were subjected to accelerate polishing using the British Wheel and the friction values recorded using the British pendulum. A detailed petrographic analysis was performed by observing the thin sections under an image analyzer. Also the loss of polish number in pure minerals was studied for correlating with the petrographic analysis. The results of the soundness tests and the laboratory chemical analysis were obtained from the ODOT laboratories. The results of this research showed that polish number is significantly affected by the insoluble residue content and the percent carbonate content. A high polish number is observed in aggregates having 60% to 70% dolomite and 20% to 30% calcite. Physical occurrences, like the crystallinity and the cementing properties of minerals also play a dominant role on the polish number. The research demonstrated that polishing tests accompanied by petrographic analysis on the aggregates could be a successful way in testing aggregate samples for their polishing properties. Data from mineralogical and AIR tests are vital in deciding the minerals that dominate the polishing properties of aggregates. A practical and screening procedure has been devised for the selection of polish test, and more detailed petrographical analysis via an image analyzer. Selection criteria were given for adoption by the Ohio Department of Transportation.

Majidzadeh, K., and L. Figueroa. Evaluation of the Effectiveness of Joint Repair Techniques and Pavement Rehabilitation Using the Dynaflect. Resource International, Westerville, OH, Dec. 1988.

Majidzadeh, K. Field Study of Performance of Continuously Reinforced Concrete Pavements. Report. No. OHIO-DOT-09-74. Ohio Department of Transportation, Dec. 1973.

In this report, the results of field observations on CRC pavements constructed in the state of Ohio are presented. The field performance parameters such as deflection, moduli variability, support conditions, crack spacing and pattern and drainage conditions are evaluated and related to pavement structural conditions. The results of pavement core strength data are utilized to develop interrelations between material properties and life expectancy of the CRC pavement structure. The concept of concrete maturity and the strength-maturity relations are used as a basis for a proposed design scheme. The results of field curing conditions and the effects of curing methods on the crack spacing and pattern have also been investigated.

This field study has shown that the crack spacing and pattern is independent of curing conditions and is mostly affected by the climatic condition prevailing during construction. It is also shown that in CRC pavements constructed using soil-cement or lime-fly ash mixture, the transverse cracks in the pavement structure have, in all instances, penetrated into the base course.

The drainage conditions in these pavements have been shown to be of critical significance. Similarly, this study has demonstrated the extent of variability observed in the construction of these pavements.

The field observation of the performance of an overlayed structure on a CRC pavement has indicated that reflection cracking would occur in areas where the continuity of steel reinforcement has been destroyed.

Majidzadeh, K. and R. Elmitiny. Long Term Observations of Performance of Experimental Pavements in Ohio. Report No. FHWA/OH-81. Resource International, Worthington, OH, July 1982.

This report presents long term evaluation data and analyses for eight experimental pavement projects constructed in Ohio. The study projects include both rigid and flexible pavements and are scattered throughout the state. Pavement age is currently approaching 10 years for some projects. The pavements were extensively monitored and tested at the time of construction, and during 1979 and 1980 as part of this research study. Collected data included pavement condition rating (PCR) of visible distress, Dynaflect defection, test properties of core and subgrade samples, and estimated remaining structural life and overlay requirements.

Majidzadeh, K. Observations of Field Performance of Continuously Reinforced Concrete Pavements in Ohio. Report No. OHIO-DOT-12-77. Ohio Department of Transportation, June 1977.

This report documents the fact that the Chang-Majidzadeh design criteria can be used to predict crack spacing in CRC pavement structures. The Chang-Majidzadeh model is also found to be in agreement with the NCHRP proposed design criteria.

The major points of agreement are as follows:

(1) The optimum average crack spacing in CRC pavements is 5 feet. Crack spacings smaller than 5 and greater that 8 feet are not desirable.
(2) Crack spacing is more uniform in thicker CRC pavements (9”) than in thin pavements (6”).
(3) Depth of steel reinforcement has a significant influence on crack spacing. As the ratio of steel depth to pavement thickness increases, an increase in crack spacing results. That is, the placement of steel at depths above mid-depth results in closer crack spacing.
(4) The results of the analysis indicate that the location of steel reinforcement affects the crack opening. The placement of steel reinforcement below mid-depth results in excessive crack opening. This finding is in agreement with the results of field observations.
(5) Optimum crack spacing, crack opening and steel stress are greatly dependent on the environmental conditions during the curing period. Air temperature and climatic conditions such as cloud cover (radiation flux) affect the temperature distribution in the pavement concrete during the plastic and hardened states. Temperature variations during early curing periods and the temperature differential during the service life affect the pavement performance.

Majidzadeh, K. The Ohio Pavement Rehabilitation Demonstration. Report No. FHWA/OH-89/017. Resource International, Westerville, OH, Feb. 1989.

This report presents a cooperative study initiated in 1983 by the Federal Highway Administration (FHWA) and the Ohio Department of Transportation (ODOT). Its purpose was to establish cost and performance data for various rehabilitation strategies in Ohio.

“The Ohio Pavement Rehabilitation Demonstration Program” consisted of ten projects: four unbonded concrete overlays, one modified concrete pavement restoration (CPR), three crack and seat projects with various asphalt overlay thickness, one thin asphalt concrete overlay on an under sealed concrete pavement with new composite shoulders, and a 6-inch asphalt concrete overlay over a D-cracked pavement with minimal joint repair.

The construction operations have been documented and the performance of each project was periodically monitored. Monitoring included condition rating, crack surveys, deflection testing, roughness measurement, and ride quality.

Majidzadeh, K., and V. Behaein. A Study to Develop a Base of Data for Joint Repair Techniques. Report No. FHWA/OH-89/007. Ohio Department of Transportation, Dec. 1988.

This study was initiated to identify and collect the data elements required to identify various joint repair techniques and then develop a computerized data base to store the data.

As a result the user will be able to:

1. Identify exact locations of each repair technique
2. List all repair techniques that were done on any given year/county/route and log mile.
3. Perform joint condition rating and enter into the system.

Majidzadeh, K. and L. O. Talbert. Performance Study of Continuously Reinforced Concrete Pavements. Report No. OHIO-DOT-03-72. Ohio Department of Highways and U.S. Department of Transportation. Sept. 1971.

Masada, T. Laboratory Characterization of Material & Data Management for Ohio – SHRP Projects (U.S. 23). Ohio University, Athens, OH, Sep. 2001.

About a decade ago, the Federal Highway Administration (FHWA) set up a national study called the Long-Term Pavement Performance (LTPP) under the Strategic Highway Research Program (SHRP) to extend pavement life through investigation of different pavement designs under various loading, environmental, subgrade soil, and maintenance conditions. The study involved many different materials and stressed the importance of collecting field and laboratory test data on their mechanistic properties.

In the current study, mechanistic properties of the pavement materials involved in the Ohio-SHRP project were measured according to the SHRP Protocols. The test program encompassed a wide array of materials and their properties, ranging from basic index properties of the subgrade soils to resilient modulus of soils and asphalt concrete to static modulus of Portland cement concrete and creep modulus of asphalt concrete. Any trends observed in the test results were pointed out to enhance our understanding of how each pavement material behaves. In some cases, previously published empirical relationships correlating basic and advanced material properties were reevaluated in light of the latest test results.

A need for integrating a large volume of data that existed for the Ohio-SHRP project was recognized even prior to the initiation of the current study. As a result, computer-based database was developed, packaged into a CD-ROM disk, and attached to this report. This user-friendly database allows a fast and easy access to all the mechanistic properties presented in this report as well as general information related to the Ohio-SHRP project.

Masada, T., S. Sargand, B. Abdalla, and L. Gigueroa. Material Properties for Implementation of Mechanistic-Empirical (M-E) Pavement Design Procedures. Ohio University, Athens, OH, Dec. 2003.

A comprehensive study was conducted to compile mechanistic property data for pavement materials specified and utilized in Ohio. The study consisted of three major components. In the first component, background information on the new mechanistic-empirical (M-E) pavement design/analysis procedures was researched and presented. In the second component, each of the twenty-eight (28) pavement –related research projects conducted for the ODOT within the last two decades was summarized with emphases placed on pavement materials properties measured and pavement distress data recorded. In the third component, reliability of the Asphalt Institute's Witczak equation was evaluated for asphalt concrete mixtures used in Ohio in light of the latest laboratory dynamic modulus test data collected by the authors. The end result of the project was a collection of recommended hierarchical material property values and prediction methods for both rigid and flexible pavements to aid highway engineers and researchers in Ohio who wish to implement the M-E procedures.

Masada, T. Laboratory Characterization of Materials & Data Management for Ohio – SHRP Projects (U.S. 23). Project No. FHWA/OH-2001/07. Ohio University, Athens, OH, Sep. 2001.

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Masada, T., S. Sargand, B. Abdalla, and L. Figueroa. Material Properties for Implementation of Mechanistic-Empirical (M-E) Pavement Design Procedures. Report No. FHWA/OH-2003/021. Ohio University, Athens, OH, Dec. 2003.

A comprehensive study was conducted to compile mechanistic property data for pavement material specified and utilized in Ohio. The study consisted of three major components. In the first component, background information on the new mechanistic-empirical (M-E) pavement design/analysis procedures was researched and presented. In the second component, each of the twenty-eight (28) pavement related research projects conducted for the ODOT within the last two decades was summarized with emphases placed on pavement material properties measured and pavement distress data recorded. In the third component, reliability of the Asphalt Institute's Witczak equation was evaluated for asphalt concrete mixtures used in Ohio in light of the latest laboratory dynamic modulus test data collected by the authors. The end result of the project was a collection of recommended hierarchical material property values and prediction methods for both rigid and flexible pavements to aid highway engineers and researchers in Ohio who wish to implement the M-E procedures.

Measurement of Dowel Bar Response in Rigid Pavement. Ohio Research Institute for Transportation and the Environment.

The effectiveness of load transfer between adjacent slabs is an important component of long term rigid pavement performance. When load transfer is minimal or non-existent, concrete slabs must carry the full weight of tuck axles across their entire length. This condition results in high dynamic tensile stresses being induced in the slab and high dynamic compressive stresses being generated in the base and subgrade. Dowel bars are placed in rigid pavement contraction joints as a mechanism for distributing traffic loads over multiple slabs through vertical shear and/or bending moments, and thereby, reducing stresses in the slab and base. Unfortunately, premature distress is often observed around rigid pavement joints. The purpose of this project was to instrument and install a total of 12 dowel bars in an in-service pavement and monitor their response under environmental cycling and dynamic loading. An examination of this date might provide some insight into the reasons for premature distress.

Minkarah, I.., A. Bodocsi, R. Miller, and R. Arudi. Final Evaluation of the Field Performance of Ross 23 Experimental Concrete Pavements. Report No. FHWA/OH-93/018. The University of Cincinnati, Dec. 1992.

This project is a continuation of the research done from 1972 to 1981 on a jointed portland cement concrete pavement test section located in the southbound lane of Ohio Route 23 in Chillicothe, Ohio. Several variables were incorporated into the pavement: joint spacing, type of base, type of dowels and type of sawcut.

Short term and long term horizontal movements caused by temperature were evaluated over a two year period. Vertical movements under known axle loads were also determined. Dynaflect and FWD were measured at the same time as the vertical movements. A statistical analysis was conducted of the horizontal and vertical movement data. A record of the damage to the pavement during the 20 year span was also made. Analysis of the statistical data and pavement damage led to conclusions about joint design and spacing limitations.

The in situ permeability of the base was measured. The concrete was examined petrographically and the extent of chloride penetration was determined.

Minkarah, I., and J. P. Cook. A Study of the Effect of the Environment on an Experimental Portland Cement Concrete Pavement. Report No. OHIO-DOT-19-75. The University of Cincinnati, October 1975.

The objective of the present study was to evaluate the effects of the pavement environment, such as temperature change and heavy truck traffic on an experimental P.C.C. pavement in Ross County, Ohio.

Variables included in the experimental pavement were 1) Joint spacing, 2) Sub-base stabilization, 3) Coating of dowel bars, 4) Configuration of the saw cut and 5) the use of skewed joints.

Horizontal slab movements caused by temperature and vertical movement of the slab ends under known axle loads were measured.

A complete record is included of mid-slab cracking and crack growth. Also included is a summary of the surface spalling of the pavement and the spalling of the bottom of the pavement at the joints.

Minkarah, I. And J. P. Cook. A Study of Field Performance of an Experimental Portland Cement Concrete Pavement. Report No. OHIO-DOT-19-74. University of Cincinnati, May 1975.

An experimental section of P.C.C. pavement on U.S. 23 in Ross County, Ohio is studied. Variables included in the study are 1) Joint spacing, 2) Sub-base stabilization, 3) Coating of dowel bars, 4) Configuration of the saw cut, and 5) the use of skewed joints.

The yearly curve of joint movement is plotted from hand gage readings. Electronic instrumentation is used to give a continuous record of daily horizontal slab movements. Deflection of the slab ends under known axle loads is measured.

A complete record to date is given of the progress of mid slab cracking. Spalling at the bottom of the pavement is measured and plotted for each of the 101 contraction joints in the project.

Munoz, S. R. and E. Y. J. Chou. Identification of Durability Problems Under Concrete Pavement Joints. Report No. ST/SS/95-004. The University of Toledo, Toledo, OH, Dec. 1995.

This study investigated curability problems encountered under concrete pavement joints. Disintegration of concrete at the bottom half of the joint, referred to as “coning”, is being discovered by ODOT engineers. For this study, concrete cores were taken at three different locations in Ohio. The core samples varied in the type of aggregate and cement used in the mix. Core samples taken at the joint showed large amounts of deterioration while samples taken at distances away revealed no signs of distress. A survey was conducted with all the Departments of Transportation in the U.S. in which nineteen states reported experiencing a similar type of concrete joint distress. The responses from the survey indicated that the cause of the distress might be from a high concentration of compressive stress or chemical activity. Laboratory tests including petrographic analysis, air content, and chloride-ion content were conducted on the core samples taken at the three sites. Also, a scanning electron microscope was used in order to see if any deleterious substances could be located and identified. The results showed that the aggregate at all sites were intact, hard, and sound. The amount of air entrainment was between 1.3 – 2.5 percent and the chloride-ion content was high. The tests revealed large concentrations of secondary ettringite crystals around the joint location and no secondary ettringite was observed at distances away from the joint. The results from the tests also indicted that leaching of the cement is occurring from prolonged saturation at the joint. It is recommended that the drainage at the joint be improved and deicers with no gypsum or sulfur be used in order to prolong the life of the joint.

The Ohio Strategic Research Program; Specific Pavement Studies. Ohio Research Institute for Transportation and the Environment, Athens, OH and ODOT, Columbus, OH, Summer 1997.

As part of its support for the Strategic Highway Research Program (SHRP), the Ohio Department of Transportation, in conjunction with the Federal Highway Administration, constructed a comprehensive test road encompassing four of nine experiments in the Specific Pavement Studies (SPS). This project affords SHRP with a unique opportunity to compare the performance of pavement sections in these experiments at one site where topography, soil, and climate are uniform.

To enhance the value of this test road, seasonal and dynamic response instrumentation were installed in 34 of the 40 test sections by civil engineering faculty, staff, and students from six universities in Ohio. Falling Weight Deflectometer and controlled vehicle loadings will be used to gather response data on these sections under a variety of environmental conditions and periodically throughout their service lives. These data will provide the pavement community with valuable insight into the effects of climate and cumulative traffic loadings on performance.

Paxton, J. T., and W. R. Feltz. Development of Laboratory and Field Methods for Detecting D-Cracking Susceptibility of Ohio Coarse Aggregates in Concrete Pavements. Report No. FHWA/OH/79/006. Ohio Department of Transportation, October 1979.

The phenomenon known as D-cracking cannot be detected in concrete pavements, prior to its appearance at the surface, by any non-destructive method other than coring. Several potential methods of detection available to the researchers were investigated on test slabs and actual pavements without success. Drilling of cores near the intersection of the longitudinal and transverse joints and visual examination of these cores will detect the advent and/or extent of D-cracking near the bottom of a pavement slab.

Several laboratory test methods were analyzed which it was hoped would indicate the d-cracking susceptibility of coarse aggregates, when used in concrete for pavement slabs. Tow methods were modified versions of ASTM C-666 A and B, two were unconfined freeze-thaw tests of the aggregate and the remaining two were standard sodium and magnesium soundness tests. The major modification of the ASTM C-666 test methods was to substitute the elongation of the test specimens measured as they undergo cycles of freezing and thawing for the weight loss determinations or sonic modulus determination. Further modifications included plotting the percent expansion against the number of cycles completed and calculating the area under the curve generated. Although ten specimens are used in testing the two high and tow low test results are removed before final analysis. The correlation of this test method with service records of various aggregates was fond to be excellent; however, when the same coarse aggregates were tested in sodium sulfate, magnesium sulfate or unconfined freeze and thaw, the results did not correlate well with the service records.

Portland Cement Concrete Pavement Using QC/QA, Supplemental Specification 888. State of Ohio Department of Transportation, January 3, 2002.

Supplemental specifications including 888.01 through 888.23. That includes information on materials, concrete proportioning, properties, and equipment, aggregate handling, mixing, concrete tests, quality control, acceptance, strength, smoothness, joint sealing, pavement thickness, sampling, core evaluation, method of measurement, basis of payments, pay adjustment, and deficiencies. Appendix 1 through 3 are included and discuss proportioning, quality control, and quality assurance.

Richards, A. M. Causes, Measurement and Prevention of Pavement Forces Leading to Blowups. Report No. OHIO-DOT-10-76. The University of Akron, Akron, OH, October 1976.

A survey o f blowup activity in Ohio’s concrete pavements was conducted. One hundred and seventy-two blowups of various severities were reported during 1975 and 1976.

A survey of blowup literature in the United States was conducted and resulted in an extensive bibliography of material dealing with jointed concrete pavements.

A method of measuring residual strains within a concrete pavement was developed. Strain gage rosettes are attached to the walls of a core hole by means of an installation tool which was invented for this project. The hole is over cored and the relief strains are measured. Availability theory has been adapted to allow computation of state of stress in the original slab at the level of the gages. Laboratory and field tests were conducted.

Computer models of the over core and an entire pavement slab were developed using the STRUDL package. Various temperature loadings and boundary conditions were studied.

Saraf, C. L. and K. Majidzadeh. Utilization of Recycled PCC Aggregates for Use in Rigid and Flexible Pavements. Report No. FHWA/OH-95/025. Resource International, Westerville, OH, June 1995.

This study reported herein was conducted to demonstrate the feasibility of using recycled crushed concrete form old pavements as aggregates in new PCC and asphalt pavements and to develop guidelines and criteria for making cost-effective decisions concerning the recycling of PCC pavements. This study included several activities such as: preconstruction evaluation of recycled PCC aggregates, construction monitoring and evaluation of mixes, post construction evaluation of mixes and data analysis.

Four test sections, each approximately 1146 feet long, were constructed on a roadway segment in Toledo areas located on I-475 (Lucas County). Each lane of this four lane road contained a PCC recycled aggregate section, PCC control section, AC recycled aggregate section and AC control section.

Cores of the old pavement (PCC) were obtained before their removal and tested in the laboratory. The aggregate from the crushed cores were then used to prepare trial mixes and measure the strength characteristics of the recycled mix. A crushing plant was designed and constructed at a quarry site to crush old pavements. This plant produced recycled aggregates for use in the mixes for test sections. Samples of recycled aggregates were used to design a mix for the construction of recycled PCC and AC test sections.

The samples of concrete and asphalt mixes were collected during the construction by RII staff and ODOT personnel. The results of tests performed on these samples are described in the report. Also, shortly after the construction of all test sections, 32 cores from rigid pavement test sections and 24 cores from flexible test sections were obtained. These samples were also tested in the laboratory to determine various characteristics of concrete and asphalt mixes. The results of these measurements are described in the report. Sixteen slabs out of a total of 216 slabs of recycled concrete mix developed transverse cracks at the mid-slab after about 2 months of their opening to traffic.

Based on the results of this study it was concluded that the use of recycled PCC aggregates in concrete mix is a feasible alternative. However, the use of sand portion of recycled aggregates in concrete mix is not practical because this material has very high absorption compared to natural sand.

Sargand, S. Application of High Performance Concrete in the Pavement System Structural Response of High Performance Concrete. Report No. FHWA/OH-2001/15. Ohio Department of Transportation, March 2002.

A concrete pavement was constructed on US 50 east of Athens Ohio to determine the influence of ground granulated blast furnace slag on the curing of a high performance concrete pavement, and on the performance of that pavement as it was subjected to environmental cycling and nondestructive testing with a Falling Weight Deflectometer (FWD). Three test sections of high performance concrete and one control section constructed with ODOT Class C concrete were instrumented and monitored closely to determine any differences in response and performance. The high performance sections contained 25% ground granulated blast furnace slag. Several joints were not sealed to evaluate their performance when compared to joints sealed in accordance with ODOT specifications.

Based upon laboratory tests and field data obtained during this study, the following conclusions were derived from this pavement. Temperature gradients generated between the surface and bottom of concrete slabs during the curing process can have a significant impact on the formation of early cracks. Large values of strain recorded in the field during the curing period indicted that the two sections of high performance pavement constructed on October 1997 would likely experience early cracking, as was observed. Field data indicted that a third high performance section and a control section containing standard ODOT class C concrete, both constructed in October 1998, had a lower probability of exhibiting early cracking, and no cracks were observed. The uncracked section of high performance concrete had less initial warping than did the control section constructed at the same time with standard ODOT Class C concrete. Early cracking in the other two cracked high performance sections precluded any comparison with the uncracked sections. FWD data indicated that the uncracked high performance section experienced slightly less deflection at the joints than did the section containing standard concrete, suggesting less curvature and less loss of support under these slabs than under slabs constructed with standard concrete. FWD joint deflections were higher in the cracked high performance sections after one year of service than before the sections were opened to traffic probably due to the presence of the cracks. Limited data suggested that moisture in the subgrade at sealed and unsealed joints was similar and, in some cases, more under the sealed joints than under the unsealed joints. FWD deflections at sealed joints were generally higher than at the unsealed joints.

Sargand, S. Application of High Performance Concrete in the Pavement System Structural Response of High Performance Concrete. Report No. FHWA/OH-2001/15. Ohio University, Athens, OH, March 2002.

A concrete pavement was constructed on US 50 east of Athens, Ohio to determine the influence of ground granulated blast furnace slag on the curing of a high performance concrete pavements, and on the performance of that pavement as it was subjected to environmental cycling and nondestructive testing with a Falling Weight Deflectometer (FWD). Three test sections of high performance concrete and one concrete section constructed with ODOT Class C concrete were instrumented and monitored closely to determine any differences in response and performance. The high performance sections contained 25% ground granulated blast furnace slag. Several joints were not sealed to evaluate their performance when compared to joints sealed in accordance with ODOT specifications.

Based upon laboratory tests and field data obtained during this study, the following conclusions were derived from this pavement. Temperature gradients generated between the surface and bottom on concrete slabs during the curing process can have a significant impact on the formation of early cracks. Large values of strain recorded in the field during the curing period indicated that the two sections of high performance pavement section and a control section containing standard ODOT Class C concrete, both constructed in October 1998, had a lower probability of exhibiting early cracking, and no cracks were observed. The uncracked section of high performance concrete had less initial warping than did the control section constructed at the same time with standard ODOT Class C concrete. Early cracking in the other two cracked high performance sections precluded any comparison with the uncracked sections. FWD data indicated that the uncracked high performance section experience slightly less deflection at the joints than did the section containing standard concrete, suggesting less curvature and less loss of support under these slabs than under slabs constructed with standard concrete. FWD joint deflections were higher in the cracked high performance sections after one year of service that before the sections were opened to traffic, probably due to the presence of the cracks. Limited data suggested that moisture in the subgrade at sealed and unsealed joints was similar and, in some cases, more under the sealed joints than under the unsealed joints. FWD deflections at sealed joints were generally higher than the unsealed joints.

Sargand. S. Continued Monitoring of Pavement in Ohio. Report No. FHWA/OH-2002/035. Ohio University, Athens, OH, Dec. 2002.

Performance and environmental data continued to be monitored throughout this study on the Ohio SHRP Test Road. Response testing included three new series of controlled vehicle tests and two sets of nondestructive tests. Cracking in two SPS-2 sections with lean concrete base confirmed observations elsewhere that PCC pavement may not perform well when placed on rigid base. Of the five types of base material used on LOG 33 and evaluated for their effect on AC pavement performance, deflection measurements on the asphalt treated base fluctuated most with changes in temperature. None of the other bases were sensitive to temperature. Cement treated base had the lowest deflection. On unbound material, bases containing large size stone have the lowest deflection. The preponderance of data collected in the laboratory and at the ERI/LOR2 site suggests that PCC pavement performs poorly on 307 NJ and CTFD bases. All sections with 25-foot slabs, except those with ATFD base, and the section with 13-foot slabs on 307 NJ base had significant transverse cracking. The 13-foot long slabs with 307 NJ base also had some longitudinal cracking. Considering the relatively short time these pavement sections had been in service, this level of performance was considered unacceptable. The ATFD base appeared to be performing best. On JAC/GAL 35, subgrade stiffness had a significant effect on dowel bar response. Looseness around dowel bars affected their ability to transfer load. Larger diameter and stiffer dowel bars provided better load transfer across PCC joints. The most effective dowel bar in these tests was the 1.5" diameter steel bar. The performance of 1" steel dowel bars were similar to 1.5" fiberglass bars. One-inch diameter fiberglass dowel bars were not recommended for PCC pavement. While undercutting PCC joint repairs initially reduced the forces in dowel bars, the effectiveness of the undercut diminished overtime. Dowel bar forces were about the same in the Y and YU types of joint repairs after some time.

Sargand, S., and G. Hazen. Coordination of Load Response Instrumentation of SHRP Pavements – Ohio University. Report No. FHWA/OH-99/009. Ohio University, Athens, OH, May 1999.

The Ohio Department of Transportation constructed an experimental pavement for the Strategic Highway Research Program (SHRP) on U.S. 23 north of Columbus, which included 40 asphalt and concrete test sections in the SPS-1, 2, 8 and 9 experiments. These sections contained various combinations of structural parameters known to affect performance.

To enhance the value of this pavement, sensors were installed in 18 test sections to continuously monitor temperature, moisture and frost within the pavement structure, and 33 test sections were instrumented to monitor strain, deflection and pressure generated by environmental cycling and dynamic loading. Also, two weigh-in-motion systems and a weather station were installed to continuously gather the necessary traffic and climatic information required to properly interpret the performance data. Six universities, including Ohio University which coordinated this effort, were responsible for installing and monitoring the instrumentation. Nondestructive testing conducted with the FWD and Dynaflect, and five series of controlled vehicle test were performed between 1995 and 1998 to assess the response of these test sections to dynamic loading. This report documents how the instrumentation was installed and monitored, provides details of the controlled vehicle tests, and summarizes results of the nondestructive testing.

Sargand, S. Development of an Instrumentation Plan for the Ohio SPS Test Pavement (DEL-23-17.48). Report No. FHWA/OH-94/019. Ohio University, Athens, OH, July 1994.

A Specific Pavement Studies (SPS) program, formulated under the Strategic Highway Research Program (SHRP), consists of nine experiments, four of which will be included in this DEL-23 project. Since the basic instrumentation plan proposed by SHRP was limited, Ohio Department of Transportation opted to develop a more comprehensive plan for DEL-23. The Ohio Test Road consists of SPS-1, SPS-2, SPS-8, and SPS-9 experiments, all constructed for this project where the climate, soil, and topography are uniform throughout. In this comprehensive instrumentation plan, thirty three sections are to be instrumented. LTPP guidelines require four instrumented sections in each of the SPS-1 and SPS-2 experiments for the study of seasonal factors and dynamic response. DEL-23 includes an additional nine instrumented sections for the SPS-1 experiment, twelve sections for the SPS-2 experiment, and two sections each in the SPS-8 and SPS-9 experiments to study structural response parameters. A total of eighteen sections will be instrumented for the study of seasonal factors, ten more sections than required by SHRP.

This report provides a detailed description of types of sensors, installation methodology, calibration procedures and wiring schematics for instrumentation of pavements for the Ohio SHRP SPS Test Road to measure environmental factors and structural response. Environmental or climatic parameters include temperature, base and subbase moisture, and frost depth. Structural response parameters entail strain, deflection, pressure, and joint opening.

Sargand, S. Effectiveness of Base Type on the Performance of PCC Pavement on ERI/LOR 2 (Interim Report for the Project Titled: Continued Monitoring of Instrumented Pavement in Ohio). Report No. FHWA/OH-2000/005. Ohio University, Athens, OH, April 2000.

This interim report discusses the current status of the ERI/LOR 2 research project that is investigating the effects of various base materials and design features on the performance of Portland concrete cement pavement. In 1990, rehabilitation for the initial project begun in 1974 was undertaken through the construction of additional test pavements in the westbound lanes of SR 2 between Station 1835+10 in Erie County and Station 90 + 23 in Lorain County.

Six base types and two aggregate sources were used in the new test sections. One of the aggregate base sources, #57 from Martin-Marietta in Woodville, Ohio, was considered resistant to D-cracking. The other, #57 from Sandusky Crushed Stone in Parkertown, Ohio, was considered susceptible to D-cracking. The six bases tested included ODOT 304, 310, 3071A, 307NJ, and asphalt and cement-treated free draining bases.

Nondestructive testing was performed in June and August 1999. Falling Weight Deflectometer (FWD) tests were conduced to determine load transfer on the test sections. Cracks in slabs were also evaluated through inspection and taking concrete cores. These core samples indicated that most of the cracks were initiated at the pavement surface and propagated downward. No D-cracking has been observed in the test sections. An extensive series of laboratory tests has also been completed to determine resilient modulus and the strength of each base type.

To date, the sections with bases 307NJ and CTFDB are performing poorly and have developed a substantial number of cracks. The ATFD base is performing the best of the test bases. Additional monitoring is needed to assess the overall performance of each base type and to address potential D-cracking.

Sargand, S. M., and G. A. Hazen. Evaluation of Pavement Joint Performance. Report No. FHWA/OH-93/021. Ohio University, Athens, Ohio, Aug. 1993.

In this study, field performance of steel and fiberglass dowels used for load transfer in rigid pavement repair sections was evaluated. Electric stain gages were cemented to dowel rods to determine shear forces, moments, torques and axial loads. Repair sections were instrumented to measure concrete and surface stresses. Loads were applied using Falling Weight Deflectometer, single and tandem axle trucks. Truck speeds were varied between 5 and 65 mph. Analysis of field data examined force variations due to truck speed, size and material for the dowels, and Y or YU joints. The dominating forces in the dowel rods were moments, and vertical shear forces. Field performance data was compared to analytical solutions using modified versions for ILLI-SLAB.

One inch diameter fiberglass dowel was not recommended for rigid pavement, and there was not a sufficient benefit to warrant (YU) joint. ILLI-SLAB was not capable of predicting true response of the joints. Recommendations were made for dowels and joint repair in rigid pavement sections.

Sargand, S. and E. Cinadr. Field Instrumentation of Dowels. Report No. ST/SS/97-002. Ohio University, Athens, OH, April 1997.

Four different types of dowels, 1 ½ inch diameter epoxy-coated steel bars, 1 ½ inch diameter fiberglass, 1 ½ deep steel and fiberglass I-beams, were instrumented with strain gages and installed. Forces that developed in these dowel bars due to curling and non-destructive testing using falling weight Deflectometer (FWD) were examined.

Based on the data obtained in this study, it can be concluded that generally moments due to curling were significantly higher than moments developed during the non-destructive testing (FWD). Also, forces in the fiberglass dowels were less than those in the steel dowels. It is obvious that dowel bars function as a load transfer mechanism at joints, but also, they served to reduce the magnitude of curling joints.

Sargand, S. and G. A. Hazen. Instrumentation of a Rigid Pavement System. Report No. FHWA/OH-97/001. Ohio University, Athens, OH, Nov. 1996.

This research on focused on development of a comprehensive field instrumentation program to measure the in-situ responses of a concrete pavement system subjected to Falling Weight Deflectometer (FWD) loading and various environmental conditions. Responses measured were slab stresses, vertical slab deflection, temperature gradient through the slab thickness, base and subgrade soil moisture content, and load transfer pressures at the slab-base interface.

Moisture content was found to increase up to 50% once an expansion crack develops. The temperature gradient through the slab was not linear. Deflections were greatest at the joints for environmental and FWD testing. Significant stresses and deflections developed in all lengths of slabs tested. Lowest stresses were recorded in the 21 foot slabs. Strain measuring sensors were able to detect stress relief due to cracking. Load transfer pressures at the slab-base interface and the moisture level of the base and subgrade did not appear to be significant.

Three-dimensional finite element modeling was shown to be effective for calculating deflections and stresses that develop due to changes in environmental factors and non-destructive testing.

Sargand,, S. Performance of Dowel Bars and Rigid Pavement. Report No. FHWA/HWY-01/2001. Ohio University, Athens, OH, June 2001.

In 1997, an experimental high performance jointed concrete pavement was constructed on US 50 east of Athens Ohio. In this pavement, 25% of the Portland cement was replaced with ground granulated blast furnace slag. Epoxy-coated steel dowel bars were used throughout most of the project to provide load transfer across the joints to adjacent slabs. Fiberglass dowels and stainless steel tubes filled with concrete were installed in a few joints to compare their effectiveness with the epoxy-coated bars. A limited number of epoxy-coated steel and fiberglass bars were instrumented with strain gauges to measure bending moments and vertical shear induced in the bars as the concrete cured, during environmental cycling of moisture and temperature in the concrete slab, and as Falling Weight Deflectometer applied dynamic loads near the pavement joints. Thermocouples were installed to monitor temperature at different depths in the concrete layer during the strain measurements. The strain data indicated that: 1) significant stresses were generated in the dowel bars and in the concrete surrounding the dowel bars soon after the concrete was placed, 2) temperature gradients in the concrete slabs caused high stresses in the bars, and 3) stress levels generated in the fiberglass dowel bars were less than those generated in the epoxy-coated steel bars.

Sargand, S. and D. Beegle. Three Dimensional Modeling of Rigid Pavement. Report No. ST/SS/95-002. Ohio University, Athens, OH, Feb. 17, 1995.

A finite-element program has been developed to model the response of rigid pavement to both static loads and temperature changes. The program is fully three-dimensional and incorporates not only the common twenty-node brick element but also a thin interface element and a three-node beam element. The interface element is used in the pavement-soil interface and in the joints between slabs. The dowel bars in the joints are modeled by the beam element, which included flexural and shear deformations. Stresses, strains, and displacements are computed for body forces, traffic loads, and temperature changes individually so that the program can be used to obtain either total stresses for design, or strain changes to compare with experimental data.

The effects of varying the material properties in the pavement, base, subgrade, interfaces, and dowels are investigated to identify those parameters which most influence the solution. Results of various interface thicknesses and dowel diameters also are presented. A further study is conducted to determine the effect of average pavement temperature on the curling stresses and displacements. Finally, results form the program are compared with experimental curling displacements and stresses.

Sehn, A. L. Evaluation of Portland Cement Concretes Containing Ground Granulated Blast Furnace Slag. Research Project No. 14559 (0). Ohio Department of Transportation and Federal Highway Administration May 2002.

A two-part laboratory experimental program was conducted to evaluate strength and durability of various concrete mix designs. In part I of the study, the influence of using grade 120 ground granulated blast furnace slag (GGBFS) on the strength and durability properties of concrete was evaluated. GGBFS was used to replace Portland cement at replacement rates ranging from 0 to 75 percent. Other test variables included the use of cements with different alkali contents, fly ash, silica fume, and Type K cement. Strength testing included compression strength, flexural strength, and splitting tensile strength. Durability testing included freeze-thaw resistance, shrinkage testing, rapid chloride ion penetration testing, and abrasion resistance testing. Based o the test results, the addition of GGBFS at rates as high as 55 percent of the total cementitious material resulted in strengths that, after 14 days, equaled or exceeded those of the baseline concrete mix. The incorporation of GGBFS in the concrete mix significantly improved the resistance to chloride ion penetration. In Part II of the study, the influence of coarse aggregate size on the strength and durability of the ODOT Class C mix designs was evaluated. Coarse aggregate sizes included #57, #467, and #357. The ODOT high performance concrete mix designs were also included in the study. Test results are presented in tabular and graphical formats.

Sehn, A. Load Response Instrumentation of SHRP Pavements – The University of Akron. Report No. FHWA/OH-2000/016.

During the early 1990's the Ohio Dept. of Transportation developed a plan to construct and instrument a series of pavement tests sections on U.S. 23 in Delaware County. The test pavements were constructed primarily during the 1995 construction season. The project includes pavements in four of the Specific Pavement Studies (SPS) of the Strategic Highway Research (SHRP). The SPS sections present in the project include: 1) SPS-1 Structural Factors for Flexible Pavements, 2) SPS-2 Structural Factors for Rigid Pavements, 3) SPS-8 Environmental Effects in the Absence of Heavy Loads, and 4) Asphalt Program Field Verification Studies.

The instrumentation for the pavement test sections was installed through a coordinated effort involving the Ohio Department of Transportation, the contractor for the project, and research teams for six universities throughout Ohio. The universities involved in the project included: 1) Case Western University, 2) Ohio State University, 3) Ohio University, 4) University of Akron, 5) University of Cincinnati, and 6) University of Toledo. Development of the instrumentation plan and coordination of the installation of the instrumentation was handled by the research team from Ohio University. Each of the participating universities was responsible for particular segments of the instrumentation. The responsibility of the University of Akron research group was to calibrate and install the earth pressure cells.

The work performed during this project consisted primarily of calibration and installation of sixty earth pressure cells for the ODOT SHRP pavement instrumentation project on U.S. Route 23 in Delaware County.

Each earth pressure cell was calibrated twice in the laboratory to determine its calibration factor and to verify proper operation and repeatability of the instrument. Results of the calibrator phase of the project indicated that each of the pressure cells functioned properly at the time of calibration and repeatable pressure cell response to applied pressure was confirmed.

The pressure cells were successfully installed in the appropriate pavement test sections as indicated in Tables 4 and 5 of the report. The only exception to this is that the pressure cells planned for installation in the pavement test section designated as SPS-1, 390105, J5 were not installed. This test section was paved without notification of the University of Akron participants.

The report contains details on the calibration procedures and the field installation procedures. The calibration factor from each calibration test and the complete responses recorded for each calibration test are included.

Sehn. A. Evaluation of Portland Cement Concretes Containing Ground Granulated Blast Furnace Slag. Report No. FHWA/OH-2002/022. University of Akron, Akron, OH, May 2002.

A two-part laboratory experimental program was conducted to evaluate strength and durability of various concrete mix designs. In Part I of the study, the influence of using grade 120 ground granulated blast furnace slag (GGBFS) on the strength and durability properties of concrete was evaluated. GGBFS was used to replace portland cement at replacement rates ranging for 0 to 75 percent. Other test variables included the use of cements with different alkali contents, fly ash, silica fume, and Type K cement. Strength testing included compressive strength, flexural strength, and splitting tensile strength. Durability testing included freeze-thaw resistance, shrinkage of testing, rapid chloride ion penetration testing, and abrasion resistance testing. Based on the test results, the addition of GGBFS at rates as high as 55 percent of the total cementitious material resulted in strengths that, after 14 days, equaled or exceeded those of the baseline concrete mix. The incorporation of GGBFS in the concrete mix significantly improved the resistance to chloride ion penetration. In Part II of the study, the influence of coarse aggregate size on the strength and durability of the ODOT Class C mix designs was evaluated. Coarse aggregate sizes included #57, #467, and #357. The ODOT high performance concrete mix designs were also included in the study. Test results are presented in tabular and graphical formats.

Stark, D. The Significance of Pavement Design and Materials in D-cracking. Report No. FHWA/OH-86/008. Construction Technology Laboratories, Skokie, IL, Dec. 1986.

A two-phase program was undertaken to verify, under field conditions, that reducing maximum aggregate particle size can minimize or eliminate D-cracking. This study was carried out also to determine the role of other materials and environmental factors in D-cracking which are not amenable to laboratory study. One phase consisted of repeat pavement surveys of existing pavements to determine whether reducing maximum particle sizes has alleviated D-cracking. The other, primary, phase consisted of monitoring the performance of a test road near Vermilion, Ohio, using visual inspections and moisture measurements and examinations of concrete cores. Visual inspections confirm that reducing the maximum particle size does minimize or eliminate D-cracking. Other observations indicate that pavement concrete on clay subgrade, stabilized granular bases with and without artificial drains, and vapor barriers, performed similarly with respect to the initial development of D-cracking. Type of joint seal, including no seal, had no significant effect of D-cracking. Moisture measurements of cores indicated an increase in degree of saturation of concrete after one year, with a general leveling off after that period. Saturation levels were, overall, somewhat higher near the bottom than near the top of the slab. Examination of cores revealed that D-cracking is developing upward from near the bottom of the slab. Other observations revealed that where maximum aggregate particle size was reduced to avoid D-cracking, a greater incidence of intermediate transverse cracking developed with attendant faulting. It is recommended that the test road continue to be monitored through visual inspection and examination of cores.

Stark, D. C. The Significance of Pavement Design and Materials in D-Cracking. Report No. FHWA/OH/91/009. Construction Technology Laboratories, Skokie, IL, June 1991.

A two-phase investigation was carried out to determine the efficacy of reducing the maximum size of coarse aggregate to minimize freeze-thaw damage and the development of D-cracking in highway pavements. This included evaluation factors not amenable to laboratory conditions. One phase consisted of repeat pavement surveys of already existing pavements to determine whether reducing maximum particle sizes of coarse aggregate alleviated D-cracking. Results are summarized in an interim report for this project, dated Dec. 1986. The other, primary phase was the construction and monitoring of a test pavement on SR2 near Vermilion, Ohio, which incorporated design as well as materials variables with respect to D-cracking (and other performance characteristics). Results after 16 years of service (1975 through 1999) indicate that reducing the maximum size of coarse aggregate can alleviate D-cracking, and that, once initiated as seen at the wearing surface, traffic loading becomes an important factor in propagating the extent and severity of deterioration. “Daylighting” the granular subbase (no artificial drains) greatly improved the rideability of the pavement, while other factors, such as source of cement, joint sealants, subbase vapor barriers, and longitudinal drains were of minor, if any, significance. Other effects on performance also were noted. For example, reducing the maximum size of coarse aggregate tended to increase the frequency of transverse cracks, many, if not most, of which were faulted. Unsealed joints appeared to perform as well as joints containing sealants. Tied concrete shoulders appeared to greatly alleviate faulting and pumping.

Transverse Cracking of High Performance Concrete Bridge Decks After One Season or Six to Eight Months. University of Cincinnati, Cincinnati, OH, TRB research in progress.

The objectives of this study are to establish better HPC concrete mixes that not only achieve the required strength, permeability, and durability properties, but also exhibit lower shrinkage, easier mixing, and finishing, and more tolerance to field variances of consolidation, curing application, and traffic vibrations due to phased construction. This will be accomplished as follows: (1) investigate the cause of cracking in the existing HPC bridge decks; (2) recommend needed changes in field controls, specifications, and concrete mixes; and (3) investigate the effectiveness of the proposed changes and solutions, and validate them by laboratory and field testing.

Williams, G. J. and E. Chou. Performance Evaluations of Rigid Pavement Rehabilitation Techniques. Report No. ST/SS/94-002. The University of Toledo, Toledo, OH, March 1994.

This study investigated the effectiveness of concrete pavement rehabilitation techniques. Six main techniques were evaluated. They were full depth repair, joint restoration, pavement overlay, concrete pavement restoration, crack and seat, and subsealing. Conclusions on the effectiveness of the techniques were based on functional and structural data collected on 10 projects around the state of Ohio. Observations of trends in the data over time and over traffic loads along with statistical analysis comprised the methods used to analyze the data for the conclusions. The results indicate joint spacing of less than 27 feet improve the effectiveness of joint/full depth repair on joint performance. Portland cement concrete overlays outperform asphalt concrete overlays both functionally and structurally. Sawing and sealing joints in asphalt concrete overlays perform better than not sawing and sealing joints in asphalt concrete overlays. Concrete pavement restoration is not very effective as a rehabilitation technique. Subsealing improves the soil conditions underneath a pavement. And finally, crack and seated Portland cement concrete pavement outperforms non-crack and seated Portland cement concrete pavement when used underneath an asphalt concrete overlay. The results obtained here should be complimented with additional data to add further confidence to these results.

North Dakota

Portland Cement Concrete Pavement: Section 550.
550.01 Description
550.02
550.03 Required Tests and Frequency
550.04

816.03 Sample Numbering
816.04
816.05 Aggregate Testing
816.06

Hudson, B. Discovering the Lost Aggregate Opportunity. ***Pit & Quarry*****, October 2003, pp. 32-34.**

An online forum draws discussion about Shilstone's Specification – eight to 18, a current concrete aggregate. Some may know this as Shilstone's Specification, although the shilstone that is credited or maybe even blamed for this hard-to-produce aggregate specification denies that he is the creator. The purpose of this aggregate specification is to make a better-quality concrete, and reduce shrinkage and curling in large floor slabs. For aggregate producers, it is difficult to manufacture. This particular specification is gaining more acceptance than most, but it may have some basic flaws. Some of these flaws are that people are applying these specs. without understanding, and they are too rigid and difficult to follow. This article included excerpts from the question and answer forum at www.aggregateresearch.com. This discussion thread was initiated by Tony Wright of Titan North America.

Hauge, H. A Discussion on Curing and Sealing. *Hard Facts*, Summer 2003.

Curing and sealing are two distinct processes. Curing is a temperature and moisture control process that ensures proper development of the engineering properties of a concrete placement. Sealing is a process in which compounds are applied to the surface of hardened concrete to reduce the penetration of contaminants into to the concrete. Sealers are typically not applied until the concrete placement has had a chance to "cure out" for 28 days.

The results of proper curing are more durable and more wear resistant concrete. Methods of curing are wet curing and membrane curing. Concrete sealers are designed to supplement, not replace, the weathering characteristics of a durable, properly cured concrete surface. Different concrete sealers are film-forming and penetrating sealers.

Duncan, T. Prescriptive vs. Performance Based Specifications for Concrete. *Hard Facts*, Summer 2003.

Specifications for ready mix concrete have not evolved at the same pace as innovations in the concrete industry. For the most part specifications today still have prescriptive provisions such as specifying the types and quantities of the mixture ingredients, limits on cementitious materials, water cement ratios, aggregate grading, etc.

Prescriptive specifications inhibit innovation and professionalism in the concrete industry. It also limits the competitiveness, profitability, economy, and assignment of responsibility for concrete construction.

The goals of the ready mix producers are as follows: 1) Requirements for concrete mixtures should be performance based of constructability and in-place properties. The concrete producer should be empowered to optimize mix designs for the intended performance without many of the normally seen prescriptive restrictions. 2) The producer is qualified t make economical decisions as effective as the engineer needs while maintaining accountably for the product. 3) The submittal process should be simplified and the concrete producer should be able to make real time adjustments to mixtures while retaining the intellectual property of the mixture composition.

Sethre, D. Aggregate Optimization: Its Time Has Come. *Hard Facts*, Summer 2003.

Aggregate optimization has been one of the least understood tools for ride and smoothness enhancements in all of he concrete paving industry up until recently. Much of the discussion has been based on durability benefits of reducing mix paste contents through the uses of uniformly graded aggregates to fill voids in the matrix. The theory states that the paste is the least durable component of concrete, while aggregate is the most durable. Even nominal attempts to fill gaps in concrete gradations have brought profound benefits for lower concrete permeability characteristics at lower paste contents, as shown by recent NDDOT funded research.

The use of more uniformly graded aggregates has been found to be a major solution to problems of segregation in normal mixes, as compared to our ordinary gap graded mixes composed of large stone and sand. US of aggregate optimization techniques improved workability to the extent that pavement smoothness was no longer an issue. Jim Lafrenz, Director of Airports as ACPA National, has a spreadsheet is available for evaluating aggregate gradations for workability.

South Dakota

Hodges, D. PCC Pavement Design Mix (memo). Division of Planning/Engineering, South Dakota Department of Transportation, June 11, 2002.
The slipform Portland cement concrete pavement mix design with Modified Class F fly ash and Type I-II cement for a project in McCook County.

Hodges, D. PCC Pavement Design Mix (memo). Division of Planning/Engineering, South Dakota Department of Transportation, July 1, 2003.
The slipform Portland cement concrete pavement mix design with Modified Class F fly ash and Type I-II cement for a project in Brown and Day County. One mix has water reducer and one does not.

Hodges, D. PCC Pavement Design Mix (memo). Division of Planning/Engineering, South Dakota Department of Transportation, May 10, 2002.
The slipform Portland cement concrete pavement mix design with Modified Class F fly ash and Type II cement for a project in Pennington County.

Bench-Bresher, J. Paving Mix Design (memo). South Dakota Department of Transportation, April 14, 2003.
Concrete materials of Sioux Falls, SD has selected these materials to be used in the class A-45 paving mix for a project in Yankton County.

Hodges, D. Class A-45 Paving Mix. South Dakota Department of Transportation.
A listing of the materials used for project NH 0235(2) in Pennington County.

Hodges, D. Paving Mix Design (memo). Division of Planning/Engineering, South Dakota Department of Transportation, August 14, 2003.
A list of the materials, selected by the contractor, to be used in the class A-45 paving mix for project NH 0012(00)189 in Walworth County.

Cross, W., E. Duke, J. Kellar, and D. Johnston*. Investigation of Low Compressive Strengths of Concrete Paving, Precast and Structural Concrete*. Report No. SD98-03-F. Office of Research, South Dakota Department of Transportation, August 2000.
This research examines the causes for a high incidence of catastrophically low compressive strengths, primarily on structural concrete. The source for the low strengths was poor aggregate paste bond associated with air void clusters and poorly formed cement paste in the interfacial region adjacent to the aggregate. An interaction between the synthetic air entraining admixtures, used as substitutes for vinsol resin, and low alkali cements was directly tied to the problem with high summertime temperatures also contributing to the problem. The synthetics appear to be more hydrophobic, form thinner walled air bubbles and develop rapid draining bubble flocculations more readily than vinsol resin, all of which can lead to significant reductions in strength. The Department specified the sole use of vinsol resin air entraining agents along with water reducers and these measures have minimized the incidence of low strengths. Laboratory testing of concrete mixes with various air entraining admixtures demonstrated an interaction was taking place with one cement and petrographic and chemical analysis of the cements used in the testing implicated alkali sulfates as a potential source of the interaction. Testing of the synthetic air entraining admixtures showed they have substantially different properties compared to vinsol resin. Mixtures of the synthetics and vinsol resin with 50% or more vinsol resin behaved similarly to vinsol alone.

Ramakrishnan, V. ***The Determination of the Permeability, Density, and Bond Strength of Non-Metallic Fiber Reinforced Concrete in Bridge Deck Overlay Applications*****. Report No. SD1998-18-F. South Dakota School of Mines and Technology, Rapid City, July 30, 2000.**

This final report presents the procedures and results of the rapid chloride permeability, density, and bond strengths of cores taken from non-metallic fiber reinforced concrete (NMFRC) and plain low slump dense concrete (LSDC) bridge deck overlays constructed earlier on the bridge at Exit 212 over I-90 (I-90/US 83), and Exit 32 on I-90.

Both the filled in-place and laboratory bond tests were done for the cores drilled in the field. The density and chloride permeability were also determined for the concrete specimens cast in the laboratory with 5 different compacting efforts, for each different concrete used in the construction of the above referenced bridge decks.

A comparison of the results from the field and laboratory mixes had shown that there was good bond between the overlay concrete and the old concrete and the bond strength was greater than the tensile strength of the old concrete, because in all cores the failure was in the old concrete. The chloride permeability mainly depended on the cement content and compacting effort used in making the cylinders. The addition of fibers did not influence the chloride permeability and density of the concrete. Recommendations were made regarding the equipment and testing procedures necessary for designing the NMFRC mix, and equipment and testing procedures required for quality control in the field.

Johnston, D. ***Evaluation of the Performance of Set Retarders and High Range Water-Reducers in Typical SDDOT Concrete Mixes*****. Report No. SD92-076-F. Office of Research, South Dakota Department of Transportation, May 1996.**

This research examines whether cement-admixture compatibility problems exist and investigates methods of reducing the potential impact of the resulting premature stiffening, rapid slump loss and unpredictable setting behavior, which may result when an undesirable interaction occurs. Severe incompatibility problems with both set retarders and high range water reducers were observed with specific samples of two of the three cements and all of the admixtures tested and appear to be directly related to the C_3A content of the cement. Although mixes using retarders did not exhibit the same degree of deterioration in concrete mix properties as high range water reducers, both admixture types developed adverse and unpredictable behavior. Set retardation was inhibited with some cement-retarder combinations and premature stiffening, rapid slump loss and inability to entrain sufficient air occurred when these same cement samples were used in concrete mixes with high range water reduces.

Delayed addition of admixtures eliminated most of the problems encountered with a 5-10 minute wait usually sufficient to restore normal behavior. Field trials utilizing set retarders and high range water reducers are recommended to develop guidelines for routine admixture use with a significant reduction in potential compatibility problems.

Bridge Deck Overlay. South Dakota Department of Transportation Materials Lab.

The types of coarse aggregate in the existing and low slump bridge decks are discussed. The fine aggregates used in the Portland cement concrete in the "Low Slump Dense Concrete Bridge Deck Overlay" and "Class A45 Concrete Fill" and the testing of the fine aggregate are discussed. The known aggregate sources are included as well as several other details regarding the PCC used for SDDOT projects.

Wisconsin

WisDOT Internet: Doing Business. Standardized special provisions (STSP) for engineering and related services consultant firms. http://dotnet/consultants/stsp.htm, accessed October 7,2003.

The standardized special provisions describe the directions and requirements of a highway work proposal that are not detailed or prescribed in the Standard Specification 2003 Edition.

Standardized special provisions are available for WisDOT eligible engineering consultants, city, county and municipal staff to download as zipped files from the WisDOT FTP server.

Attached:

- QMP Concrete Pavement Rural, Item 415.1198.S; Incentive Strength Concrete Pavement, Item 415.2000.S
- QMP Concrete Urban, Item 415.1195.S; Incentive Strength Concrete Pavement, Item 415.2000.S

QMP Specs WisDOT on Disc:

- QMP Concrete Pavement Rural, Item 415.1198.S; Incentive Strength Concrete Pavement, Item 415.2000.S. (415 060)
- Concrete Masonry (501 010)
- QMP Concrete Urban, Item 415.1195.S; Incentive Strength Concrete Pavement, Item 415.2000.S. (415 061)

I-90-94 Wis Conc Pavement

Power Point Presentation: RED Reports - Wisconsin Dells PCC Pavements, FWHA TWG. Includes photos showing removal and replacement of cracked PCC pavement. No text.

Standard Specifications for Highway and Structure Construction (CD). Wisconsin Department of Transportation, 2003 Edition.

APPENDIX D. SUMMARY COMPILATION OF STATE PRACTICES

Mix Design Summary
Mix Verification and Quality Control Summary
Typical Mix Designs

Mix Design Summary

			Georgia	Indiana	Iowa	Kansas	Louisiana	Michigan	Minnesota	Missouri
Who provides mix design			Contractor/Supplier*	State*	State&Contractor/Supplier*	Contractor/Supplier*	Contractor/Supplier	Contractor/State	Contractor*	Non QC/QA (State) QC/QA (Contractor)
Mix design procedure			state specific procedure/past experience*	other; many contractors have general mix to start with	A state specific procedure (based on shilstone gradatin) / Another procedure	State Specific	State Specific, Contractor's decision		Industry Standard	State Standard/Other*
Specified concrete properties in contract documents	Fresh Concrete	Workability/Slump	X	non QC/QA		X	X	X	X	X
		Bleeding								
		Segregation								
		Set								
		w/cm ratio	X	QC/QA and non QC/QA	X	X	X	X	X	X
		Plastic Shrinkage Cracking		min cement content and spec						
	Hardened Concrete	Strength at Opening	X	contractor will develop mix base on time to get on it - 550 pr.flex			X		X	X
		Strength at 28 days	X		X*	X	X	X		X
		Coefficient of Thermal Expansion								
		Drying Shrinkage								
		Permeability		only bridge decks					X*	
	Concrete Durability	Resistance to freezing and thawing				X (need more info)				
		Resistance to sulfate attack				X (need more info)				
		Resistance to ASR				X (need more info)				
		Abrasion Resistance				X (need more info)				
		Corrosion Resistance								
	Other	Specify	Air content (fresh)	Air content pay factor for QC/QA: lot range, consistency, at the plant, point of acceptance; sec.501.28 not test behind the paver				Air content, concrete temp	HPP - Strength Data	Air content
Rank of desired concrete properties (1 = most important)	Fresh Concrete	Workability/Slump	1		2	1				specification
		Bleeding	4			4				10
		Segregation	5			5			X*	3
		Set	2		3	2	4			8
		Plastic Shrinkage Cracking	3			3	2			2
	Hardened Concrete	Strength/Stiffness	1			1				specification
		Coefficient of Thermal Expansion (CTE)	4			4	5			11
		Drying Shrinkage	2			3	3			9
		Permeability	3			2	8		X*	6
	Concrete Durability	Resistance to freezing and thawing	2		1	1	6			1
		Resistance to sulfate attack	5			3				7
		Resistance to ASR	3			1				4*
		Abrasion Resistance	1			3	1			5
		Corrosion Resistance	4	No		3	7			12
	Other	Specify								
Typical values for mix design parameters			*							
	W/C ratio	Min	0.45			0.40	none	none		none
		Max	0.53	QC (0.45); non QC (0.487)	0.45 / 0.48	0.45*	0.53	0.5	0.40	0.48
		Typical	lower than typical*	0.42-0.43	QMC Pav. / Class C	0.42	0.48	0.45		0.45
	Slump	Construction Method	SF	SF	SF	SF	SF	SF/FF with no WR	SF	SF
		Min	0	1.25		0.5	1		1	none
		Max	3.5*	3.0		1.75	2.5	3	2	2.5
		Typical	1.0-1.5		2.5-3.0"	1.25		1.5		1.25
		Construction Method	FF	FF	FP	FF	FF - vibrated	SF/FF with MRWR	FF	FF
		Min	0	2	1/2"	2	2	??	3	none
		Max	3.5	4	4.0"	4	4	6	4	3.5
		Typical	2.0-2.5		3.5"	2.5		??		3
	Air Content	Application	Standard paving	Sec.501 (QC)*	FP	SF*	All	SF	pavement	QC/QA - PCCP (behind paver)
		Lower Limit	3	5.7	6.0	4	3	5.0	5.0	5.5
		+/-			1.0					
		Upper Limit	6.5	8.9		7	7	8.0	8.0	8.5
		+/-								
		Application	24 hr accelerated	Sec.502 (non QC)					HP pavement	Non QC/QA PCCP (ahead of paver)
		Lower Limit	3.0	5.0					5.5	4.0
		+/-								
		Upper Limit	6.0	8.0					8.5	7.0
		+/-								
	Water Content	Application		Sec 501 (QC)	QMC	MA-2*	Pavement (Type B)	Need more info	Pavement	SF - Typical Values
		Lower Limit (lb/cu. Yd)	242		213	Need more info		Need more info		254
		Upper Limit (lb/cu. Yd)	275	198	235	Need more info	289	Need more info	240	271
		Application		Sec.502 (non QC)	Class C	All concrete, MA-1	Pavement (Type D)			FF - Typical Values
		Lower Limit (lb/cu. Yd)			223	Need more info	269			264
		Upper Limit (lb/cu. Yd)		275	240	Need more info				281
		Application				SF, MA-3*				
		Lower Limit (lb/cu. Yd)				Need more info				
		Upper Limit (lb/cu. Yd)				Need more info				
	Cementitious Content	Application	Standard paving	Sec.501 (QC)	QMC	MA-2 & Coarse and Fine	SF pavement (Type B, 1 1/2" max)	Need more info	pavement	SF - QC/QA*
		Lower Limit (lb/cu. Yd)	541	440	540	602	545	Need more info		564
		Upper Limit (lb/cu. Yd)	658		560			Need more info	600	none
		Application	Lane replacement	Sec.502 (non QC)	Class C	All concrete, MA-1	SF pavement (Type D, 2" max)		HES pavement	SF - Non QC/QA
		Lower Limit (lb/cu. Yd)	752	564 (specified)	571	619	508			564
		Upper Limit (lb/cu. Yd)			640				>600*	602
		Application				SF, MA-3				FF
		Lower Limit (lb/cu. Yd)				521				588
		Upper Limit (lb/cu. Yd)								625

			Nebraska	New York	North Carolina	North Dakota	Ohio	South Dakota	Texas	Wisconsin
Who provides mix design			State	State&Contractor/Supplier*	Contractor/Supplier*	State (engineer designed)	State&Contractor/Supplier*	State	Contractor/Supplier	Contractor
Mix design procedure			State Specific	state specific procedure	ACI 211.1*	State specific	ACI 211.1 (QC/QA spec) / State Std. Spec.*	past experience/ACI 211.1	ACI 211.1	State Specific/Past Experience
Specified concrete properties in contract documents	Fresh Concrete	Workability/Slump		X (Table 501 - 3)	X	X	1-3" std. & QC/QA	X	X	X
		Bleeding								
		Segregation		X (Table 501 - 3.03 B)						
		Set			X*					
		w/cm ratio	X	X (Table 501 - 3)	X	X	0.50 std. / 0.45 QC/QA		X*	X
		Plastic Shrinkage Cracking		X (502 - 3.14)						
	Hardened Concrete	Strength at Opening		X (502 - 3.18)	X*		600psi center point flex. -std.&QC/QA	X		X
		Strength at 28 days			X*	X ??	not required - std.4000psi+1.65σ-QC/QA	X		X
		Coefficient of Thermal Expansion								
		Drying Shrinkage								
		Permeability			X*					
	Concrete Durability	Resistance to freezing and thawing		X	X*		ASTM C666 Proc B@ 350 cycles*			
		Resistance to sulfate attack		X						
		Resistance to ASR		X	X*					
		Abrasion Resistance			X*				X	
		Corrosion Resistance			X*					
	Other	Specify		Air		Air content	Field: air content (6%); smoothness (profilograph); thickness (design -1/2")	Air and concrete temperature	Air/CTE/ASR (Need more info)	
Rank of desired concrete properties (1 = most important)	Fresh Concrete	Workability/Slump	X			4	6	X	1	
		Bleeding			3		14		1	
		Segregation			1		15		1	
		Set				5	13		1	
		Plastic Shrinkage Cracking			2		4		1	
	Hardened Concrete	Strength/Stiffness				1	2		1	
		Coefficient of Thermal Expansion (CTE)			5		8		1	
		Drying Shrinkage			4		3		1	
		Permeability				2	7	X	1	X
	Concrete Durability	Resistance to freezing and thawing				3	1		1	X
		Resistance to sulfate attack			6		10		1	
		Resistance to ASR					9	X	1	
		Abrasion Resistance					5		1	
		Corrosion Resistance					11		1	
	Other	Specify								
Typical values for mix design parameters										
	W/C ratio	Min							none	
		Max	0.45		0.559 (plain) / 0.538 (fly ash)	0.48	0.45 (QC/QA) / 0.50 (Std.)	mix design dependant	0.45	0.42
		Typical	need more info	0.44*	0.491 / 0.500 / 0.45 (note)	0.42	0.45 (SF)		need more info	0.40
	Slump	Construction Method	SF*	SF		SF	SF*	SF	need more info	SF
		Min	0				1.0	0	need more info	
		Max	3		1.5 SF / 3.0 FP	3	3.0	2	need more info	2.5
		Typical		40mm	1.5 / 3.0	1.5	1.0	need more info		1.5
		Construction Method		FF*		FF	FP	FF - A45 mix		FF
		Min		50mm			1.0	1		2
		Max		65mm		3	6.0	3		4
		Typical		Adjusted accordingly		2.5	4.0	need more info		4
	Air Content	Application	SF Pavement 47B-3625*	Class C (std. Mix)	concrete pavement*	SF	SF or PF*	SF	need more info	SF
		Lower Limit	5.0	5.0	5.0	5.0	6.0	5.0	need more info	5.5
		+/-			1.50%		2.0		need more info	
		Upper Limit	7.5	8.0		8.0		7.5	need more info	8.5
		+/-							need more info	
		Application	Bridge Deck	Class F (501 - std. HES)		FF		FF		All except SF
		Lower Limit	5.0	5.0		5.0		5.0		4.5
		+/-								
		Upper Limit	7.0	8.0		8.0		7.5		7.5
		+/-								
	Water Content	Application	SF Pavement 47B-3625	Class C	concrete pavement	SF	*	SF	need more info	Pavement
		Lower Limit (lb/cu. Yd)			258			225	need more info	225
		Upper Limit (lb/cu. Yd)	254	266	275	267.4		260	need more info	266
		Application				FF		FF		
		Lower Limit (lb/cu. Yd)		Class F				272 Average		
		Upper Limit (lb/cu. Yd)		272		267.4				
		Application								
		Lower Limit (lb/cu. Yd)								
		Upper Limit (lb/cu. Yd)								
	Cementitious Content	Application	SF Pavement 47B-3625	Class C	concrete pavement*	SF	Std. Mix	SF*	need more info	pavement
		Lower Limit (lb/cu. Yd)	565		526	564	550	624 Typical	need more info	565
		Upper Limit (lb/cu. Yd)		605	564		600	624 - typical	need more info	
		Application	Bridge Deck - 47BD-4350	Class F		FF	QC/QA (55.888)	FF*		
		Lower Limit (lb/cu. Yd)	657			564	ACI 211	680 - typical		
		Upper Limit (lb/cu. Yd)		716				680 - typical		
		Application								
		Lower Limit (lb/cu. Yd)								
		Upper Limit (lb/cu. Yd)								

			Georgia	Indiana	Iowa	Kansas	Louisiana	Michigan	Minnesota	Missouri
	Maximum Size of coarse aggregate (inches)		1.0" (nominal)	1.0" (top sieve)*	1.5"	1	2	Need more info	2	1
	Coarse Aggregate	Application	All pavements		QMC	Pavement*		Need more info	pavement	SF
		Lower Limit (lb/cu. Yd)	1750		1650	1000		Need more info	no requirement	11.06 ft^3/yd^3
		Upper Limit (lb/cu. Yd)	1900		1800	2000		Need more info	no requirement	11.34ft^3/yd^3
		Application			Class C					FF
		Lower Limit (lb/cu. Yd)			1150					10.88ft^3/yd^3
		Upper Limit (lb/cu. Yd)			1650					11.16ft^3/yd^3
	Fine Aggregate	Application	All pavements	Sec. 501 (QC)	QMC	Pavement*	Pavement*	Need more info	pavement	SF
		Lower Limit (lb/cu. Yd)	1150	35-50% of total agg.	1210			Need more info	no requirement	6.78 ft^3/yd^3
		Upper Limit (lb/cu. Yd)	1300		1350			Need more info	no requirement	6.95 ft^3/yd^3
		Application		Sec.502 (non QC)	Class C					FF
		Lower Limit (lb/cu. Yd)		35-45% of total agg.	1350					6.67 ft^3/yd^3
		Upper Limit (lb/cu. Yd)			1725					6.84 ft^3/yd^3
	SCMs commonly used in concrete mix design	Class F Fly Ash	X*	X*				X*	X*	
		Application	all except accelerated	501 and 502				pavement	pavement	
		Class C Fly Ash	X	X	X		X*	X	X	X*
		Application	all except accelerated	501 and 502	SF, FP		all	pavement	pavement	pavement
		GGBFS Slag	X*	X	X		X*	X*	X	
		Application	early strength not required	allowed but not often; fly ash cheaper	SF, FP		all	pavement	pavement	
		Silica Fume				X			X	
		Application		many issue/spec change to ternary		bridges			bridge deck	
		Metakaolin								
		Application								
		Volcanic Ash/Pumicite								
		Application								
		Calcinated Shale								
		Application								
		Opaline Shale								
		Application								
		Calcinated Clay								
		Application								
		Diatomaceous Earth								
		Application								
		Other								
		Application								
	Chemical admixtures commonly used in concrete mix design	Air entraining admixtures	X	X	X	X	X	X	X	X
		Application	All pavements	501 and 502	SF, FP	pavement	pavement	pavement	pavement	all pavements
		Coventional water reducer	X	X*	X	X*	X	X	X	X
		Application	All pavements	501 and 502	SF, FP	pavement	pavement	pavement	pavement	pavement
		Mid-range water reducer	X	X	X		X	X	X	X
		Application	Lower water content	501 and 502 (not often)	SF, FP		pavement	pavement	pavement	pavement
		Accelerator	X					X	X*	
		Application	Opening traffic early					patch repair	no response	
		Retarder	X	X	X		X	X	X	
		Application	Haul time	501 and 502	Long haul, hot day		pavement	pavement	bridges	
		Corrosion inhibitor								
		Application								
		Shrinkage reducer								
		Application								
		ASR inhibitors (I.e. Lithium)							X*	
		Application							pavements	
		Hydration control admixtures							X	
		Application							none for paving	
		Other (describe)								
		Application								
Typical combinations of cement, SCM, and chemical admixtures for paving mixes	Paving mix 1	Cement type	Type 1 & 2	PC and Blended (copmly Sec.901.01)	Type 1	Type I/II (Low Alkali, 0.6 maximum)	Type IS	Need more info	I	Type I
		Batch weight (lb/yd)	541-752	min. 440		550 ??	254	Need more info	400	573
		SCM	F or C fly ash, or slag*	pozzolan max. 20%+-5% of PC	Class C	Typically, none are used.	GGBFS Slag	Need more info	Class C fly ash	none
		Batch weight (lb/yd)			20%		254	Need more info	170	
		Chemical admixture 1	WR (3-5 oz/CWT)		AEA	AEA	AEA	Need more info	WR	AEA
		dosage (fl oz/cwt)	Mid range WR (3-5 oz/CWT)			0.5 to .75	0.8 to 1.0	Need more info	unknown	0.5 to 3.0
		Chemical admixture 2	Accel. (3 gal./yd)		WR	WR	WR	Need more info	AEA	
		dosage (fl oz/cwt)	Retarder (<6 oz/CWT)			5.0	4.0 to 8.0	Need more info	unknown	
	Paving mix 2	Cement type	AEA (2-5 oz/CWT)	PC and Blended (copmly Sec.901.01)*	Type 1&2		Type I/II		I	Type I
		Batch weight (lb/yd)		min. 564			508		360	486
		SCM	*	fly ash max.20% / GGBFS max.30% of PC	Class C				GGBFS	Class C Fly Ash
		Batch weight (lb/yd)			20%				190	86
		Chemical admixture 1		types A-E prior to written approval	AEA		AEA		WR	AEA
		dosage (fl oz/cwt)					0.8 to 1.0		unknown	0.5 to 3.0
		Chemical admixture 2			WR		WR		AEA	
		dosage (fl oz/cwt)					4.0 to 8.0		unknown	
	Paving mix 3	Cement type		PC and Blended (copmly Sec.901.01)					i	Type I (1/2 sack reduction)
		Batch weight (lb/yd)		min. 564					450	465
		SCM		fly ash max.10% / GGBFS max.15% of PC					Class C fly ash	Class C Fly Ash
		Batch weight (lb/yd)							120	81
		Chemical admixture 1		types A-E prior to written approval					WR	AEA
		dosage (fl oz/cwt)							unknown	0.5 to 3.0
		Chemical admixture 2							AEA	Type A WR*
		dosage (fl oz/cwt)							unknown	unknown

			Nebraska	New York	North Carolina	North Dakota	Ohio	South Dakota	Texas	Wisconsin
	Maximum Size of coarse aggregate (inches)		1	0.5" (CA 1); 1.0" (CA 2)*	1.5" (1.0" nominal)*	1.5	1.0"*	1.5"		1.5
	Coarse Aggregate	Application	SF Pavement 47B-3625	variation from 2.80=corrected sand	concrete pavement	FF	std. mix -slag -gravel (limestone also)	SF	need more info	pavement
		Lower Limit (lb/cu. Yd)	777		1800	~60% of total aggregate	1360 (slag)	1680	need more info	1860
		Upper Limit (lb/cu. Yd)	1033		2000			1790	need more info	2170
		Application	Bridge Deck - 47BD-4350			SF	QC/QA	FF		
		Lower Limit (lb/cu. Yd)	683			~60% of total aggregate	ACI 211	1670		
		Upper Limit (lb/cu. Yd)	974					1770		
	Fine Aggregate	Application	SF Pavement 47B-3625	Class C	concrete pavement	SF	std. mix -slag -gravel	SF	need more info	pavement
		Lower Limit (lb/cu. Yd)	1927	35.8% sand	1800	~40% of total aggregate	1160	1200	need more info	930
		Upper Limit (lb/cu. Yd)	2285		2000		1350	1300	need more info	1240
		Application	Bridge Deck - 47BD-4350	Class F		FF	QC/QA	FF		
		Lower Limit (lb/cu. Yd)	1695	34.6% sand		~40% of total aggregate	ACI 211	1125		
		Upper Limit (lb/cu. Yd)	2154					1225		
	SCMs commonly used in concrete mix design	Class F Fly Ash	x	X*	X		X	X	X*	
		Application	pavement	max. 20%	concrete pavement			pavement	pavement	
		Class C Fly Ash	X	X*	X	X*	X		X	X
		Application	pavement		concrete pavement	pavement			pavement	all
		GGBFS Slag		X	X		X		X*	X
		Application		20% for ASR use 6% microsilica	concrete pavement				pavement	all
		Silica Fume	X	X						
		Application	bridge deck overlay	bridge decks, structural work, microsilica overlay						
		Metakaolin		X*						
		Application		bridge decks for HP mixes						
		Volcanic Ash/Pumicite								
		Application								
		Calcinated Shale								
		Application								
		Opaline Shale								
		Application								
		Calcinated Clay		X						
		Application		bridge deck; substitute for silica fume						
		Diatomaceous Earth								
		Application								
		Other								Badger Pozzolan*
		Application								pavement
	Chemical admixtures commonly used in concrete mix design	Air entraining admixtures	X	X	X	X	X	X	X	X
		Application	pavement	paving	concrete pavement	pavement		pavement	pavement	pavement
		Coventional water reducer	X	X	X	X*	X	X	X	X
		Application	pavement	paving	concrete pavement	pavement		pavement	pavement	pavement
		Mid-range water reducer	X			X*	X		X	
		Application	structures			pavement			fast track pavement	
		Accelerator		X			X	X		
		Application		limited to PCC repairs			patching	patching, fast track		
		Retarder		X	X		X	X	X	
		Application		always required on decks	concrete pavement		for concr. temp over 75; discharge after 60min (have to use it)	pavement	pavement	
		Corrosion inhibitor		X						
		Application		special appliactions i.e. precast						
		Shrinkage reducer								
		Application								
		ASR inhibitors (I.e. Lithium)	research project UNL?					X		
		Application						experimental use in structures		
		Hydration control admixtures								
		Application								
		Other (describe)								
		Application								
Typical combinations of cement, SCM, and chemical admixtures for paving mixes	Paving mix 1	Cement type	Type I/II	Type II (Class C)	*	Type I/II	Type 1	I/II	need more info	Type I/II
		Batch weight (lb/yd)	423		421 (526 typical)	394.8	600 / 550	561	need more info	395
		SCM	Class F fly ash	20% pozzolan	126 (fly ash - 1:1.2)	Class C fly ash		Class F Fly Ash - Modified	need more info	Class C fly ash
		Batch weight (lb/yd)	141			169.2		124	need more info	170
		Chemical admixture 1	WR	WR		AEA	as recommended	AEA - Daravair M	need more info	WR
		dosage (fl oz/cwt)	manufacturer recommendation			manufacturer recommendation	/	unknown	need more info	3
		Chemical admixture 2	AEA	AEA		WR	A or D water reducer	WR - Daracem 65 WR	need more info	AEA
		dosage (fl oz/cwt)	manufacturer recommendation			manufacturer recommendation		unknown	need more info	1
	Paving mix 2	Cement type	Type IPN (15 to 25% Natural pozzolan)	Type II (Class F)			Type 1	I/II		Type I/II
		Batch weight (lb/yd)	564		451 (564 typical)		550	510		395
		SCM	Class C or F fly ash*		136		C or F fly ash	Class F Fly Ash - Modified		GGBFS
		Batch weight (lb/yd)	Total pozzolan content < 25%				90	112		170
		Chemical admixture 1	WR	WR			as recommended	AEA - Daravair R		WR
		dosage (fl oz/cwt)	manufacturer recommendation					unknown		3
		Chemical admixture 2	AEA	AEA				WRDA 82		AEA
		dosage (fl oz/cwt)	manufacturer recommendation					3.0		1
	Paving mix 3	Cement type	Type IPF	Type III (HES)			Type 1	I/II		
		Batch weight (lb/yd)	564				385	570		
		SCM	none*				Slag (grade 100 or better)	Class F Fly Ash - Modified		
		Batch weight (lb/yd)	0				165	125		
		Chemical admixture 1	WR	WR			A or D water reducer	AEA - MB MBVR		
		dosage (fl oz/cwt)	manufacturer recommendation	(no chloride accelerators)				unknown		
		Chemical admixture 2	AEA	AEA				WR - MB Master Pave		
		dosage (fl oz/cwt)	manufacturer recommendation					unknown		

		Georgia	Indiana	Iowa	Kansas	Louisiana	Michigan	Minnesota	Missouri
Compatibility problems between mix components like SCMs and chemical dmixtures	(1) Less than expected water reduction	X*							
	(2) Rapid loss of slump	X	can happen when fly ash conter goes up						
	(3) Fast set	X				X*			
	(4) Abnormally retarded setting	X	can happen when have multiple admixtures from different company		X (possibility)	X*		X*	
	(5) Other (describe)	uncontrollable air					retarded set at high temperatures ??	Plastic shrinkage cracks*	Mixing problems and inconsistent strength and air.
	(6) Other (describe)	poor workability						Rapid loss of slump*	
Complete mix designs (lb/yd) / dosages (fl oz/cwt) for the above symptoms	Symptom #	!!! Have 2 examples			4	4 (mix design is not available)	5	4	5 (I-255 PCCP)
	Water				Need more info	X	Need more info	Need more info	240
	Portland cement				Need more info	X	Need more info	Need more info	523
	Fly ash class C				Need more info		Need more info	Need more info	92
	Fly ash class F				Need more info		Need more info	Need more info	
	Slag				Need more info	X	Need more info	Need more info	
	Silica Fume				Need more info		Need more info	Need more info	
	WR (oz/cmwt)				Need more info		Need more info	Need more info	
	MRWR				Need more info	X	Need more info	Need more info	6.0
	HRWR				Need more info		Need more info	Need more info	
	AEA (oz/cmwt)				Need more info	X	Need more info	Need more info	1.3
	Accelerator				Need more info		Need more info	Need more info	
	Retarder				Need more info	X	Need more info	Need more info	
	Other (describe)				Need more info		Need more info	Need more info	
	Correction for symptom				Need more info	Reduced retarder	Need more info	Need more info	Remains unexplained. Mixing time could be one factor.
	Symptom #							5	5 (bridge overlay)
	Water							Need more info	233
	Portland cement							Need more info	626
	Fly ash class C							Need more info	
	Fly ash class F							Need more info	
	Slag							Need more info	
	Silica Fume							Need more info	50
	WR							Need more info	
	MRWR							Need more info	6.0
	HRWR							Need more info	
	AEA							Need more info	1.3
	Accelerator							Need more info	
	Retarder							Need more info	
	Other (describe)							Need more info	
	Correction for symptom							Need more info	Water meter at plant was not accurate. A different concrete plant was used.
	Symptom #							6	5 (PCCP overlay, I-70)
	Water							Need more info	267
	Portland cement							Need more info	655
	Fly ash class C							Need more info	70
	Fly ash class F							Need more info	
	Slag							Need more info	
	Silica Fume							Need more info	
	WR							Need more info	3.0
	MRWR							Need more info	
	HRWR							Need more info	
	AEA							Need more info	1.4
	Accelerator							Need more info	
	Retarder							Need more info	
	Other (describe)							Need more info	
	Correction for symptom							Need more info	Build up of material on drum blade and the use of Type 3 cement.
Combined aggregate gradation design/analysis procedure (yes/no)		yes	No (not for pavement)	yes	yes	yes	no	yes	yes
	describe	required for fine and coarse agg.*		Shilstone gradation; use 0.45 Power; % retained for information only	Typically, contractors use Shilstone	Need more info	ASTM 57 with some modifications	8/18 Chart and JMF	QC/QA project
Aggregate sources approval system (yes/no)		yes	yes	yes	yes	yes	yes	no	yes
	explain	SOP 1. Frequent monitoring from Pit& Quarry Branch. Must be on QPL 1 or 2. Montly sampling from active source. Do wel- hired 2 new geologists.	Sec.904 *AP pavement *agg. pavement graded	All carbonate sources in Iowa are based on ledge control. Sources are ranked by physical and chemical characteristics of F/T (pore size) and salt susceptibility (XRD/XRF).	F/T beams for limestones, ASR for sands and gravels	Clay lumps, friable materials, iron ore, coal and lignite, flat and elongated, wood	Tests are done before project begins.		The following tests are performed on new sources to determine the uses for a particular aggregate. Freeze/Thaw Testing, Specific gravity, absorption, soundness, LA abrasion, Soundness by water/alcohol freeze. Next, aggregates must meet quality requirements for PCCP. No aggregate can be used unless it has been approved by the State Central Lab. See file for more detailed info.
Do you require testing of cementitious materials, beyond normal		yes	yes	no	no	no	unknown	no ?? (need to check)	no
	If yes, what tests?	SOP 5.Portland cement-AASHTO M85; Fly ash-AASHTO M295; Blended cement-AASHTO M240 Slag-AASHTO M302	Sec.90 *random sample for verification from plant site *entire AASHTO M85 tests						

		Nebraska	New York	North Carolina	North Dakota	Ohio	South Dakota	Texas	Wisconsin
Compatibility problems between mix components like SCMs and chemical dmixtures	(1) Less than expected water reduction								
	(2) Rapid loss of slump								
	(3) Fast set								
	(4) Abnormally retarded setting			X		X*		X	X
	(5) Other (describe)			air entrainment problems - design issue - fluctuating LOI		air entrainment with high LOI fly ash	no compatibility problems	Problems obtaining strength	
	(6) Other (describe)								
Complete mix designs (lb/yd) / dosages (fl oz/cwt) for the above symptoms	Symptom #					abnormally retarded setting		4	4
	Water							need more info	NR
	Portland cement							need more info	395 ??
	Fly ash class C							need more info	170 ??
	Fly ash class F							need more info	
	Slag							need more info	
	Silica Fume							need more info	
	WR (oz/cmwt)							need more info	3
	MRWR							need more info	
	HRWR							need more info	
	AEA (oz/cmwt)							need more info	1
	Accelerator							need more info	
	Retarder							need more info	
	Other (describe)							need more info	
	Correction for symptom					limit the use of fly ash or slag between April to October to limit exposure to cooler water		need more info	eliminated fly ash
	Symptom #					air entrainment with high LOI fly ash		5	
	Water							need more info	
	Portland cement							need more info	
	Fly ash class C							need more info	
	Fly ash class F							need more info	
	Slag							need more info	
	Silica Fume							need more info	
	WR							need more info	
	MRWR							need more info	
	HRWR							need more info	
	AEA							need more info	
	Accelerator							need more info	
	Retarder							need more info	
	Other (describe)							need more info	
	Correction for symptom					limit LOI to 3%max. on fly ash by spec.		need more info	
	Symptom #								
	Water								
	Portland cement								
	Fly ash class C								
	Fly ash class F								
	Slag								
	Silica Fume								
	WR								
	MRWR								
	HRWR								
	AEA								
	Accelerator								
	Retarder								
	Other (describe)								
	Correction for symptom								
Combined aggregate gradation design/analysis procedure (yes/no)		no	yes	no	no	no	not currently		no
	describe	gradation limits for CA and FA	MM 9.1, AASHTO T21, sand 703.07, CA 703.02 (SC)	Some contractors may use (woul dallow)		tried it on bridge deck, could not finish it			
Aggregate sources approval system (yes/no)		yes	yes	yes	yes	yes	yes	unknown	yes
	explain	abrasion, clay lumps & shale, freeze and thaw soundness, plasticity index, sodium sulfate soundness, calcim carbonate, organic impurities, mortar-making properties	APPROVED LIST *criteria *geology how test *have good durable agg. *703.02	*approved lis of coarse and fine agg. based on LA, soundness, mortar strength etc. *approvd list of sources *section 1000 spec (concrete 700)	Aggregate sources are approved based on initial pit tests and monitored over time. Don't have a formal list of approved sites. Tests include light weight pieces, organic impurities, mortar-making properties, sodium sulfate soundness, shale content, iron oxide particles, lignite and coal soft particles, and L.A. abrasion.	There is an agg. certification program. Agg. suppliers must be certified in order to be used in ODOT projects. - tested for F/T - approved by year	ASTM 1260 for sand before use. Need more info on aggregate sources approval system.		wear, soundness, freeze/thaw
Do you require testing of cementitious materials, beyond normal		no	yes	yes	no	yes	yes	unknown	yes
	If yes, what tests?		random mill testing; destination batch plant; AASHTO M85	*chem. and physical prop based on AASHTO M85, ASTM C618 and AASHTO M302		Monthly mill certs are required by the department every 180 days per cement source/type/concrete producer. Testing performed by Central Office. - normally ASTM - LOI is different	need more info		Comp. cubes, activity index for SCMs

			Georgia	Indiana	Iowa	Kansas	Louisiana	Michigan	Minnesota	Missouri
Required tests for concrete mix design	Fresh Concrete tests	Slump	X	X		X	Need more info	X	X	X
		Test method	GDT 27	AASHTO T119 (502)		AASHTO T 119		unknown	AASHTO T 119	AASHTO T119
		Air content	X	X	X	X	Need more info	X	X	X
		Test method	GDT 26	AASHTO T152 or C173 (502&503)	AASHTO T152 (IM 318)	AASHTO T 152		unknown	AASHTO T 152	AASHTO T152
		Unit weight		X	X	X	Need more info		X	
		Test method	GDT 28 (not req.)	AASHTO T121	AASHTO T121 (IM 340)	AASHTO T 121			AASHTO T 121	
		Time of setting								
		Test method								
		Plastic shrinkage cracking susceptibility								
		Test method								
		Heat of hydration								
		Test method								
	Hardended concrete tests	Resistance to freezing and thawing		not for PCC but agg. approval					yes*	
		Test method		ASTM C666					ASTM C-666, Method B	
		Strength	X	X	X		X	yes	yes	X
		Typical design strength		570 in 7 days (501 - 1/3 pt.flex.)	640psi for QMC		AASHTO T-22	unknown	500 psi flexural	Typical Strength: 4650psi. Minimum strength: 3500 psi.
		Test method	AASHTO T22	AASHTO T97	AASHTO T97			unknown		28-Day AASHTO T22
		Permeability					X (required?)		yes	
		Test method					ASTM C1202		2500 coulumb max., 28-day for HPP	
		Shrinkage								
		restrained/free								
		Test method								
		Creep								
		Test method								
	Fibers used in paving mixes	Steel					X		X	X
		Polypropylene			used in research	X	X		X	
		Polyester							Not sure	
		Polyolefin			used in research	X			X	X
		Nylon								
		Carbon								
		Other (describe)	do use fibers in bridge deck overlay - poly		typically used in UTW					
	Was there a change in the water content?				slight adjustment in water	yes			yes	not significantly
	Where chemical admixtures used?				normal	yes			water reducer	Type A WR
	Other comments					WR added	no records		The fibers drove up the water demand. Water reducers were used more recently with polyolefin fibers.	The minimum cement content was increased from 6.0 to 6.6sk/yd. Fine and coarse aggregate was changed to 45/55 by volume vs. 38/62 (Standard Ratio).
	Rank the primary concerns about concrete durability, (1)not a concern, (2)rarely a concern, (3)sometimes, (4)often, (5)always	Freeze-thaw resistance / Scaling resistance	5	will send	5 (F/T)	5	1		5	5
		DEF susceptibility	2	will send	2	1	1		3	2
		ASR susceptibility	3	will send	2	5	3		4	3
		Chemical attack	2	will send	2	1	2		2	5
		Abrastion resistance	4	will send	2	1.5	4		2	5
		Fatigue cracking	3	will send	4	5	4		1	1
		Other (describe)								
		Rank								
		COMMENTS	1. do submit but follow old mixes 2. use old mixes 37. range for various mixes 40. for hand point 87. Binary blends - fly ash or GGBFS 91. Sec.430 - temp. requirement for slag % 131. max. fly ash 15%, slag up to 50% 139. mostly fly ash; one source for Class C; can control air in C better than F; LOI varies; Loose lot of air in transit; 1.25-2 replacement of fly ash for cement makes total 26-28% fly ash 153. depends on specific materials - LOI 205. secs.800&801 for coarse and fine agg. Respectively; agg. is normally granite; limits flat and elongated; Georgia river rock *Class 1 - 564lbs (cement, natural sands take up water); normal - 0.53w/c; HES - 0.47w/c (up to 752lbs. cement); Sec.430 - mainline Sec.439 - special (Class3>4000psi); Sec.504 - 24hr accelerated; 11.2 & 7 7.5cf for coarse&fine agg.; In south, up to 11.4cf of sand (better sand)	1. QC/QA: will copy 500 sec.of spec. mix parameters and contractors - 90% --- Non QC/QA - cookbook; in 500 sec.; by voulme; min cement content; mix w/c; do a trial batch 46. 100% pay 74. 100% passing 1" sieve; Use #8 (Sec.904); D-cracking issue 87. no ternary 111. WR - A or D; Trial batches are required if you change (add or take off admixture) 137. 502 spec. -substitute more fly ash back in than cement out;substitution and 20% increase; 501 spec.-coincide; fly ash an additive	1. State&contractoe provides std. Class C; Supplier provides QMC Pavement 10. MOR-TPL	1. State may assist contractor in designing mix proportions. 36. 0.49 w/cm ratio is maximum for FF paving 46. 0.25mm is the maximum air void spacing factor. Any concrete with a spacing factor greater than 0.37mm shall be removed. AVA equipment is used for testing. 56. All concrete except mainline pavement. 62. Optimized PCCP concrete 75. .35 to .63 range by mass of total aggregate. Shilstone method can be used to provide justification for aggregate proportions. 81. Coarse and fine aggregates are proportioned at 50%-50% ratio by mass. Adjustments ratio can be made to improve workability. Shilstone can provide justification. 111. Super low C3A retarded set with conv. WR??	81. Typically, concrete mixes contain a lot of sand because it is inexpensive. Typically, concrete mixes contain a lot of sand because it is inexpensive. 89. Allow up to 20% Class C Fly Ash. 91. All up to 50% GGBFS Slag. Slag is most common SCM. 155. Typically, fast set is environmentally related. If more two or more chemical admixtures are used, they are required to be the same brand. 156. Have had some occurences of slow set with slag and retarder. Typically, slow set is environmentally related. If more two or more chemical admixtures are used, they are required to be the same brand.	87. 30 % maximum 91. 40% maximum, used commonly	1. State provies mix design for projects < 5000 c.y. 13. 2500 coulumb max, 28 days for HPP 22. Encourage well-graded aggregate 8/18 chart for HPP. Monitor vibration during paving. 28. Encourages use of additives and pozzolans to lower permeability in hardened state. 70. HES mixes are not encouraged. 87. Class F fly ash not used since late 1970's. 115. Not commonly used. 123. Fly ash and slag are used as ASR inhibitors. They are more effective than Lithium according to lab tests. 156. Maximum dosages of water reducers in combination with high SCMs replacements have caused retarded sets. 157. Maximum dosages of water reducers in combination with high SCMs replacements have caused plastic shrinkage cracks. 158. Rapid loss of slump has been caused by using the maximum dosage of WR, but not always with SCMS. 222. Freeze/thaw test is only run when potential for recycling is performed.	2. Non QC/QA project are standard state mix designs. QC/QA mixes are by contractor's method. QC/QA mixes often have optimized gradations. The ACI absolute volume method is often used. 31. Gravel in southern part of state 65. 1/2 sack cement reduction allowed with optimized gradation. 89. 15% max Class C Fly Ash. 151. If a Type A WR is used, contractor can reduce minimum cement content by 1/4 - sack/yd^3.

			Nebraska	New York	North Carolina	North Dakota	Ohio	South Dakota	Texas	Wisconsin
Required tests for concrete mix design	Fresh Concrete tests	Slump		X	X	X	X	X		X
		Test method		ASTM C143	AASHTO T119	AASHTO T 119	C143	SD 404		AASHTO T 119
		Air content		X	X	X	X	X		X
		Test method		ASTM C231	AASHTO T152	AASHTO T 152	C231 / C173	SD 403		AASHTO T 152
		Unit weight		X	X	X	X*	X		
		Test method		ASTM C138	ASTM C138	AASHTO T 121	C138	SD 411		
		Time of setting								
		Test method								
		Plastic shrinkage cracking susceptibility								
		Test method								
		Heat of hydration								
		Test method								
	Hardended concrete tests	Resistance to freezing and thawing		X	X	yes	X*			
		Test method		NY 5023P (will send)	AASHTO T126, AASHTO T97	ASTM C-666, Method A	ASTM C666, PROC B: 350 cycles (SC)			
		Strength		X		yes	X	X		yes
		Typical design strength				compressive ??	*The standard procedure is based on a given mix design that should achieve 4000psi: the pavement design is based on the 3rd point flexural strength of 750psi; acceptance (opening to traffic) is based on center point flexural strength of 600psi. *For QC/QA, cores are taken and compression test.Required strength of the concrete is 4000psi+1.65(std.dev.)psi	Need more info		650 psi flexural
		Test method		ASTM C39 (std. compression)		AASHTO T-22	ASTM C293; ASTM C39&42	SD 420		AASHTO T 22
		Permeability		X						
		Test method		T 277 (bridge decks - not required)						
		Shrinkage								
		restrained/free								
		Test method								
		Creep								
		Test method								
	Fibers used in paving mixes	Steel						X*	X*	
		Polypropylene		X*	X*		1 research project - weigh station			X
		Polyester					1 research project - 4"0" - twin UTW		X*	
		Polyolefin	X*	X		X*		X*		
		Nylon		X						
		Carbon								
		Other (describe)								
	Was there a change in the water content?					yes		Info available in research report	unknown	no
	Where chemical admixtures used?			WR, AEA		AEA		Info available in research report	unknown	
	Other comments				don't know how the mix design was adjusted	No adjustment to mix design, fibers added per manufacturer's specifications.		Info available in research report	none	slump remained the same
	Rank the primary concerns about concrete durability, (1)not a concern, (2)rarely a concern, (3)sometimes, (4)often, (5)always	Freeze-thaw resistance / Scaling resistance	5	5	1	5	5	5	need more info	5
		DEF susceptibility					1	1	need more info	
		ASR susceptibility	5	4	3	2	1	5	need more info	
		Chemical attack			5	3	2	3	need more info	
		Abrastion resistance		5 (friction)	2	2	3	3	need more info	
		Fatigue cracking	3		4	2	4	3	need more info	3
		Other (describe)		shrinkage cracking; scaling on bridge decks	drying shrinkage cracking				need more info	
		Rank			Jim (1,5,2,5,5)				need more info	
		COMMENTS	38. The maximum slump may be exceeded by use of water reducer. 46. Currently, Nebraska is starting to test air content behind the paver. 139. Class C or F fly ash may be substituted in the mix design provided the total pozzolan content does not exceed 25%. 147. No additional fly ash substitution is allowed. 239. Very limited use of fibers, only a short test section, bonded overlay	1. Table 501-3; HES - no standard (502 2.02) 37. w/c adjusted based on slump 42. fixed forms can increase slump through WR 74. spec. Table 501 - 2 87. mostly Class F; sludge fly ash costs the same 89. one source; HP or DP class 95. fits into MSF requirements 237. manual; std. Table; 703.02 2 often for CA; 703.07 sand gradation	1. contractor submit lab data - reviewed by DOT 2. not specified but commonly used as a guideline 6. for cement used 9-10. 14 days -600psi flexure at 1/3 point; take team breaker to site and calibrate 13. inherent in cementitious content; not a concrete test 14. same as above; not test but required 5% 16. 6 known reactive aggreagates: special requirements, low alkali cement, use pozzolan; source approval 17. abrasion of aggregate 18. corrosion inhibitor specified at times; source approval 46. point of acceptance at grade 65. fly ash - 1:1.2 / slag - 1:1 74. can use 67; 57m - modified SC 129. 526 min cementitous - max. fly ash 20%; normally no slag (35-50% substitution) normally Lafarge in Virginia in east part of the state ready mix ternary would be allowed 237. allow in slope protection - maybe used once - maybe in AC	89. Coal creek supply 111. contractor request, contract documents 113. contractor request, contract documents 239. 1 research project	1. State has a standard procedure; A new QA/QC spec. requires that the contractor provides the mix design; Support spec. QA/QC 888 2. Strength - 28; Do mix design test batch and sup mix results 14. agg. only; not PCC 38. do many requirement 46. sample ahead of paver 56. controlled by cement content or w/c ratio 74. #57 - materials in sectins 700,701,703,705 156. 701 B - one district complains a lot; modify C618 to lower LOI from 6% to 3% 214. do in field 222. Area under the curve (% expansion vs cycles)<2.05. This is for approval of the aggregate not the specific mix .	65. Cementicious content includes a 112 lb/cy of Class F Fly ash typically. 68. Cementious content includes 123 lb/cy of Class F Flay ash typically. 236. Experimental project - 0.6% of mix. 239. Polyolefin fibers used in a few bridge deck overlays, typically 25lb/sy. See research report on file.	7. 7-day strength is now correlated to 28-day strength. 87. Class F Fly Ash is most common. 91. El Paso: requires GGBFS @ 30% to 50%. ???? 236. thin bonded and UTW pavements 238. 2 inch thin overlays??	107. Ash from incinerated paper mill sludge

Mix Verification and Quality Control Summary

State	Mix Verification				Quality Control								
	Do you require field trial-batch testing?	If yes, what tests are required?	Do you require tests on field material prior to paving?	If yes, what tests are required?	Air test required?	Air test method?	Slump test required?	Slump test method?	Strength test required?	Strength test 1	Strength test 2	Strength test 3	Other QC test required?
Georgia	yes	air, slump, comp. strength	yes	agg. (gradation), admixtures, cement and SCM (run chemistry), on QPL dowel baskets (sample twice/week), steel, submitted sample from stockpile (must be approved gradation)	yes	GDT 26	yes	GDT 27	yes		Beams (SC)	Cylinders (SC)	moisture test on agg, weekly sampling of materials
Indiana	no				yes	501;502	yes	502	yes	Maturity (SC)	Beams (SC)		unit weight - 501; relative yield - 502
Iowa	no		no		yes	AASHTO T152 (1/350yd3)	no		yes	Maturity (SC)	Beams (SC)		
Kansas	no		no		yes	AVA and AASHTO T 152	yes	AASHTO T 119	yes		Beams (SC)	Cores (SC)	unit weight, PCC temp, density
Louisiana	no		yes	cement, gradation, QPL compliance	yes	TR -202 (AASHTO)	yes	TR -207(AASHTO)	yes		Beams (SC)	Cylinders	
Michigan	yes	unknown	yes	unknown	yes	unknown	yes	unknown	yes		Beams (SC)	Cylinders (SC)	PCC Temp
Minnesota	no		yes	aggregate (SC)	yes	AASHTO T 152	yes	AASHTO T 119	yes	Maturity (SC)	Beams (SC)	Cylinders (SC)	
Missouri	no		yes	Sieve analysis, deleterious content	yes	AASHTO T 152	yws	AASHTO T 119	yes			Cylinders (SC)	Thickness-AASHTO T 148, Smoothness spec
Nebraska	no		yes	aggregate/cementious materials (SC)	yes	NDR T 121	no		yes			Cylinders	
New York	for HES	502	yes/no	approved materials ony; pre-approved	yes	ASTM C231	yes	ASTM C143	yes	all have been done in the lab			
North Carolina	no		no		yes	AASHTO T152	yes	AASHTO T119	yes	Maturity (SC)	Beams (SC)	Cylinders (SC)	
North Dakota	yes	slump, air, comp and flexural strength	yes	aggregate	yes	AASHTO T 152	yes	AASHTO T 119	yes		Beams (SC)	Cylinders (SC)	yield test, unit weight
Ohio	no		no		yes	C231 or 173	yes	C143	yes	Maturity (SC)	Beams (SC)	Cylinders (SC)	smoothness and thickness
South Dakota	no		no		yes	SD 403	yes	SD 404	yes			Cylinders	PCC Temp, Unit weight, gradation, agg moisture
Texas	yes	pilot beams - 7 day correlation?	yes	pilot beams - 7 day correlation?	unknown	unknown	unknown	unknown	yes	Maturity (SC)	Beams	Cylinders	PCC Temp - max 95F ??
Wisconsin	no		yes	compressive strength	yes	AASHTO T 152	yes	AASHTO T 119	yes			Cylinders	PCC Temp

Note: SC = see comment.

State	Quality Control												
	General Comments	Comment 1	Com-ment 2	Comment 3	Comment 4	Com-ment 5	Comment 6	Com-ment 7	Com-ment 8	Com-ment 9	Comment 10	Comment 11	Comment 12
Georgia	*have paving schools since they don't d lot of of PCC (every pavin gproject takes 1/2 day) *Jay does them all - do require contractors people to come *superint., paving formen, plant operato *have all involved in project starts; sampling, building stockpiles, mix design	*Sample R/M on monthly basis so they can start paving based on this			*do pull sample of cash materials *sample steel also visual check							Third point - AASHTO T97	AASHTO T22 - depending on specification could by yardage or lot
Indiana		*a trial is required to do mix design. Do it in field before project starts *501.17 adjustments									501,502	501, 502	
Iowa											for opening of 500psi MOR-CPL	third point - 1/10000yd3 information for Design Office	
Kansas												Beams determine when pavement can be opened to traffic	compressive strength and depth
Louisiana												Third point used sometimes?	
Michigan												Beams determine when pavement can be opened to traffic	Cylinders are tested at 28 days
Minnesota					Absorption, % carbonates, % spall						If requested by contractor, but new curve must be completed for mix change	3rd point	projects < 2500 cu yd
Missouri													28-day AASHTO T22
Nebraska					Approved aggregate source list								
New York							hardened air (TM 501 08T)				normal strength; meet requirement; info only for Class C		
North Carolina											ASTM C1074 (some projects)	AASHTO T126&T97	not generally specified but sometimes used optionally or in special cases
North Dakota	No QC/QA program, only QA				Contractor performs aggregate test from pit (aggregate gradation, thin and elongated, soft rock, iron oxide)							3rd point, 500psi for traffic	3000 psi ??
Ohio				materials should already be pre-approved or certified							in development	std. spec. - center	QC/QA spec. - on cores
South Dakota	No QC/QA program, SDDOT performs all tests												
Texas											some maturity testing		
Wisconsin													

Typical Mix Designs

	Georgia			Indiana			Iowa			Kansas			Louisiana			Michigan			Minnesota		
	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
Description	Class 3 Pavement	Class 1 Pavement	Class 1 Pavement	mix design submitted to project engineer (not Dist. Mats. Engr.)				QMC		MA-3	MA-3	MA-3				Need typical mixes					
Water (lb/cy)	267	170.4lt	170.4				228	216		238	234	248	242	258					210	210	200
Portland Cement (lb/cy)	480	324kg	273kg				457	471		540	520	605	507	273					400	360	450
Fly Ash Class C (lb/cy)	125		61kg				114	83											170		120
Fly Ash Class F (lb/cy)																					
Slag (lb/cy)														273						190	
Silica Fume (lb/cy)																					
Coarse Aggregate Type	Aggreagate #57	#57 stone	#57 stone				1669	1395		Rock	Rock	Rock	unknown	unknown					unknown	unknown	unknown
CA (lb/cy)	1868	1067kg	1067							1323	1670	1384	unknown	unknown					2250	1950	1900
Fine Aggregate Type										Sand	Sand	Sand	unknown	unknown					unknown	unknown	unknown
FA (lb/cy)	1153	751kg	729				1393	1264		1618	1367	1499	unknown	unknown					900	1200	1250
WR Type	Euclid Retarder 75	Boral LR	Boral LR				x	Eucon WR		unknown	unknown								unknown	unknown	unknown
WR dosage (oz/cwt)	12(oz/yd3)							4		8.7	2.8								unknown	unknown	unknown
MRWR (oz/cwt)													5.2	3.0							
HRWR (oz/cwt)																					
AEA Type	Euclid AEA 92	Boral Air 40	Boral Air 40				x	AEA 92											unknown	unknown	unknown
AEA dosage (oz/cwt)	3(oz/yd3)							1		1.1	0.6	3	1.2	0.7					unknown	unknown	unknown
Target Air (%)	4.5	5	5				6.0	6		7.0	6.5	6.5	unknown	unknown					unknown	unknown	unknown
Accelerator																					
Retarder																					
Other																					
Comments for Mix 1	PC - Type 1 (Southern Cement); fly ash - Boral Material Tech., Juliette, GA; FA - Atlanta Sand&Burke Pit Gaillard, GA; CA - Florida Rock Palmer Station #57; unit weight 146.7 lb/ft3; strength @7=4157psi, @28=5530psi												Type IS cement used on mix								
Comments for Mix 2	PC - Type 1 (Southdown); FA - natural(Williams Sand Comp.-GA Source#198F), crushed(Martin Marietta-Jefferson Quarry); CA - Martin Marietta-Jefferson Quarry; slump(44.5&51mm); strength @24hr=2330-2690psi, @28d=730-910psi(beam), 4390-4930psi(cylinder); WR&AEA - Monroe Admix., Monroe, NC						Cement-Lafarge; fly ash-Lousia; CA-Stone city; FA-Anamosa pit; design slump 1.5"						Type IS cement used on mix								
Comments for Mix 3	PC - Type 1 (Southdown); FA - natural(Williams Sand Comp.-GA Source#198F), crushed(Martin Marietta-Jefferson Quarry); CA - Martin Marietta-Jefferson Quarry; slump(44.5&51mm); strength @24hr=2030-2370psi, @28d=765-880psi(beam), 4090-4140psi(cylinder); fly ash - Boral Flayash, Stilesboro, GA Bowen Plant; WR&AEA - Monroe Admix., Monroe, NC																				

	Missouri			Nebraska			New York			North Carolina			North Dakota			Ohio		
	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
Description	State 1	State 2	Contractor Optimized	47B-Alt 1	47B-Alt 3	47B-Alt 4	Need typical mix designs			Pavement class concr.			094-128WB	094-240	094-349	Need typical mix designs.		
Water (lb/cy)	233	244	240	254 max	254 max	254 max				259	259		214.91	216.56	224.91			
Portland Cement (lb/cy)	486	573	523	423	564	564				490	576		394.8	394.8	394.8			
Fly Ash Class C (lb/cy)	86		92										169.2	169.2	169.2			
Fly Ash Class F (lb/cy)				141						104								
Slag (lb/cy)																		
Silica Fume (lb/cy)																		
Coarse Aggregate Type	Limestone	Limestone	Limestone	Limestone	Limestone	Limestone							unknown	unknown	unknown			
CA (lb/cy)	1926	1953	1890	901	901	901				1952	1952		unknown	unknown	unknown			
Fine Aggregate Type	Sand	Sand	Sand	Sand	Sand	Sand							unknown	unknown	unknown			
FA (lb/cy)	1147	1151	1111	2102	2102	2102				1144	1144		unknown	unknown	unknown			
WR Type			GRT Polychem, 400 NC	unknown	unknown	unknown				POZZOLITH-80	POZZOLITH-80		WRDA-82	WRDA-82	?			
WR dosage (oz/cwt)			6.0	unknown	unknown	unknown				as recom.	as recom.		3.0	3				
MRWR (oz/cwt)																		
HRWR (oz/cwt)																		
AEA Type	unknown	unknown	GRT Polychem VR	unknown	unknown	unknown				MB AE 90	MB AE 90		unknown	unknown	unknown			
AEA dosage (oz/cwt)	0.5 to 3.0	0.5 to 3.0	1.3	unknown	unknown	unknown				as recom.	as recom.		1.2	1.2	unknown			
Target Air (%)	unknown	unknown	6.0	6.0	6.0	6.0				5.0	5.0		6.0	6.0	6.5			
Accelerator																		
Retarder																		
Other																		
Comments for Mix 1	See file for source info. Type I cement.			Type I/II cement						Cement - Holcim(Holly Hill); Pozzolan - Proash; CA - Pomona Quarry/Greensboro; FA. - Hall Pit/Lemon Springs; AEA & WR - Master Builders; Slump - 1.50"; mortar content - 15.67 cu.ft								
Comments for Mix 2				Type IPF cement (15% to 25% class C fly ash).						Cement - Holcim(Holly Hill); Pozzolan - Proash; CA - Pomona Quarry/Greensboro;FA - Hall Pit/Lemon Springs; AEA&WR - Master Builders; Slump - 1.50"; mortar content - 15.67 cu.ft								
Comments for Mix 3	Mix contains 450 of IA and 1440 of CA.			Type I/II cement														

	South Dakota			Texas			Wisconsin		
	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3	Mix 1	Mix 2	Mix 3
Description	74-45-77	A-45	PCEMS 6116	Need typical mix designs.			A	A-S	A-FA
Water (lb/cy)	253	265	236				232	232	232
Portland Cement (lb/cy)	557	570	510				565	395	395
Fly Ash Class C (lb/cy)									170
Fly Ash Class F (lb/cy)	123	125	112						
Slag (lb/cy)								170	
Silica Fume (lb/cy)									
Coarse Aggregate Type	Quartize	Limestone	Limestone				unknown	unknown	unknown
CA (lb/cy)	1690	1720	1720				2028	2015	2002
Fine Aggregate Type	Sand	Sand	Sand				unknown	unknown	unknown
FA (lb/cy)	1183	1162	1298				1092	1085	1078
WR Type	WRDA 82	MB MBVR	WRDA 82				unknown	unknown	unknown
WR dosage (oz/cwt)	unknown	unknown	3.0				unknown	unknown	unknown
MRWR (oz/cwt)									
HRWR (oz/cwt)									
AEA Type	Daravair M	MB Master Pave	Daravair R				unknown	unknown	unknown
AEA dosage (oz/cwt)	unknown	unknown	unknown				unknown	unknown	unknown
Target Air (%)	unknown	6.5					unknown	unknown	unknown
Accelerator									
Retarder									
Other									
Comments for Mix 1	CA - Concrete Materials, Sioux Falls, SD. FA - Higman Sand & Gravel, Akron, IA. Fly ash from Coal Creek. More info on file.						State specified concrete mixes with 35% FA and 65% CA.		
Comments for Mix 2	CA - Pete Lien & Sons, Rapid City, SD. FA - Birdsall Sand & Gravel, Creston SD. Coal creek fly ash. More info on file.						State specified concrete mixes with 35% FA and 65% CA.		
Comments for Mix 3	CA - Pete Lien & Sons, Rapid City, SD. FA - Birdsall Sand & Gravel, Creston SD. Coal creek fly ash. More info on file.						State specified concrete mixes with 35% FA and 65% CA.		

APPENDIX E. PROBLEM PROJECT DATA COLLECTION FORM

MATERIAL AND CONSTRUCTION OPTIMIZATION

FOR PREMATURE PAVEMENT DISTRESS IN PCC PAVEMENTS

DATA COECTION FORM

This form can be used for new pavements or overlays. Cracking from obvious design errors, subbase failures, or other non-concrete related causes need not be included. This is intended to include past projects where distress became a concern on projects less than 15 years old. Please use one form per project.

Name of Individual(s) Completing Form: ______________________________

Title/Position: ____

Phone: ____________________

Address: ____

State ______________ Highway Route ______________ Length of Project ______________

Year Constructed ________ Project Number ________________________

General Location ____

1. In general, what was the problem and how severe was it?

   ____

   ____

   Rank its severity 1 – 5 (5=very severe) ___

2. Which Mix Characteristic(s) do you think caused the problem? (Check all that apply)
   Workability ___ Consistency ___ Shrinkage ___ Strength ___ Air Content ___
   Permeability ___ Other ____________________________________

Describe the nature of the problem: ____

____

____

3. Do you feel there was a material related cause? Yes ____ No ____

If yes, describe: ____

____

____

4. Do you feel there was a construction related cause? Yes _____ No _____

If yes, describe: ____
____
____

Was this within the specifications and normal construction practices?
Yes _____ No _____

5. Do you feel there was an environmental related cause? Yes_____ No _____

If yes, describe: ____

6. Did the problem persist throughout the project? Yes _____ No _____

If no, how much of the project? ____

What changed (Weather, certain material, etc.)? _________________________

7. What tests were used to identify the causes? _________________________
____

8. What information / tests would have helped in identifying the problem prior to / during construction? ____
____
____

9. Are project level construction records or materials information available?
Yes_____ No _____

10. Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)
Yes _____ No_____
If yes, describe: ____

11. Have changes been made to your specifications or design methods to prevent a repeat of this problem, and if so what change was made?
Yes _____ No_____
If yes, describe: ____

APPENDIX F. PARTICIPATING STATES PROBLEM PROJECTS

Item	Value
Names	Steven Krebs
Title/Position	Chief Pavements Engineer Wisconsin Department of Transportation
Address	3502 Kinsman Blvd. Madison, WI. 53704
Phone	608 246-5399
E-mail	steven.krebs@dot.state.wi.us
State	Wisconsin
Highway Route	Interstate 90/94
Length of Project	20 + miles
Year Constructed	1991
Project Number	Several Projects
General Location	Interstate 90/94 from STH 33 to STH 16 & 12 (Lyndon Station)
In general, what was the problem?	The problem was cracking along the transverse joint, which are skewed. Also we have discovered the concrete has delaminated/debonded to the dowel bars. Fairly severe.
Rank its severity 1-5 (5=very severe)	3
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	True
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	True
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	

Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	2
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1
Do you feel there was an environmental related cause?	2
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	We have done FWD testing.
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/23/2003 10:36:45 AM

Item	Value
Names	Steven Krebs
Title/Position	Chief Pavements Engineer Wisconsin Department of Transportation
Address	3502 Kinsman Blvd. Madison, WI. 53704
Phone	608 246-5399
E-mail	steven.krebs@dot.state.wi.us
State	Wisconsin
Highway Route	US Highway 8
Length of Project	2 miles
Year Constructed	1992
Project Number	
General Location	Rhinelander bypass.
In general, what was the problem?	Longitudinal cracking
Rank its severity 1-5 (5=very severe)	5
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	True
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	2
Construction Related Cause Describe	

Was this within the specifications and normal construction practices?	1
Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	We cut beams and broke them.
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	2
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	2
If yes, describe:	
Date/Time	6/24/2003 3:52:00 PM

Item	Value
Names	George Woolstrum
Title/Position	
Address	
Phone	402-479-4791
E-mail	gwoolstr@dor.state.ne.us
State	NE
Highway Route	Nebraska 2
Length of Project	5 miles
Year Constructed	1991
Project Number	F-2-3(1014)
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	3
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	True
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/24/2003 5:17:19 PM

Item	Value
Names	George Woolstrum
Title/Position	
Address	
Phone	402-479-4791
E-mail	gwoolstr@dor.state.ne.us
State	NE
Highway Route	Nebraska
Length of Project	
Year Constructed	0
Project Number	
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	0
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	0
Material Related Cause Describe	
Construction Related Cause	0
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	0

Do you feel there was an environmental related cause?	0
Environmental Related Cause Description	
Did the problem persist throughout the project?	0
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	0
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	0
If yes, describe:	
Have changes been made to your specifications or design methods?	0
If yes, describe:	
Date/Time	6/25/2003 9:59:44 AM

Item	Value
Names	George Woolstrum
Title/Position	
Address	
Phone	402-479-4791
E-mail	gwoolstr@dor.state.ne.us
State	NE
Highway Route	Nebraska 2
Length of Project	11 miles
Year Constructed	1996
Project Number	F-2-7(1014)
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	2
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	True
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	2

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	2
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/25/2003 3:52:03 PM

Item	Value
Names	George Woolstrum
Title/Position	
Address	
Phone	402-479-4791
E-mail	gwoolstr@dor.state.ne.us
State	NE
Highway Route	US-77
Length of Project	5 miles
Year Constructed	1991
Project Number	F-77-1(1011)
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	2
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	True
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/26/2003 9:46:02 AM

Item	Value
Names	George Woolstrum
Title/Position	
Address	
Phone	402-479-4791
E-mail	gwoolstr@dor.state.ne.us
State	NE
Highway Route	US-136
Length of Project	1.4 miles
Year Constructed	1988
Project Number	F-136-7(1003)
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	4
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	True
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	2
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/26/2003 12:10:56 PM

Item	Value
Names	Todd Hanson
Title/Position	
Address	
Phone	515-232-8210
E-mail	todd.hanson@dot.state.ia.us
State	IOWA
Highway Route	I-80
Length of Project	5.47
Year Constructed	1987
Project Number	IR-80-6(126)209--12-48
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	4
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	True
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	True
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/27/2003 11:22:16 AM

Item	Value
Names	Todd Hanson
Title/Position	
Address	
Phone	515-232-8210
E-mail	todd.hanson@dot.state.ia.us
State	DALLAS
Highway Route	I-80
Length of Project	15.7
Year Constructed	1987
Project Number	IR-80-3(57)106--12-2548
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	4
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	True
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	True
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	2
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/27/2003 11:28:29 AM

Item	Value
Names	Todd Hanson
Title/Position	
Address	
Phone	515-232-8210
E-mail	todd.hanson@dot.state.ia.us
State	Pottawattamie
Highway Route	I-29
Length of Project	15.7
Year Constructed	1994
Project Number	IM-29-4(38)58--13-78
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	4
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	True
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	True
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/27/2003 11:34:40 AM

Item	Value
Names	Todd Hanson
Title/Position	
Address	
Phone	515-232-8210
E-mail	todd.hanson@dot.state.ia.us
State	Lee
Highway Route	US 61
Length of Project	5.92
Year Constructed	1992
Project Number	DE-RP-518-1(10)--33-56
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	4
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	True
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	2
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	6/27/2003 11:41:27 AM

Item	Value
Names	James M. Parry, P.E.
Title/Position	
Address	
Phone	608-246-7939
E-mail	james.parry@dot.state.wi.us
State	Wisconsin
Highway Route	I-90/94
Length of Project	5 Miles
Year Constructed	1991
Project Number	1101-03-71
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	5
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	True
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	2
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	2
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	7/1/2003 2:51:14 PM

Item	Value
Names	Douglas J. Schwartz
Title/Position	
Address	
Phone	651-779-5576
E-mail	doug.schwartz@dot.state.mn.us
State	Minnesota
Highway Route	I-35
Length of Project	8.6 miles
Year Constructed	1992
Project Number	0980-127
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	2
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	True
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	True
Mix Permeability	False
Mix Other	True
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	0

Do you feel there was an environmental related cause?	2
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	0
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	2
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	7/1/2003 3:18:00 PM

Item	Value
Names	James M. Parry, P.E.
Title/Position	
Address	
Phone	608-246-7939
E-mail	james.parry@dot.state.wi.us
State	Wisconsin
Highway Route	STH 35-Tower Ave-City of Superior
Length of Project	5 miles
Year Constructed	1997
Project Number	8010-07-23
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	3
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	True
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	1
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	2

Do you feel there was an environmental related cause?	2
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	2
If yes, describe:	
Date/Time	7/1/2003 3:19:44 PM

Item	Value
Names	James M. Parry
Title/Position	
Address	
Phone	608-246-7939
E-mail	james.parry@dot.state.wi.us
State	Wisconsin
Highway Route	STH 16 - 7th Street
Length of Project	2 Miles
Year Constructed	2000
Project Number	7575-08-71
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	4
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	2
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	1

Do you feel there was an environmental related cause?	2
Environmental Related Cause Description	
Did the problem persist throughout the project?	2
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	1
If yes, describe:	
Have changes been made to your specifications or design methods?	2
If yes, describe:	
Date/Time	7/1/2003 3:54:15 PM

Item	Value
Names	Douglas J. Schwartz
Title/Position	
Address	
Phone	651-779-5576
E-mail	doug.schwartz@dot.state.mn.us
State	Minnesota
Highway Route	I-35
Length of Project	3.0 miles
Year Constructed	1989
Project Number	7080-42
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	3
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	True
Mix Consistency	True
Mix Shrinkage	True
Mix Strength	True
Mix Air Content	True
Mix Permeability	True
Mix Other	True
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	2
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	0

Do you feel there was an environmental related cause?	2
Environmental Related Cause Description	
Did the problem persist throughout the project?	1
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	0
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	2
If yes, describe:	
Have changes been made to your specifications or design methods?	0
If yes, describe:	
Date/Time	7/1/2003 4:05:33 PM

Item	Value
Names	Douglas J. Schwartz
Title/Position	
Address	
Phone	651-779-5576
E-mail	doug.schwartz@dot.state.mn.us
State	Minnesota
Highway Route	TH 71
Length of Project	3.06 miles
Year Constructed	2000
Project Number	3412-60
General Location	
In general, what was the problem?	
Rank its severity 1-5 (5=very severe)	1
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	True
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	True
Mix Other Describe	
Describe the nature of the problem:	
Material Related Cause	1
Material Related Cause Describe	
Construction Related Cause	2
Construction Related Cause Describe	
Was this within the specifications and normal construction practices?	0

Do you feel there was an environmental related cause?	1
Environmental Related Cause Description	
Did the problem persist throughout the project?	2
If no, how much of the project:	
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	
What information / tests would have helped in identifying the problem prior to / during construction?	
Are project level construction records or materials information available?	1
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	2
If yes, describe:	
Have changes been made to your specifications or design methods?	1
If yes, describe:	
Date/Time	7/1/2003 4:33:15 PM

Item	Value
Names	Jason Blomberg
Title/Position	Sr. Research and Development Assistant
Address	Missouri Department of Transportation Central Laboratory 1617 MO Blvd. Jefferson City, MO 65109
Phone	(573) 526-4338
E-mail	blombj@mail.modot.state.mo.us
State	Missouri
Highway Route	I-70
Length of Project	3 Miles
Year Constructed	1991
Project Number	J5I0448
General Location	Westbound lanes of I-70 in Cooper County, MO. West of Lamine River Bridge to 0.4 miles east of Rt. K.
In general, what was the problem?	This project was an bonded concrete overlay in which cracks were observed two days after placement. Areas of sand pockets and segregation failed and needed to be replaced. Approximately 5 reflective cracks/panel occurred within 90 days after placement.
Rank its severity 1-5 (5=very severe)	5
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	True
Mix Consistency	True
Mix Shrinkage	False
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False

Describe the nature of the problem:	**Workability and consistency were the problem mix characteristics. The mixes were delivered to the jobsite unmixed and segregated.**
Material Related Cause	**1**
Material Related Cause Describe	**Flash setting could have been occurring due the use of Type 3 cement.**
Construction Related Cause	**1**
Construction Related Cause Describe	**Material issue caused the concrete to build up and harden in the drum and the blades of the mixer at the central batch plant causing further mixing problems.**
Was this within the specifications and normal construction practices?	**2**
Do you feel there was an environmental related cause?	**2**
Environmental Related Cause Description	
Did the problem persist throughout the project?	**1**
If no, how much of the project:	**The problem persisted throughout the project.**
What changed (weather, certain material, etc.)?	
What tests were used to identify the causes?	**Visual observations of unmixed material were made at the site and many loads were rejected. Unfortunately, the blades of the mixer were not checked until after project completion.**
What information / tests would have helped in identifying the problem prior to / during construction?	**Concrete mixing equipment needs to be checked prior to the pour and possibly during the pour if flash setting is occurring.**
Are project level construction records or materials information available?	**1**
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	**1**
If yes, describe:	**Yes, some construction and materials information is available.**
Have changes been made to your specifications or design methods?	**0**
If yes, describe:	**MoDOT is in the process of implementing new QC/QA performance related specifications for concrete paving.**
Date/Time	**7/10/2003 12:53:30 PM**

Item	Value
Names	Thomas M. Hearne, Jr.
Title/Position	Pavement Analysis Engineer
Address	NCDOT - Pavement Management Unit 716 West Main Street Albemarle, NC 28001
Phone	704-983-4019
E-mail	thearne@dot.state.nc.us
State	North Carolina
Highway Route	I-440
Length of Project	Estimate 1 mile (Affects the I-440 part of a 6.1 mile project including I-40)
Year Constructed	2000
Project Number	8.1404201
General Location	I-440 Beltline in Raleigh, North Carolina
In general, what was the problem?	Transverse cracks in 4"" bonded concrete overlay
Rank its severity 1-5 (5=very severe)	4
Which Mix Characteristic(s) do you think caused the problem?	
Mix Workability	False
Mix Consistency	False
Mix Shrinkage	True
Mix Strength	False
Mix Air Content	False
Mix Permeability	False
Mix Other	False
Mix Other Describe	Shrinkage of mix is a possible contributor to the problem
Describe the nature of the problem:	Transverse cracks near mid-slab in 4"" bonded concrete overlay
Material Related Cause	1
Material Related Cause Describe	Shrinkage possibly contributes to problem

Construction Related Cause	**1**
High temperatures during placement of thin overlay on Describe rigid base with joint spacings varying from 18 to 25 ft in length creates potential for problems with drying shrinkage.	
Was this within the specifications and normal construction practices?	**1**
Do you feel there was an environmental related cause?	**1**
Environmental Related Cause	**High temperatures**
Description Did the problem persist throughout the project?	**1**
If no, how much of the project:	
What changed (weather, certain material, etc.)?	**Cracking was not as severe when air temperature was lower**
What tests were used to identify the causes?	**Cores, Distress Surveys**
What information / tests would have helped in identifying the problem prior to / during construction?	**Good engineering judgment--high risk of failure**
Are project level construction records or materials information available?	**1**
Were any post-construction investigative tests performed on the pavement? (Cores, petrography, in-place strength, etc.)	**1**
If yes, describe:	**Various strength tests, compression wave velocities, distress surveys**
Have changes been made to your specifications or design methods?	**1**
If yes, describe:	**Use smaller slab lengths for overlay**
Date/Time	**7/14/2003 2:20:59 PM**

MIX DESIGN			PRESCONSTRUCTION MIX VERIFICATION			CONSTRUCTION QUALITY CONTROL		
Exists	Further Develop	Needed	Exists	Further Develop	Needed	Exists	Further Develop	
C/ XRD	TGA		DSC (Portable)	TGA		DSC (Portable)		
F			XRF (Portable)					
F			XRF (Portable)					
ine	Laser Particle Size Analyzer		Blaine					
lstone Proportions 8 & 45 Power			Shilstone Proportions 8/18 & 45 Power			Shilstone Proportions 8/18 & 45 Power	Optical Grading (Scanning)	
	Shape/Texture							
	Iowa Pore Index							
TM 187 (Vicat)	Automated ASTM 403			Automated ASTM 403				
TM 359 (False Set)	Modified ASTM 359 Coffee Cup Test Dan Johnston Test		ASTM 359	Modified ASTM 359 Coffee Cup Test Dan Johnston Test				
erted Slump	VSA	Mini VSA	Inverted Slump	VSA	Mini VSA	Inverted Slump		Mini V
								Coarse
ncrete Temperature	Heat Signature		Concrete Temperature	Heat Signature			Heat Signature Automated Concrete Temp.	
. Strength Tests			Maturity Curve	Temperature Match Cure		Maturity Temperature (Slab)	Temperature Match Cure	
. Strength Tests								
ssure Meter (ASTM 231) it Weight	AVA		Pressure Meter (ASTM 231) Unit Weight	AVA		Pressure Meter (ASTM 231) Unit Weight		Simple
ear Traverse	MO-Image Analysis MI- Image Analysis		Linear Traverse		New Test Image Analysis Test (Scanner)			New Te (Scanne
oid Chloride	Rapid Migration Test							Curing/
E (AASHTO)			CTE (AASHTO)					
			Temperature Sensors (HIPERPAV)			Temperature Sensors (HIPERPAV)		
e Shrinkage Test	Restrained Shrinkage Test (AASHTO TP)							