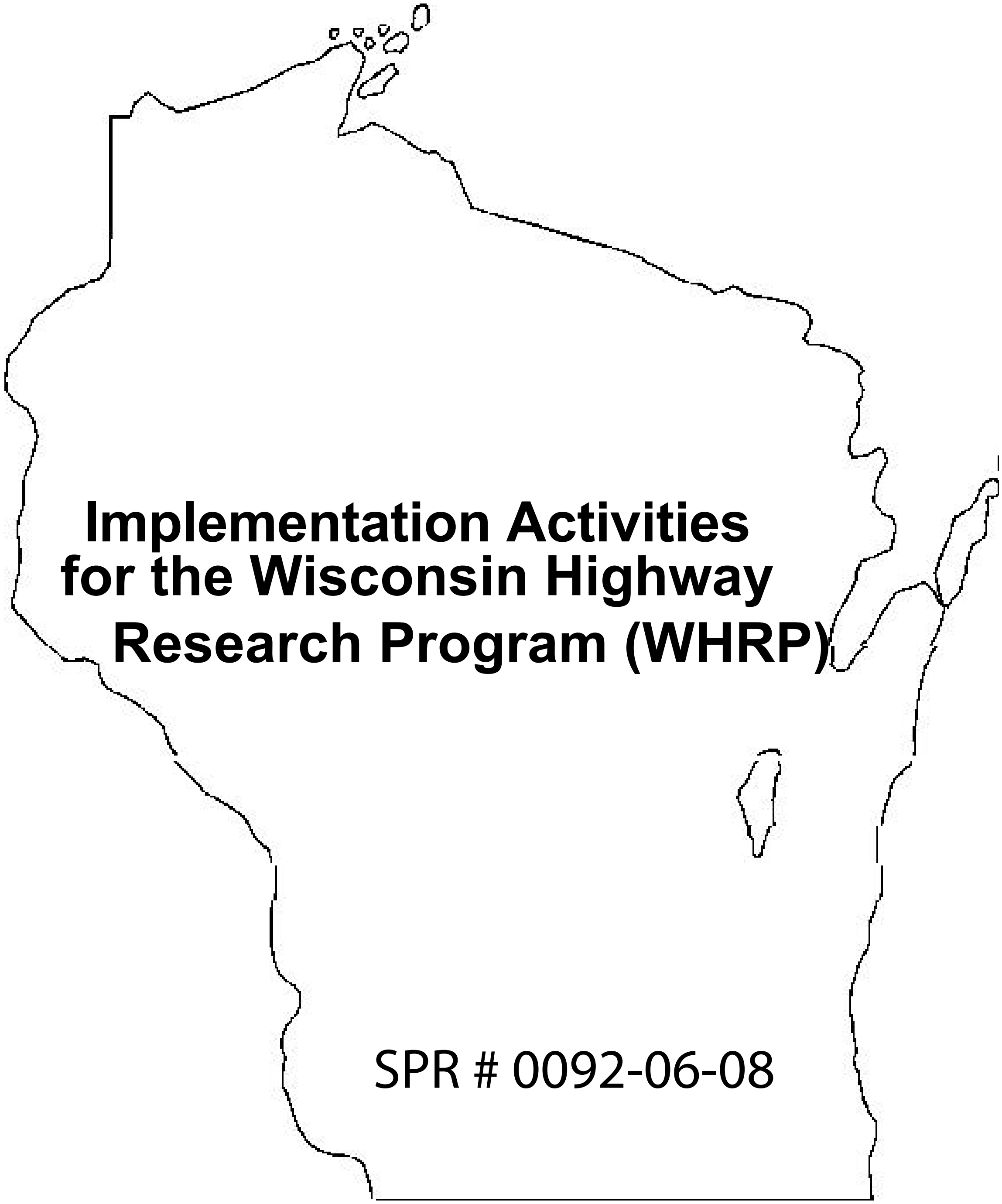
Wisconsin Highway Research Program



Implementation Activities for the Wisconsin Highway Research Program (WHRP)

SPR # 0092-06-08

Andrew Hanz and Hussain Bahia

University of Wisconsin - Madison

March 2010

WHRP 10-08

Technical Report Documentation Page

1. Report No. WHRP 10-08	2. Government Accession No	3. Recipient's Catalog No
4. Title and Subtitle Implementation Activities for the Wisconsin Highway Research Program		5. Report Date March 2010 6. Performing Organization Code
7. Authors Hanz, Andrew, Bahia, Hussain		8. Performing Organization Report No.
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Wisconsin Madison 2205 Engineering Hall 1415 Engineering Dr. Madison, WI 53706		10. Work Unit No. (TRAIS) 11. Contract or Grant No. WisDOT SPR# 0092-06-08
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Division of Business Services Research Coordination Section 4802 Sheboygan Ave. Rm 801 Madison, WI 53707		13. Type of Report and Period Covered Final Report, 2005-2010 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Wisconsin Highway Research Program (WHRP) Steering Committee commissioned an implementation pilot program in 2006 to facilitate the incorporation of research results into the programs, standards, and processes of the Wisconsin Department of Transportation (WisDOT). The program had two main objectives, the first of which was to provide additional funding for each WHRP Technical Oversight Committee (TOC) that allowed researchers to work with WisDOT in providing technology transfer presentations and developing draft specification language or design/construction guidance based on the results of the initial research project. The second objective was to identify processes and committees responsible for initiating changes that integrated research results into the standard practice. To support these implementation activities, the WHRP Steering Committee approved $60,000 in funding, with the intent to distribute evenly amongst the four TOCs to promote implementation of completed research projects that showed promising results.

17. Key Words Research Implementation, Flexible Pavements, Rigid Pavements, Geotechnics, Structures	18. Distribution Statement No restriction. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield VA 22161		
19. Security Classif.(of this report) Unclassified	19. Security Classif. (of this page) Unclassified	20. No. of Pages	21. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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This research was funded through the Wisconsin Highway Research Program by the Wisconsin Department of Transportation and the Federal Highway Administration under Project # 0092-06-08. The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

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Wisconsin Department of Transportation Project 0092-06-08

Implementation Activities for the Wisconsin Highway Research Program (WHRP)

Submitted to:

The Wisconsin Department of Transportation

Research and Communication Services Section

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October 15, 2009

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1: BACKGROUND

The Wisconsin Highway Research Program (WHRP) Steering Committee commissioned an implementation pilot program in 2006 to facilitate the incorporation of research results into the programs, standards, and processes of the Wisconsin Department of Transportation (WisDOT). The program had two main objectives, the first of which was to provide additional funding for each WHRP Technical Oversight Committee (TOC) that allowed researchers to work with WisDOT in providing technology transfer presentations and developing draft specification language or design/construction guidance based on the results of the initial research project. The second objective was to identify processes and committees responsible for initiating changes that integrated research results into the standard practice.

To support these implementation activities, the WHRP Steering Committee approved $60,000 in funding, with the intent to distribute evenly amongst the four TOCs to promote implementation of completed research projects that showed promising results. The following projects were selected:

Table 1: Summary of FY 2006 Implementation Activities

TOC	Title	Researcher
Flexible Pavements	Implementation of Project 0092-01-02: Using the Gyratory Compactor to Evaluate Mechanistic Properties of WisDOT Mixtures	Ahmed Faheem – UW Madison
Geotechnics	Implementation of Projects 0092-45-15,45-18, 00-12, 03-12: Equivalency of Alternative Working Platforms and Their Pavement Design Strength Contribution	Tuncer Edil – Geo-Engineering LLC.
Rigid Pavements	Implementation of Project 0092-04-11: Research and Development of the Application of the FHWA's HIPERPAV Model	Mauricio Ruiz – The Transtec Group
Structures	Implementation of Project 0092-01-06: Rehabilitation Techniques for Concrete Bridges	Al Ghorbanpoor – UW Milwaukee

All projects were scoped with a 12-month timeframe in order to promote a quick transition from an "implementation project" to a tangible change in practice. Unfortunately, the broad scope relative to the level of funding, and delays by both the researchers and the affected WisDOT Technical groups caused these projects to be extended 12 months or more. Detailed descriptions of these activities are provided in subsequent sections of this report.

2: SUMMARY OF FUNDED IMPLEMENTATION ACTIVITIES

2. 1: Implementation of Project 0092-01-02: Using the Gyratory Compactor to Evaluate Mechanistic Properties of WisDOT Mixtures

1. Objectives and Tasks

The main objective of this project was to further refine and promote the findings of project 0092-01-02 to frame as a practical technology for use by Hot Mix Asphalt (HMA) users through technology transfer and supplemental testing. Testing was conducted to verify performance thresholds published through the original research and develop a methodology for differentiating between HMA mixtures currently specified by WisDOT. To accomplish this objective the following tasks were defined:

- Development of a Technical Summary Document and Concept Presentation
- Supplemental Laboratory Testing
- Marketing and Knowledge Transfer

2. Proposed vs. Actual Schedule – Summary of No Cost Time Extensions

The original project duration was intended to be 12 months, from August 1, 2006 – August 1, 2007. The actual completion date of the project was September 30, 2008, an extended duration of 13 months. Table 2 provides a summary of the no cost time extensions.

Table 2: Summary of No Cost Time Extensions – Flex TOC Implementation

Original End Date	Expected End Date	# of Extensions	Duration (Months)	Reason for Extension
8/1/2007	3/31/2008	2	7	Completion of Supplemental Testing
	9/30/2008		6	TOC Review and Approval of Final Report.

3. Deliverables and Assessment of Implementation

The following deliverables were provided as part of this research and are available on the WHRP website (http://www.whrp.org/research-areas/flex/flex_0092-06-08.html):

- Technical Summary: Results of Previous Research and Motivation for Further Work.
- Technical Presentation: December 2006 Wisconsin Asphalt Pavement Association (WAPA) Conference.
- Test Procedure in AASHTO Format.

- Analysis Template for Practical Use: Excel format posted on WHRP website.
- Final Report: Summary of results and recommendations for further practice. Other deliverables included as Appendices.

The project established performance thresholds using a wider range of mixture designs in terms of both design traffic level and materials. Thus far, the technology has not been widely implemented by WisDOT or industry. However it is expected that as efforts continue related to implementation of the Mechanistic Empirical Design Guide, the research will have potential for more prevalent use as a mixture design and quality control tool.

2. 2: Implementation of Projects 0092-45-15, 45-18, 00-12, and 03-12: Equivalency of Alternative Working Platforms and Their Pavement Design Strength Contribution

1. Objectives and Tasks

This implementation effort synthesized the results of five completed and one in-progress research projects related to the use of different materials, natural and recycled, for use in subgrade stabilization. The projects incorporated into this study are as follows:

Completed

- 0092-45-15: Effectiveness of Geosynthetics in Stabilizing Soft Subgrades
- 0092-45-18: Field Performance of Subbases Constructed with Industrial By-Products
- 0092-00-12: Equivalency of Subgrade Reinforcement Methods
- 0092-03-12: Development of Methodology to Include Strength Contribution of Select Subgrade Materials in Pavement Structures
- 0092-07-05: Development of Testing Methods to Determine Interaction of Geo-grid Reinforced Granular Material for Mechanistic Pavement Analysis

In-Progress

- 0092-04-10: Monitoring and Evaluation of Fly Ash Stabilized Subgrade Constructed by Wisconsin DOT

The results of the aforementioned research projects were used to develop a design tool that included definition of both equivalent thicknesses and contribution to pavement design strength for the eight select material alternatives allowed under the WisDOT Subgrade Improvement specification. The tool is intended for use by WisDOT pavement designers and project managers.

2. Proposed vs. Actual Schedule – Summary of No Cost Time Extensions

The original project duration was intended to be 12 months, from August 1, 2006 – August 1, 2007. The actual completion date of the project was March 31, 2009, 19 months after the original completion date. Table 3 provides a summary of the no cost time extensions.

Table 3: Summary of No Cost Time Extensions – Geotech TOC Implementation

Original End Date	Expected End Date	# of Extensions	Duration (Months)	Reason for Extension
8/1/2007	5/31/2008	3	10	Completion of Supplemental Testing
	12/31/2008		7	Completion of Supplemental Testing
	3/31/2009		3	TOC Review and Approval of Final Report

3. Deliverables and Assessment of Implementation

The following deliverables were provided for this report and are available on the WHRP website:

- Final Report: Recommended revisions to current list of available subgrade improvement options and a table summarizing recommended thicknesses and contributions to pavement design.
- Specification Language: Recommendations and the corresponding table summarizing the structural contribution to design of eight select material alternatives have been written for inclusion into the Facilities Development Manual (FDM).

The TOC approved these recommendations, submitted by the researcher in March of 2009. The changes have not yet been incorporated into current WisDOT design manuals. There will be continued follow to ensure that the recommendations are evaluated in adequate time to impact the FDM and other pertinent guidance documents.

2. 3: Implementation of Project 0092-04-11: Research and Development of the Application of the Federal Highway Administration's HIPERPAV Model to Wisconsin

1. Objectives and Tasks

This project was focused on transitioning the FHWA HIPERPAV software customized for Wisconsin materials and conditions developed in the original research project from a research tool into practice. Implementation activities were focused on promoting the technology and making it readily available to WisDOT and industry. Specifically, the following tasks were defined:

- Workshops to train WisDOT staff, contractors, and consultants within the different WisDOT regions.
- Integration of HIPERPAV into the quality management program (QMP) specifications and Facility Development Manual (FDM).
- Validation of the HIPERPAV model for Wisconsin conditions.

2. Proposed vs. Actual Schedule – Summary of No Cost Time Extensions

The project was completed by its intended end date of August 1, 2007, however numerous related follow up activities were funded in subsequent fiscal years. These activities included a HIPERPAV Phase IIa and IIb that focused on providing technical support and further refining the software developed in the original research project. Phase IIb was completed on July 30, 2009.

3. Deliverables and Assessment of Implementation

The following deliverables were provided for this project and are available on the WHRP website:

- Technology Transfer Presentations: Overview and Summary of new developments in HIPERPAV Wisconsin software. Workshops were conducted in Madison, Eau Claire, and Green Bay, WI.
- Customized version of the HIPERPAV Wisconsin software available at http://www.hiperpav.com/index.php?q=node/103.
- Final report of all HIPERPAV related activities available at: http://www.whrp.org/research-areas/rigid/rigid_0092-08-33.html.

The HIPERPAV software is currently used on a voluntary basis, except in the Northwest Region where it is required. WisDOT is currently considering mandatory use and the costs associated with upgrading to the most current version of the software.

2. 4: Implementation of Project 0092-01-06: Rehabilitation Techniques for Concrete Bridges

1. Objectives and Tasks

Implementation activities involved use of workshops and presentations to disseminate, the findings of the 0092-01-06 study to a larger audience, and cooperation with WisDOT personnel developing specifications language. These objectives were accomplished through the following tasks:

- Preparation and Delivery of Workshops.
- Specification Development: Use comments from workshops and WisDOT staff input to develop draft specification language.

2. Proposed vs. Actual Schedule – Summary of No Cost Time Extensions

The original project duration was intended to be 12 months, from August 1, 2006 – August 1, 2007. The actual completion date of the project was December, 31, 2008, 17 months after the original completion date. These extensions were due to contracting and review delays, and were not the fault of the researcher. Table 4 provides a summary of the no cost time extensions.

Table 4: Summary of No Cost Time Extensions – Structures TOC Implementation Project

Original End Date	Expected End Date	# of Extensions	Duration (Months)	Reason for Extension
8/1/2007	1/1/2008	3	5	Project extended due to WHRP Adminstrative delay. Between UW Madison and UW Milwaukee in executing the subcontract.
	7/1/2008		6	Delays in convening the WisDOT meeting to develop specifications.
	12/31/2008		6	TOC Review and Approval of draft specifications

3. Deliverables and Assessment of Implementation

The deliverables originally provided in the work plan were modified. In lieu of technology transfer workshops to an expanded audience within WisDOT, it was decided that a national presentation of the research results would a more appropriate venue. The TOC decided on this change in venue due to difficulties in scheduling regional presentations and to take advantage of the opportunity to present at a national level. The research project was presented at the Paint and Coatings Expo held on January 28, 2008 in Los Angeles, CA. The presentation included discussion of the research by Professor Al Ghorbanpoor and how it is being incorporated into WisDOT practice by TOC member, Ed Fitzgerald. The full summary of the revised set of deliverables is provided below:

- Technology Transfer Presentation: Given by Dr. Al Ghorbanpoor and Ed Fitzgerald at the PACE Workshop. Available at http://www.whrp.org/research-areas/structures/structures_0092-06-08.html.
- Specification Development: The specification provided by the research team was modified by WisDOT as a standard plan section. In addition, the following note was inserted into the Standard Plan Sheets:

"STRANDS SHALL BE FLUSH WITH THE END OF GIRDER. FOR GIRDER ENDS EMBEDDED COMPLETELY IN CONCRETE, ENDS OF STRANDS SHALL BE COATED WITH NON-BITUMINOUS JOINT SEALER. FOR GIRDER ENDS THAT ARE FINALLY EXPOSED, COAT THE GIRDER ENDS, EXPOSED STRAND ENDS, AND ALL NON-BONDING SURFACES WITHIN 2 FEET OF THE GIRDER ENDS WITH A NON-PIGMENTED EPOXY CONFORMING TO AASHTO M-235 TYPE III, GRADE 2, CLASS B OR C.THE EPOXY SHALL BE APPLIED AT LEAST 3 DAYS AFTER MOIST CURING HAS CEASED AND PRIOR TO THE APPLICATION OF THE SEALER."

3: DEFINITION OF A PROCESS FOR IMPLEMENTATION OF RESEARCH AND OPPORTUNITIES FOR WHRP INPUT

The second objective of this implementation effort was to define a general process to integrate research results into practice. This included definition of the operational components related to implementation in hopes of making the process more quantifiable and efficient. Successful implementation of research is dependent on 1) establishment of guidelines; 2) identifying funding mechanisms available, if necessary for implementation; and 3) clear definition of the connection between WHRP and WisDOT technical groups to improve the process and use of implementation as a performance measure.

For the 2006 – 2009 fiscal years, each TOC was provided $15,000 annually for the purpose of implementation activities. It was to the discretion of the TOCs as to whether to use these funds to add to a new project or to a recently completed one. Based on the results of this three-year pilot program, it was decided that it was counter-productive to differentiate between implementation and new research in development of the TOC's annual research projects. A new concept for prioritization of research ideas was introduced in which the committees consider new ideas, implementation activities, and completed projects pending further action in their funding cycle. To support these efforts, WHRP provides a list of all completed research activities and their status to the committees in the research prioritization meeting. This report is defined as a "Summary of Outcomes of Completed Projects." The report is updated annually to incorporate newly completed projects and update any associated changes in specification. Projects are split into two categories:

- Implemented: Projects that have resulted in a change in practice or verified current practice.
- Not Implemented: Projects that have resulted in further research activities, implementation projects, were found not able to be implemented, or are pending action.

To further support implementation, the following process was defined:

1. The TOC will review the "Summary of Outcomes of Completed Projects" to identify projects that are candidates for implementation. In the event that a project cannot be implemented or the outcome has been previously determined this information will be documented in by WHRP.
2. Selected projects are submitted to the appropriate WisDOT Technical Team for discussion. The WHRP Technical Oversight Committee membership is composed of both agency and industry members that are represented on the technical teams.
3. The Technical Team will determine the aspects of research results that should be implemented and will assume the responsibility of developing draft specifications, special provisions, or other guidance as well as identify the need for pilot projects. Refined practices will be submitted for inclusion in specifications.
4. The Technical Team will coordinate with the Publications and Construction Standards Manager to confirm deadlines for submitting changes to be incorporated into WisDOT guidance documents.

A schematic of this process is presented in Figure 1. Both the process and the flow chart were approved by the WHRP Steering Committee in the April 11, 2008 Steering Committee Meeting.

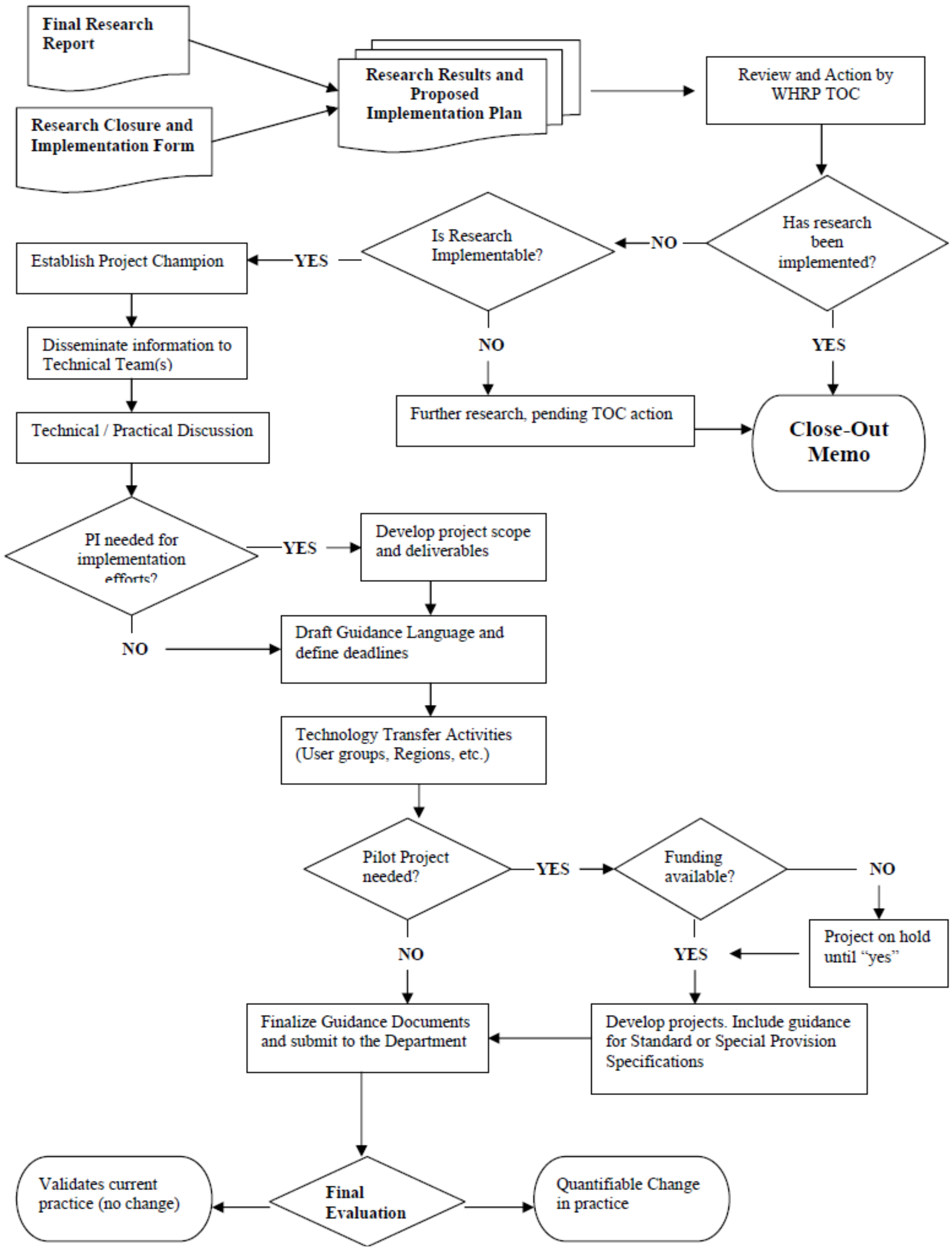

Figure 1: Process for Post Project Implementation

4: LESSONS LEARNED, CONCLUSIONS, AND RECOMMENDATIONS

Results of this pilot project indicate that the implementation process used in the WHRP program was in need of further improvement. Specific to the projects summarized as part of this report, significant delays were encountered for three of the four TOCs, with an average delay of approximately 17 months. The project that was completed on time was part of a three-phase project with a combined duration of 23 months at a cost of $45,000. The intent of these projects was to provide the funding to promote short-term implementation activities to move research results into practice within one year. Based on the statistics, it is clear this objective wasn't met. Due to a variety of circumstances, it appears that the timeline of 12 months was inadequate. The reasons for the delays are as follows:

- Inadequate funding to properly staff and execute the projects.
- Time commitment required by committee members and staff to oversee implementation projects while continuing oversight of research activities.
- Difficulty in clear definition of the proper scope for an implementation project. In most cases, the scope of the implementation projects awarded was more reflective of further research activities.
- The need for better coordination between WHRP and Technical Team activities to ensure that promising research results are discussed in a timely fashion and deadlines for submittal of specification changes are met.

Based on the results of these implementation activities and the delays encountered in completing this pilot project, WHRP staff recommends that the program re-evaluates the process to consider implementation or research projects. It is proposed that successful research implementation requires consideration of the practical application of research results in all phases of the research projects including: research ideas generation, project oversight, and technology transfer activities.

Successful implementation starts in the ideas generation and solicitation phases of the research process through consideration of potential implementation for new research ideas as well as review of completed projects that have not been implemented. To promote these ideas, WHRP has instituted a new research prioritization policy that requires consideration of completed research efforts in need of additional funding alongside new research ideas. The WHRP Steering Committee approved this process at the September 19, 2008 meeting. WHRP staff provides the TOCs with a summary of the outcomes of their completed projects that identifies projects that 1)have/have not been implemented; 2)resulted in further research; 3)resulted in an implementation project, or 4)are pending further action. This summary, used to promote discussions at the research prioritization meetings, ensures that TOC members make the appropriate recommendations to the WisDOT Technical Teams. A summary of the results of this analysis for all TOCs is provided in Figure 2.

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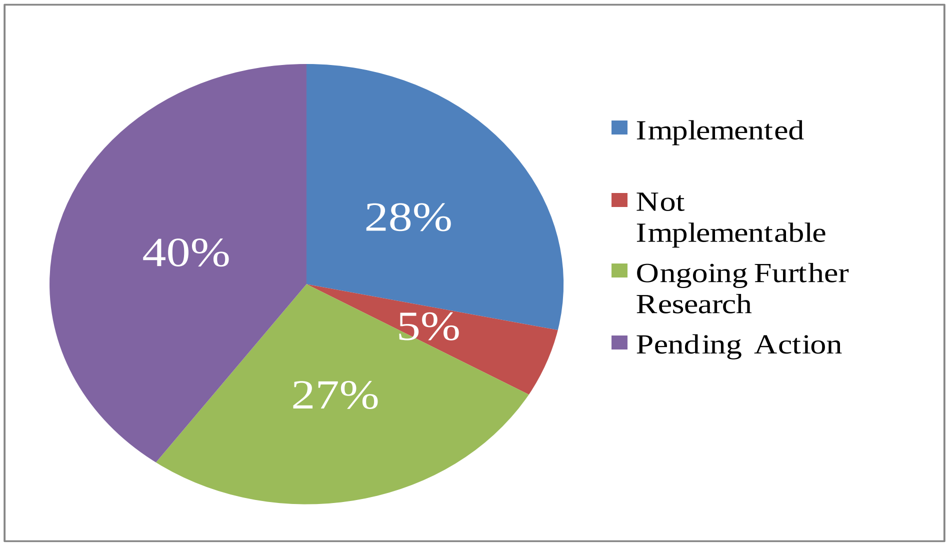

Figure 2: Summary of Outcomes of Completed Projects – September 2008

WHRP Staff identified that of the 60 projects completed from the inception of WHRP to September 2008, 67% (40 projects) are pending action or have led to further research. Based on this analysis, it is clear that there is an opportunity for the committees to re-evaluate completed research efforts and to 1)move forward by funding further research or implementation activities or 2) to classify those that will not be implemented and to close the project to any further research activities. These changes were implemented for the FY 2010 funding cycle and resulted in identification of many projects that need to be resubmitted to the Technical Teams for evaluation. Also three projects were identified as in need of further research and funded accordingly. The proposed process clarifies the relationship and responsibilities between WHRP Staff, the Technical Oversight Committees, and WisDOT Technical Teams, in terms of moving research results into practice.

There is also an opportunity to integrate implementation concepts into the research solicitation process. Definition of expected outcomes or changes in practice by the TOC in the Request for Proposal requires proposing researchers to submit an implementation plan. This allows for the TOC to evaluate the researcher's understanding of WisDOT practices and the opportunities for implementation of expected research results in the proposal review phase. Furthermore, establishment of an implementation plan provides a reference point in the monitoring of progress, allowing for more efficient project oversight. As a result committees dedicated a significant amount of time discussing the implementation plans given in the proposals and were able to select the researcher that provided the best opportunity to produce research products most promising for implementation.

The final opportunity to promote implementation of research results is improved technology transfer at the conclusion of the research project. Current WHRP policy requires the researcher provide a closeout presentation of their project to the TOC. This process has been effective in ensuring that TOC comments are incorporated into the final report. However, in some cases, technology transfer is more effective if the research presentation is available to a wider audience. This concept was piloted through a Technology Transfer Workshop hosted by WHRP and the Flexible Pavements TOC to close out a research project that was defined by the committee as high impact. The workshop included presentations by TOC members related to the importance of the research project and a presentation of the research results by the principal investigator. The entire workshop was captured as a Webinar using GoTo meeting, a web conferencing application. Approximately 40 people attended the workshop with an additional six joining remotely using GoTo Meeting. The entire webinar is available on the research project page (http://www.whrp.org/research-areas/flex/flex_0092-08-06.html).

The success of the technology transfer workshop identified a clear opportunity for WHRP to improve dissemination of research results at the end of a project. Improvement of technology transfer activities will be a focus as WHRP moves forward in the implementation of research results. Planned activities include encouraging the TOCs to identify high impact projects and to work with WHRP to conduct similar workshops. There is also an opportunity to provide Continuing Education Units (CEUs) for attendance at these workshops, which becomes of more importance as WisDOT implements the requirement for Professional Engineers to obtain 30 CEUs bi-annually to maintain their certification. Furthermore, WHRP will evaluate the feasibility of providing a Webinar for all completed research projects. It is possible that certain aspects of these webinars may be integrated into current WisDOT training practices. WHRP is currently working with the Steering Committee to determine when it is appropriate to hold workshops as opposed to webinars that allows these presentations to reach a wider audience.

In conclusion, this initial pilot project provided a successful first step towards promoting implementation of research results. As shown in the previously provided summary, the individual research projects selected for implementation were successful. However, of more importance was the identification of opportunities to improve implementation of WHRP research projects and how these opportunities were integrated into new policies. These policies include the following:

- **Improved coordination between the WHRP TOCs and the WisDOT Tech Teams.** A flow chart was provided to define the process by which research results are reviewed and submitted to the Tech Teams for evaluation.
- **Definition of Implementation as a Research Performance Measure:** The results "Outcomes of Completed Research Projects" analysis provide a tangible implementation performance measure for use by the WisDOT research staff to annually evaluate the program.
- **Improved Solicitation and Proposal Evaluation Procedures:** A clear need was established to integrate implementation into the development of the RFP and proposal review processs.
- **Opportunities for Technology Transfer:** Clear opportunities were identified to allow research results to reach a wider audience and potentially be integrated into WisDOT training practices and Professional Engineer CEU requirements.

Appendix A: Deliverables for Implementation of Project 0092-01-02: Using the Gyratory Compactor to Evaluate Mechanistic Properties of WisDOT Mixtures

WISCONSIN HIGHWAY RESEARCH PROGRAM

#0092-06-08 Flex TOC Implementation

Implementation of WisDOT Project 0092-01-02: Using the SuperPave Gyratory Compactor to Measure Mechanical Stability of WisDOT Asphalt Mixes

Final Report of Implementation Activities

By

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SUBMITTED TO THE WISCONSIN DEPARTMENT OF TRANSPORTATION

September 30, 2008

Disclaimer

This research was funded through the Wisconsin Highway Research Program by the Wisconsin Department of Transportation and the Federal Highway Administration as part of Project # 0092-06-08. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

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Acknowledgements

The authors would like to thank the WisDOT Hot Mix Asphalt Technical Team for their input to the project. Special thanks go to Ms. Judie Ryan, WisDOT Bureau of Technical Services, WisDOT Regional Staff, and Dr. Erv Dukatz and Mr. Dustin Preble, Mathy Construction for their help in providing and testing materials for the project. The authors would also like to thank Mr. Barry Kuzay, UW Madison undergraduate student for all his help in materials collection and testing related to this project.

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Background

In Federal Fiscal Year 2006 the Wisconsin Highway Research Program (WHRP) developed and launched an implementation pilot program aimed at discovering an improved process to transition research results into practice. The program is an on-going two-year effort that provides funding for each WHRP Technical Oversight Committee (TOC) to facilitate implementation of research project results through technology transfer and training efforts. The funds are also used for the researchers involved in the project to work with WisDOT to develop draft guidance documents based on research results. The other objective of the program is to identify processes and committees responsible for approval and authorization of use in pilot projects to further evaluate the potential for a change in standard practice.

Due to WisDOT's commitment for the transitioning from the current empirical pavement design procedures to the new Mechanistic Pavement Design, WisDOT Project 0092-01-02: "Using the Gyratory Compactor to Measure Mechanical Stability of Asphaltic Mixtures" was selected as one of the first the research projects to implement. The project investigated the potential for the SuperPave Gyratory Compactor to provide estimates of the mechanical behavior of mixtures that can be used in the new design procedure. Mechanistic Pavement Design procedures require measurements collected with complex equipment and test methods in order to quantify the mechanical behavior of HMA mixes. These test methods are not practical enough to be used for quality control or quality assurance in practice. Also, logistical issues and high costs associated with equipment procurement and training has prevented WisDOT from cataloging common HMA mixes to date. These limitations identified the need for a surrogate test to allow industry and the agency to obtain information related to the mechanical properties of HMA mixtures commonly used in Wisonsin and to develop simple quality management test protocols. Research results from Project # 0092-01-02 showed potential to use the Superpave gyratory compactor, which is used currently for volumetric mixture design and for quality management as the surrogate test. The results of this test are expected to bridge the gap between specifying HMA mixtures based on only volumetrics, which is the current practice, and evaluating their mechanical properties, which will be needed for the new pavement design procedure.

This implementation project served the purpose of synthesizing the fundamental concepts and recommendations published in the original research study report into a package that can easily be understood and applied to everyday practice. The following tasks describe the work plan approved and conducted for the project:

1. Technology Transfer and Marketing of Concept to Raise Awareness.
    1. Outreach of Activities to Raise Awareness of the Concept
        a. Concept Presentations
        b. HMA Tech Team Meetings
    2. Technology Transfer
        a. Test Methods in Standard Format
        b. Data Analysis Tools
        c. Draft CMM (Construction and Materials Manual) Guidance Language (Pending)
2. Supplemental Laboratory Testing

1. Materials Collection, Testing, and Analysis
    a. Evaluation of plant produced E3, E10, and E30 mixes to make recommendation of densification indices based on ESAL level.
    b. Comparison to recommendations published in original research report.
2. Conclusions
3. Recommendations

3. Follow Up
    1. Identify equipment needs or modifications to existing equipment.
    2. Audience feedback in terms of comments and thoughts on future uses.
    3. Measurement of satisfaction of use of the new methods.
    4. Research Ideas
4. Marketing Strategy for Knowledge Transfer
    1. Definition of the WisDOT review process (ex: flow chart) for document submittals. Includes definition of required approval groups and their processing deadlines.

The following is a summary of the work completed for each task. .

1: Technology Transfer and Marketing of Concept

The research team and project oversight participants identified raising awareness of the new concept for both WisDOT and industry as an important objective. Additional technology transfer through development of procedures and user-friendly analysis tools were also acknowledged as critical steps to successful implementation.

1.1: Outreach Activities to Raise Awareness of the Concept

The following outreach activities were conducted to introduce the information to regional and statewide bureau WisDOT representatives and members of the industry. Outreach materials are included in Appendices B-C.

a. Presentations:
    - "Research Pays Off Conference" August 17, 2006: Concept presentation by Andrew Hanz from UW Madison and Judie Ryan from WisDOT. Conference was a joint effort between the Wisconsin and Iowa Departments of Transportation focused on bringing research results into practice.
    - WAPA (Wisconsin Asphalt Pavement Association) Conference November 28th, 2006: The following efforts were made at the WAPA Conference to promote the implementation project:
        - Project poster was showcased in an exhibition booth.
        - Technical summary document was distributed at the conference and posted on the WHRP website (Appendix B). The document provides a short description of the methods used in the original research and its potential benefits.
        - As part of the a presentation on WHRP update at the WAPA conference DR. Hussain Bahia presented the project as an example of research implementation.

**Power Point Version of all presentations are available at
http://www.whrp.org/Implementation%20%20Projects/06/Flex/index.htm

HMA Technical Team Meeting May 16, 2007: Andrew Hanz provided a brief introduction of the project, distributed technical summaries and solicited input from the Tech Team as to how the research may be applied and for any materials they could provide to supplement the original research results. There was a clear interest in this project expressed by the members of the team.

1.2: Preparing Matrerials for Technology Transfer

Technology Transfer materials developed in this project are compiled in Appendix A. The following is a brief description of each of the Technology Transfer activities.

a. Test Method in Standard Format: Developed a test procedure in similar format to AASHTO T 312 (formerly TP4): Standard Method for Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by means of the SuperPave Gyratory Compactor. This new method is provided in Appendix A1.
b. Data Analysis Tools: A user-friendly Excel spreadsheet was developed to reduce the analysis time required for technicians running the test. The sheet automatically calculates the densification indices using height, gyration effort, and density data entered by the user. The spreadsheet also contains instructions for data entry and a data summary sheet. The data summary sheet then provides a densification curve, the calculated densification indices, and pertinent volumetric data. An example of this output sheet is included in Appendix A2.
c. Construction and Materials Manual Guidance: CMM Guidance in terms of acceptable threshold values should be defined and included in the manual. Initial values based on the data collected in this project and the original research project have been recommended.

2. Supplemental Laboratory Testing

The implementation team met prior to the construction season in early May 2007 and discussed the focus of the supplemental testing and logistical issues related to obtaining raw mixture samples. It was decided that testing would include at least two mixes representing the three traffic loadings of E-3, E-10 and E30, for direct comparison to densification indices published in the original research report. WisDOT and industry would provide the extra mix samples for testing by UW and when possible, use the gyratory compactor in their field laboratories to compact a sample to 250 gyrations. Additional data points were also obtained using materials available from work performed by UW Madison for other projects.

2.1: Materials Collection, Testing and Analysis

The implementation team collected production materials from Wisconsin contractors and WisDOT in the form of plant produced loose mixture. This provides a direct link to the field. The materials were compacted in the laboratory and analyzed using procedures detailed in the

Technical Summary (Appendix B1). A summary of the mixtures tested and the detailed results of analysis are summarized in Appendix B2.

Comparison of the limits proposed using the results of the original research project and the results for the new mixtures showed mixed differences. Revising the limits was necessary to reflect the response of the new materials. The revised limits were derived by combining the results of both the research and implementation mixtures. Tables 1 and 2 show the comparison of the original and the revised limits.

Table 2. 1: Comparison of Proposed Limits for Research Data Set and Combined Data Set – Construction Resistance Indices

Mixture Type	Maximum CFI Research	Maximum CFI Combined	Difference	Maximum CDI Research	Maximum CDI Combined	Difference
E3	370	300	-70	280	230	-50
E10	420	360	-60	320	260	-60
E30	620	500	-120	470	380	-90

Table 2. 2: Comparison of Proposed Limits for Research Data Set and Combined Data Set – Traffic Resistance Indices

Mixture Type	Minimum TFI Research	Minimum TFI Combined	Difference	Minimum TDI Research	Minimum TDI Combined	Difference
E3	1000	2400	1400	400	800	400
E10	2000	3000	1000	800	1000	200
E30	4500	5000	500	1200	1600	400

Based on the results shown in the above tables, the construction indices (CFI, and CDI) did not show significant change when comparing the research data with the combined research and implementation data. On the other hand, new thresholds for mixture traffic resistance (TFI, andTDI) for each ESAL level were proposed. The new thresholds limits are provided in Table 3.

Table 2. 3: Proposed Revised Limits for Constructability and Traffic Resistance Indices

Constructability

Mixture Type	*Maximum CFI*	*Maximum CDI*
E3	300	250
E10	360	300
E30	500	400

Traffic Resistance

Mixture Type	*Minimum TFI*	*Minimum TDI*
E3	2400	800
E10	3000	1000
E30	5000	1600

2.2: Conclusions

The following are conclusions pertain to the supplemental testing performed as part of this implementation study:

- The collected data confirms the validity of utilizing densification indices as a surrogate for the force indices measured using the PDA.
- The wide distribution of results for all ESAL levels demonstrates that mixtures also exhibit a wide range of mechanical behavior within each ESAL level. These findings are consistent with dynamic modulus testing results published in a separate WHRP study (0092-04-07). The proposed procedure will allow contractors to optimize mix designs to provide a mixture to meet expected constructability and traffic resistance.
- Due to the differences demonstrated in Tables 2, it is clear that more data collection is necessary before final traffic densification thresholds can be established. Proposed procedures for additional data collection are provided in the recommendations section of this report.
- The consistency in the values measured for the construction indices (CFI and CDI), while the traffic indices (TFI and TDI) show wide range of values, confirm that in mixture design, the constructability of the mixture receives more attention when designing a new mix compared to mechanical stability. This is probably due to the fact that there is no test currently specified to evaluate the mixtures' ability to resist traffic during its service life.

2.3. Recommendations

The following are recommendations based on the supplemental testing conducted in the implementation study:

- A continuous process of data collection should be established to define the appropriate densification limits based on mixes placed in Wisconsin. The process should be utilized to ensure that a diverse data set in terms of aggregate source and mix type is obtained. The only deviation from the procedure used in this study is that mixes should be compacted to a higher number of gyrations (500-600 gyrations) in order to achieve 98% Gmm density. This is necessary to allow for more accurate estimation of the TDI.

- Compaction to high densities presents the potential for crushing of the aggregates. This behavior is best identified using the Gyratory Load Plate. More details regarding this topic can be found in the final research report. http://www.whrp.org/Research/Flex/flex_0092-01-02/index.htm.
- There is incentive from both an agency and industry standpoint to clearly define densification thresholds and use them to optimize mix designs for a given ESAL level. Optimized mix designs
- Until thresholds have been established the procedure should not be used as a surrogate to mechanical mixture testing.

3. Follow up

The following summary lists details of impact of the implementation project and feedback received from users.

3.1: Equipment Impact:

No modification to existing equipment is required, however purchase of a Pressure Distribution Analyzer (PDA) plate would be beneficial in order to validate calibration or verify results on a periodically.

3.2: Audience Feedback

The following list of audience questions were documented during presentations and group discussion:

a) Is this information intended to be used during the mix design process only?
b) Is there an opportunity to use the resultant information as a department acceptance tool?
c) What is the current availability and cost of equipment?
d) Is future use intended to affect standard specification requirements or be used as guidance-type information?
e) What is the anticipated benefit and will the greater gain be by the department or the contractor?
f) Is there a potential for additional automation (import capability of data) to the worksheet tool?
g) Would there be any anticipated difference in laboratory procedures versus field procedures?

3.3: User Satisfaction

At the time of this writing no contractors had used the PDA plate or non-plate process. It is anticipated that in conjunction with the department obtaining the simple performance test equipment that parallel testing will begin in order to pursue the idea of determining if this newly developed process can serve as a field control tool to compliment mechanistic evaluation of mixture designs.

The above summary may also serve as a general template to build on and be used for anticipating issues for future research topics.

3.4: Future Research Needs and Potential for Use

The WisDOT Tech Team is committed to moving past evaluation of mix designs solely on volumetrics through its efforts in implementing the Mechanistic Empirical Pavement Design Guide (MEPDG) and purchase of a Simple Performance Tester (SPT). Asphaltic mixture evaluation through the dynamic modulus and flow number parameters required by the MEPDG involves a significant time investment in materials preparation, testing, and data analysis. The ability to estimate mixture stability through the technology developed in this research has shown promise by providing information pertaining to mixture stability without mechanical testing. From an agency standpoint, the Traffic Densification Index or Traffic Force Index could be used as a quality control acceptance criterion to ensure the in-situ mixture properties are consistent with those submitted in the original project mix design. Furthermore, accurate estimates and correlations to dynamic modulus and flow number could provide design inputs for low volume traffic facilities for which the costs related to extensive mixture testing cannot be justified. In terms of benefit to the industry, estimates of mixture stability could be used during production and allow for identification of promising mixes for mechanical evaluation during their mix design optimization.

Although potential use of this technology is promising, at this time defining acceptable threshold limits for acceptance of mixture stability is not feasible. Analysis of the mixes collected in the field part of this implementation project showed wide ranges of measured response for a given ESAL level. These findings are consistent with the evaluation of E* published in WisDOT project 0092-04-07 which found E* values for E-3 mixes that exceeded those measured for E-10 mixes. The aforementioned discrepancies must be resolved before the TDI can be applied as a reliable estimate of mixture stability. WHRP has funded a further investigation of SPT characterization for FY-08 and FY-09 that has the potential to resolve these issues.

Due to department budget constraints, the delay in obtaining testing equipment has limited validation of this particular research. However, that delay has presented an opportunity to use results of the implementation efforts to implement WHRP research project findings. This research project has helped to lay a foundation of understanding that measuring mechanical properties of HMA is only one aspect to the eventual goal of improving HMA specification and performance. It is also anticipated that eventual changes will involve further collaborative efforts between department personnel, academia, industry, and FHWA, which will enhance statewide awareness about the need to improve practice.

For this specific project of mechanical properties of HMA, it is suggested that WisDOT continue collecting mix samples, compacting them to a gyration level equaling or exceeding 98% Gmm, and use the analysis template delivered through this project to collect more data for CDI and TDI of plant produced mixtures. Further evaluation will provide more robust averages for use in establishing performance thresholds to be incorporated into Construction and Materials Manual

Guidance. Refinement of the CDI and TDI thresholds through a pilot project would provide a useful tool to WisDOT as they transition to acceptance of mixes based on mechanical criteria.

4. Strategy for Knowledge Transfer, Lessons Learned from this Project

Another objective of this implementation effort was to define the general process to get research results used into practice. There are three operational components related to implementation that must be more clearly defined to make it more efficient and quantifiable. Successful implementation of research is dependent on 1) the establishment of guidelines; 2) identifying funding mechanisms available, if necessary, to promote implementation; and 3) clear definition of the connection between WHRP and WisDOT technical groups to improve the process of implementation.

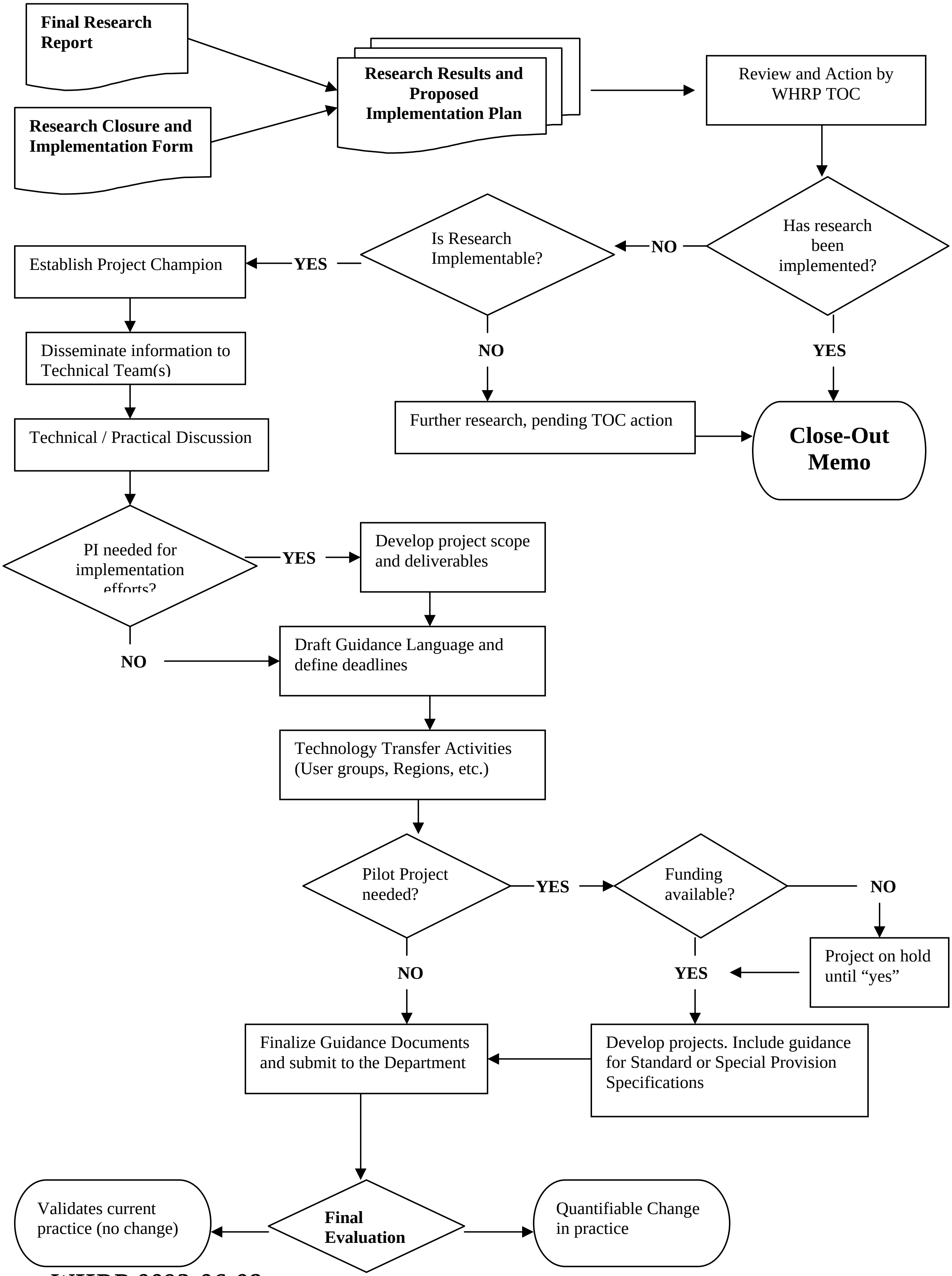
Currently, WHRP suggests that each Technical Oversight Committee to spend a maximum $15,000 on implementation efforts, which could involve multiple projects. The TOC assumes the responsibility of scoping implementation projects such that the end result is a change in WisDOT Guidance or industry practice. This study involved selection and development of an implementation project based on previously completed research. However, the TOC identified another mechanism for funding implementation in FY 2008 by incorporating implementation activities and related funding within a new research contract. This approach identifies an implementation champion at the onset of the research project and establishes implementation as a contractual component to be monitored throughout the review of technical progress for the specific research project. In prioritizing implementation activities the TOC must consider the advantages of front-end implementation with the disadvantage of not committing the funds to implement completed research.

From a WisDOT perspective, implementation is quantified through research that results in a change in practice or validation of current practice. Changes in practice are initiated through the HMA Technical Team, thus this group plays a vital role in implementation of research results. Currently, a connection between WHRP and the Tech Team exists through joint WisDOT and industry participation. However, to realize the full benefit of research a clear process for implementation must be defined. The process includes dissemination of the research results to the Tech Team and identification of deadlines, format, and WisDOT contacts for draft specification, CMM, or FDM guidance to ensure that viable candidates for implementation can be included in the appropriate guidance documents and thus put into practice as soon as practical. The following outlines the proposed process for implementation activities. This process will also be communicated in the flow chart provided as Figure 1.

Proposed Process for Implementation

1. Research will be evaluated for implementation by the Flexible Pavements TOC through review of the final report and discussion at the research closeout presentation. WHRP will then follow up with the TOC to ensure the intended action was taken. Results will be reported in the WHRP Summary of Outcomes of Completed Projects. In the event the findings have been implemented prior to the completion of the project, a closeout memo will be developed and filed.
2. Implementable research will be discussed with the Tech Team. By design the WHRP Flexible Pavements Oversight committee includes many members of the HMA Tech Team from both industry and WisDOT. It is important that these members continue to serve as the champions for bringing potentially implementable research results to the Tech Team for discussion.
3. The Tech Team will determine aspects of research results they would like to see implemented and will assume the responsibility of developing draft guidance and practical evaluation through pilot projects. Refined practices will be submitted for inclusion in specifications.
4. The timing of these activities will be discussed with the Publications and Construction Standards manager to confirm deadlines for submitting changes to WisDOT's guidance documents and ensure that adequate time is available for development and committee review before any final draft submittals.
5. In the case that the research is not implementable, a closeout memo from the WHRP to the WisDOT Research and Communications Section explaining why the research was not implementable will be developed.

Figure 4. 1: Process for Post Project Implementation



Appendix A: Technology Transfer Materials

Appendix A1: Test Method

Proposed Procedure to Determine Constructibility and Mechanical Stability of Asphaltic Mixtures Using the Superpave Gyratory Compactor.

1. Scope

1.1. This procedure covers mixtures used in the Superpave Gyratory Compactor. The mixtures are to be prepared according to the Superpave procedure including selection of materials, and mixing and compaction temperatures.

2. Referenced Documents

AASHTO Standards:

T312 Method for Preparing and Determining the Density of Hot Mix Asphalt Specimens by Means of the Superpave Gyratory Compactor

T209 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures

T166 Bulk Specific Gravity of Compacted Mixtures Using Saturated Surface-Dry Specimens

PP-28 Standard Practice for Superpave Volumetric Design for Hot Mix Asphalt

PP-35 Standard Practice for Evaluation of Superpave Gyratory Compactors

3. Important Note

3.1. The raw data should be available in spreadsheet format with one column for the gyration number and another for the corresponding height.

3.2. Samples should be compacted as close to 98% Gmm as possible, however a threshold of 600 Gyrations should not be exceeded.

3.3. Sample volumetric properties shall be obtained using AASHTO standards mentioned above

3.4. The traffic level should be either one of (E0.3, E1, E3, E10, E30)

4. General Description

This document is intended to determine the densification indices to evaluate the quality of hot mix asphalt (HMA) specimens created using the Superpave gyratory compactor (SGC). The densification indices are defined as:

4.1. Construction Densification Index (CDI): Represents the work required to compact the mixture from its density after being placed by the paver to the required density of the mix after roller compaction. This index is calculated by estimating the area from 8 gyrations (representing the paver screed compaction) to 92% Gmm, which represent 8 % air voids as required for HMA acceptance in Wisconsin. Lower values of CDI are desired because they represent a mix that is more workable and easier to compact to achieve 92% Gmm.

4.2. Traffic Densification Index (TDI): Represents the ability of the mixture to resist densification under traffic loading over its service life. The index is calculated by estimating the area under the curve from 92%Gmm (initial in-place density) to 98% Gmm, the theoretical terminal density of the pavement. High values of TDI are desirable. They represent a mix that is better able to maintain its stability and resist permanent deformation/damage.

5. Significance of Use

5.1. This method is designed to evaluate the ease of compaction of hot mix asphalt when prepared using the Superpave gyratory compactor. Ease of compaction is represented by the CDI. In addition, this method is designed to evaluate the ability of the hot mix asphalt to resist traffic load. The resistance of the mixture to compaction beyond 92% Gmm is used to calculate the value of TDI, which is an indicator of the mixture mechanical stability.

6. Procedure

6.1. Copy and paste the raw height data in the "raw data" sheet in the appropriate columns.
6.2. Go to "Analyzed data" sheet and input the sample title in cell B1 and volumetric properties in cells B2 to B5, and the traffic level in cell D5.
6.3. The template will calculate the densification energy indices automatically (CDI and TDI).
6.4. The densification curve will be created in the "Densification Curve" sheet showing the cut off points for the each densification energy.
6.5. The tab titled: "Summary and Print" will include all the necessary information of the compacted sample.

7. Calculations

7.1. Using the height data of compacted samples in the SGC, the increase in density of HMA can be calculated using AASHTO PP-28.
7.2. The %Gmm verses number of gyrations plot is generated based on calculations determine above. This plot is called the densification curve.
7.3. The CDI is calculated as:
CDI= sum of change in % Gmm from the eighth gyration to the gyration corresponding to 92% Gmm
7.4. The TDI is calculated as:
TDI = Sum of change of %Gmm from gyration corresponding to 92% Gmm to gyration corresponding to 98% Gmm.

8. Report

8.1. Report the following information
8.1.1. Construction densification index (CDI)
8.1.2. Traffic densification index (TDI)

9. Precision and Bias

9.1. Since this is a practice, precision and bias statement are not needed.

Appendix A2: Analysis Template

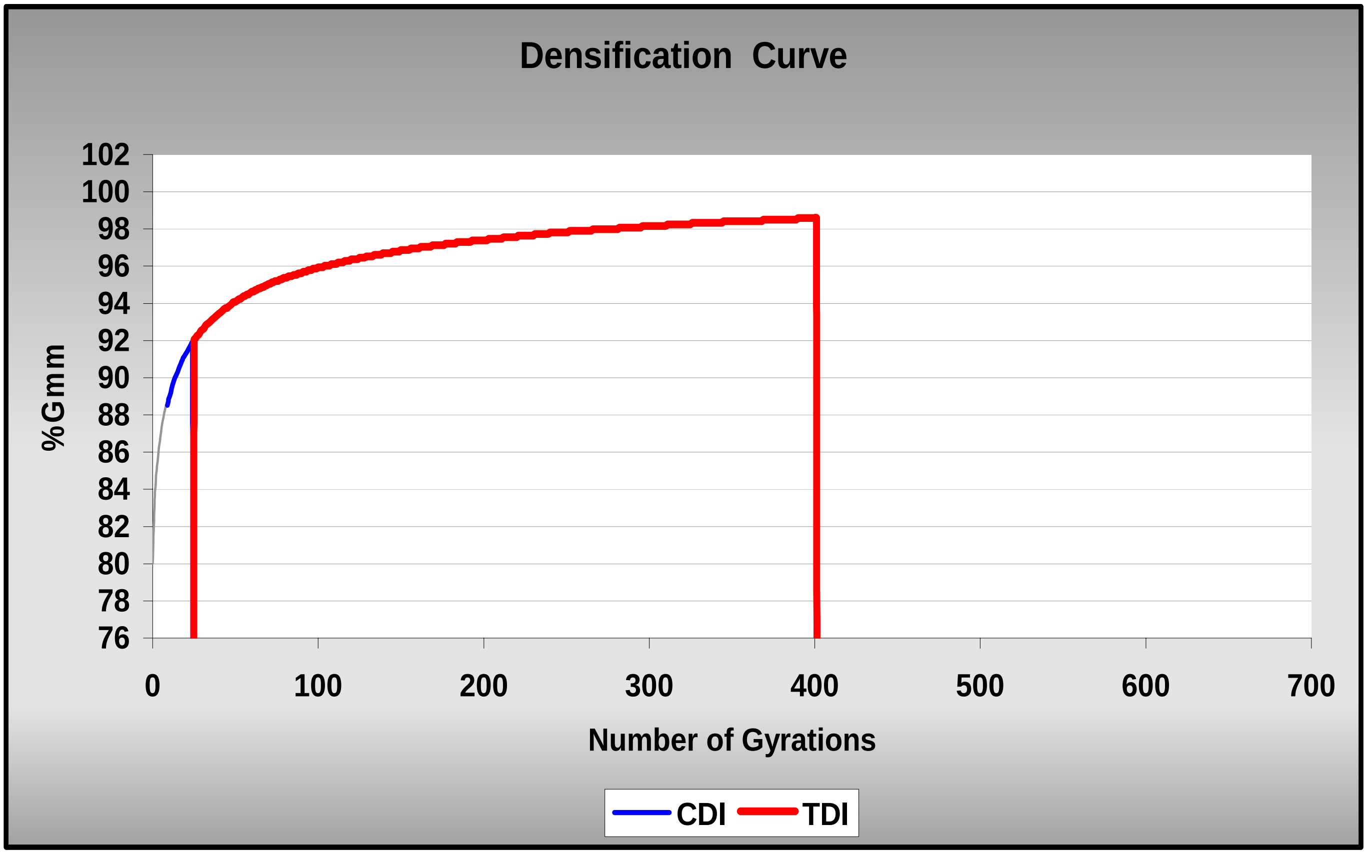
Instructions for Use

THIS SPREADSHEET WAS DEVELOPED BY THE ASPHALT GROUP OF THE UNIVERSITY OF WISCONSIN -MADISON AS PART OF WHRP IMPLEMENTATION EFFORTS FOR THE FLEX TOC. **Updated 3/31/08**
<u>Instructions</u>
Important note: The raw data should be available in excel format with one column for the gyration number and another for the corresponding height.
Samples should be compacted as close to 98% Gmm as possible, however a threshold of 600 Gyrations should not be exceeded.
1- Copy and paste the raw height data in the "raw data" sheet in the appropriate columns.
2- Go to "Analyzed data" sheet and input the sample title in cell B1 and volumetric properties in cells B2 to B5, and the trafic level in cell D5. The traffic level should be either one of (E0.3, E1, E3, E10, E30)
3- The template will calculate the densification energy indices automatically (CDI and TDI).
4- The densification curve will be created in the "Densification Curve" sheet showing the cut off points for the each densification energy.
5- The tab titeled:"Summary and Print" will include all the nessecary information of the compacted sample. The Sheet is set for printing, so no changes are required.

Analysis Tool Output

Figure A2. 1: Sample Analysis Tool Output

THIS SPREADSHEET WAS DEVELOPED BY THE ASPHALT GROUP OF THE UNIVERSITY OF WISCONSIN -MADISON AS PART OF WHRP IMPLEMENTATION EFFORTS FOR THE FLEX TOC



Data Summary

Nini	8	%Gmm@ Nini	88.51
Ndes	100	%Gmm@ Ndes	95.95
N Max	160	%Gmm@ Nmax	96.95
VMA	11.75	VTM	1.41
VFA	88.02		
CDI	203.7		
TDI	1889.92		

Figure A2.1 is the sample output from the template. The figure indicates the gyration levels used to calculate the CDI and TDI. The output is not meant to show the areas related to calculations related to CDI and TDI.

Superpave Gyratory Compactor Implementation Project
Technical Summary – Invitation to Participate

Background

Current Superpave mix design specifications base acceptance of the mix on volumetric properties only, without considering mechanical stability or constructability of the mixtures. The purpose of this project is to provide a simple procedure to improve the current specification by considering mix resistance to construction and to rutting damage under traffic loading. The procedure requires only compaction data obtained from the Superpave Gyratory Compactor, taking advantage of the current use of the SGCs in industry. The use of a standard industry tool allows using the procedure with little additional time investment but providing important information regarding the quality of mixes used in Wisconsin with regard to mechanical stability and constructability. A more informed economic decision in selecting mixtures for a given set of conditions is the expected outcome.

Proposed Procedure

The test procedure is based on a new concept for analyzing the SGC data. The concept is best realized by changing the log-scale in the plot of %Gmm vs. Log Gyrations, normally used to plot the SGC data (See left plot Figure B1.1), to a plot of %Gmm vs. Gyrations normal scale (See plot on right Figure B1.1).

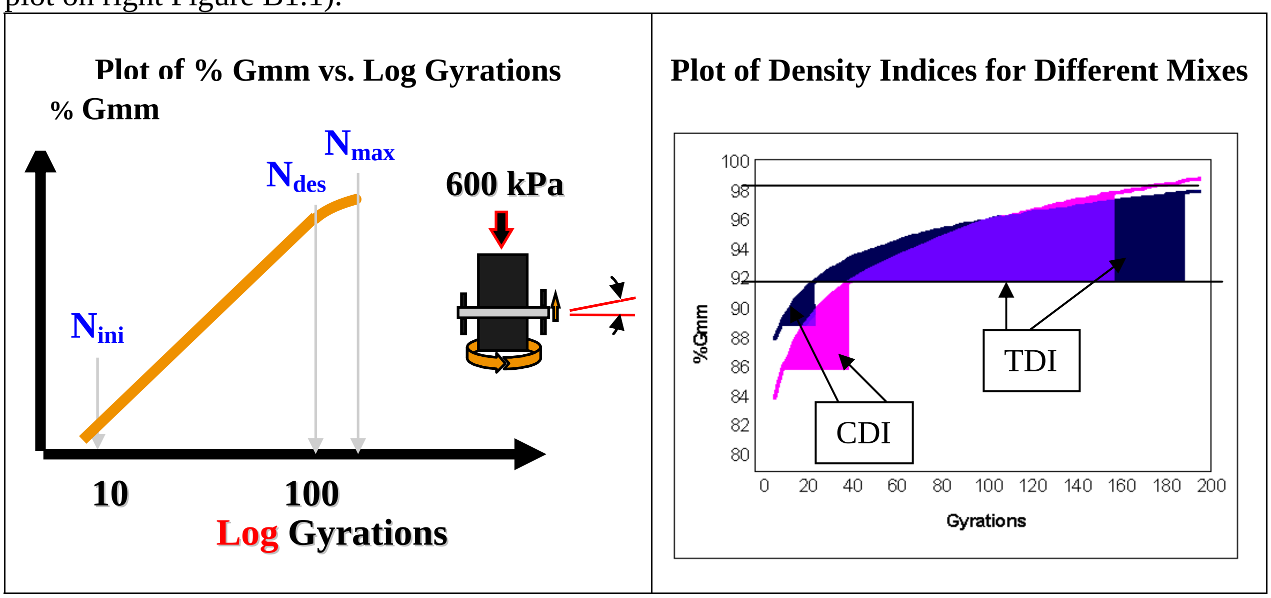


Figure B1. 1: Summary of Compaction Curves

This new plot allows the examination of the area under certain portions of the densification curve to quantify the amount of effort required to construct a mix and also the ability of a mixture to resist rutting due to traffic loading. The relationship between the two areas under the compaction curve can be used to define two important indices:

- **Construction Densification Index (CDI):** Represents the work required to compact the mixture from its density after being placed by the paver to the required density of the mix after roller compaction. This index is calculated by estimating the area from 8 gyrations (representing the paver screed compaction) to 92% Gmm, which representd 8 % air voids as required for HMA acceptance in Wisconsin. Lower values of CDI are desired because they represent a mix that is more workable and easier to compact to achieve 92% Gmm.
- **Traffic Densification Index (TDI):** Represents the ability of the mixture to resist densification under traffic loading over its service life. The index is calculated by estimating the area under the curve from 92%Gmm (initial in-place density) to 98% Gmm, the theoretical terminal density of the pavement. High values of TDI are desirable. They represent a mix that is better able to maintain its stability and resist permanent deformation/damage.

Initial Validation of the Concept

Although the concepts of CDI and TDI are sound, they are also based only on volumetrics, and thus needed to be verified using mechanics principles and performance based testing. Validation was achieved using two approaches: (1) Force measurements in the SGC, and (2) Rutting measurements using the newly developed simple performance testing. Following are the details of validations completed in the project.

Validation Using the Force Measurements

In order to be able to measure the forces in the mix during compaction, the research team at UW-Madison developed a device that can be inserted into the SGC mold prior to compaction. The device, which was developed by support from FHWA, was named the Pressure Distribution Analyzer (PDA), see figure below. The PDA measures the work required (force, R, and eccentricity, e) to densify the mix as it is being compacted in the SGC. These measurements, in conjunction with the sample height data recorded by the SGC, provide a physical measure of the resistance of the mixture to densification. Schematics of the PDA are provided in the Figure B1.2.

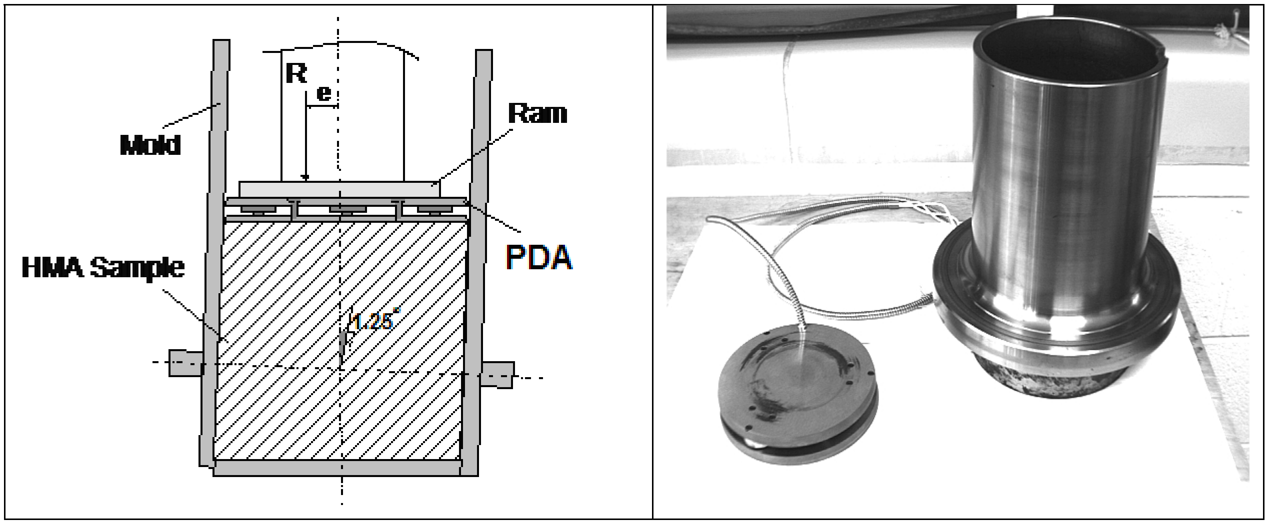


Figure B1. 2: Schematic of Pressure Distribution Analyzer

Measurements from the PDA allowed for the definition of force indices (the Construction Force Index (CFI) and the Traffic Force Index (TFI) as a representation of the resistive force of the mix during compaction and traffic loading. These force indices are measured using the same points on compaction curve as the densification indices. These similarities allowed for the examination of the relationship between the densification indices and the force indices. Figure B1.3 shows an example of the relationship between the TDI, which is estimated from volumetric data only, and TFI, which is determined from force measurements. The results clearly validate the concept of using the volumetric to estimate resistance of mixtures to force.

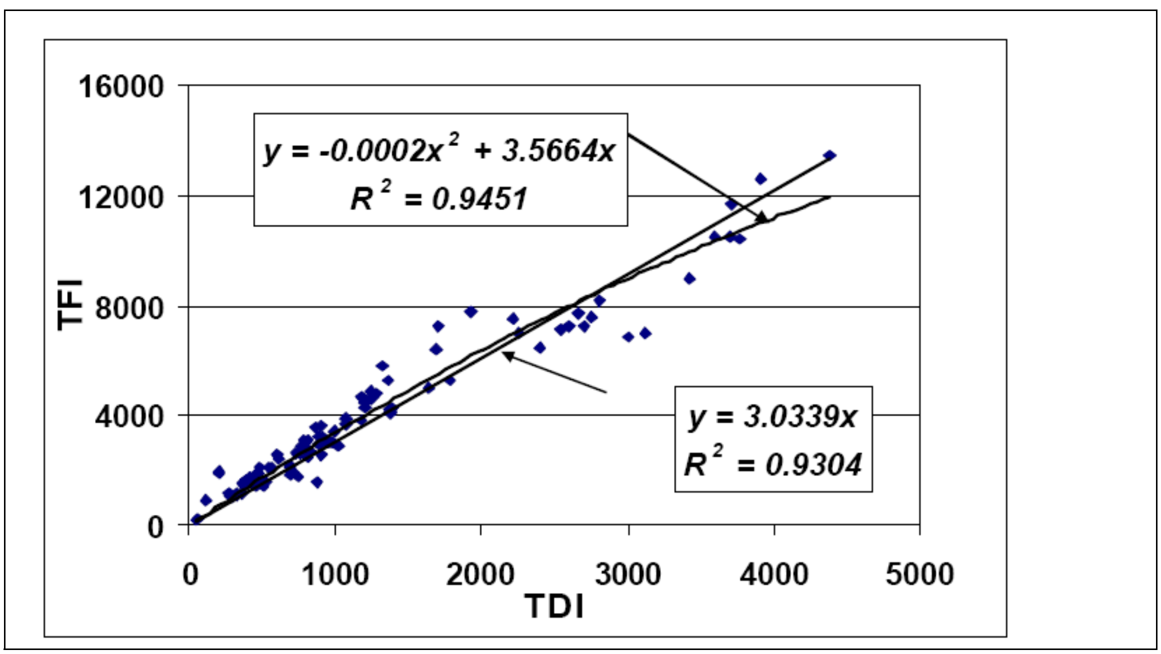


Figure B1. 3: Correlation of TFI to TDI

Although the use of the PDA is highly recommended because it measures force directly, the cost and additional analysis required for using the PDA makes difficult to implement at this time. More field work will be done to verify if the PDA is necessary and at this time the concept of using the SGC data for estimating indices will be first tried.

Validation using the Simple Performance Test Results

The second validation attempt was to evaluate the ability of the density indices to predict performance as measured in the lab. Rutting is an important aspect of pavement performance that directly relates to mechanical stability of mixtures. The simple performance test, recently developed as part of the AASHTO new ME design Guide (NCHRP 9-19), was used in this study to measure rutting performance of mixtures compacted in the SGC. This test procedure uses two parameters to quantify rutting performance; Flow Number (FN), and Rate of Deformation. Both of these parameters were measured and compared with the TFI numbers.

The plots of the data, in Figures B1.4 and B1.5, show a strong correlation between both measures (flow number (FN) and permanent deformation) and the force index (TFI). The existence of this relationship is important in realizing that the material property measured in the SGC (TFI) reflects the predicted mixture behavior in terms of instability under traffic loading measured by the simple performance test.

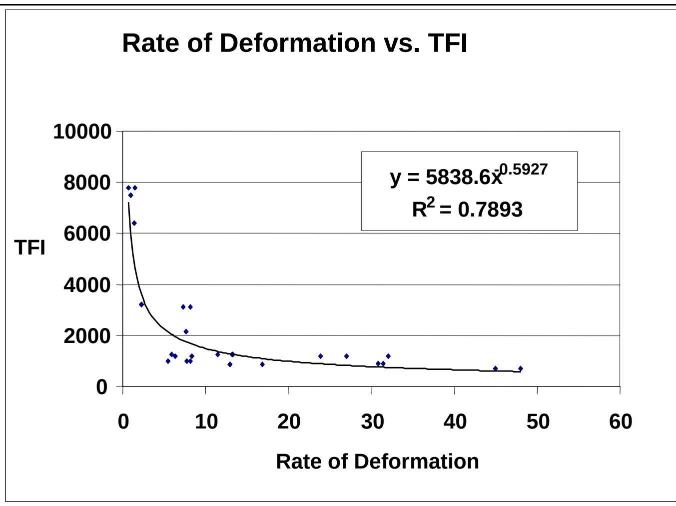


Figure B1. 4: Correction of TFI and Rate of Deformation

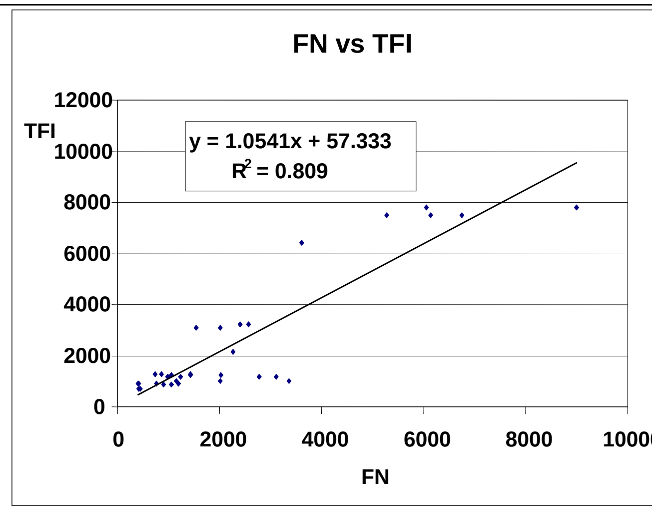


Figure B1. 5: Correlation of TFI and Flow Number (FN)

Why Should the Results of this Research be Implemented by Industry and WisDOT?

The researchers of this study show evidence that the current specifications requiring densities at a certain number of gyrations for a given traffic level are insufficient in characterizing the performance of the asphalt mix. Both the agency and industry are taking unnecessary risks by relying solely on the specification using volumetrics and ESALs.

The following two figures explain why the researchers are making this claim. In Figure B1.6 mixes with very similar density properties exhibit drastically different behavior in terms of mechanical stability (frictional resistance). As shown below at an equal density of 98 % Gmm one mix shows a frictional resistance of more than 144 (KPa) while the other is showing a value of 36 KPa.

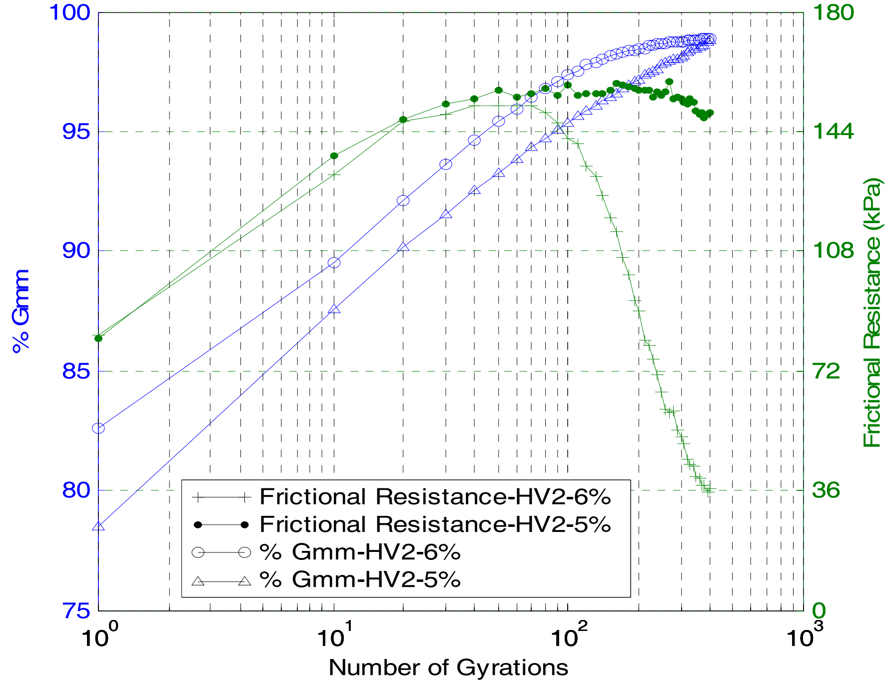


Figure B1. 6: Comparison of Densification and Friction Resistance for Stable and Failing Mixes

In Figure B1.7, the ESAL designations, used to design mixes for different traffic levels in the current WisDOT practice, are plotted versus the TFI (Force Index). As shown, some mixtures designated as E3 have higher TFI than mixtures that are designated as E10 mixes and mixes designated as E 30. It is therefore too risky to use the current practice without measuring the force index, or an indicator of it, such as the density index. (TDI).

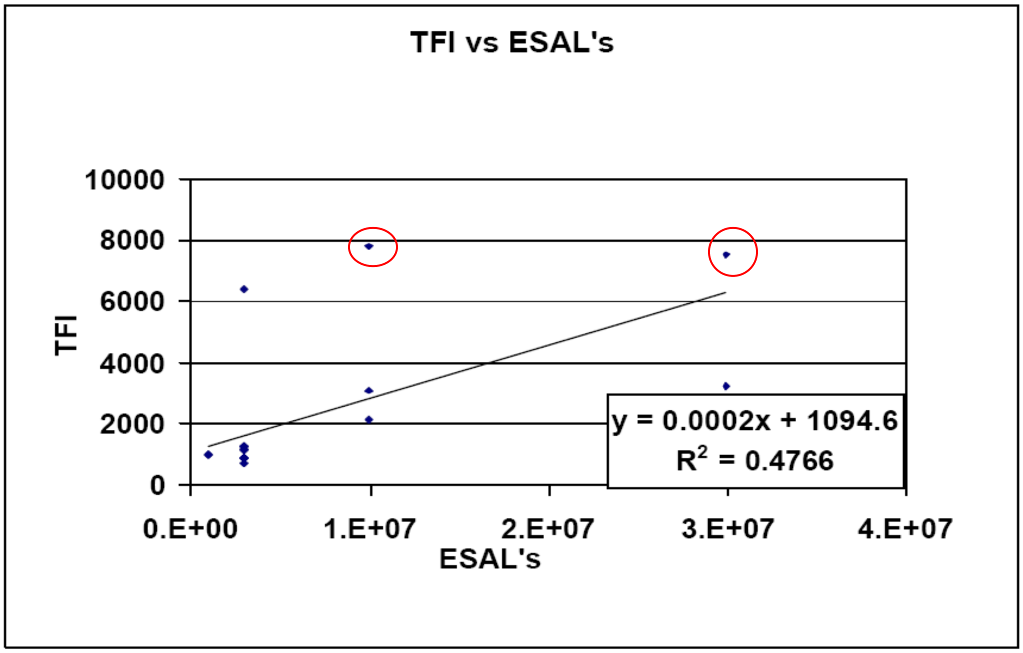


Figure B1. 7: Comparison of TFI vs. Different Mix Types (E1, E3, E10, and E30)

The examples shown above have convinced the Flexible Pavements Technical Oversight Committee (TOC) of WHRP to select the results of this project for implementation. The implementation could provide a useful supplement to the existing practice as an opportunity to select mixes with optimum material behavior and economics. This could benefit both industry and the agency.

Similar to any standard practice, criteria for acceptance is needed. The existing results led the researchers to select the following acceptance limits as a function of EASL type of mixture (Figure B1.8). A maximum level of CDI (to ensure proper compaction) and a minimum level of TDI (to ensure proper resistance to traffic) are listed for each mixture. It is the hope of the research team that these values will be verified and adjusted as a larger database of mixes is gathered from industry participation in this implementation project.

The establishment of these guidelines will allow both WisDOT and Industry reduce the uncertainty and possible risks associated with selection of mixes that under-perform or fail from excessive permanent deformation. The above criteria will be refined as results from more mixes are obtained; giving threshold CDI and TDI values using Wisconsin mixes that will aide in the development of future better mix designs.

Constructability

Mixture Type	*CDI Maximum value*
E3 (ESALs=3 e6)	**250**
E10	**300**
E30	**400**

Traffic Resistance

Mixture Type	*TDI min value*	*TFI (Optional)*
E3	**400**	**2000**
E10	**800**	**3000**
E30	**1200**	**4000**

Figure B1. 8: TFI and TDI Thresholds for a Given Mix Type

Project Implementation Team

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Appendix B2: Summary of Laboratory Evaluation of Implementation Efforts

Table B2. 1: Summary of Mixture Testing and Analysis

Sample	AC	CDI	TDI	CFI	TFI	%Gmm Nini	Predicted TDI	Predicted TFI	ESALS	Nmas (mm)
SA-3-01	5.1	35	662	72	2046	89	662	2046	3.E+06	12.5
SA-3-02		26	651	60	2061	89	651	2061	3.E+06	
SB-3-01	5.4	63	923	130	2637	91	923	2637	3.E+06	12.5
SB-3-02		61	913	106	2746	91	913	2746	3.E+06	
SC-10-01	6.2	549	1220	606	4851	86	1841	5570	1.E+07	9.5
SC-10-02		526	1241	596	4900	86	1971	5591	1.E+07	
SD-10-01	5.2	251	1614	349	4633	88	1614	4633	1.E+07	12.5
SD-10-02		266	1620	365	4623	88	1620	4623	1.E+07	
SE-30-01	5.2	98	791	196	3743	90	2085	7040	3.E+07	12.5
SE-30-02		90	817	169	3805	90	2044	6885	3.E+07	
SF-30-01	4.8	222	1435	315	5023	88	1974	6040	3.E+07	12.5
SF-30-02		203	1316	290	5146	88	1990	5836	3.E+07	
SG-10-01	5.6	122	904	202	3599	90	1526	3599	1.E+07	12.5
SG-10-02		130	880	212	3505	89	1640	3505	1E+07	
SH-10-01	5.3	148	1651	238	4686	89	1651	4686	1E+07	12.5
SH-10-02		119	1418	238	5494	89	1600	5494	1E+07	

Table 2 provides a summary of mixes evaluated as part of the implementation project. The 400 gyrations used to compact the samples was not adequate to densify the mix to 98% Gmm, the mixes that could not reach the density required for direct measurement of the TDI are highlighted in gray. In these cases the compaction curve to calculate the TDI, and the work curve used in computing the TFI were estimated using a statistical model to extrapolate mixture densification up to 98% Gmm.

The model used is shown below:

$$\%Gmm = aEXP(bN)^{c}$$

Where a, b, and c are constants selected such that the error between the %Gmm predicted and the actual %Gmm is less than 5%. The variable N represents the gyration number. This model was also used to predict the work per gyration by replacing the %Gmm with W_r (work) in the previous equation.

It is important to note that compaction of the sample as close as possible to 98% Gmm is preferable. However, compaction to such high density presents the potential for aggregates within the mix to be crushed, a phenomenon that cannot be identified solely through the TDI calculation. Use of the Pressure Distribution Analyzer (PDA) during compaction allows the opportunity to measure the resistive forces of the mixture during compaction. An indication the aggregates are being crushed is a drastic drop in the resistive forces in the mix. Further detail regarding this topic is available in the original research report.

Further analysis is conducted to verify the trends of obtained results. The correlation between the TDI and the TFI shown in Table 1 is provided in Figure B2.1.

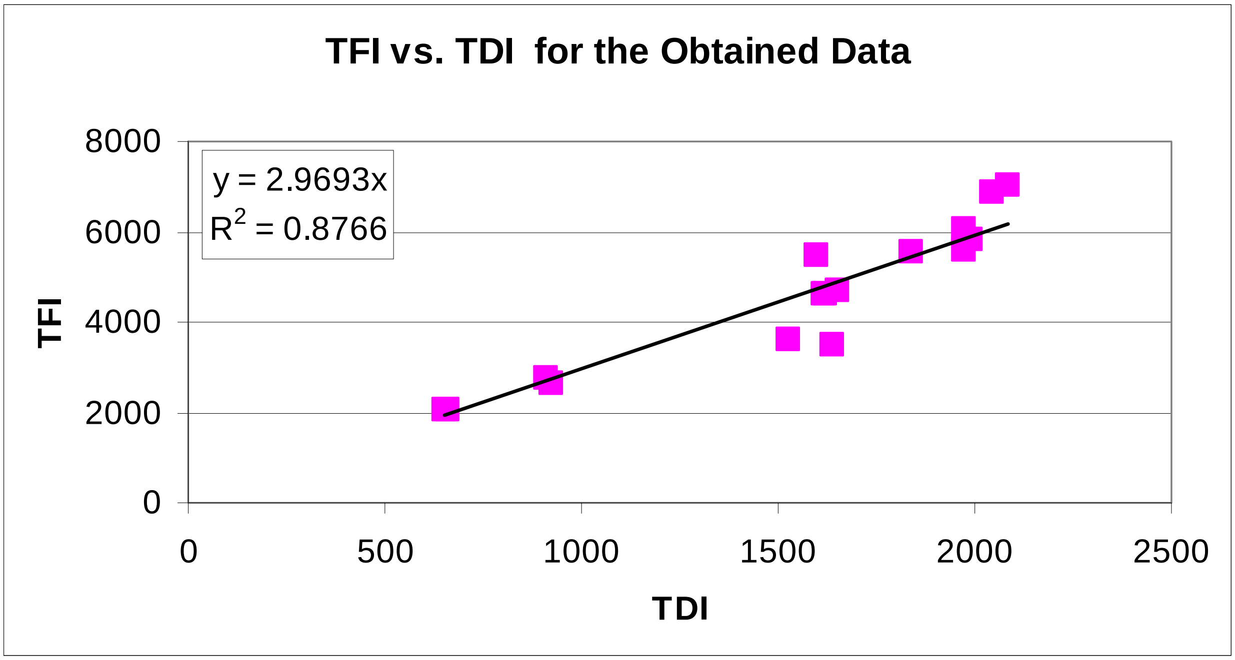


Figure B2. 1: Correlation of TFI and TDI for Implementation Mixes Collected

Figure B2.1 in the Technical Summary provided in Appendix A provides a plot of TDI vs. TFI for the mixtures tested in the original research project. Comparison of the slope of the regression line using the data from the original data and the slope of the regression line using data from the implementation project mixes in Figure B2.1, shows that the slopes are very similar. Thus, the relationship between the TFI and the TDI is consistent for both data sets. This indicates a fundamental relationship exists between the indices.

The construction indices are also correlated. Figure B2.2 shows the relationship between the CDI and the CFI. The figure shows that the relationship between both indices is linear with a slope of approximately one.

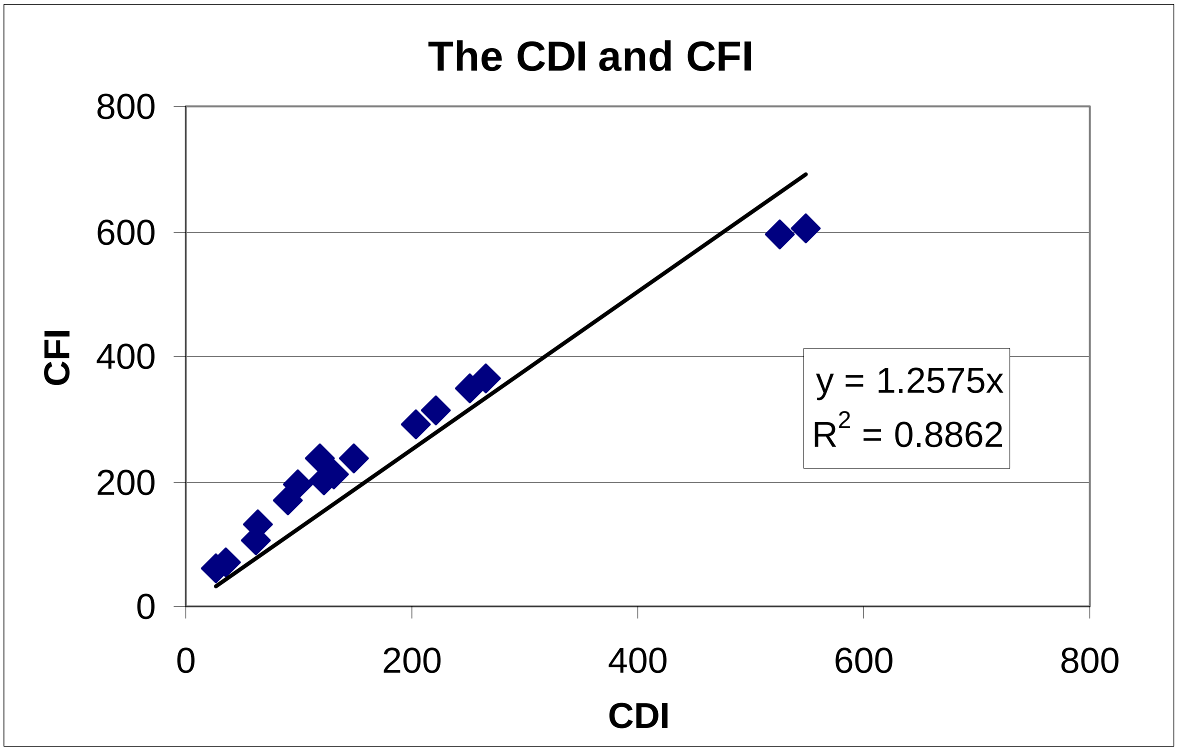


Figure B2. 2: Correlation of the Construction Indices

Based on the test results summarized in Figures B2.1 and B2.2, it can be concluded that the use of densification indices obtained from the SGC are viable candidates as surrogates to the force indices obtained using the Pressure Distribution Analyzer. The use of these surrogate indices is only appropriate in the absence of the PDA.

To establish limits for the indices based on the different ESAL levels of the mix, the force indices of TFI and CFI as measured by the PDA were plotted against the ESAL value for the mixes. Figures 4 and 5 show the distribution of the indices values from the original study and the collected field data for implementation.

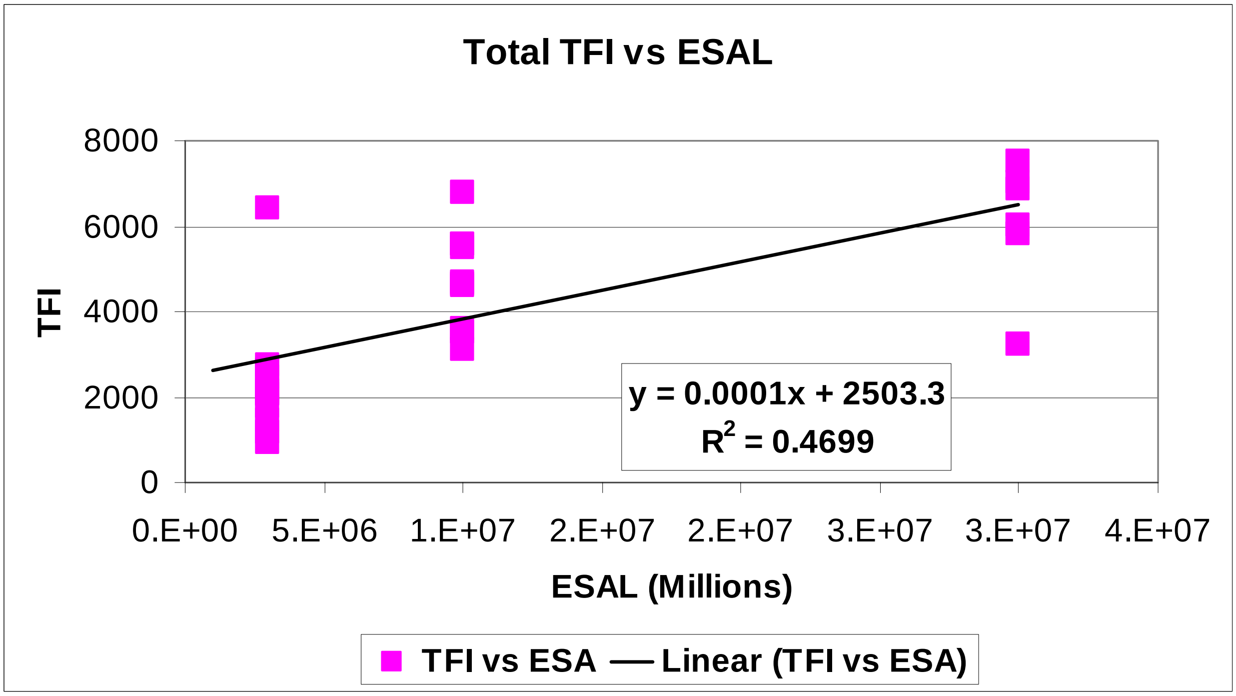


Figure B2. 3: TFI Values of Combined Results from the Original Research and the Implementation Mixes

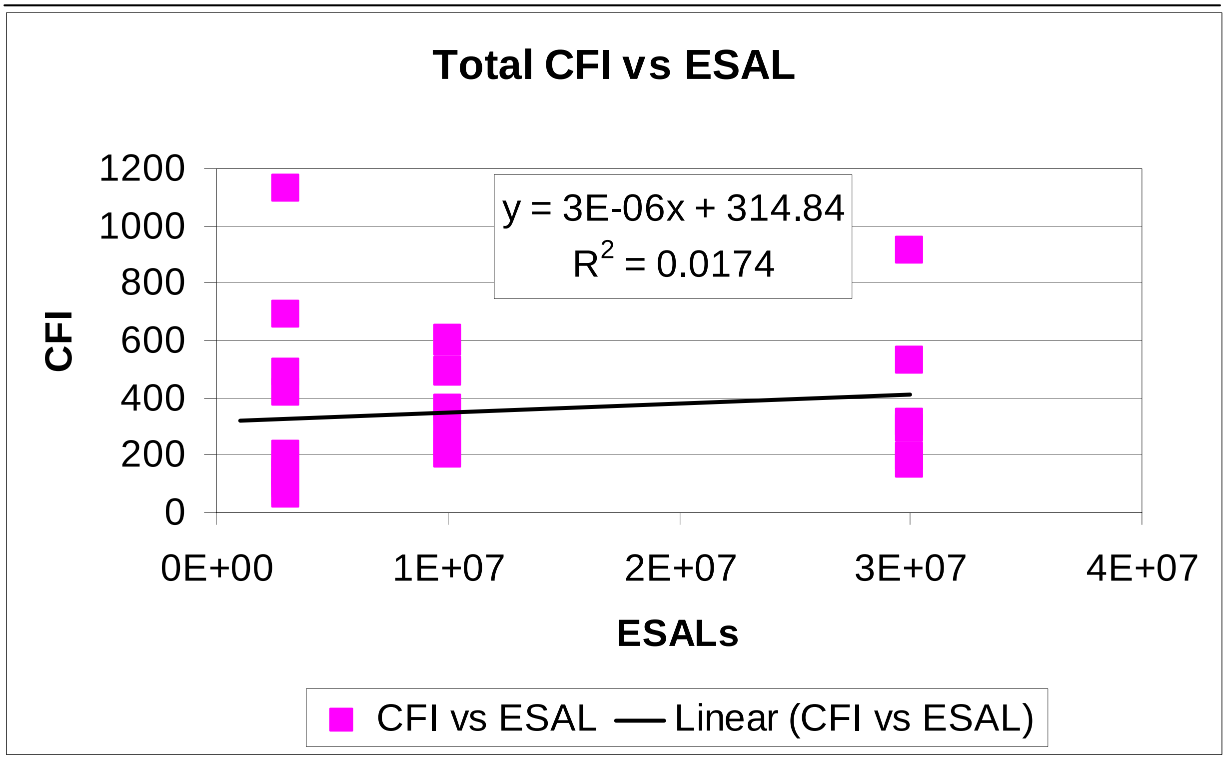


Figure B2. 4: CFI Values of Combined Results from the Original Research and the Implementation Mixes

The distribution of mixture performance for all ESAL levels tested shown in Figures B2.3 and B2.4 clearly show that in terms of mechanical properties there is a wide range of behavior. This indicates that some mixtures were over designed while others were under designed. Data collected from the implementation efforts combined with data generated in the original study improves the resolution of the proposed limits. For statistical fairness, the average index values using the both data sets at each traffic level are plotted against the ESAL level to establish the proposed limits. Figures B2.5 and B2.6 demonstrate the relationship between the averaged indices verse the ESAL level.

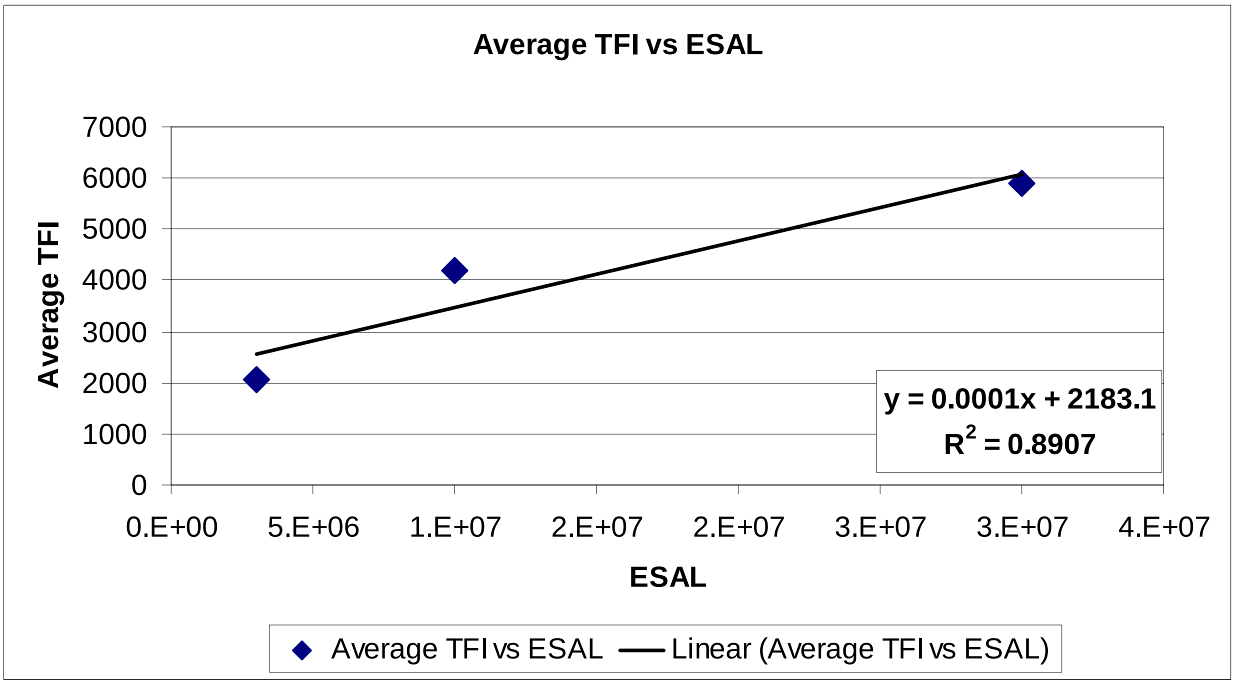


Figure B2. 5: Average TFI vs. ESAL Level

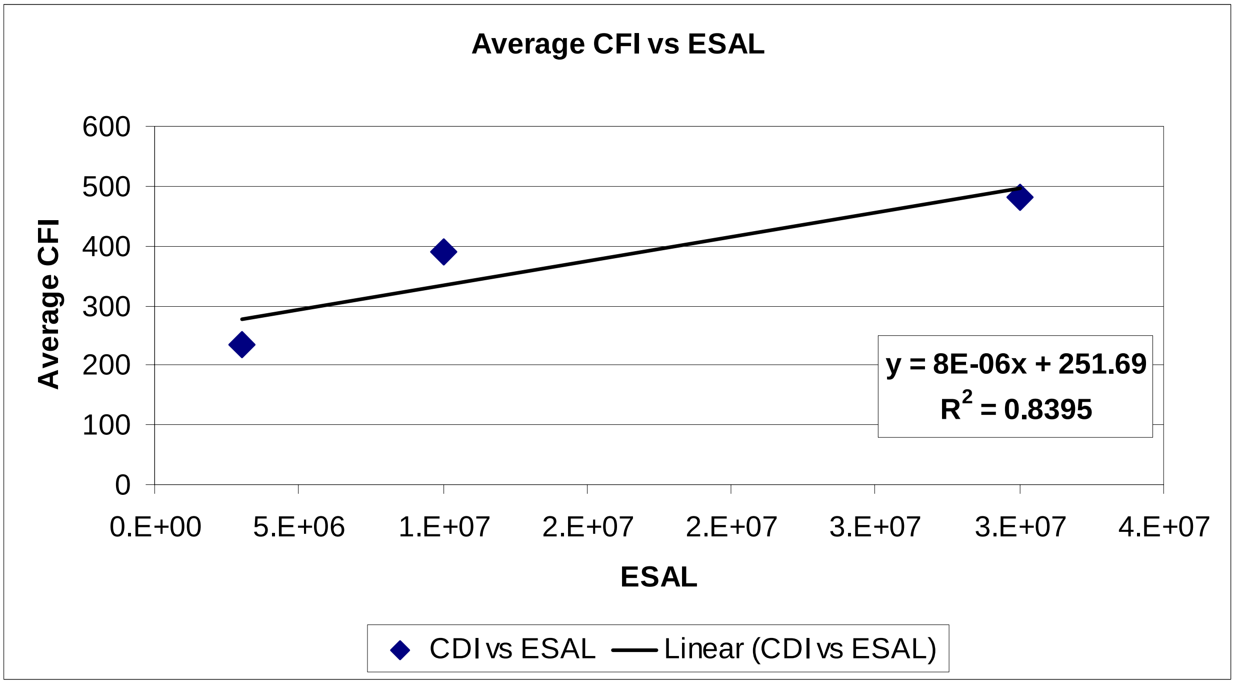


Figure B2. 6: Average CFI vs. ESAL

The proposed limits of the CFI and the TFI are be derived from the Figures B2.5 and B2.6. The limits for the CDI and TDI are estimated based on the correlation between the force indices and the densification indices shown in Figures B2.3 and B2.4. Tables 3.1-3.3 provide the proposed limits based on all of the data available.

2006 Mid-Continent Transportation Research Forum and Workshop

"Making Research Pay Off"

August 17–18, 2006 Madison, Wisconsin

Concurrent Session 3 : Flexible Pavements

Moderator: Leonard Makowski

WisDOT SE-Region and WHRP – Flex TOC Chair

WHRP – Wisconsin Highway Research Program

Directed by Steering Committee Membership:

- WisDOT, Academia, FHWA, Industry, TOC reps

Driven by 4 Technical Oversight Committees

- Flexible Pavements
- Rigid Pavements
- Geotechnical
- Structures

WHRP Report # 0092-01-02

Using the Gyratory Compactor to Measure Mechanical Stability of HMA

Research Team:

Dr. Hussain Bahia and
Ahmed Fatin Faheem Mahmoud
Department of Civil and Environmental Engineering
University of Wisconsin-Madison

Project Background

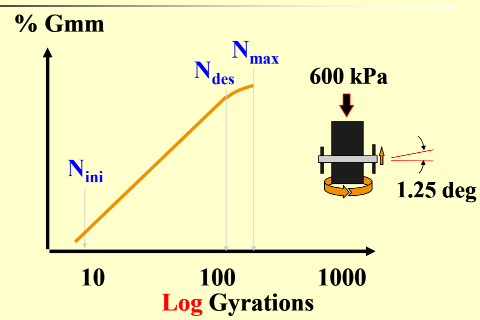
- Best mixture designs should include:
  - Volumterics for production, and
  - performance testing for traffic/climate
- Difficulty:
  - Performance testing requires more equipment and time up front.
- ***Can the SGC be used as a surrogate ?***
  - The SGC can be used to evaluate aggregate interlock.
  - The binder PG grade can estimate binder contribution to damage resistance.

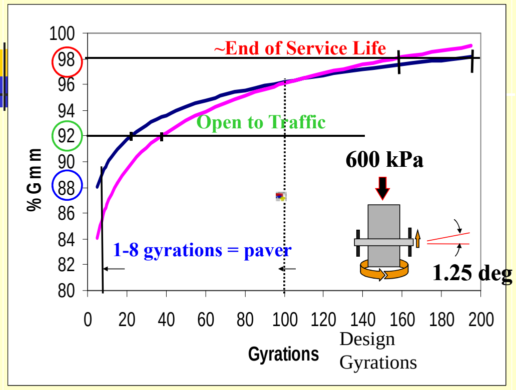
Research Hypothesis

- The main hypothesis of this research :

The stability of an asphalt mixture can be predicted from compaction parameters, measured or estimated, using the Superpave gyratory compactor

Superpave Volumetric Design Criteria





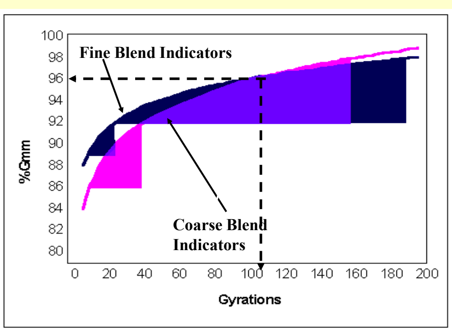
New Information

Changing the Log Scale allows for the calculation of the following indices

CDI (88 – 92 %Gmm):
Construction Densification Index
- Desired to be low for more workable mix

TDI (92-98 % Gmm):
Traffic Densification Index
- Desired to be high for long pavement surface life

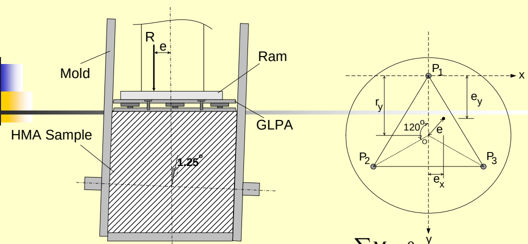
Superpave Mixes can show different performance Energy Indicators



Validation Using Mechanics

- CDI and TDI were conceptually sound ideas but needed validation and to be explained mechanically
- Need to understand forces in the mix during compaction and measure them.
- A Shear Load Plate was developed by the researchers as an instrument to verify these concepts.

Use of the Shear Plate (PDA) to Calculate Eccentricity of load



$$R = P_1 + P_2 + P_3$$

$$M(t) = R * e(t)$$

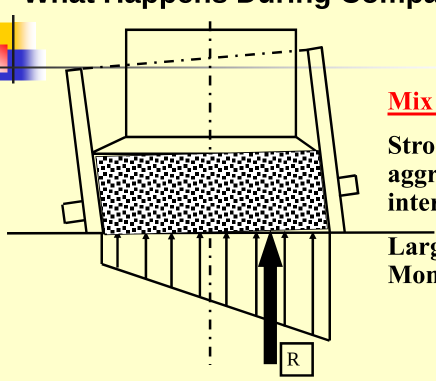
$$\sum M_x = 0 \Rightarrow e_y$$

$$\sum M_y = 0 \Rightarrow e_x$$

$$e = \sqrt{e_x^2 + (r_y - e_y)^2}$$

The Pressure Distribution Analyzer

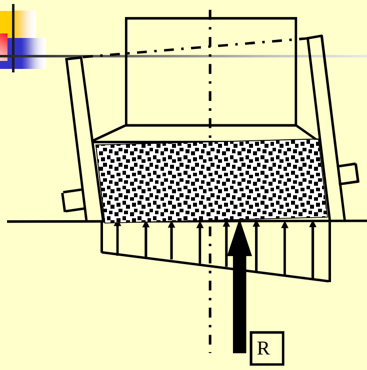
What Happens During Compaction?



Mix A

Strong aggregate interlock

Large Moment

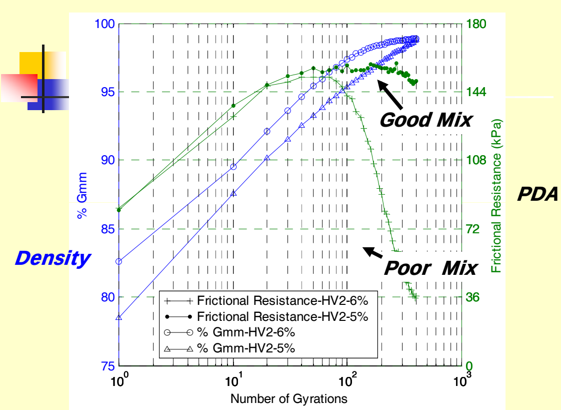


Mix B

Less aggregate interlock

Small Moment

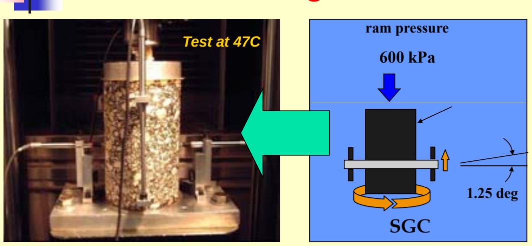
Shear Plate Used in the SGC Compaction Mold



How Do These Parameters Correlate to Field Performance?

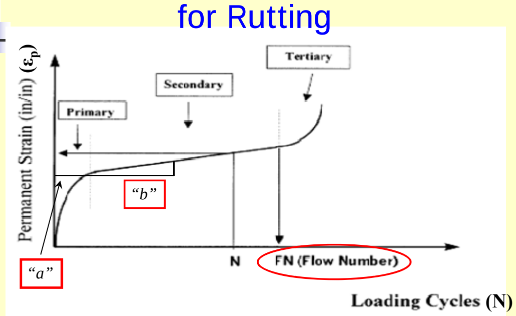
- The practical importance of these indices examined the following by using the rutting test (NCHRP 9-19):
  - Rate of Deformation
  - Flow Number: number of cycles at which mixture flows rapidly (tertiary condition)

For AASHTO ME Design Guide Can we estimate Mixture Rutting from SGC?



Relating the Gyratory to Performance Testing

Testing to Evaluate Resistance for Rutting



After the NCHRP-465 report , 2002

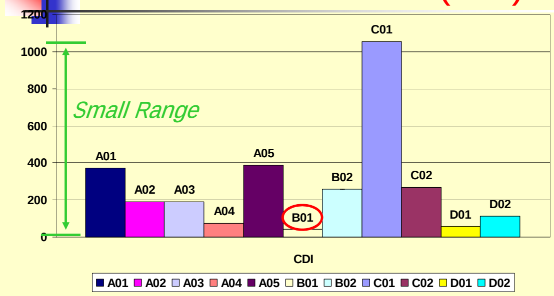
Is the Shear Plate Essential?

- Rutting parameters were used to evaluate correlation for tests using:
  - TDI (Traffic Densification Index) using SGC
  - TFI (Traffic Force Index) using PDA
- Examine correlation between TDI and TFI to see if TDI can be used as a surrogate index

Experimental Program

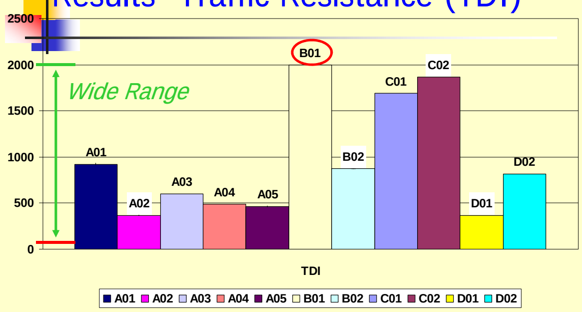
- Four sources of Aggregates
- Two gradations used (fine and dense graded or "S"-shaped)
- Various levels of fine aggregate angularity
- Two PG Grades
- PDA plate used to collect shear data

Results: Construction (CDI)



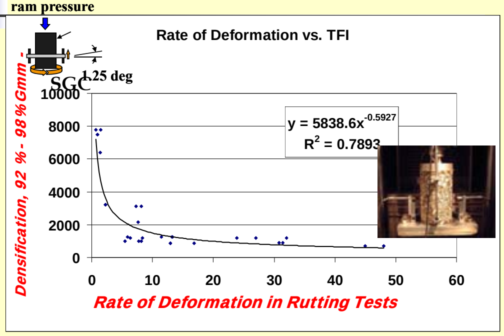
Average CDI values for all mixes

Results- Traffic Resistance (TDI)



Average TDI values for all mixes

Good correlation between densification in SGC and rutting



Is the Shear Plate Essential?

Correlation Between TDI and TFI

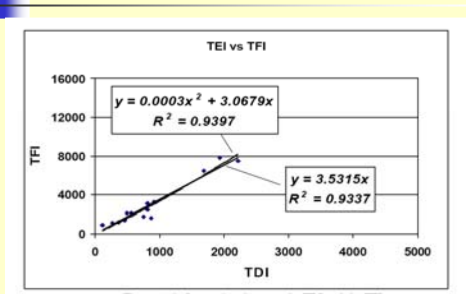


Figure 4.19: Comparison between the TDI and the TFI

Recommendations

The SGC can be used as a tool for mixture mechanical stability prediction.

It is recommended that :

- Traffic densification indices (TDI) be used as guidance for all mixtures regardless of their volumetric properties.
- Conduct performance testing when possible to validate and reevaluate thresholds

Conclusions / Remarks

- There is no current standard for performance testing of asphalt mixtures
- We can, however, reduce possible combinations of mixture variables using the SGC.
- SGC results can be better used to study
  - Constructability of mixtures
  - Aggregate contribution to traffic resistance

Benefits of Implementation

- Begin preparation for language of AASHTO ME Design Guide
- Able to Catalog Materials based on current and historic performance
- Troubleshooting Tool
- Field Verification

Benefits of Implementation

The following table was generated and recommended to indicate minimum threshold levels

ESAL	MinTDI	MinTFI
1.00E+06	750	250
3.00E+06	1000	300
1.00E+07	2000	600
3.00E+07	4500	1500

It should be noted these mixes were laboratory rut tested, and field validation should be the next consideration (pilot)

Benefits of Implementation

Cost savings in preventing the unexpected

Impacts and Implementation

HMA Technical Team

(WisDOT Statewide Bureaus, Regions, FHWA, Industry)

- Evaluate research findings for feasible implementation
- Subcommittee to address guidance procedures and cataloging
- Propose research ideas to WHRP-TOC (ex:field validation)

Impacts and Implementation

WHRP Implementation Pilot Project

- Technical Documents and Concept Presentation Preparation
- Supplemental Laboratory Testing
- Marketing Strategy for Knowledge Transfer
- Formal Follow up

Implementation Deliverables

Technical Documents

- Prepare documents and formal presentation (facilitate knowledge transfer)
- Develop test methods (standard format)
- Data analysis and interpretation tool (user friendly spread sheet)

Implementation Deliverables

Supplemental Lab Tests

- Complement the original data set with small comparative study involving modified binder

(ex: one aggregate structure, multiple binder contents, lab produced mix)

Implementation Deliverables

Knowledge Transfer Strategy

- Identify appropriate WisDOT process areas (flowchart) for document submittals
- Define review groups and necessary deadlines
- Provide concept presentation at pertinent conferences and technical meetings (statewide)

Implementation Deliverables

Follow Up

- Identify additional equipment needs
- Feedback (capture audience comments, provide presentation evaluations)
- Measurement of Satisfaction (identify use/users and any benefit realized)
- Clear outline of future needs and research

Additional Links

Visit WHRP website for full report(s)

- www.whrp.org

Link to research through the WISDOT website

- www.dot.wisconsin.gov

Report Title:

Using the Gyratory Compactor to Measure Mechanical Stability of Asphalt Mixes

Questions ??

Appendix B: Deliverables for Implementation of Project 0092-45-15,45-18, 00-12, 03-12: Equivalency of Alternative Working Platforms and Their Pavement Design Strength Contribution

IMPLEMENTATION RECOMMENDATIONS
OF
EQUIVALENCY OF ALTERNATIVE WORKING PLATFORMS
AND
THEIR PAVEMENT DESIGN STRENGTH CONTRIBUTION

Submitted to the

WISCONSIN HIGHWAY RESEARCH PROGRAM
WISCONSIN DEPARTMENT OF TRANSPORTATION

By

Geo Engineering Consulting, LLC
3100 Lake Mendota Dr Unit 503
Madison, Wisconsin 53705

March 26, 2009

IMPLEMENTATION RECOMMENDATIONS

PROBLEM STATEMENT

Implementation of research results is an emphasis area of the Wisconsin Highway Research Program (WHRP) Steering Committee. The WHRP Geotechnical Technical Oversight Committee decided in their November 15, 2005 meeting to complete implementation work on two items. These are: (1) Determining the equivalent thicknesses of the eight select material alternatives and (2) Determining the pavement design strength contribution of these same eight select material alternatives. This will pull information from several separate, completed projects. The proposed recommendations follow.

BACKGROUND

The WHRP sponsored 4 separate projects related to the implementation items. Two of these projects were initiated prior to the formation of the WHRP, but completed under the oversight of WHRP. These projects are:

WHRP 06-01 (0092-45-15): Effectiveness of Geosynthetics in Stabilizing Soft Subgrades – Tuncer Edil and Craig Benson, Department of Civil and Environmental Engineering, UW-Madison, October 2005.

WHRP 06-02 (0092-45-18): Field Performance of Subbases Constructed with Industrial Byproducts – Tuncer Edil and Craig Benson, Department of Civil and Environmental Engineering, UW-Madison, October 2005.

Two additional more comprehensive and focused projects were initiated by the WHRP that also related to the previous two projects and built on them. These two projects are:

WHRP 06-03 (0092-00-12): Equivalency of Subgrade Reinforcement Methods – Tuncer Edil and Craig Benson, Department of Civil and Environmental Engineering, UW-Madison, October 2005.

WHRP 06-05 (0092-03-12): Development of Methodology to Include Strength Contribution of Select Subgrade Materials in Pavement Structures – Tuncer Edil and Craig Benson, Department of Civil and Environmental Engineering, UW-Madison, October 2005.

These projects directly relate to the objectives of the implementation plan and their findings form the knowledge base for the implementation plan. However, some materials were not tested in the reports above. The following recently completed project reports provided additional information with respect to these materials.

WHRP 07-05 (0092): Development of Testing Methods to Determine Interaction of Geogrid-Reinforced Granular Material for Mechanistic Pavement Analysis – Tuncer Edil and Dante Fratta, Department of Civil and Environmental Engineering, UW-Madison, October 2008.

WHRP 04-10 (0092): Monitoring and Evaluation of Fly Ash Stabilized Subgrade Constructed by the WISDOT– Tuncer Edil and Dante Fratta, Department of Civil and Environmental

Engineering, UW-Madison, October 2008. RECOMMENDATIONS REGARDING SELECT MATERIAL ALTERNATIVES FOR WORKING PLATFORMS

The Wisconsin Department of Transportation has identified eight select material alternatives for stabilization of soft subgrades. This list of select materials is composed of:

1. Breaker run stone (See FDM Chapter 11, Section 5, Subject 15 for gradation requirements)
2. Breaker run stone with geogrid (See Section ooXX00 Part 2.02 for geogrid requirements)
3. Grade 1 granular backfill (See Section 209 for gradation requirements)
4. Grade 2 granular backfill (See Section 209 for gradation requirements)
5. Pit run sand and gravel (See FDM Chapter 11, Section 5, Subject 15 for gradation)
6. Pit run sand and gravel with geogrid (See Section ooXX00 Part 2.02 for geogrid requirements)
7. Fly ash, lime and cement stabilization
8. Salvage materials or industrial by-products with optional geogrid

Recommendations for equivalent thickness for each select material are presented based on the research contained in the WHRP reports cited above as well as other research and literature. Additional alternatives are also proposed. Fig. 1 shows the appearance of these materials.

Breaker run stone

Breaker run stone was the reference material in the research projects and extensive data is available for it. Breaker run is a select material, which has a reasonably narrow definition although some variation in this category of materials is expected. There is extensive experience in the WisDOT regarding this material. Therefore, the originally set **16 inches** thickness is still recommended. Additional tests (WHRP 07-05) also support breaker run as an ultimate material to compare the other alternatives against.

Breaker run stone with geogrid

In the research program, a specific geogrid was tested with Grade 2 granular backfill in the laboratory and the same geogrid was used in the STH 60 with breaker run stone in the working platform construction. Geogrid interacts with a relatively thin material (couple of inches thick at most); therefore this material in contact with the geogrid is important. If very large grains and cobbles of breaker run are avoided in a cushion layer on the geogrid, we can assume that the characteristics of the granular material become secondary. Geogrid properties are on the other hand could have a significant impact. Geogrid aperture size, rib strength and overall wide width stiffness all may have a role. The overall interaction, however, cannot be judged on the basis of these geogrid characteristics. A pullout test was recommended in the research project to assess an interaction modulus for different geogrid-granular material combinations. This issue is addressed again in a recent research project (WHRP 07-05). If large grains of breaker run are in contact with the geogrid, interaction with geogrids with typical aperture size (25-33 mm) is not likely for modulus increase. However, geogrid still is likely to provide a beneficial membrane action (like a geotextile would) limiting total deformation of the working platform. Gravel-size fraction of breaker run would interact with the geogrid as demonstrated in STH 60 where boulders were removed by hand. Based on the thickness reduction observed with a woven geotextile providing membrane action (WHRP 06-03 (0092-00-12), it is recommended that materials classified as breaker run reinforced with geogrid to have a thickness of **12 inches**. The geogrid requirements given in Section 00XX00 Part 2.02 for Type 2 geogrid should be followed.

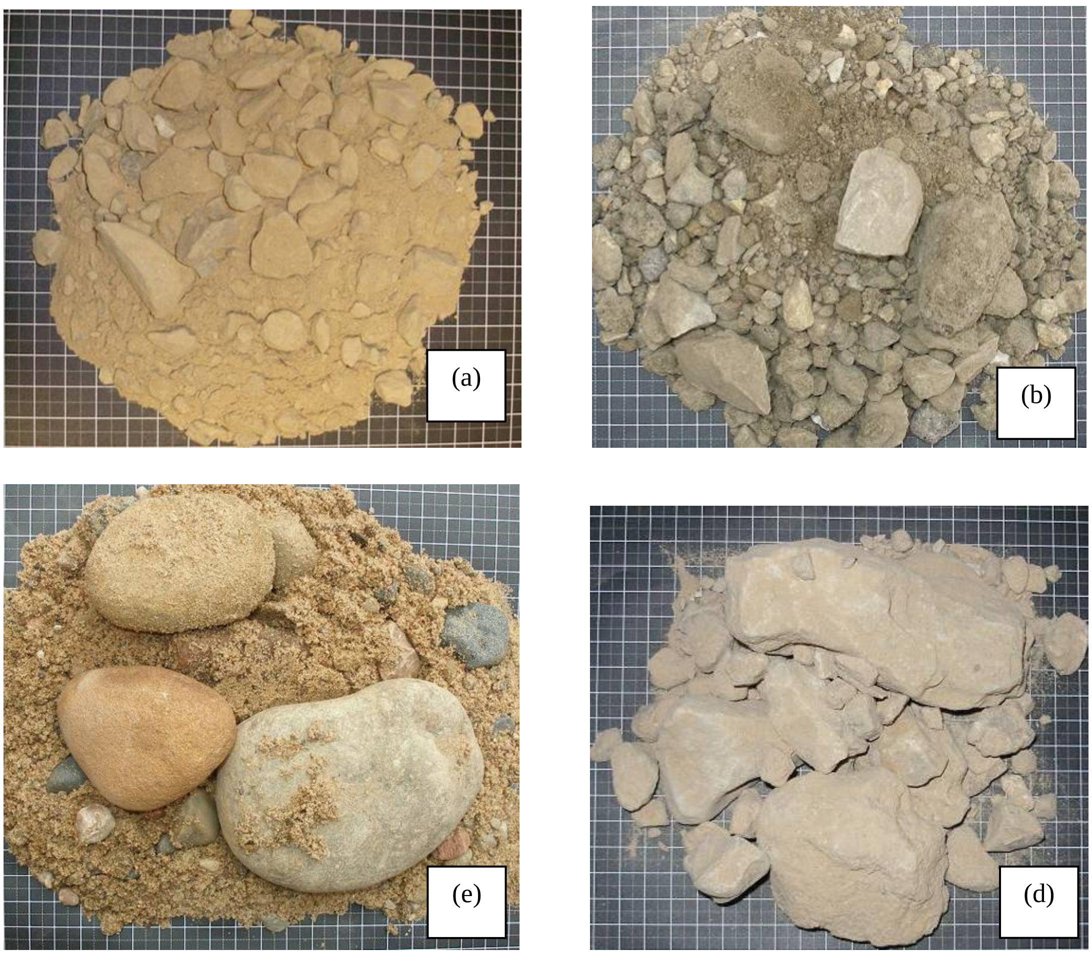


Figure 1. Photographs of some of the typical materials. Bold divisions on graph paper are 10 mm increments and fine lines are 5 mm increments: a. Grade 2 gravel, b. RPM, c. Pit run sand and gravel, and d. Breaker run.

Grade 1 granular backfill

Grade 1 granular backfill is similar to Class 5 aggregate of MNDOT. In other words, Class 5 meets Grade 1 granular backfill gradation requirements. Based on the tests on Class 5 aggregate, it is recommended that the thickness for materials classified as Grade 1 granular backfill is **17 inches**.

A new alternative material: Grade 1 granular backfill with geogrid

It is recommended that materials classified as Grade 1 granular backfill reinforced with geogrid to have a thickness of **12 inches**. The aperture size of the geogrid should be equal or less than 3.5 times D_{50} of Grade 1 materials for positive mechanical interlock. Typical aperture sizes are in the range of 25-33 mm. Most Grade 1 granular backfill is likely to meet this requirement. The geogrid requirements given in Section 00XX00 Part 2.02 for Type 2 geogrid should be followed.

Grade 2 granular backfill

Grade 2 granular material was extensively tested in the research projects. Based on a review of all the tests, it is recommended that the thickness for materials classified as Grade 2 granular backfill is **20 inches**.

A new alternative material: Grade 2 granular backfill with geogrid

Grade 2 granular material was extensively tested with geogrids in the research projects. Based on a review of all these tests, it is recommended that materials classified as Grade 2 granular backfill reinforced with geogrid to have a thickness of **13 inches**. The aperture size of the geogrid should be equal or less than 3.5 times D_{50} of Grade 2 materials for positive mechanical interlock. Typical aperture sizes are in the range of 25-33 mm. Most Grade 2 granular backfill is likely to meet this requirement. The geogrid requirements given in Section 00XX00 Part 2.02 for Type 2 geogrid should be followed.

Pit run sand and gravel

Pit run sand and gravel may have 50% or more grains larger than 2". Therefore, specimen testing such as CBR and resilient modulus is not possible, similar to breaker run. A plate load testing scheme similar to the large scale model experiments used previously but in a box was implemented in (WHRP 07-05) along with a novel geophysical approach. This material's behavior is intermediate between breaker run stone and granular backfill materials. The thickness recommended is **18 inches.**

Pit run sand and gravel with geogrid

Pit run sand and gravel with geogrid was tested in WHRP 07-05. Pit run sand and gravel may have 50% or more grains larger than 2"; however, it has a significant gravel and sand fraction and benefits from geogrid interaction. Based on the findings regarding membrane action, pit run sand and gravel with geogrid is recommended to have a thickness of **12 inches.** The aperture size of the geogrid should be equal or less than 3.5 times D_{50} of pit run sand and gravel materials for positive mechanical interlock. Typical aperture sizes are in the range of 25-33 mm. Not all pit run sand and gravel is likely to meet this requirement, however, some will. The geogrid requirements given in Section 00XX00 Part 2.02 for Type 2 geogrid should be followed.

Fly ash, Lime and Cement Stabilization

Fly Ash

Results relating to fly ash stabilization were reported in the research projects and in their appendices. There is now a significant knowledge base for fly ash stabilization and monitoring data available up to 7 years for fine-grained subgrades (USCS designations of CL, ML, CL-ML, SM, SC). Soils containing organic matter require special attention since organic matter inhibits cementation reactions and may require higher fly ash content than typical for inorganic subgrades. Since the materials involved in chemical stabilization are not standard (subgrade soils and also the binders), there is a huge range of possibilities. So the specifications in this class need to be primarily in terms of stabilized material properties such as CBR or unconfined compressive strength rather than thickness. Layer thickness is typically constrained to 8-12 inches and cannot be varied extensively because of practical considerations. This thickness nonetheless allows sufficient support as a working platform because of the higher strength and modulus generated. However, reactions and resulting stabilized material properties currently are hard to predict and need to be assessed by laboratory tests. The laboratory-developed properties, on the other hand, appear to be always lower (up to 50%) than those realized in the field, thus requiring adjustment. Current WisDOT Item 900xx provides appropriate guidelines for fly ash stabilization of subgrades. Both Class C fly ash as well as other fly ashes that do not qualify as Class C but self-cementing can be specified. Typical fly ash content on dry weight basis is 10-14%. The moisture content of the mix is important in developing the required strength and is not always possible to control. Typically wet conditions (i.e., in situ moisture contents of up to 7% wetter than the optimum moisture content) exist and require fly ash treatment. Wisconsin research indicates that a **CBR of 10** or more is achievable with 10% Class C fly ash in 7 days in such wet fine-grained inorganic subgrades. If fly ash is used as a precaution against future rain events during construction and mixed when the subgrade is not too wet, moisture content may need to be adjusted up to the optimum moisture content of the mixture obtained in the laboratory by adding moisture during mixing. Wisconsin research indicates that a **CBR of 15** or more is achievable with 10% Class C fly ash in 7 days at the mixture optimum moisture content in fine-grained inorganic subgrades. Subgrades consisting of coarse-grained (sand and gravel) materials typically do not require a working platform but if they are very wet fly ash may be used to dry and strengthen them. Recently published “Soil Stabilization and Pavement Recycling with Self-Cementing Coal Fly Ash” by the American Coal Ash Association Educational Foundation (2008) provides additional guidelines and data.

Lime Stabilizattion

Lime stabilization works on somewhat different principles than fly ash or cement stabilization. It is particularly useful in high plasticity clays in reducing their swell potential and increasing strength. Lime is more effective in reducing plasticity and thus swelling but less effective in increasing strength when compared to fly ash. There is limited experience with lime stabilization in Wisconsin.

Cement

Cement stabilization is similar to fly ash stabilization because of the cementitous reactions. It can be reviewed based on the experience with fly ash stabilization. Typically lower cement content (e.g., 4%) is required to achieve similar improvement with higher Class C fly ash content (e.g., 10%). There is limited experience with cement stabilization in Wisconsin.

A new alternative material: Salvaged materials or industrial by-products

This category can cover a wide range of non-standard materials with which relatively little experience exists. The research projects tested three such likely granular materials (**foundry sand, foundry slag, and bottom ash**). There is additional experience with recycled pavement materials (typically pulverized asphalt layer and some base course). Therefore, there is now some experience to update the FDM recommendations and be more specific. Because of their nature, these materials can vary depending on the source and the thickness recommendations need to be based on CBR and modulus test results. The research projects propose a way of determining the thickness of these materials based on the CBR and modulus data. However, it is possible to recommend typical ranges of CBR values and corresponding thicknesses.

The chart given in Fig. 2 can be used to decide the equivalent thickness of granular industrial byproducts for a maximum total deflection of 25 mm (1 inch) during typical construction traffic based on their measured CBR obtained at the specified field compaction conditions. The CBR assumed for breaker run (i.e., 80) has no practical consequence, because the CBR of breaker run only affects the scale of the abscissa in Fig. 2. The points in Fig. 2 correspond to h_a/h_b computed based on large-scale model experiments where h_a the thickness of the equivalent alternative granular material and h_b is is the thickness of the breaker run (i.e., 16 inches) working platform. A smooth curve is drawn through the points for granular materials for an equivalent total deflection of 25 mm (1 inch). The graph also indicates that working platforms may need to be very thick layers for alternative materials having a CBR ratio < 0.25. Thus, some materials may not be viable alternatives to breaker run because the required thickness will render the alternative material uneconomical. Also, materials having CBR < 20 (i.e., CBR ratio < 0.25) generally are not recommended for use as a subbase, which could preclude their use for working platforms.

The point corresponding to **foundry sand** was not included in Fig. 2, because this point is inconsistent with the trends observed for the more granular materials. CBR of foundry sand is sensitive to moisture content because of the bentonite content of foundry sand and can range from 4 to 40 depending on bentonite and water content. Foundry sands with a bentonite content of less than 6% are not very sensitive to moisture conditions and can be treated like regular sands and Fig. 2 for granular materials can be directly used to determine the working platform thickness based on CBR. The CBR of non-plastic foundry sands at optimum compaction conditions can be estimated from:

$$CBR = 32.4\gamma_{dm} - 1.93P_{200} - 264R_o - 361 \qquad (1)$$

where γ_{dm} (standard Proctor maximum dry unit weight) is in kN/m^3, P_{200} (percent passing #200 sieve) in %, and R_o (Krumbein particle roundness (varies between 0.55 and 0.69 for most foundry sands) in decimal. The physical interpretation of these relationships is logical for a non-plastic cohesionless soil. Shearing resistance of cohesionless soil is strongly influenced by interparticle friction, which increases with higher dry unit weight and particle angularity. An increase of fines or particle roundness causes a decrease in interparticle friction and lower CBR. The CBR of plastic foundry sands at optimum compaction conditions can be estimated from:

$$CBR = 178R_o - 7.6\gamma_{dm} - 4.25AC \qquad (2)$$

where γ_{dm} (standard Proctor maximum dry unit weight) is in kN/m^3, AC (active clay content) in %, and R_o (Krumbein particle roundness) in decimal.

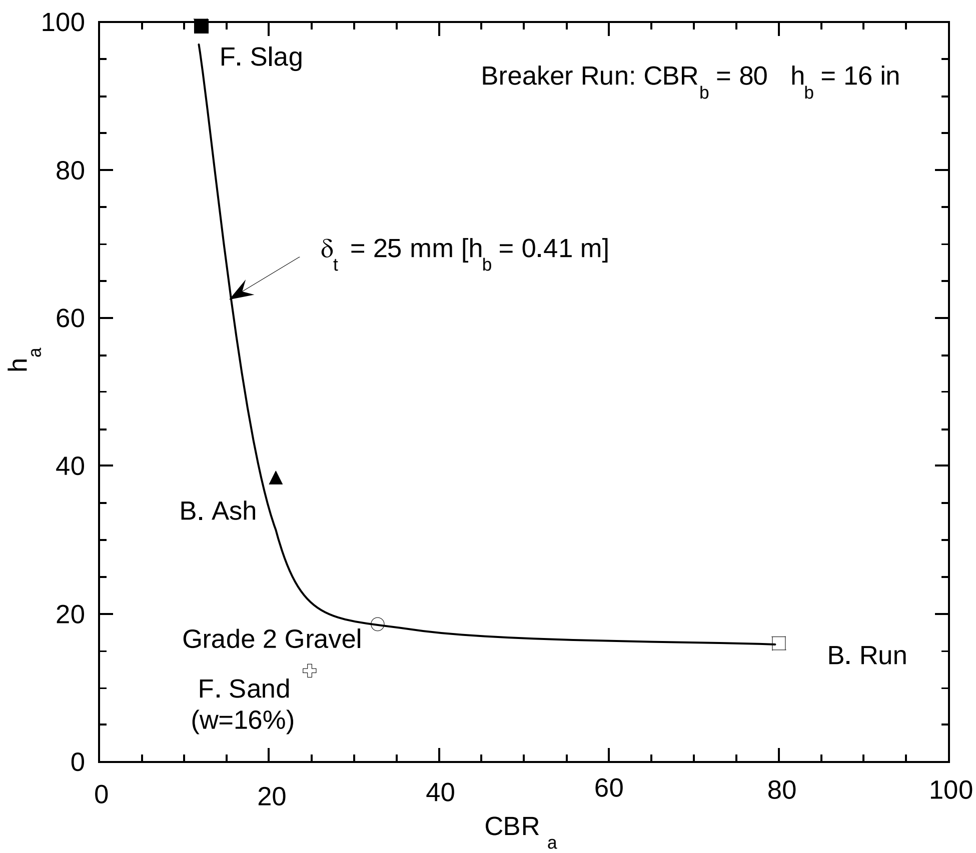


Fig. 2 . Design chart relating thickness of working platform of a granular alternative material (h_a) required to limit total deflections to 25 mm (1 inch) as a function of CBR_a of alternative material.

Recycled pavement materials can be included among the granular salvage materials that can be used in constructing working platforms. Grain size distribution of these materials can be specified during the pulverization process but they typically contain less large-size particles than pit run sand and gravel but coarser than sand-size materials than pit run sand and gravel and Grade 1 and 2 granular backfill materials. CBR of recycled pavement materials is not very sensitive to moisture content like other granular materials. **CBR of 20** is recommended for recycled pavement materials. Fig. 2 can be used for determining working platform thickness. A thickness of **19 inches** is recommended in the absence of CBR testing.

.

There is no specific experience with **recycled concrete aggregate**; however, it can be treated like the other granular salvaged materials. Fig. 2 can be used based on measured

CBR to determine the working platform thickness. Experience in other states indicates that recycled concrete aggregate performs similar to new aggregate. A thickness of **19 inches** is recommended in the absence of CBR testing.

Salvaged materials or industrial by-products with geogrid

There is limited information regarding geogrid improvement of granular salvaged materials such as foundry sand, foundry slag, bottom ash, recycled pavement material, recycled concrete aggregate. Based on the experience with other granular materials, the following recommendations are made. The aperture size of the geogrid should be equal or less than 3.5 times D_{50} of these materials for positive mechanical interlock. Typical aperture sizes are in the range of 25-33 mm. Most of these materials are likely to meet this requirement. The flexural stiffness and the initial true tensile modulus of the geogrid should also be sufficiently high. Minimum average roll values of 750,000 mg-cm and 400 kN/m (or 27,000 lb/ft) are recommended respectively for flexural stiffness and initial true tensile modulus. Junction efficiency should be in excess of 90%. The thickness can be reduced by **5 to 7 inches due to geogrid reinforcement** from the thickness required for the unreinforced material.

RECOMMENDATIONS REGARDING EIGHT SELECT MATERIAL ALTERNATIVES FOR STRUCTURAL CONTRIBUTION TO DESIGN

The new empirical-mechanistic design guidelines require resilient modulus for material characterization and each layer is taken into account in the design individually. Working platform would then be considered as an extra layer and can be treated as a subbase layer. It is thickness is determined during working platform selection as described above. The recommended summary resilient moduli to be used in design are listed in Table 1.

Based on the moduli a layer coefficient is calculated using:

$$a_3 = 0.249 \log M - 0.977 \tag{3}$$

where a_3 is layer coefficient of working platform (treated as subbase) and M is modulus in psi. For the recommended thickness in inches, the structural number contributed by the working platform (SN_3) is obtained from:

$$SN_3 = a_3 D_3 \tag{4}$$

where D_3 is the recommended working platform thickness.

Table 1. Recommended Moduli for Select Working Platform Materials

Working Platform Material	Recommended Modulus for Design (MPa)	Recommended Modulus for Design (psi)	Layer Coefficient	Thickness (in)	Structural Number
Breaker run stone	300	42918	0.18	16	2.8
Breaker run stone with geogrid	300	42918	0.18	12	2.2
Granular backfill Grade 1	175	25036	0.12	17	2.0
Granular backfill Grade 1 with Geogrid	260	37196	0.16	12	1.9
Granular backfill Grade 2	125	17883	0.08	20	1.6
Granular backfill Grade 2 with Geogrid	188	26896	0.13	13	1.6
Pit run sand and gravel	280	40057	0.17	18	3.0
Pit run sand and gravel with geogrid	400	57225	0.21	12	2.5
Fly ash stabilized subgrade	200	28612	0.13	12	1.6
Foundry sand*	80	11445	0.03	16	0.5
Foundry slag*	100	14306	0.06	99	5.7
Bottom ash*	100	14306	0.06	38	2.2
Recycled asphalt pavement material	80	11445	0.03	19	0.6
Recycled concrete aggregate	100	14306	0.06	19	1.1

*The recommendations for these industrial byproducts are based on typical materials tested; however, resilient modulus for these materials should be obtained at the specified compaction conditions.

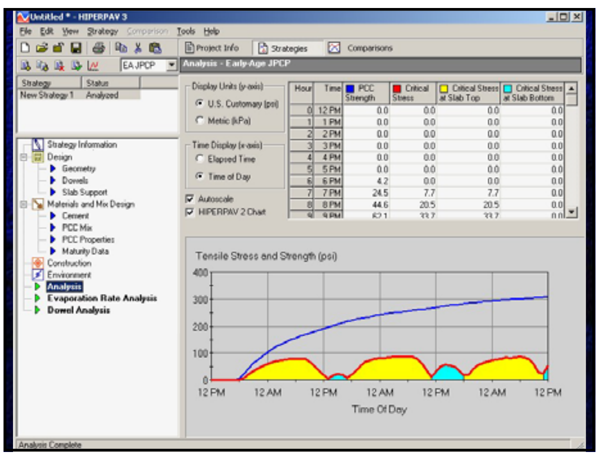
Appendix C: Deliverables for Implementation of Project 0092-04-11: Research of the Application of FHWA's HIPERPAV Model to Wisconsin

HIPERPAV Background and New Developments

HIPERPAV
WISCONSIN

15 November 2005
Madison, Wisconsin

presented by
J. Mauricio Ruiz, P.E.
Yadhira A. Resendez



How did it start?

Mid-80's

- Concrete Paving Industry
  - Pave it fast
  - Time counts

    or
  - Be ready to lose significant rehabilitation opportunities
- After that message, over 100 trial projects were completed in US under SP 201

How did it start?

Fast-track Findings

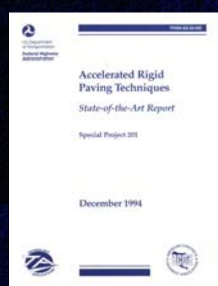
- Hot mixes on cold days?
- Blankets? Yes? No?
- Thermal shock? Curling/warping, cracking?
- Strength gain and opening time?
- Saw cutting and cracking?
- Internal stresses?

How did it start?

SP 201 (Fast-track) Findings

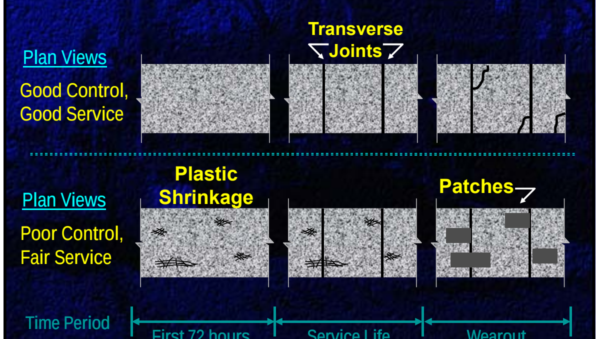
Very positive results, but with two concerns:

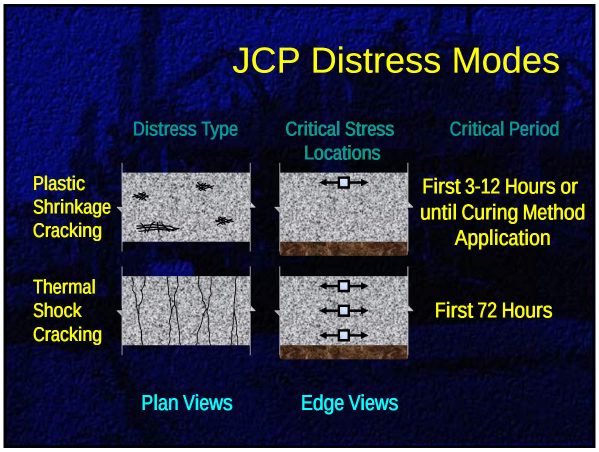
1. What value to open to traffic?
2. What about the influence of temperature on performance?

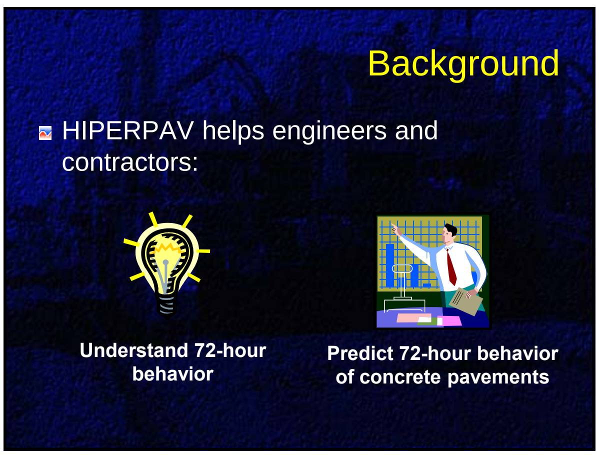


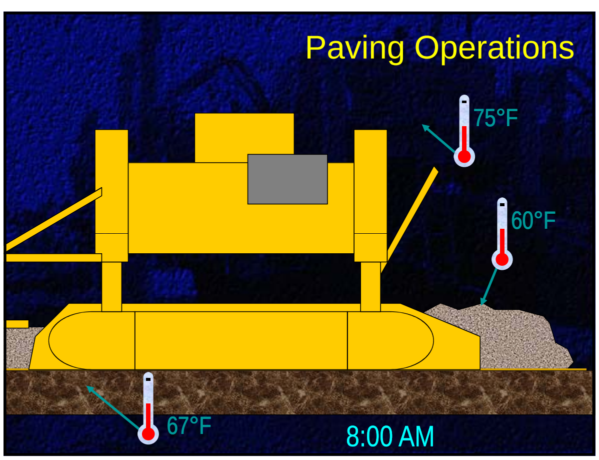
FHWA-SA-94-080

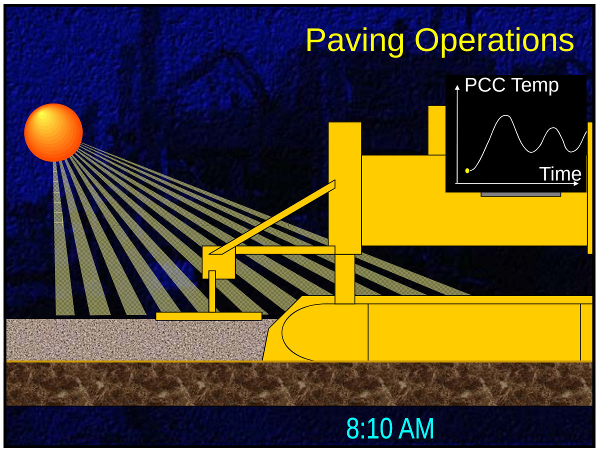
Effects of Temperature & Moisture

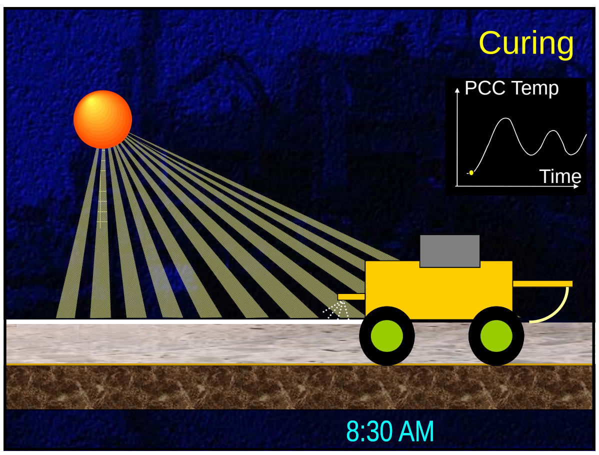


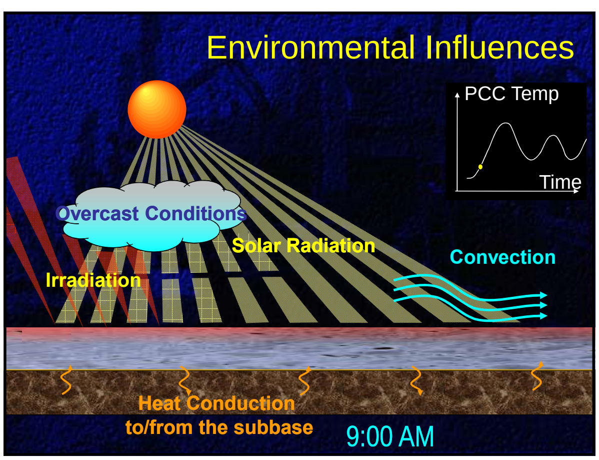

JCP Distress Modes
Distress Type
Critical Stress Locations
Critical Period
Plastic Shrinkage Cracking
First 3-12 Hours or until Curing Method Application
Thermal Shock Cracking
First 72 Hours
Plan Views
Edge Views

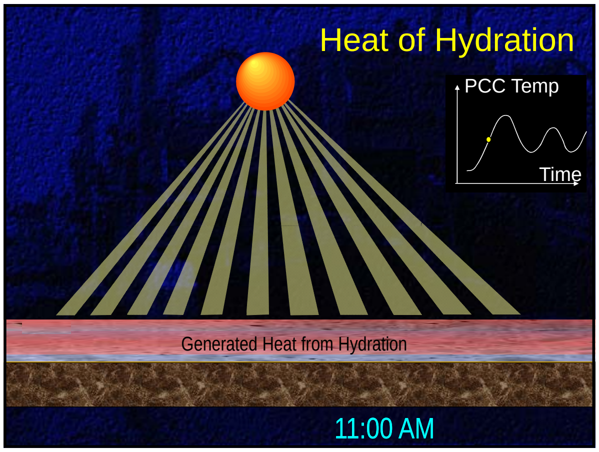

Background
HIPERPAV helps engineers and contractors:
Understand 72-hour behavior
Predict 72-hour behavior of concrete pavements

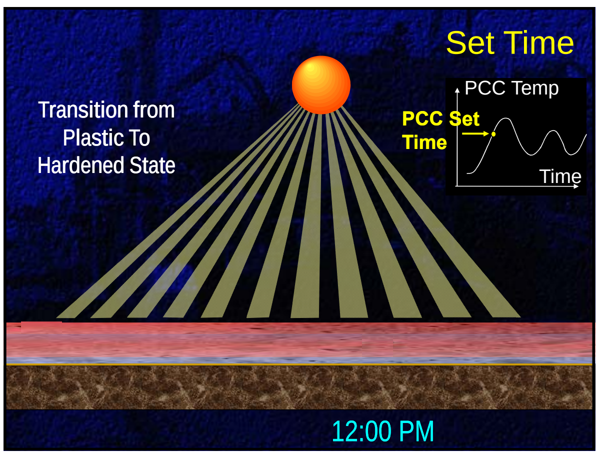

Paving Operations
75°F
60°F
67°F
8:00 AM

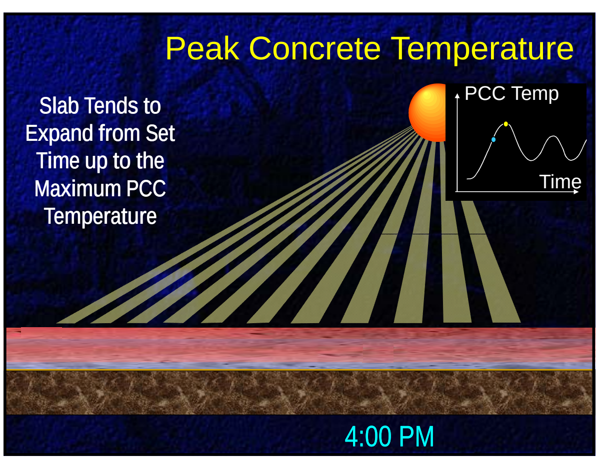

Paving Operations
PCC Temp
Time
8:10 AM

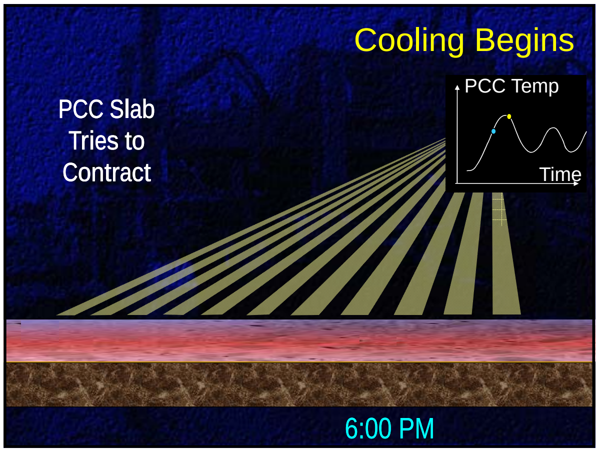

Curing
PCC Temp
Time
8:30 AM

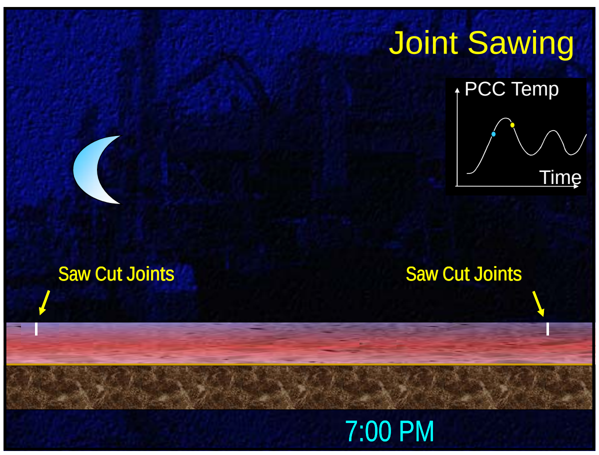

Environmental Influences
PCC Temp
Time
Overcast Conditions
Solar Radiation
Convection
Irradiation
Heat Conduction
to/from the subbase
9:00 AM

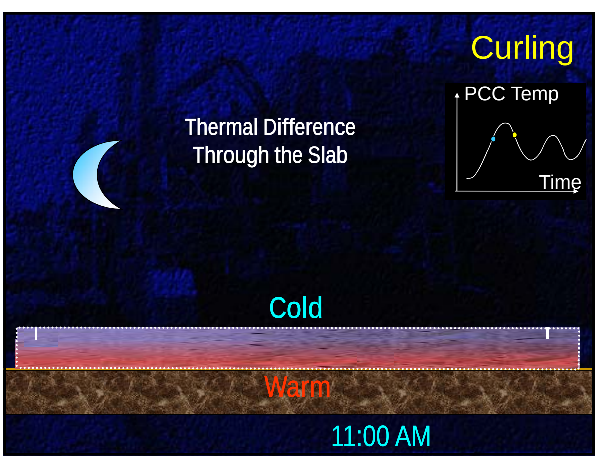

Heat of Hydration
PCC Temp
Time
Generated Heat from Hydration
11:00 AM

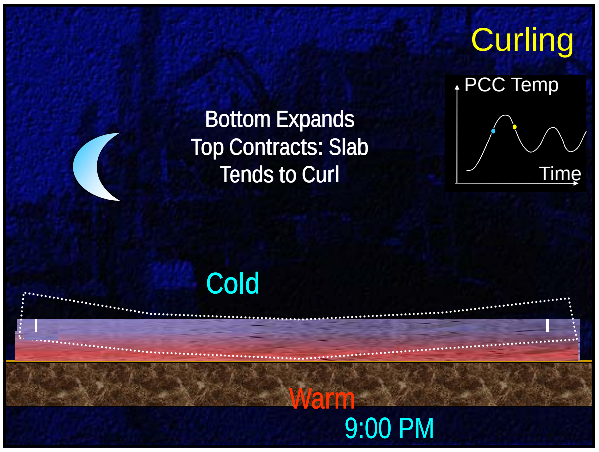

Set Time
Transition from Plastic To Hardened State
PCC Temp
PCC Set Time
Time
12:00 PM

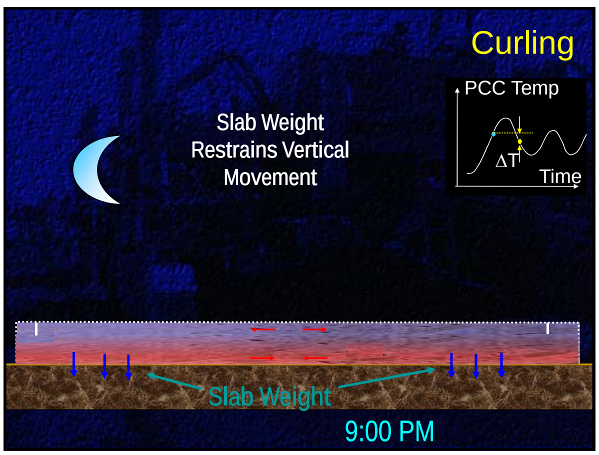

Peak Concrete Temperature
Slab Tends to Expand from Set Time up to the Maximum PCC Temperature
PCC Temp
Time
4:00 PM

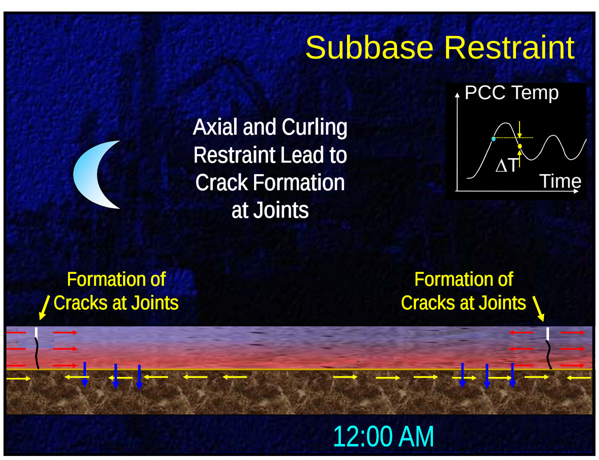

Cooling Begins
PCC Temp
PCC Slab
Tries to
Contract
Time
6:00 PM

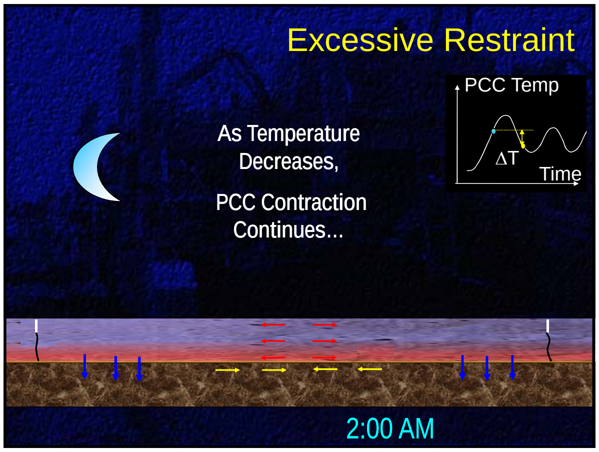

Joint Sawing
PCC Temp
Time
Saw Cut Joints
Saw Cut Joints
7:00 PM

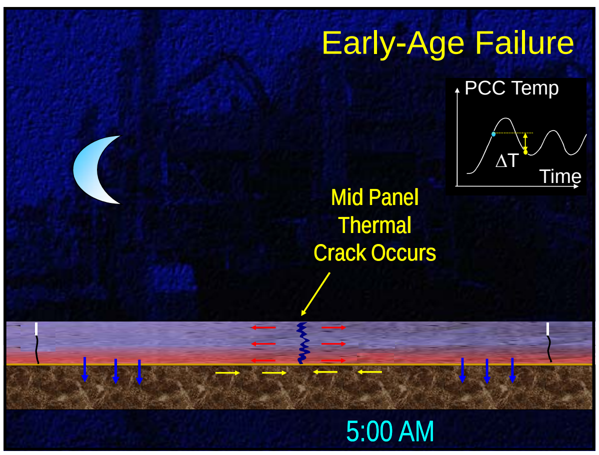

Curling
PCC Temp
Thermal Difference
Through the Slab
Time
Cold
Warm
11:00 AM

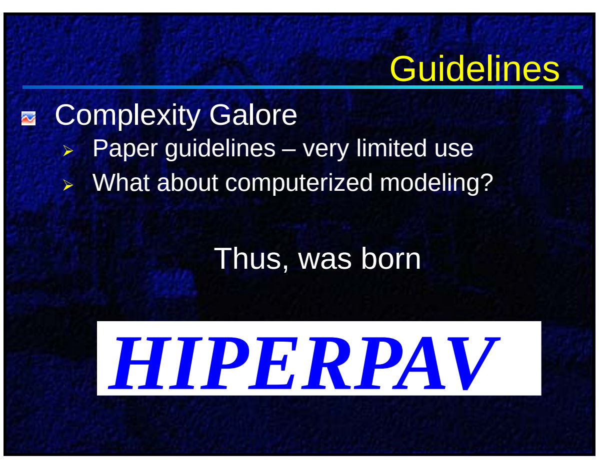

Curling
PCC Temp
Time
Bottom Expands
Top Contracts: Slab
Tends to Curl
Cold
Warm
9:00 PM


Curling
PCC Temp
ΔT
Time
Slab Weight
Restrains Vertical
Movement
Slab Weight
9:00 PM


Subbase Restraint
PCC Temp
ΔT
Time
Axial and Curling
Restraint Lead to
Crack Formation
at Joints
Formation of
Cracks at Joints
Formation of
Cracks at Joints
12:00 AM


Excessive Restraint
PCC Temp
ΔT
Time
As Temperature Decreases,
PCC Contraction Continues...
2:00 AM

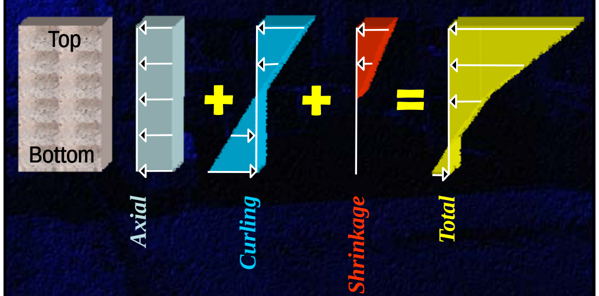

Early-Age Failure
PCC Temp
ΔT
Time
Mid Panel Thermal Crack Occurs
5:00 AM


Guidelines
Complexity Galore
Paper guidelines – very limited use
What about computerized modeling?
Thus, was born
HIPERPAV

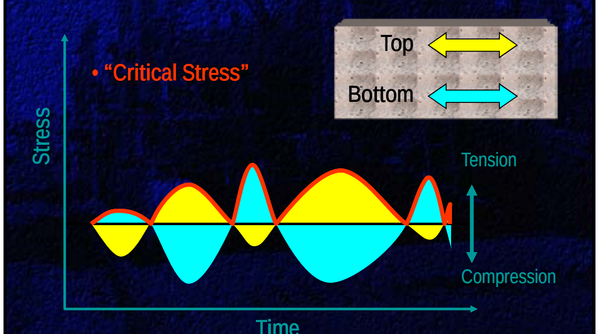
Systems Approach

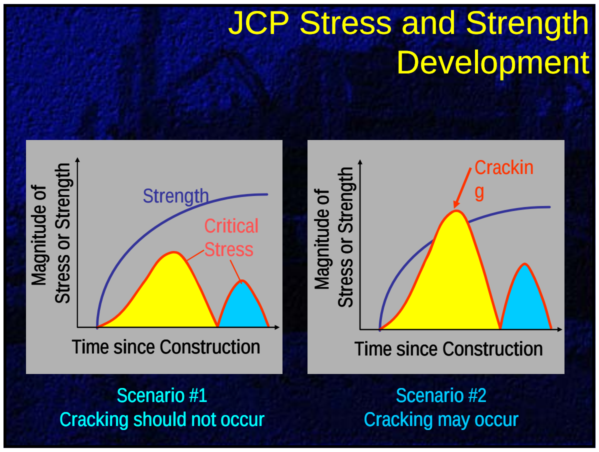
- In the past, many individual models have been developed to address pavement behavior
- HIPERPAV uses the **Systems approach** to unify all the models into one useful tool
- The **Systems approach** integrates:
  - Design parameters
  - Material properties
  - Environmental conditions
  - Construction activities

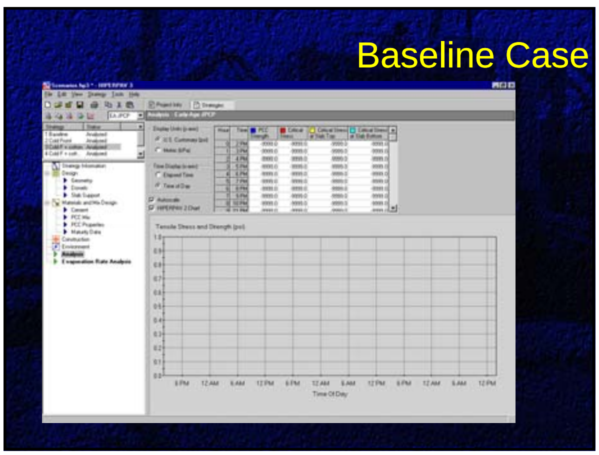
Superposition of Stresses

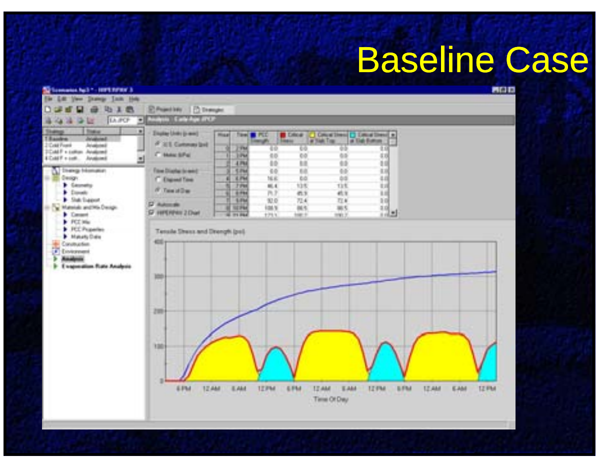


Critical Stress




JCP Stress and Strength Development
Magnitude of Stress or Strength
Strength
Critical Stress
Time since Construction
Magnitude of Stress or Strength
Crackin g
Time since Construction
Scenario #1
Cracking should not occur
Scenario #2
Cracking may occur


Baseline Case

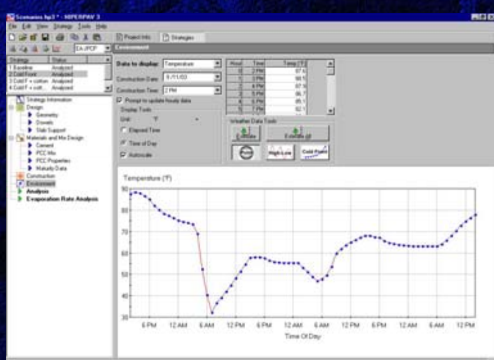

Baseline Case

Question

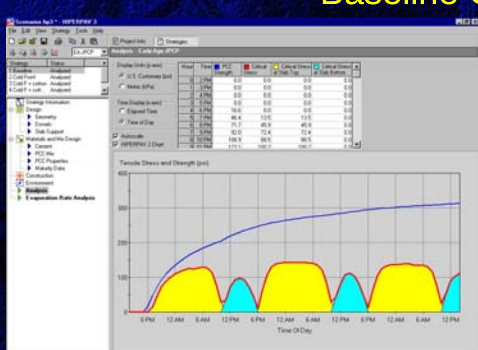
Well, that's nice…

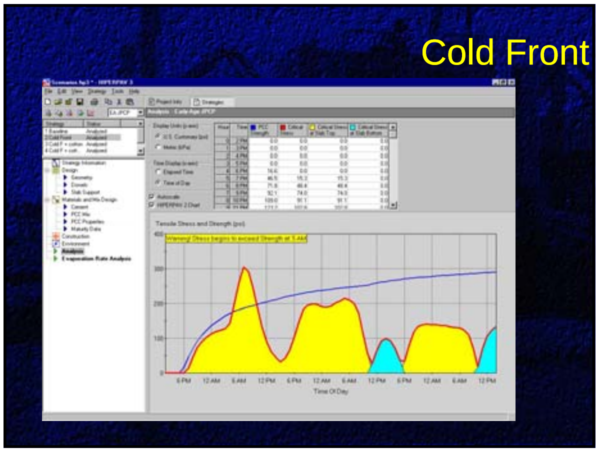
But, what if the weather is not "ideal"?

Cold Front

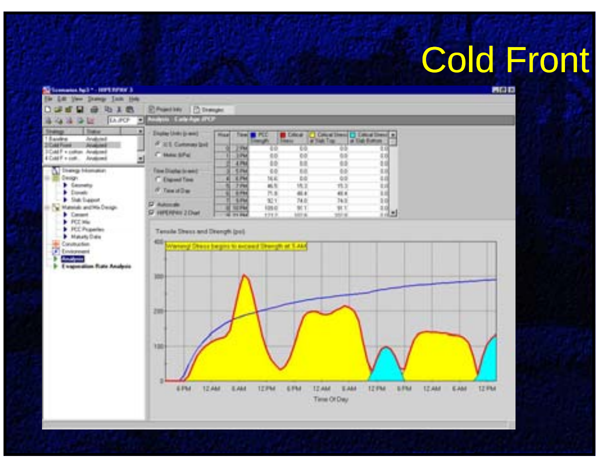


Baseline Case

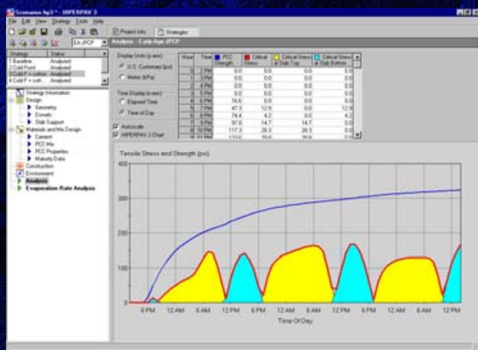



Cold Front


Question
What Now?
Maybe some Blankets?


Cold Front

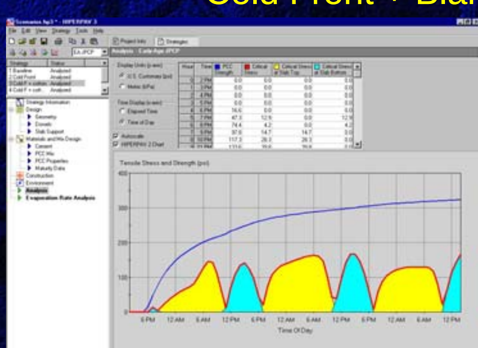
Cold Front + Blankets



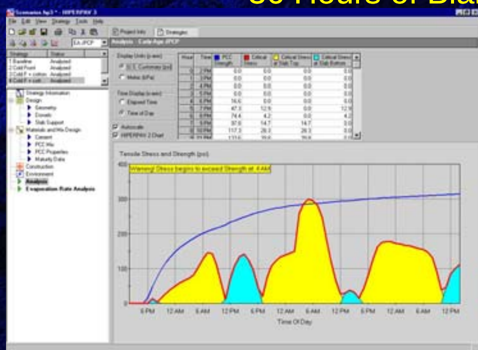
Question

What happens if I have to open to traffic in 36 Hours?

Cold Front + Blankets



Cold Front + 36 Hours of Blankets



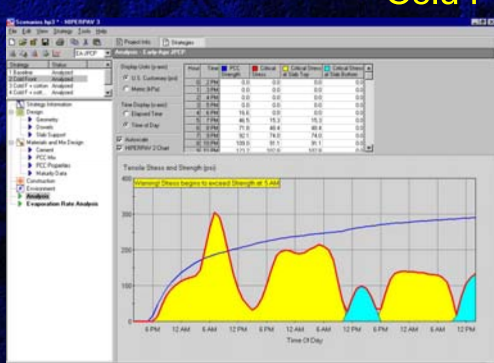
(Blankets removed at 36 hours)

Question

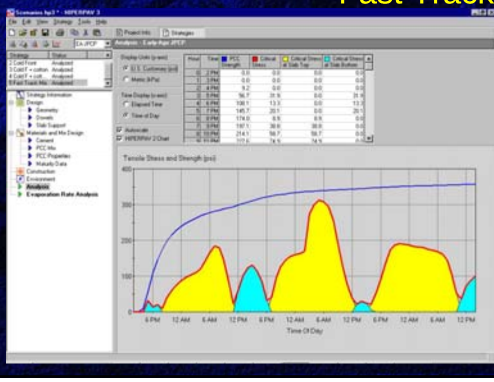
Is there another way?

What about a Fast-Track Mix?

Cold Front



Cold Front + Fast Track Mix

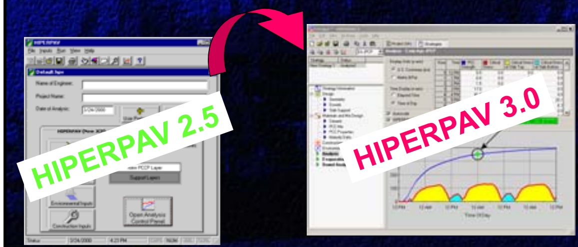


What are typical uses?

- Predict responses in cold and hot weather paving
- Predict potential strength gain for tight closures and opening to traffic
- Determine effects of design parameters on stress development
  - Joint spacing, thickness, base type
- Determine optimal mix characteristics
- Forensic studies – crack development

Recent HIPERPAV Validation

HIPERPAV Versions



Software Features

- New Graphical Interface √
- Geographical Weather Database √
- Analysis of Multiple Strategies √
- Strategy Comparison √
- Input Range Validation √
- Reference Database √
- Software Tutorial √

Software Features

- Cement and Admixtures Characterization √
- Strength Conversion Tool √
- Estimate Weather from Database √
- Equivalent Age Maturity Method √
- Slab Support Characterization √
- Sawcutting Options √
- PCC CTE and Shrinkage Inputs √
- Tabular and Graphic Inputs √


Thank you!
Any Questions?
It's QUESTION TIME!!

HIPERPAV Wisconsin Customization

HIPERPAV
WISCONSIN

15 November 2005
Madison, Wisconsin

presented by
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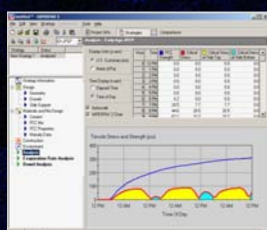
Yadhira A. Resendez

Background

- HIPERPAV is a tool to better understand early-age concrete pavement behavior.
- Current terminology and default inputs represent the entire nation.
- Better acceptance will be obtained by customizing HIPERPAV.

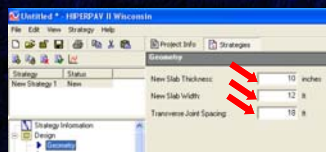


Presentation Outline

- Enhancements
  - General
  - Options
  - Geography
  - Cement
  - PCC Mix
  - Environment
  - Construction
  - Analysis

General

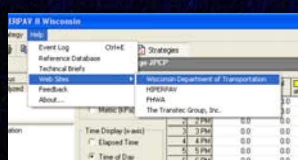
- Input validation ranges and typical defaults for Wisconsin included



- Can open FHWA HIPERPAV 3 files

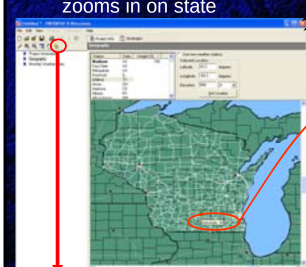
Options

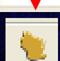
- Electronic version of WisDOT spec book linked directly to the software



Geography

- Geography map zooms in on state





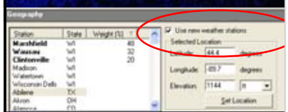
Zoom to Wisconsin

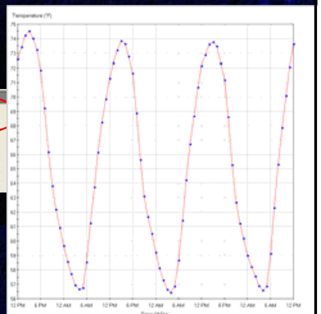
- Geographic features added

- Station selection 508 compliant

Geography

Using additional local weather stations

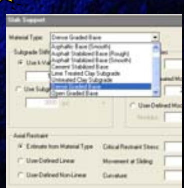




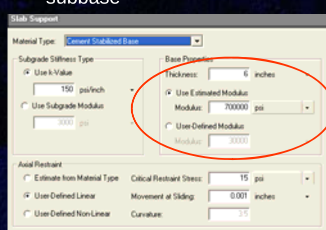
Without using new weather stations

Slab Support

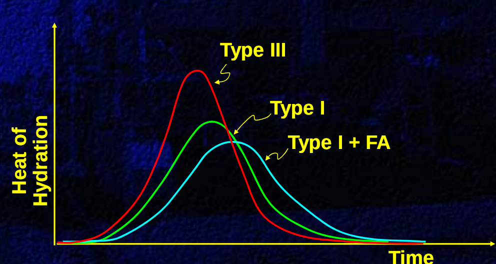
- Subbase selection

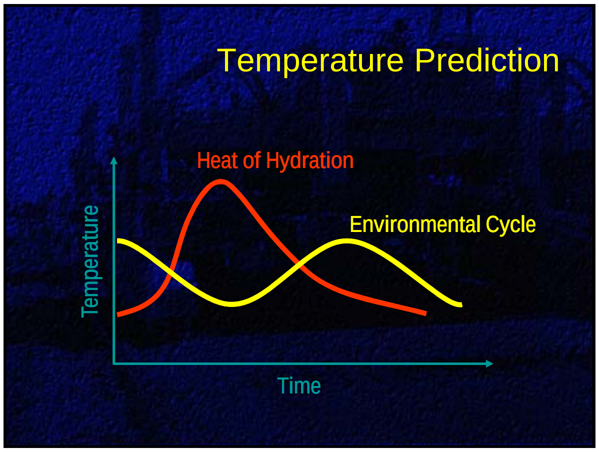


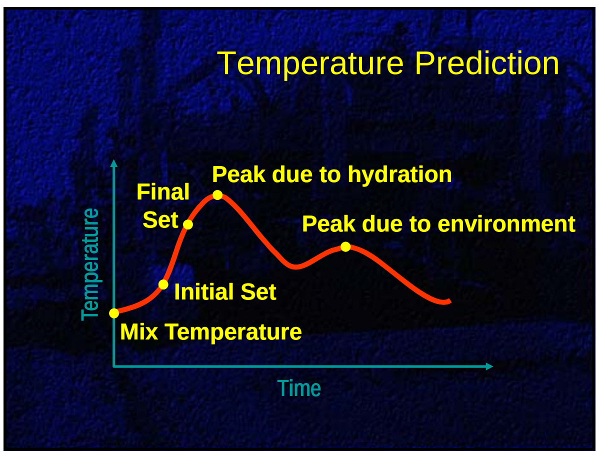
- Subbase stiffness values updated with selection of subbase

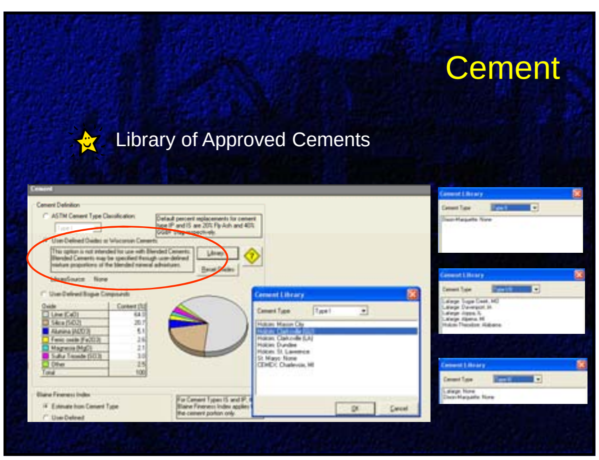


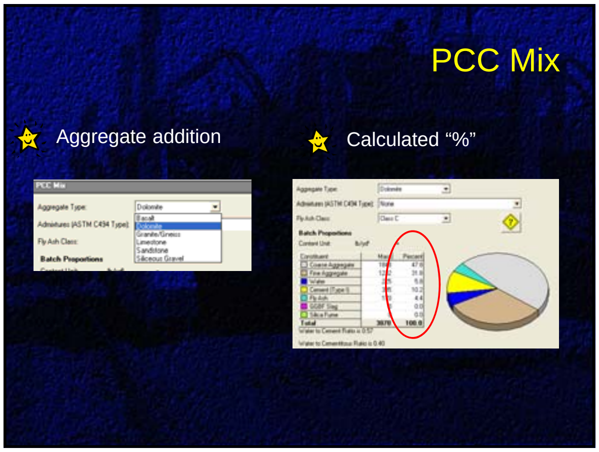
Temperature Prediction

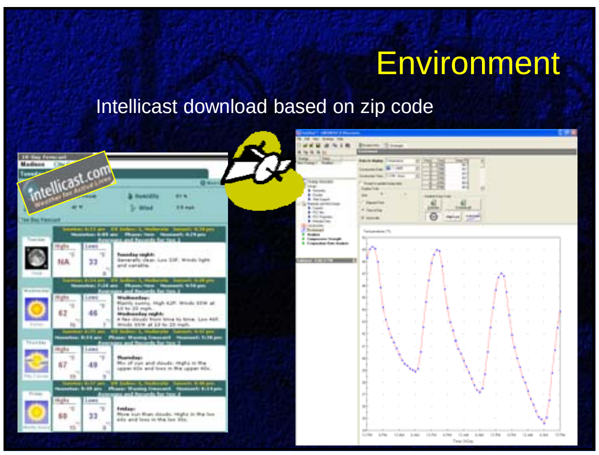


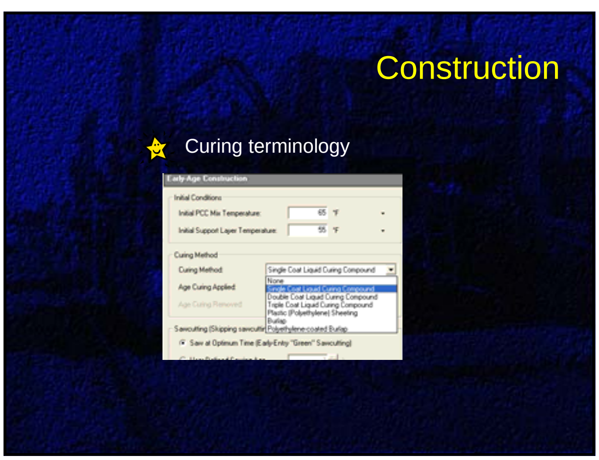

Temperature Prediction
Heat of Hydration
Environmental Cycle
Temperature
Time

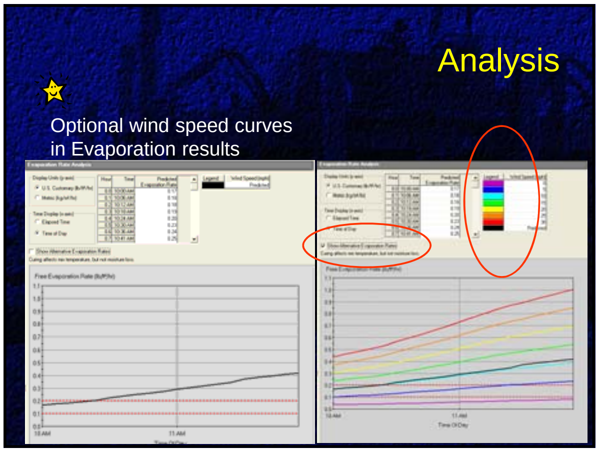

Temperature Prediction
Peak due to hydration
Final Set
Peak due to environment
Initial Set
Mix Temperature
Temperature
Time

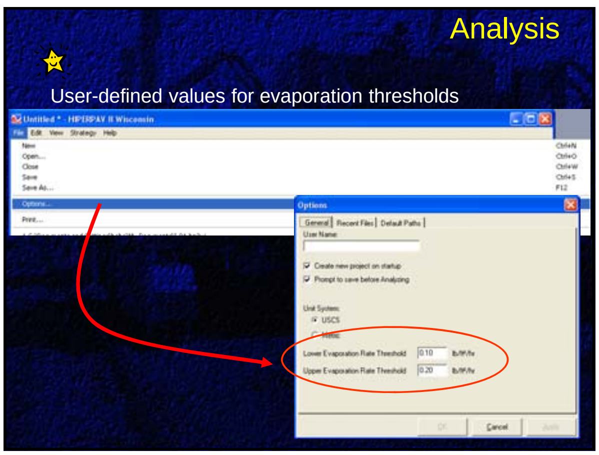

Cement
Library of Approved Cements

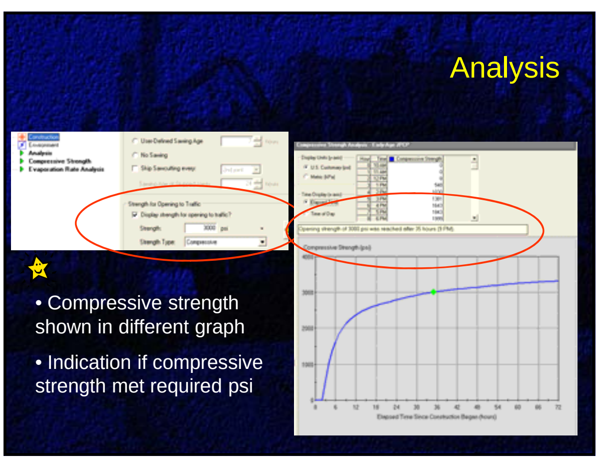

PCC Mix
Aggregate addition
Calculated "%"


Environment
Intellicast download based on zip code


Construction
Curing terminology


Analysis
Optional wind speed curves in Evaporation results


Analysis
User-defined values for evaporation thresholds


Analysis
• Compressive strength shown in different graph
• Indication if compressive strength met required psi

Thank you!

Any Questions?

Appendix D: Deliverables for Implementation of Project 0092-01-06: Rehabilitation Techniques for Concrete Bridges

Application of Protective Coating for Rehabilitation of Wisconsin Concrete Bridges

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Edward A. Fitzgerald, Wisconsin DOT

Habib Tabatabai, University of Wisconsin-Milwaukee

PACE 2008 Conference – Los Angeles, CA, January 2008

What Was the Need for the Project and How Does it Effect Bridge Owners in Wisconsin?

- As a Maintenance Engineer for the DOT in Wisconsin for over 20 years , I am also a Certified NBI Bridge Program Manager and am responsible for Bridge as well as Roadway repair and maintenance in the SW Region of Wisconsin.

Some of the Problems in the Field:

- **The following slides will show some of the things we were seeing at our beam ends and the problems of salt infiltration not only cosmetically but eventually structurally as well.**


04/10/2007


04/10/2007


04/10/2007


09/12/2007


09/12/2007

Points of Concern

- Corrosion damage of girder ends
- Water leaking through faulty expansion joints
- Resulting in steel corrosion and the spalling of concrete

Points of Concern

- Repair: complete removal followed by reconstruction
- Common Issues:
  - Reoccurring spalls due to inadequate bond
  - Contaminants in adjacent areas migrate to the repair region

What We Were Doing:

- Spending many dollars and man hours on cleaning and patching with cementitious materials.
- Damage was already done and by patching we only created a cosmetic solution that only lasted a few years.


05/08/2007

What Was Needed:

- A research project that would give an unbiased evaluation of what we were doing wrong and some definitive solutions to fix the problem.
- The evaluations would include many of the coatings and materials readily available to the industry and how they performed. (note: the unique part of this study was the acceleration of the salt infiltration process.)

The Results of the Study:

- Showed us what not to do.
- Provided us with a proactive solution to the problem.
- Changed our Bridge construction manual.
- Saved bridge facility owners money.
- Changed our bridge inspection/repair process.

Future Studies:

- The success of this project has provided us with an opportunity to use existing data and materials to do further study.
- This new project will give us unbiased research to substantiate industry claims on coatings and sealers and other methods of rebar protection, spall prevention, and repair techniques beyond beam ends.

Work at the University of Wisconsin-Milwaukee

Experimental Program Objectives

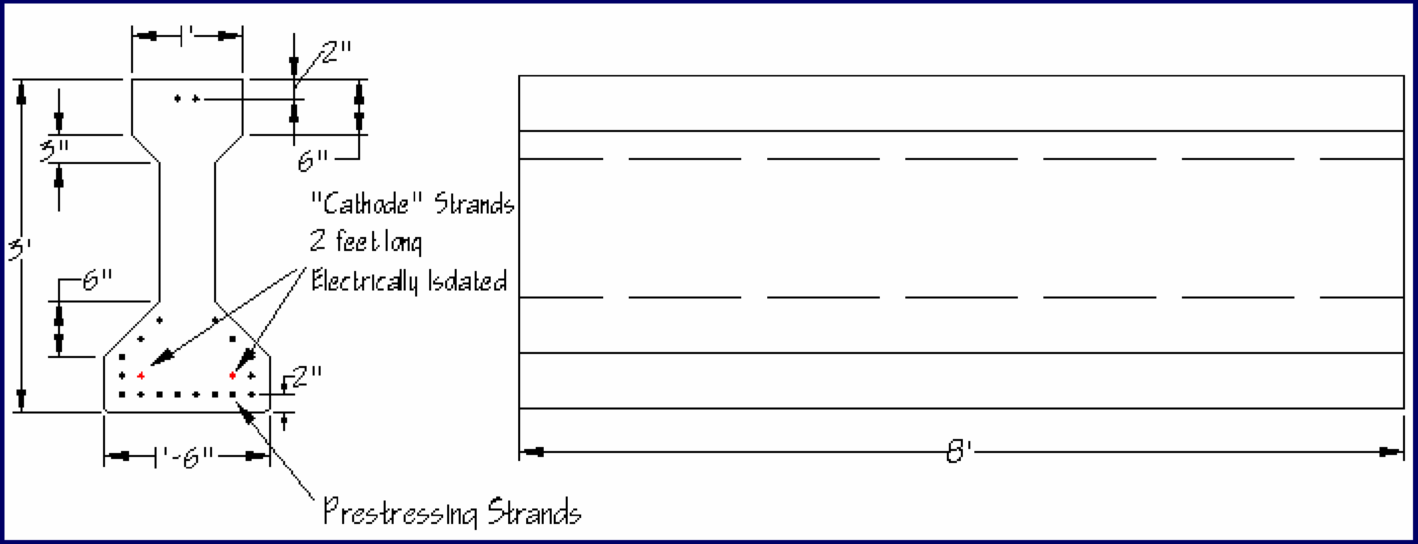
- Determine the effectiveness of a sealer, epoxy coating, polymer (resin) coating, and FRP wrap in protecting against corrosion damage in new members (PS beam ends)
- To establish the effectiveness of these treatments and patch repairs in reducing/preventing continued corrosion in members that are already contaminated with chlorides

Experimental Program Overview

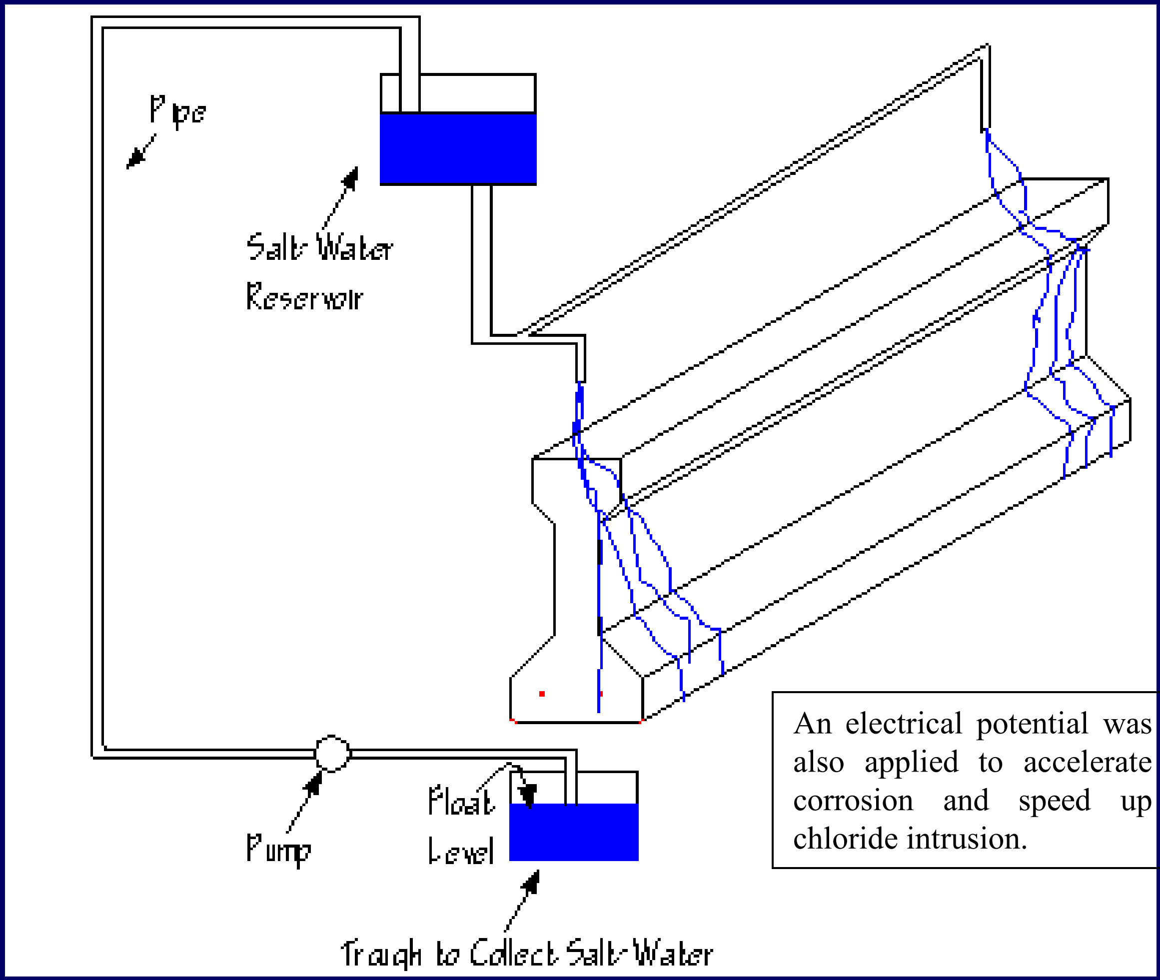
- Performing laboratory tests on five new 8-ft-long prestressed concrete bridge I-beams
  - Subjected to wet/dry cycles of salt laden water (6% NaCl solution) for 18 mo.
  - Subjected to galvanostatic accelerated corrosion methods
- Selected end regions were pretreated, while others remained untreated
- After 6 months, some of the previously untreated beam-ends were patch repaired or subjected to one of the surface treatments

Specimens

- 8-ft long AASHTO Type II prestressed concrete beams
- 18 - ½ inch diameter grade 270 low relaxation 7-wire prestressing strands
- Grade 60 conventional reinforcement
- 2 electrically isolated strands (cathode bars)

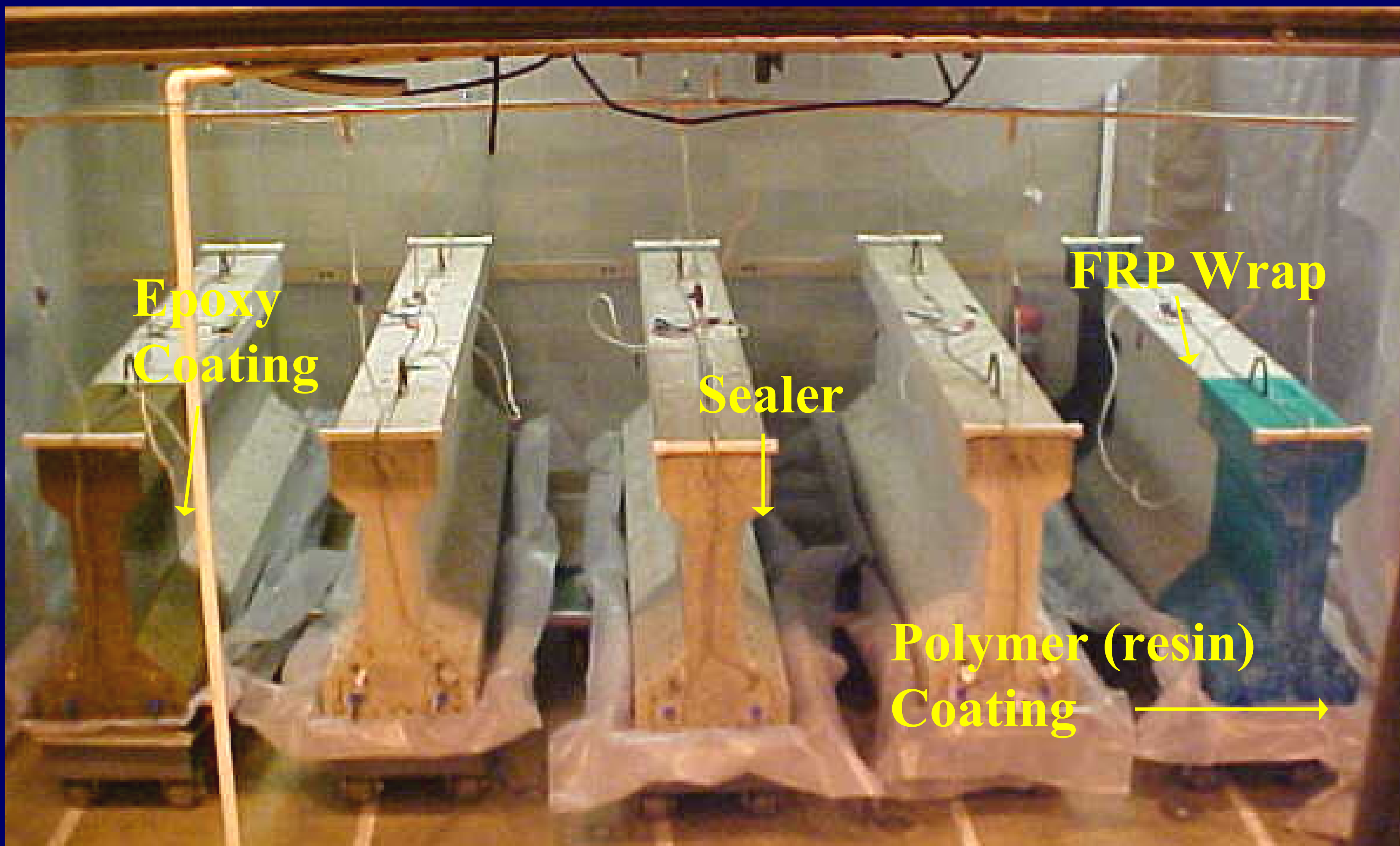


Salt-Water Distribution System



An electrical potential was also applied to accelerate corrosion and speed up chloride intrusion.

Experimental Set-up



Repair Materials

- Carbon Fiber Reinforced Polymer (CFRP)
  - REPLARK 30 manufactured by Mitsubishi Chemical Corporation
  - Consists of: carbon fiber fabric, primer, putty, and resin
  - 2 layers at 90° to one another (after application of primer and putty)
- Polymer (Resin) Coating
  - The resin component of the RELPLARK 30 system
  - 2 coats applied with paint roller (after application of primer and putty)

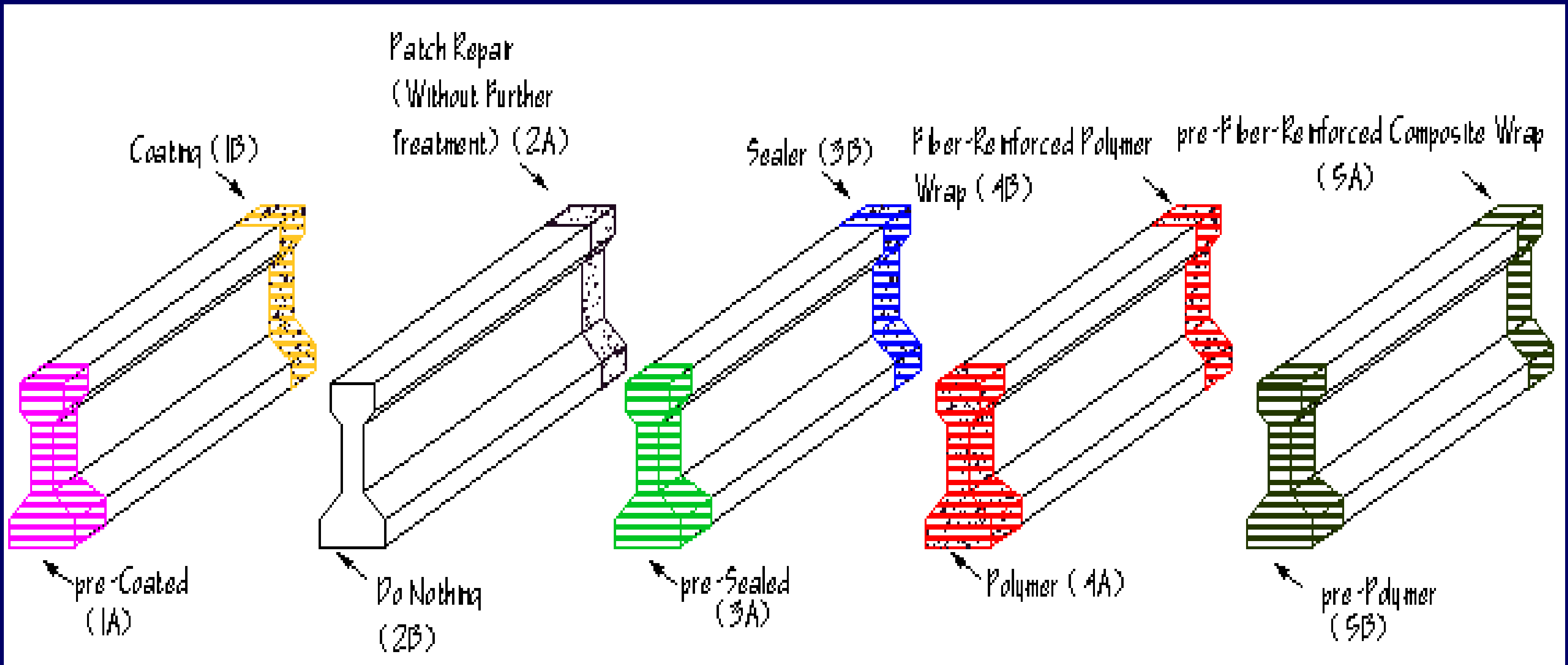
Repair Materials

- Epoxy Coating
  - MASTERSEAL GP Epoxy Sealer
  - 2 coats
- Sealer
  - MASTERSEAL SL 40 VOC
  - A solvent based silane penetrating sealer
  - 2 coats

Repair Materials

- Patch Material
  - Vericoat Supreme: a one component, microsilica and latex modified, nonsag repair mortar produced by Euclid Chemical Company
  - Designed for trowel applied vertical and overhead repairs
- Patch Material Bond Agent
  - CORR-BOND: composed of specialty water based epoxy and selected cementitious components produced by the Euclid Chemical Company

Repair Plan



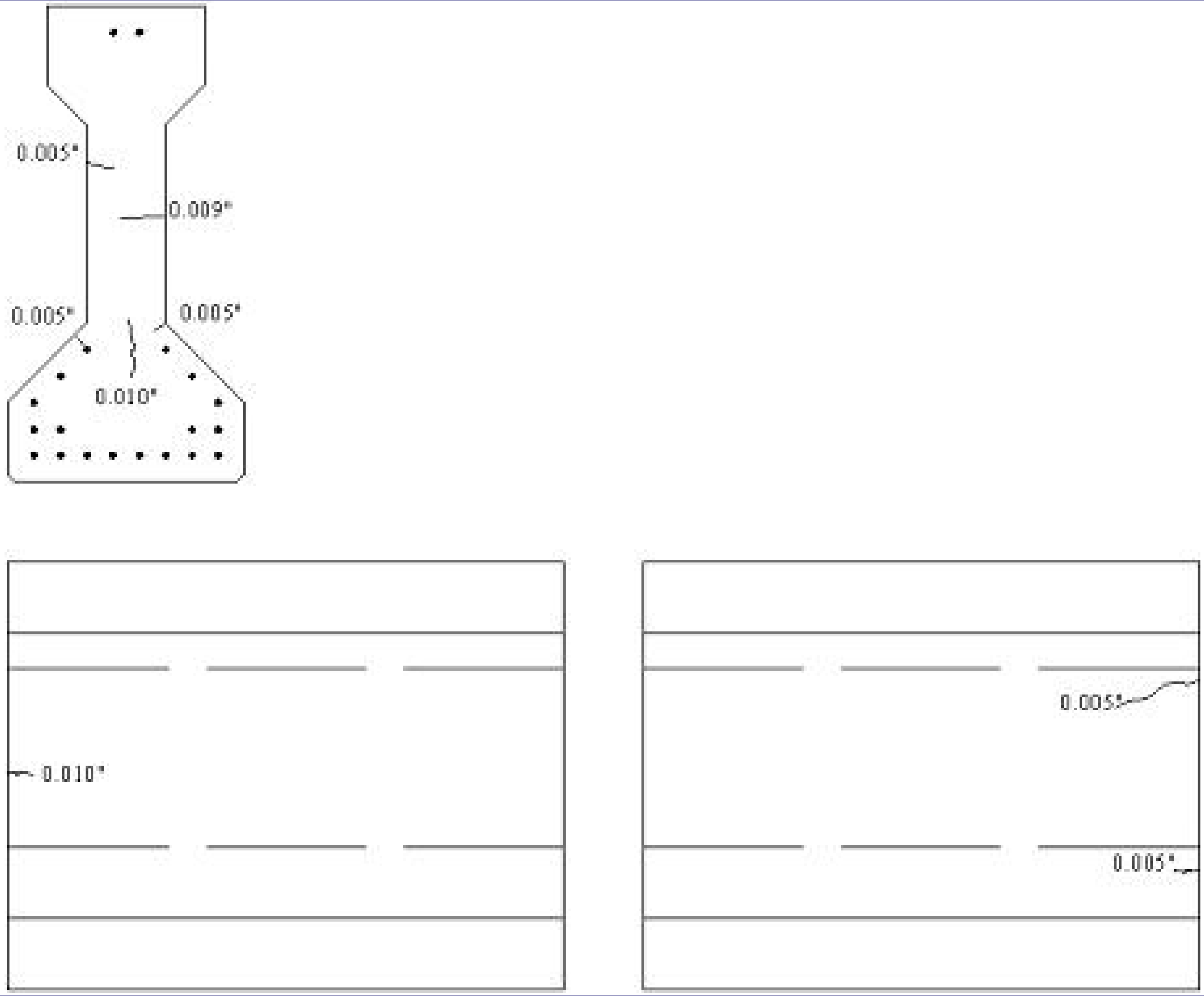
Patch Repair
(Without Further
Treatment) (2A)
Coating (1B)
Sealer (3B)
Fiber-Reinforced Polymer
Wrap (4B)
pre-Fiber-Reinforced Composite Wrap
(5A)
pre-Coated
(1A)
Do Nothing
(2B)
pre-Sealed
(3A)
Polymer (4A)
pre-Polymer
(5B)

Comparative Chloride Content Ratings

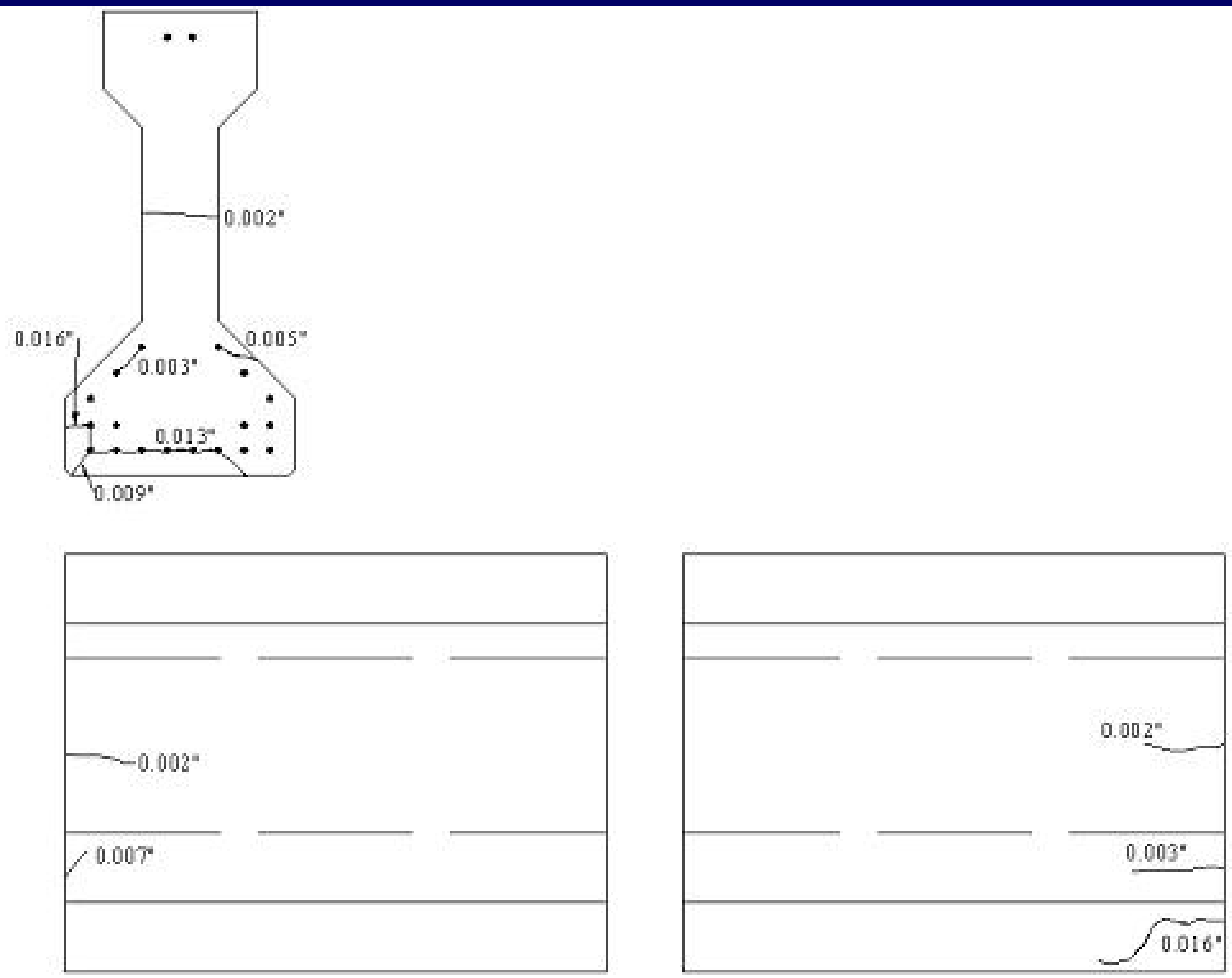
Beam-End	Rating at 0.75 in.	Rating at 1.5 in.	Ave. Rating
1A	1	1	1
1B	3	2	2.5
2A	3	1	2
2B	8	8	8
3A	1	1	1
3B	2	2	2
4A	4	5	4.5
4B	3	2	2.5
5A	1	1	1
5B	1	2	1.5

Ratings based on a range from 1 to 8 (1 best, 8 worst)
White rows correspond to beam-ends that were treated after 6 months of exposure.

Crack Map – 1A (18 Months)



Crack Map – 2A (18 Months)



Dissection – 2B

Overall Assessment

Beam End	Description	Chlorides	Cracking	Corrosion	Overall Rating
1A	Epoxy Coated From Day 1	1	2	3	**6**
1B	Epoxy Coated After 6 Months of Exposure	2.5	4	7	**13.5**
2A	No Treatment Applied	2	6	5.5	**13.5**
2B	Patch Repair After 6 Months of Exposure	8	7	8	**23**
3A	Silane Sealer Applied from Day 1	1	5	3.5	**9.5**
3B	Silane Sealer Applied After 6 Months of Exposure	2	8	5.5	**15.5**
4A	Polymer Resin Coating Applied After 6 Months Exp	4.5	3	6	**13.5**
4B	FRP Wrap Applied After 6 Months of Exposure	2.5	1	7	**10.5**
5A	Polymer Resin Coating Applied From Day 1	1	1	2	**4**
5B	FRP Wrap Applied From Day 1	1.5	1	2	**4.5**

Conclusions

- Experimental work:
  - The best overall results were obtained when either FRP wrap or polymer coatings were applied from Day 1
  - The application of treatments after 6 months of exposure was far less effective than treatment on Day 1
  - Epoxy coating was the next best effective method

Recommendations

- Use polymer coating or epoxy coating on beam ends in new projects prior to installation in the field.
- For existing bridges, apply either polymer coating or epoxy coating as early as possible before chloride contamination and corrosion take hold

Recommendations (Cont.)

- When corrosion and damage is advanced, patch alone would not be durable. Consider coating the patch with polymer or epoxy coatings.
- These results can equally apply to pier caps, columns, and abutments.

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