EVALUATION OF ALTERNATIVE DOWEL BAR MATERIALS

Draft Interim Report

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Introduction

The HITEC Mission

The Highway Innovative Technology Evaluation Center (HITEC) was established to facilitate the introduction of new or innovative technology in the highway market. In the past, the process for introducing new products often caused inadvertent barriers to innovation. This occurred for many reasons, one of which was the lack of objective technical information upon which the product could be accepted. Demonstrating a new product to each individual highway agency is inefficient, time consuming, and often cost prohibitive, particularly to small companies or individual entrepreneurs.

Based upon the interest and support of many stakeholders in the highway community, including government officials, contractors, consultants, manufacturers, researchers, and organizations, including the American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), and the American Society of Civil Engineers (ASCE), HITEC was established to facilitate the introduction of new technologies in the highway community. HITEC is structured to facilitate the conduct of consensus-based, nationally accepted performance evaluations of new and innovative products for the highway community. HITEC operates as an independent entity under ASCE's Civil Engineering Research Foundation (CERF). While the name HITEC and the phrase "new and innovative technologies" carry a strong connotation of highly technical products associated with the electronics and computer industries, HITEC evaluates almost any product, system, service, material, or equipment that the owner believes can be productively used on the nation's highways and that the owner wants to introduce to the market using a national consensus based evaluation.

The HITEC Process

Applicants are invited to submit applications describing their "product," its function, and any available test or performance data. If the application is accepted, HITEC establishes a Technical Evaluation Panel of "experts," which includes nationally recognized individuals from the user community, private sector, and academia. The goal is to assemble a panel that has relevant expertise in technical areas related to the new product. The panel meets with the applicant or their representatives and establishes a Comprehensive Evaluation Plan (Plan) tailored to the "product." This plan addresses the specific questions and concerns that the panel believes must be answered if the "product" is to be nationally accepted. The Plan, once approved by the applicant, is then executed under the guidance of the Panel. Upon completion, HITEC drafts a Final Report that is reviewed by the Panel in conjunction with the applicant and is ultimately presented for distribution to the highway community.

Evaluation and Testing Plan for Alternative Dowel Bars

One of HITEC's on-going projects is the evaluation of alternative dowel bars for load transfer in jointed concrete pavements. A variety of materials are being evaluated, including fiber reinforced polymer (FRP) bars, stainless steel bars and pipes, and conventional epoxy-coated dowel bars. Pavement projects incorporating these alternative dowel bars were constructed as early as 1996, and a document was prepared by HITEC in May 1998 (included as Appendix A) that details the procedure for evaluating the constructed projects. The evaluation plan limited the variables to the dowel materials and limited the materials to a selected few offered by the applicant materials industries. The evaluation plan consists of three parts: literature review, field Installations, and laboratory investigations.

The principal thrust of the May 1998 HITEC Evaluation Plan was to be on the observation and testing of field installations completed or planned by various state highway agencies (SHAs). However, based on the current information available, it is proposed to emphasize monitoring the 5-year (or longer) field performance (including coring of selected joints) and to eliminate materials testing of full-length field samples after the initial 5-year evaluation period. There are a number of reasons for this proposed change including:

- No SHAs (except for the Ohio 1983 and 1985 projects) have taken full-length field samples.

- There are few standard test protocols, particularly for the FRP materials.

- There is not a universally acceptable model that is capable of predicting expected performance from variations in the material properties obtained during testing.

- Previous coring of dowel specimens in Ohio and Iowa has shown minimum deterioration due to corrosion during the 5-year field evaluation period, making any significant findings unlikely. At this early age, socketing in the concrete around the dowel or delaminations in the concrete at the dowel bar are more likely to be the important performance indicators.

- Sufficient test results are available to characterize the range of materials properties of interest (information is available from Ohio, Iowa, University of Manitoba, and the University of West Virginia, with research underway in California).

Based on these considerations, a modified field evaluation and testing plan is proposed and included later in this report.

The focus of this Interim Report is on the use of 1.5-in diameter fiber reinforced polymer (FRP) bars; 1-5-in diameter, Type 304 stainless steel solid or clad bars; 1.5-in diameter, Type 304 stainless steel, concrete-filled tubes or pipe; and 1.5-in diameter, epoxy-coated mild steel smooth round dowels (as the control). Table 1 summarizes some of the alternative dowel bar materials commonly in use.

Table 1. Summary of alternative dowel bar materials (Smith 2002b).

Material Type	Description	Advantages	Disadvantages	Nominal Cost
FRP Composite Bars	A solid bar made up of a composite material consisting of a matrix binder (such as polyester, vinyl ester, or epoxy), a reinforcing element (such as fiberglass or carbon fiber), and fillers.	• Not susceptible to corrosion • Durable • High tensile strength • Light weight /easy to handle • Closer in relative stiffness to PCC than steel bars, which reduces damage at dowel interface	• More expensive than epoxy-coated steel bars • Lower modulus of elasticity and shear strength than epoxy-coated steel bars • Low specific gravity (bar may float to surface during vibration if not secured)	• $6.61 to $8.81 per kg ($3 to $4 per lb) • $4 to $9 per dowel *(depends on diameter)*
FRP Composite Tubes Filled with Cement Grout	An FRP composite tube filled with a high-strength cement grout for strength and deformation resistance.	• Not susceptible to corrosion • Durable • Less expensive than solid FRP composite bar • Closer in relative stiffness to PCC than steel bars, which reduces damage at dowel interface	• More expensive than epoxy-coated steel bars • Lower modulus of elasticity and shear strength than epoxy-coated steel bars	• $4 to $9 per dowel *(depends on diameter)*
Plastic-Coated Dowel Bars	A carbon steel bar containing a thin layer (about 0.5 mm [0.020 in]) of plastic coating, such as polyethylene.	• Corrosion resistance • Relatively moderate cost • Does not bond to PCC (may not require bond breaker coating) • Maintains low pull-out resistance	• Potential for damage during construction handling • Greater relative stiffness of bar compared to PCC may cause damage at dowel interface	• $3 to $6 per dowel *(depends on diameter)*
Solid Stainless Steel Bars	Low carbon steels (less than 1 percent) that contain at least 10.5 percent chromium by weight for corrosion resistance. Type 316 is commonly used for dowel bars.	• Strong corrosion resistance • Durable • High tensile strength • Long service lives (50–75 years) • Fully recyclable • No special handling requirements	• More expensive than epoxy-coated steel bars • More difficult to handle than FRP bars • Higher relative stiffness than FRP bars	• $4.40 to $5.28 per kg ($2 to $2.40 per lb) • $18 to $20 per dowel *(depends on diameter)*
Stainless Steel Clad Bars	Stainless steel cladding (commonly Type 316 and between about 1.8 to 2.3 mm [0.07 to 0.09 in] thick) metallurgically bonded to a conventional carbon steel core.	• Strong corrosion resistance • Durable • High tensile strength • Long service lives (50–75 years) • Cheaper than either FRP or solid stainless steel bars • No special handling requirements	• More expensive than epoxy-coated steel bars (but not as expensive as solid stainless steel bars) • More difficult to handle than FRP bars • Higher relative stiffness than FRP bars	• $1.10 to $1.65 per kg ($0.50 to $0.75 per lb) • $6 to $11 per dowel *(depends on diameter)*
Stainless Steel Tubes Filled with Cement Grout	A stainless steel tube filled with a high-strength cement grout for strength and deformation resistance.	• Strong corrosion resistance • Durable • High tensile strength • Long service lives (50–75 years) • Cheaper than either FRP or solid stainless steel bars • No special handling requirements	• More expensive than epoxy-coated steel bars (but not as expensive as solid stainless steel bars) • More difficult to handle than FRP bars • Higher relative stiffness than FRP bars	• $5 to $10 per dowel *(depends on diameter)*
Epoxy-Coated Steel Bars	A carbon steel bar containing a fusion-bonded epoxy coating (commonly between 0.2 to 0.3 mm [0.008 to 0.012 in] thick) which acts as a barrier system against moisture and chlorides.	• Resistance to corrosion • High tensile strength • Cheapest of all corrosion-resistant bars	• Long-term effectiveness of corrosion protection may be an issue • Coating can easily be nicked or scratched during construction handling • Greater relative stiffness of bar compared to PCC may cause damage at dowel interface	• $0.66 to 0.77 per kg ($0.30 to $0.35 per lb) • $2.50 to $5.00 per dowel *(depends on diameter)*

History of HITEC Evaluation Plan for Alternative Dowels

Initial field installations of FRP and stainless steel dowels began in 1996 in conjunction with the FHWA High Performance Concrete Pavement HPCP (TE-30) project (originally referred to as the High Performance Rigid Pavement [HPRP] project). At about the same time, a document titled *Preliminary Assessment of Alternative Materials for Concrete Highway Pavement Joints* was prepared (Porter and Braun 1997). This report consisted of a literature review and the results of a HITEC survey that included 36 responses from state highway agencies. The intent of that report was to provide HITEC with information to determine whether or not the use of alternative materials for concrete highway joints was worth a more thorough and rigorous evaluation. Both the Composites Institute and the Specialty Steel Industry of North America sponsored the original non-proprietary evaluation program. A Technical Evaluation Panel was established to guide the evaluation effort. The original panel members are listed in the May 1998, HITEC Evaluation Plan (included as Appendix A), with the current panel members listed in Appendix B.

The principal thrust of the evaluation was to be on the observation and testing of field installations. Periodic evaluations and a 5-year summary report were to be developed for each project by the various state highway agencies. These field projects were being developed as part of FHWA's HPCP Program. A summary of the status of that comprehensive HPCP effort will be provided later as well the current status of projects in Ohio, Iowa, Illinois, and Wisconsin which are the major focus of this Interim Report.

The preliminary assessment referenced above was the initial literature review. On September 26, 2003, APTech developed an Annotated Literature review that was provided to the Technical Evaluation Panel (TEP).

The second and concurrent part of the field installations program was an evaluation of "old" FRP and stainless steel dowels from concrete pavement joint repair installations made in Ohio in 1985 on I-77 in Guernsey County and FRP dowels installed in 1983 in Ohio on State Route 7 in Belmont County. In addition to condition surveys and deflection testing, cores and full-length dowels were cut from the Ohio pavements and used in additional laboratory evaluations. The results of this effort are documented in the report *Fiber-Reinforced Polymer (FRP) Composite Dowel Bars …a 15-year durability study* by the Composites Institute (MDA 1999). Also, RJD Industries, Inc. developed a 2-page summary *Long Term Field Performance of GFRP Pavement Dowels* and a report *FRP Dowel Bars, Analysis of Fiber Reinforced Polymer Dowels Removed From Active Roadways* (McCallion 1999). This second part of the effort has been completed.

The third and final part of the field program was to be the removal and laboratory evaluation, at the conclusion of the 5-year observation period, of sample cores and full-length dowels from the alternative materials dowel joints placed as a part of this experiment. An updated field evaluation and testing plan will be presented later in this interim report containing a proposed change to eliminate the retrieval and testing of the full-length dowel samples at least at this time.

In addition to the industry funding, a HITEC State Pooled Funds Study has solicited additional funding to continue evaluations on this project. A contract for SPR-2(204) started July 1, 1999, and that study was replaced by TPF5028 on February 13, 2002.

Reporting

Under the original evaluation plan, a report was to be prepared by HITEC that documented the performance of the alternative dowel bar installations at the conclusion of the 18-month observation period. However, that report was never prepared and the current interim report will serve provide the current update to the dowel bar performance.

In regards to related FHWA HPCP information, the TEP was furnished copies of the *High Performance Concrete Pavements: Project Summary* prepared by APTech (Smith 2002a) and *High Performance Concrete Pavements: Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements,* also prepared by APTech (Smith 2002b). These documents provided an excellent summary of the more comprehensive HPCP (TE-30) alternative dowel bar evaluation effort. Current, FHWA is preparing an updated summary report on the HPCP projects, which is expected to be published in 2005. That document will provide information on the 16 HPCP or related projects evaluating alternative dowel bar materials including the projects that are the focus of this interim report. The related projects contain dowel bar material types, sizes, and spacing, which are outside of the scope of this more limited HITEC Evaluation. FHWA has made a copy of the July 2004 draft report available for review (QES 2004).

Quarterly progress reports have been provided since the letter contract between HITEC and APTech was executed on July 2, 2003. An Annotated Bibliography was e-mailed to the TEP on September 26, 2003. From December 19, 2003 to August 4, 2004, a stop work order was issued by HITEC. Quarterly progress reports were e-mailed on October 11, 2003; January 6, 2004; April 8, 2004; October 11, 2004; and January 8, 2005.

Annotated Literature Review

Since the project was established, there have been a number of significant changes. The major change has been the significant increase in the number of projects included in the FHWA TE-30 HPCP program. The updated draft report on the HPCP projects (QES 2004) contains 16 dowel bar or related projects including a much larger range of variables. As provided in the Letter Agreement, the focus of this Interim Report will be limited to seven sites in four States (OH 2; IA 2; IL 1, 2, and 3; and WI 2 and 3). Portions of the updated draft report on the HPCP projects (QES 2004) for the focus projects is included in Appendix D for information.

Also, the major emphasis of this Interim Report will be on the performance of 1.5-in diameter FRP dowels, 1.5-in diameter Type 304 solid or clad stainless steel dowels or concrete-filled tubes compared to 1.5-in diameter epoxy-coated mild steel dowels. These restrictions also limit the conclusions that can be drawn from the testing results available. For example, FRP diameter increases or bar spacing reductions have been shown in the laboratory to provide similar deflection and load transfer performance as the 1.5-in diameter epoxy-coated mild steel dowels used as the control. Also, some of the constructed projects have used Type 316L stainless steel which provides enhanced corrosion protection compared to the Type 304L stainless steel.

In addition, there are a other research studies, either recently completed or ongoing, being performed on the use of alternative dowel bars at a number of venues, including Iowa State University (Cable, Porter, and Guinn 2003), the University of Manitoba (Murison 2004; Murison, Shalaby, and Mufti 2005), the University of California at Davis (Bian 2003), and West

Virginia University (GangaRao 2004; Gupta 2004). There have also been a number of accelerated load testing studies of alternative dowel bar size, spacing, and materials that can provide additional insight into expected performance. A study using the Heavy Vehicle Simulator (HVS) was completed in California and a study in Kansas (Melhem 1999) is also available. Two recent reports evaluating alternative materials for retrofit dowels were published by the University of Minnesota (Odden, Snyder, and Schultz 2003; Popehn, Schultz, and Snyder 2003). A study using the Minne-ALF to evaluate Type 316 stainless steel Schedule 40 unfilled structural pipe (1.66-in outside diameter and 0.14-in wall thickness) is currently underway at the University of Minnesota. The results of these evaluations should be considered in any expanded study of alternative dowel bar materials.

The report, *Load Transfer Design and Benefits for Portland Cement Concrete Pavements,* (ERES 1996) provides information on the history and benefits of dowel bar load transfer in jointed concrete pavements. The beneficial effect of dowels is also documented in the Long-Term Pavement Performance (LTPP) KEY FINDINGS from LTPP Analysis 2000-2003 (FHWA 2004a). Data from the LTPP program clearly demonstrate that dowels significantly reduce faulting and significantly increase the transverse joint load transfer efficiency.

Performance Issues

One of the key questions regarding the use of conventional epoxy-coated dowel bars is whether corrosion is at all compromising their long-term performance. There are very limited data available documenting the extent of the problem. However, the interest in the use of alternative dowel bar suggest that there is at least the perception of a significant problem. Until better nationwide data are available, each state will have to evaluate their pavement performance to determine if this is a significant issue, and if so, whether or not the use of alternative dowel materials is cost-effective for their specific design conditions (traffic, climate, deicing applications, etc.).

The major performance issue identified so far relates to the significantly lower load transfer efficiencies (LTEs) of the 1.5-in FRP dowels after only a few years and under relatively low accumulated ESALs (10 million maximum in 6 years on IL 1, and much less on all the other projects). This statement is based on the performance of the FRP dowels compared to alternative materials at the same locations during falling weight deflectometer (FWD) testing in the spring or fall of the year when the joints are not locked up. As expected for the short performance period being evaluated, all the pavements sections were reported to be generally in very good condition at the end of the 5-year evaluation period. Only the 5-year evaluation report for the Wisconsin projects has not been received. However, laboratory test results and particularly the results of field evaluations of the HPCP projects raise concern about the long-term performance of these FRP materials. There appears to be a need for a consensus on what is considered acceptable load transfer performance for the short term (5-year evaluation period) and for the long term (30 years or longer).

Recent laboratory testing results bear out this concern about the long-term performance capabilities of FRP dowels. For example, research at Iowa State University showed lower load transfer efficiencies for 1.5-in solid FRP dowels, with the recommendation for increasing dowel size or decreasing dowel spacing (Cable and Porter 2003). The draft West Virginia University research report provides considerable information on these options based on lab testing and field evaluation studies (GangaRao 2004). The University of Manitoba study also looks at larger FRP tubes (2- or 2.5-in diameter) filled with mortar due to concerns about the performance of 1.5-in solid FRP dowels (including lower load transfer efficiencies and higher bearing stresses in the concrete at the joint face than the 1.5-in epoxy-coated mild steel dowel used as a control) (Murison 2004; Murison, Shalaby, and Mufti 2004). The recent University of Minnesota evaluation suggests looking at 2-in diameter FRP dowels to have similar performance to 1.5-in epoxy-coated mild steel dowels (Odden, Snyder, and Schultz 2003). Also, they concluded that the differential deflection at the joint (maximum of 5 mils), in addition to load transfer efficiency, is an important failure criterion. It was also recommended that the partial failure criterion of 70 percent or less LTE be tightened to 85 percent or less to allow for more useful comparisons between the details being evaluated (Popehn, Schultz, and Snyder 2003). Caution is necessary when evaluating load transfer efficiencies if the maximum deflection is very low so this factor also needs to be considered. Conversely, if the maximum deflection is very high, it indicates poor base/subbase/subgrade support which has been shown to be a significant problem particularly on some project with unstabilized permeable bases. It is suggested that these criterion be considered for this evaluation.

Recently (November 2004), the results of coring on the OH 2 project (located on U.S. 50 near Athens, Ohio, and built in 1997) have become available. The coring of the FRP materials showed no significant distress. However, the coring (4-in diameter) of the epoxy-coated dowels and the concrete-filled Type 304 stainless steel tubes or pipes showed significant distress in the adjacent concrete (although the core was not centered on the dowels). Further investigation by the Ohio DOT using 6-in diameter cores is planned to determine if the coring contributed to the distress observed . FWD data collected in both 2001 and again in 2004 was also made available. Load history data was collected but not analyzed. Appendix C contains photos of the cores taken from the U.S. 50 project in Athens, Ohio, along with the most recent FWD data.

The unexpected coring findings raise some additional questions about the long-term effectiveness of the epoxy-coated and Type 304 stainless steel dowels. HIPERPAV II may be helpful in evaluating the early age stresses on the OH 2 project which may have contributed to the delaminations in the concrete near the dowel bars. This updated version of the model used earlier information from the instrumented dowels on the OH 2 project to evaluate the expected short-term performance of jointed concrete pavement. However, it is likely that the poor support from the New Jersey unstabilized permeable base is the major cause of the distress in the concrete near the more rigid epoxy-coated steel dowels and concrete-filled Type 304L stainless steel tubes or pipe. A recent Michigan research report *Qualify Transverse Cracking in PCC from Loss of Slab-Base Contact* evaluates this factor in more detail (Hansen, Peng, and Smiley 2004).

On the Iowa project, 4-in diameter cores of the FRP dowels showed no distress (Cable and Porter 2003). Although the photo in the 2003 Final Evaluation Report appears to show cracking at the dowel bar level on core sample #9 taken at station 630+40, this was determined to be duct tape used to help determine the location of the dowel. They were able to center the cores over the dowels by using a nail taped to the dowel so the FRP dowel could be located. However, they reported that the solid stainless steel dowels could not be cored. The minimum load transfer efficiency of all dowels (including FRP) exceeded 79 percent in Iowa, which is higher than reported on projects in the three other states. Additional research in Iowa is now underway to evaluate elliptical FRP and elliptical epoxy-coated steel dowels (Cable, Porter, and Guinn 2003).

Absorptivity of the FRP composite material is another concern. Research underway at the University of California, Davis, (Bian 2003) and the Draft West Virginia University Report (Gupta 2004) is currently addressing this concern.

It should be noted that reviews of monitoring data from other HPCP projects raise similar concerns about low LTEs. For example, in the Michigan 1 project, both the European section (variably spaced 1.25-in, plastic-coated dowels) and the control section (1.25-in epoxy-coated mild steel dowels) exhibited LTEs less than 70 percent (Buch, Lyles, and Becker 2000; Weinfurter, Smiley, and Till 1994). Similarly, the KS 1 project has a number of epoxy-coated steel dowel sections with LTEs 70 percent (Wojakowski 1998). Further, a recent LTPP analysis indicated several 1.5-in epoxy-coated dowel bars exhibited LTEs of 40 percent or less (FHWA 2004a). The probable reason given for the low LTEs on the LTPP evaluation is poor consolidation, but it is also possible that this may be due to horizontal cracking of the concrete slab at the dowel bar level caused by high initial curling/warping, poor support, and/or heavy overloads. Follow-up evaluations of these sections (by others) should be performed to verify the probable cause of these poor LTEs with standard design and construction practices which have usually performed very well.

Applications of Alternative Dowel Bars

All the seven sites evaluated are new construction. Some of the accelerated testing research has been performed on rehabilitated sections including load transfer restoration by dowel bar retrofit. The original Ohio sections (part 2 of the 1998 Evaluation Plan) included evaluation of dowel specimens from full-depth patches.

Status of Field Installations

This section describes the performance of the alternative dowel bar installations that feature 1.5-in FRP, 1.5-in Type 304 solid stainless steel, 1.5-in Type 304 stainless steel clad and tubing, and 1.5-in epoxy-coated dowel bars. These installations are found in projects in Ohio, Iowa, Illinois, and Wisconsin. Table 2 summarizes all HPCP projects incorporating alternative dowel bars.

Ohio

In 1998, the Ohio Department of Transportation completed the construction of three TE-30 pavement projects, all located on U.S. 50 near Athens. One of the projects evaluates the use of alternative dowel bars, including conventional epoxy-coated steel dowel bars, type 304 stainless steel tubes filled with cement grout, and FRP composite dowel bars; several of these dowel bars were instrumented to allow investigation of dowel response under a variety of loading and environmental conditions and to compare the measured responses of different types of dowel bars (Sargand 2001).

The instrumented dowels were monitored under both environmental and dynamic loading for the first few months after paving. An analysis of the strains in the FRP composite and conventional epoxy-coated steel bars revealed the following (Sargand 2001):

Table 2. FHWA HPCP projects evaluating alternative dowel bar materials (Smith 2002a).

Project/ Location	Date Built	Type of Load Transfer Devices	Dowel Diameter
Illinois 1 I-55 SB, Williamsville	1996	Epoxy-coated dowels	38 mm (1.5 in)
Illinois 1 I-55 SB, Williamsville	1996	FRP composite dowels (*RJD Industries, Inc.*)	38 mm (1.5 in)
Illinois 2 Route 59, Naperville	1997	Epoxy-coated dowels	38 mm (1.5 in)
Illinois 2 Route 59, Naperville	1997	FRP composite dowels (*RJD Industries, Inc.*)	38 mm (1.5 in) 44 mm (1.75 in)
Illinois 2 Route 59, Naperville	1997	FRP composite dowels (*Corrosion Proof Products, Inc.*)	38 mm (1.5 in)
Illinois 2 Route 59, Naperville	1997	FRP composite dowels (*Glasforms, Inc.*)	38 mm (1.5 in)
Illinois 3 U.S. 67 WB, Jacksonville	1999	Epoxy-coated dowels	38 mm (1.5 in)
Illinois 3 U.S. 67 WB, Jacksonville	1999	FRP composite dowels (*RJD Industries, Inc.*)	38 mm (1.5 in)
Illinois 3 U.S. 67 WB, Jacksonville	1999	FRP composite dowels (*Strongwell Corporation*)	38 mm (1.5 in)
Illinois 3 U.S. 67 WB, Jacksonville	1999	FRP composite dowels (*Creative Pultrusions, Inc.*)	38 mm (1.5 in)
Illinois 3 U.S. 67 WB, Jacksonville	1999	FRP composite tubes filled with cement grout (*Concrete Systems, Inc.*)	51 mm (2 in)
Illinois 3 U.S. 67 WB, Jacksonville	1999	Type 316L stainless steel clad dowels (*Stelax Industries, Inc.*)	38 mm (1.5 in)
Illinois 4 Route 2 NB, Dixon	2000	FRP composite tubes filled with cement grout (*Concrete Systems, Inc.*)	51 mm (2 in)
Illinois 4 Route 2 NB, Dixon	2000	Type 316L stainless steel tubes filled with cement grout	38 mm (1.5 in) 44 mm (1.75 in)
Illinois 4 Route 2 NB, Dixon	2000	Type 316L stainless steel clad dowels (*Stelax Industries, Inc.*)	38 mm (1.5 in) 44 mm (1.75 in)
Iowa 2 U.S. Route 65, Des Moines	1997	Epoxy-coated dowels	38 mm (1.5 in)
Iowa 2 U.S. Route 65, Des Moines	1997	FRP composite dowels (*Hughes Brothers, Inc.*) (203- and 305-mm [8- and 12-in] spacings)	48 mm (1.88 in)
Iowa 2 U.S. Route 65, Des Moines	1997	FRP composite dowels (*RJD Industries, Inc.*) (203- and 305-mm [8- and 12-in] spacings)	38 mm (1.5 in)
Iowa 2 U.S. Route 65, Des Moines	1997	Solid stainless steel dowels (203- and 305-mm [8- and 12-in] spacings)	38 mm (1.5 in)
Kansas 1 K-96, Haven	1997	Epoxy-coated dowels	32 mm (1.25 in)
Kansas 1 K-96, Haven	1997	FRP composite tubes filled with cement grout (*Concrete Systems, Inc.*)	51 mm (2 in)
Kansas 1 K-96, Haven	1997	X-Flex™ Device (*Kansas State University*)	—
Michigan 1 I-75, Detroit	1993	Plastic-coated dowels	32 mm (1.25 in)
Michigan 1 I-75, Detroit	1993	Epoxy-coated dowels	32 mm (1.25 in)
Minnesota 1 I-35W, Richfield	2000	Epoxy-coated dowels	38 mm (1.5 in)
Minnesota 1 I-35W, Richfield	2000	Type 316L stainless steel clad dowels (*Stelax Industries, Inc.*)	38 mm (1.5 in) 44 mm (1.75 in)
Minnesota 1 I-35W, Richfield	2000	Type 316 solid stainless steel dowels (various manufacturers)	38 mm (1.5 in)
Minnesota 1 I-35W, Richfield	2000	Plastic-coated dowels (PCC shoulders only)	38 mm (1.5 in)
Minnesota 2 Mn/Road Low Volume Road Facility, Albertville	2000	Epoxy-coated dowels	25 mm (1.0 in) 32 mm (1.25 in)
Minnesota 2 Mn/Road Low Volume Road Facility, Albertville	2000	FRP composite dowels	32 mm (1.25 in) 38 mm (1.5 in)
Ohio 2 U.S. Route 50, Athens	1997/1998	Epoxy-coated dowels	38 mm (1.5 in)
Ohio 2 U.S. Route 50, Athens	1997/1998	FRP composite dowels (*RJD Industries, Inc.*)	38 mm (1.5 in)
Ohio 2 U.S. Route 50, Athens	1997/1998	Stainless steel (type 304) tubes filled with cement grout	38 mm (1.5 in)
Wisconsin 2 WI 29, Owen	1997	Epoxy-coated dowels (5 layout configurations)	38 mm (1.5 in)
Wisconsin 2 WI 29, Owen	1997	FRP composite dowels (*RJD Industries, Inc.*)	38 mm (1.5 in)
Wisconsin 2 WI 29, Owen	1997	FRP composite dowels (*Creative Pultrusions, Inc.*)	38 mm (1.5 in)
Wisconsin 2 WI 29, Owen	1997	FRP composite dowels (*Glasforms, Inc.*)	38 mm (1.5 in)
Wisconsin 2 WI 29, Owen	1997	Type 304L solid stainless steel dowels (*Avesta Sheffield, Inc.*) (2 layout configurations)	38 mm (1.5 in)
Wisconsin 2 WI 29, Owen	1997	Type 304L stainless steel tubes filled with cement grout (*Damascus Bishop Tube Company*)	38 mm (1.5 in)
Wisconsin 3 WI 29, Hatley	1997	Epoxy-coated dowels (2 configurations)	38 mm (1.5 in)
Wisconsin 3 WI 29, Hatley	1997	FRP composite dowels (*Strongwell Corporation*)	38 mm (1.5 in)
Wisconsin 3 WI 29, Hatley	1997	FRP composite dowels (*Glasforms, Inc.*)	38 mm (1.5 in)
Wisconsin 3 WI 29, Hatley	1997	FRP composite dowels (*Creative Pultrusions, Inc.*)	38 mm (1.5 in)
Wisconsin 3 WI 29, Hatley	1997	FRP composite dowels (*RJD Industries, Inc.*)	38 mm (1.5 in)
Wisconsin 3 WI 29, Hatley	1997	Type 304L solid stainless steel dowels (*Slater Steels, Inc.*)	38 mm (1.5 in)

- Environmental forces (thermal curling and/or moisture warping) produced greater bending moments in both the steel and FRP composite dowel bars than dynamic loading forces. The dynamic bending stresses induced by a 12,800-lb load were considerably less than the environmental bending stresses induced by a 5.4 ^{o}F temperature gradient.

- Significant stresses were induced by the steel dowel bars early in the life of this pavement as it cured late in the construction season under minimal temperature and thermal gradients in the slab. PCC pavements paved in the summer under more severe conditions may reveal even larger environmental stresses.

- Steel dowel bars induced greater environmental bending moments than FRP bars.

- Both types of dowel bars induced a permanent bending moment in the PCC slabs during curing, the magnitude of which is a function of bar stiffness.

- Curling and warping during the first few days after PCC placement can result in large bearing stresses being applied to the PCC around the dowels. This stress may exceed the strength of the concrete at that early age and result in socketing around the bars.

- Steel dowel bars transferred greater dynamic bending moments and vertical shear stresses across transverse joints than FRP composite bars of the same size.

LTEs on the OH 2 project in 2001 are shown in figure 1. Again, these results are for the steel and FRP composite dowels only. The stainless steel tubes were not instrumented because the thin tube thickness did not permit the machining of a flat surface for the attachment of the lead wires (Sargand 2001). The results of this instrumented dowel project have been used in the development of HIPERPAV II.

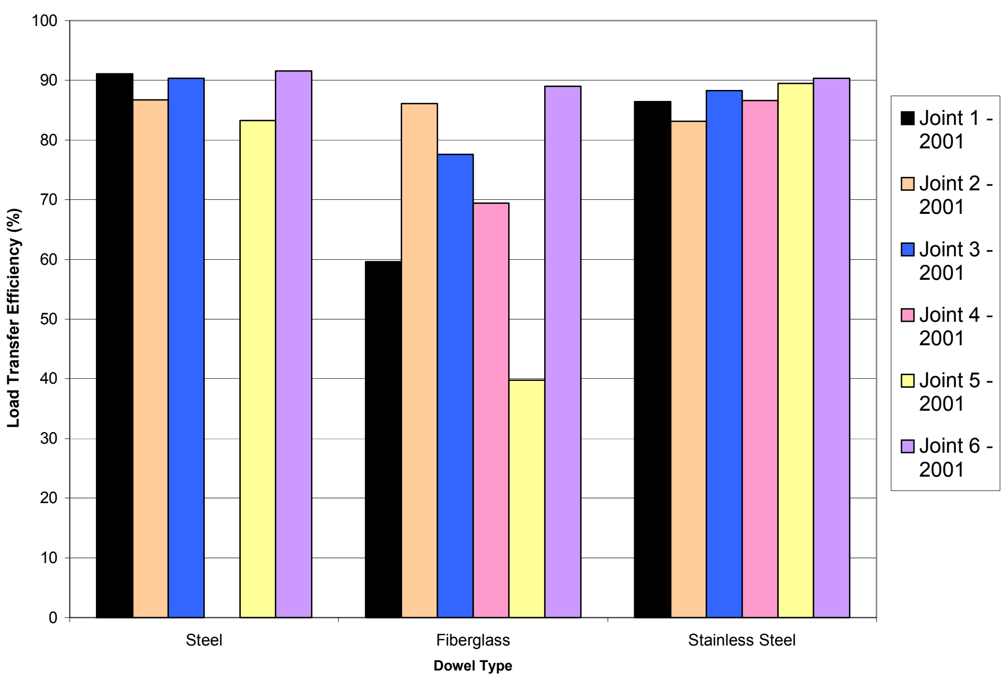

Figure 1. LTE measurements for OH 2 project.

Additional FWD testing and coring was performed on this project in 2004 (Roger Green, personal communications, November 17 and December 28, 2004). Photos of the cores and the FWD data are included in Appendix C. FWD testing in 2001 and 2004 was performed during relatively high temperatures, which significantly affects the conclusions that can be made from the data. Load history data was collected but not analyzed. The 4-in diameter cores taken of the epoxy-coated dowels and the concrete filled Type 304 stainless steel showed delaminations of the concrete at the dowel bar level. As corrosion of the stainless steel dowel at this age is unlikely, the cause of the cracking is most likely due to the high early environmental stresses noted during construction and/or the poor support provided by the New Jersey unstabilized permeable base combined with the more rigid steel dowel bar properties. Further evaluation of this issue, including additional FWD testing at lower temperatures and additional 6-in diameter cores, is planned in 2005.

Results from evaluation of removed field samples (Part 2 of the 1998 Evaluation Plan) are available in the Composites Institute Report (MDA 1999). Reviews of Dynaflect deflection data showed LTEs in the 40s for both the epoxy coated and FRP dowels during cooler weather (McCallion 1999). The reported low LTEs with good performance will require additional investigation to determine the reason for this apparent discrepancy. The different deflection equipment (FWD and Dynaflect), different testing temperatures, different testing procedures (location of the load plate, number of drops, whether load history information was gathered on the last drop), and different analysis procedures significantly compound the complexity of the analysis of the data and attempts to compare testing results.

Iowa

The Iowa Department of Transportation and Iowa State University have conducted a significant amount of dowel bar research including the evaluation of alternative materials. The following summaries and conclusions have been reached based on the data collected during the study (Cable and Porter 2003):

- All dowel materials tested are performing equally in terms of load transfer, joint movement, and faulting over the 5-year evaluation period.
- Stainless steel dowels do provide load transfer performance equal to or greater than epoxy-coated dowels in this study on the average over 5 years.
- FRP dowels of the sizes tested in this research should be spaced no greater than 8-in spacings to gain load transfer performance at the same level as epoxy-coated steel dowels at 12-in spacing.
- No deterioration due to road deicers was found on any of the dowel materials retrieved in the 2002 coring operation. (note: the Type 316L solid stainless steel dowels could not be cored).

The following items should be considered for future research in the area of alternative dowel materials (Cable and McDaniel 1998):

- Future research is needed on the methods of securing FRP dowels into basket assemblies for construction.

- Efforts must be made to reduce the cost of FRP and stainless steel solid dowels to make them cost competitive with epoxy-coated steel dowels if they are to be included in highway work.

- Laboratory work in the area of consideration of shape, spacing, and chemical composition of the FRP dowels is essential for specification development in the future.

Additionally, it was noted that the FRP tie bars floated during insertion. It appears there would be a similar problem with FRP dowels if a dowel bar inserter were used. However, this was not reported to be a problem in Wisconsin. Also, the problem of locating FRP or stainless steel dowels (in baskets or with an inserter) needs to be evaluated.

The FRP dowels had only 79 percent LTE compared to 84 percent with the solid stainless steel or 90 percent with the epoxy-coated mild steel. This appears to be a statistically significant difference. Cable and McDaniel (1998) conclude "From the test data it appears that a longer period of time (10 to 20 years) would be necessary to draw any conclusions on the relative performance of the material types."

Iowa State University prepared a report, *Assessment of Dowel Bar Research,* that summarizes dowel projects and investigations since 1990 (Porter and Guinn 2002). This information was used by the authors to identify gaps in the current knowledge base and to develop recommendations and conclusions. The authors recommended that universal testing procedures for both laboratory and field conditions first be determined so that a correct, consistent comparison between dowel bar types can be made. A standardized dowel bar testing procedure was considered vitally important.

Illinois

Illinois has four projects evaluating the use of alternative dowel bars (some in conjunction with sealed or unsealed joints). The oldest was built in 1996 on a weigh station ramp on I-55 near Williamsville; it was soon followed by a project on Route 59 near Naperville in 1997 and a project on U.S. 67 near Jacksonville in 1999 (Gawedzinski 1997). The most recent project was constructed in 2000 on Route 2 in Dixon. Dowel bar types evaluated in the various projects include FRP composite dowels, cement grout-filled FRP tubes, type 316L stainless steel clad dowels, type 316 stainless steel tubes filled with cement grout, and conventional epoxy-coated dowel bars. Consideration is being given to including elliptical steel and FRP dowels in a future project.

The Illinois DOT has been monitoring the performance of these sections, including regular measurements of load transfer efficiency. Test sites are monitored with an FWD on a monthly, semi-annual, or annual basis, depending upon test schedules. After up to 4 years of service, all of these sections were performing well (Gawedzinski 2000). The LTE data for the sections containing FRP dowels is lower and more variable than that for the section containing conventional epoxy-coated steel dowel bars.

One construction issue that arose on at least one of the Illinois projects involved the method used to secure the FRP composite bars to the dowel basket. During the construction of IL 2, it was noted that the fiber composite bars were loose and only partially attached to the upper support wire of the basket (Gawedzinski 1997). A special metal spring clip was devised to secure the dowel bars to the basket so they did not move when the PCC was placed.

The 1996 project, IL 1, included 64, 1.5-in diameter, FRP dowels in four contraction joints in an entrance ramp to I-55 from a truck weigh station. At an age of 7.5 years and over 10.1 million ESALs the joints show little damage or distress. However, initial testing in 1998 showed all FRP dowels with less than 75 percent LTEs. More frequent testing is planned at this site to evaluate the cause of the response to the FWD testing. A bituminous aggregate mixture subbase (BAM) was used.

The 1997 project, IL 2, consisted of five different FRP sections and the epoxy coated dowel bar control section. A plot of the LTE measurements is shown in figure 2. This shows that all five FRP sections had LTEs less than 85 percent soon after construction. Overall performance of the FRP joints (range 65 to 80 percent LTE after 6 years and 1.3 million ESALs) appears to be very close to the behavior of the epoxy coated steel control set (minimum of 83 percent LTE after 6 years). IL 1 and IL 2 did not have any stainless steel dowels. This project had a granular subbase.

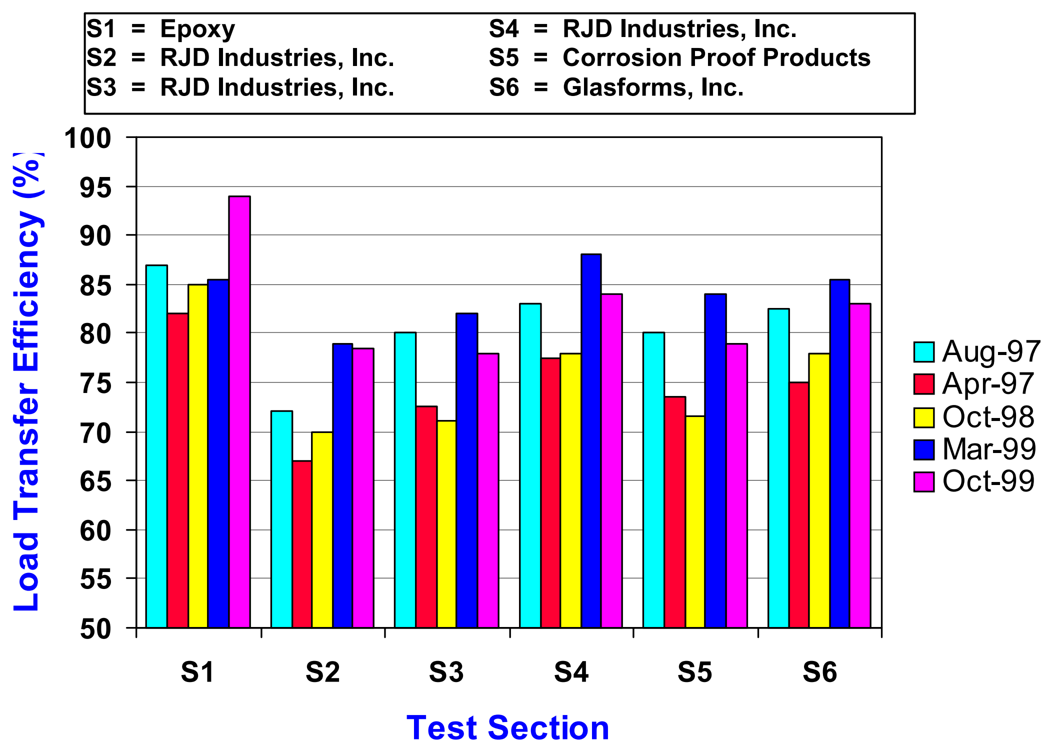

Figure 2. LTE measurements on IL 2 project (Gawedzinski 2000).

The 1999 project, IL 3, consisted of five alternative dowel sections (3 different solid 1.5-in diameter FRP composite dowels, 1 FRP tube filled with hydraulic cement grout, and 1 Type 316 stainless steel clad dowel) and two epoxy-coated steel dowel control sections, one with sealed joints and the other with unsealed joints. This project had a cement aggregate mixture subbase (CAM2 with a minimum of 200 lbs of cement per cubic yard). The control section with epoxy-coated dowels, the epoxy-coated dowel section with unsealed joints, the stainless steel clad carbon steel dowel section, and the fibrillated wound fiber composite bars exhibited better load transfer and lower joint deflections than the pultruded fiber composite bars.

The 2000 project, IL 4, included stainless steel tubes filled with cement grout, Type 316L stainless steel clad carbon steel tubes, and fiber composite tubes filled with cement grout. Two different diameters, 1.5 and 1.75 in, were used for the stainless steel tubes and for the stainless steel clad dowels. The fiber composite tubes were formed using a pultrusion process and had a diameter of 2 in. The pultrusion process produced a much smoother bar, compared to the first generation, fibrillated bars. All joints were to remain unsealed. On this project all test sections had LTEs greater than 85 percent in 2003 after only about 130,000 ESALs.

The four Illinois projects have the most extensive FWD testing data available, which should help evaluate the performance of the various alternative dowel materials in the future. Presently all four test sites appear to be performing well and as expected. No signs of spalling, faulting, or other pavement distress are visible at any of the four test sites. It is too soon to tell what effect the generally lower LTEs on the FRP composite dowel sections will have on long term performance. Proposed expansion of the study will include a test site to evaluate the performance of elliptical dowel bars, both fiber composite and carbon steel.

Wisconsin

The Wisconsin DOT constructed three experimental PCC projects under the TE-30 program, two in the summer of 1997 and one in the summer of 2002. The older projects (both located on Highway 29, one between Owen and Abbotsford and one between Hatley and Wittenberg) were constructed to evaluate the use of alternative dowel bars, alternative dowel bar spacings, and variable pavement cross sections (Crovetti 1999). The dowel bars included in the study are standard epoxy-coated steel dowel bars, type 304L solid stainless steel dowel bars, FRP composite dowel bars, and type 304L stainless steel tubes filled with cement grout. All were placed in standard dowel configurations with 12-in spacings with the exception of some of the solid stainless steel dowel bars, which were placed in configurations clustering three and four dowel bars in the wheelpath of the outer lane (Crovetti 1999).

These sections are performing well after only a few years of service. FWD testing of transverse joint load transfer has been conducted on the projects, with the results for the outer lane wheelpaths of WI 2 and WI 3 shown in figures 3 and 4. Generally speaking, the late season tests (October 1997 and November 1998) indicate significantly reduced LTE for the FRP composite dowels, although the LTE measurements in the summer do not indicate any significant differences within the test sections, probably because of the increased aggregate interlock brought about by the closing of the joints due to the warmer temperatures (Crovetti 1999, Smith 2002). The use of impact echo testing to determine dowel bar locations on WI 2 was inconclusive for the solid stainless steel dowels and the Type 304L stainless steel tubes filled with cement grout. Additional field testing was conducted in 2004 and the summary of performance is expected to be available in mid-2005. No coring of any dowels has yet been performed.

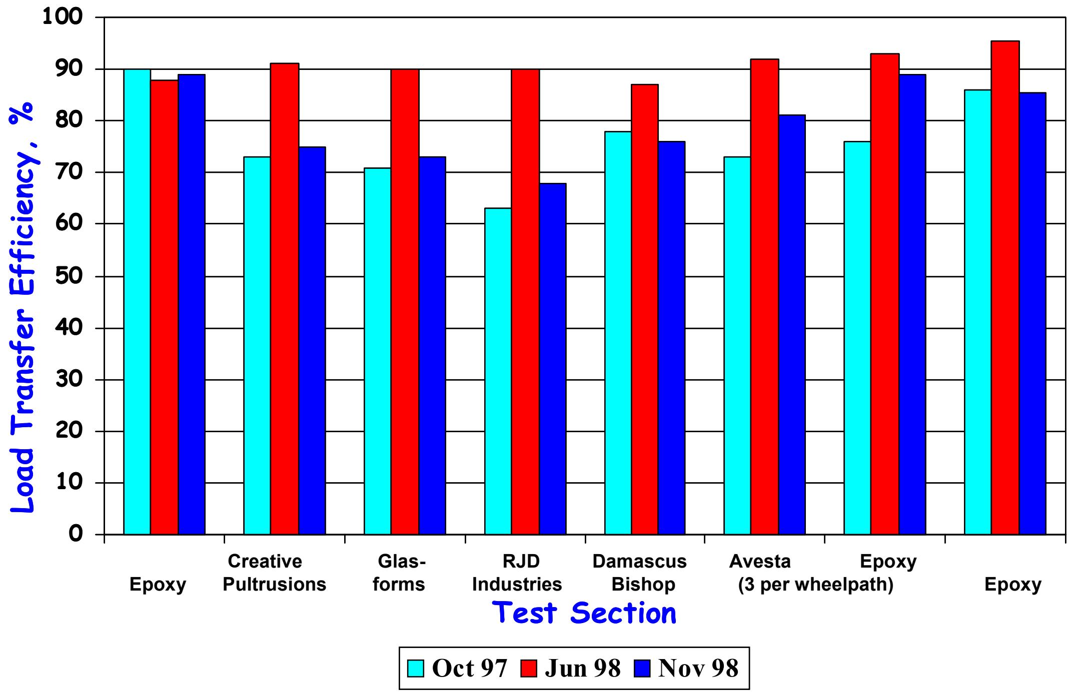

Figure 3. LTE measurements for WI 2 project (Smith 2002b).

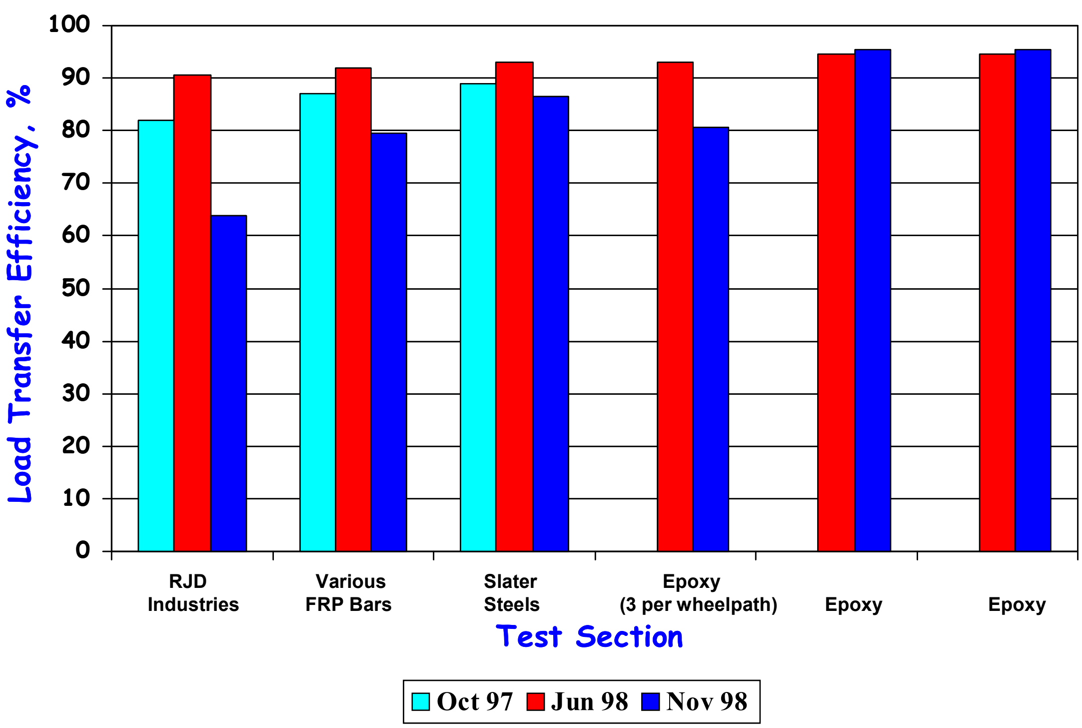

Figure 4. LTE measurements for WI 3 project (Smith 2002b).

The more recent HPCP project (WI 4) was constructed in September 2002 with a design life of 50-years (QES 2004). Dowel bars were Type 316L solid stainless steel. One problem was the flexibility of the baskets made with 0.125-in diameter wire, and as a result 0.19-in diameter wire will be specified on future projects. This project is too new to have any significant findings.

Updated Field Evaluation and Testing Plan

The 5-year evaluation reports have been received from the major focus projects in OH, IA, and IL. The 5-year evaluation report for WI 2 and WI 3 is currently being prepared and should be available in mid-2005. The updated CPTP report should also be available later in 2005. Updated information after 7 years was obtained for OH 2 (see appendix C). Based on Iowa data and the results of the follow-up OH 2 data, it appears that the evaluations should continue for at least another 5 years to make it possible to develop significant recommendations.

Based on completed Iowa State University and University of Manitoba research, the draft West Virginia University research report, the accelerated testing of alternative materials for retrofitted dowels at the University of Minnesota, and the research underway at the University of California at Davis, there appears to be little need for additional laboratory materials testing at this time. Instead, the emphasis should be on continued annual FWD testing during cool weather and on taking six (three with over 85 percent LTE and three preferably with 70 percent or less LTE), 6-in diameter cores of the various alternative dowels at the sites of interest as soon as practical. The highest priority for coring should be on the sites with the lowest LTEs and highest differential deflections. It appears a more comprehensive evaluation (by others) of the 16 HPCP alternative dowel materials projects is warranted to look at different FRP material alternatives and to examine the reason for the low LTEs of some of the epoxy-coated dowel control sections.

There would appear to be very limited value from extracting and testing three full-length dowels from each experimental site at this time for the following reasons:

- The Composites Institute evaluation of full-length, 15-year old dowels showed some deterioration of the epoxy-coated mild steel dowels (control), no deterioration of the 1-in diameter FRP dowels (other than mechanical erosion caused by excessive joint movement), and no deterioration of the Type 304 stainless steel tubes filled with cement mortar. No full length dowel samples have been taken on any of the HPCP test sections.

- A 5-year evaluation of the IA 2 project (Cable and Porter 2003) reported no deterioration. In the photos, there appears to be some delamination in the concrete near the FRP and epoxy-coated dowels: however, the visual examination of the cores revealed no cracking. Cores could not be taken of the Type 316L solid stainless steel dowels.

- There are still no standard field or laboratory testing protocols for most alternative dowel bar materials.

- There are no models available for routine use which would allow performance predictions of the alternative dowel materials (Porter and Guinn 2002; FHWA 2004b). The current U of CA-Davis study is calibrating models with an expected mid-2005 completion date.

- Additional field performance monitoring studies are considered more valuable than additional laboratory testing at this time. FWD testing (with revised testing and analysis guidelines) and limited coring of dowels at joints will provide the most useful comparative performance data. Failure criterion for joint load transfer should be developed. Note: Generally, coring of the dowels and removal of three full-length specimens for testing at the end of the 5-year evaluation period was not performed on the existing projects as proposed in the 1998 Evaluation Plan.

- Six (three with high LTEs and three with low LTEs) 6-in diameter cores of the alternative material dowels at the various test sites should be taken and the cores and alternative dowel specimens examined. FWD testing including the load history should be taken over the dowels on both the approach and leave slabs prior to coring. This is particularly critical given the photos taken (2004) of cores of epoxy-coated steel dowels and Type 304L concrete-filled stainless steel tubes from OH 2 after 7 years. Horizontal delaminations at the dowel bar level appear to be a more serious issue than socketing around the dowels at the joint face. This type of distress warrants additional investigation.

The extracting and testing of three full-length dowels from each HITEC experimental site could be done at a later date if desired. At this time, it is believed that an expanded evaluation (by others) of the HPCP alternative dowel projects would appear to be more helpful in developing application guidelines than additional laboratory testing to verify material properties.

In order to evaluate the issue of corrosion of epoxy-coated mild steel dowels (or delaminations in the concrete due to the more rigid steel dowels), it is recommended that cores be taken of some representative projects that are 15 to 30 years old. At least three cores should be taken on each project at locations with high LTEs and low differential deflections and also three cores at location with low LTEs (70 percent or less) and/or differential deflections over 5 mils. It is suggested that 10 to 12 projects in each state be evaluated. It is also suggested that the cores include the outermost dowel in the truck lane, one dowel in the wheel path, and one dowel between the wheel paths. This is a critical issue when determining whether the provision of more corrosion resistant dowels or materials less rigid than large diameter mild steel dowels is likely to be cost effective. FWD testing over each of the dowels on both the leave and approach slabs should be conducted before coring so the reason for low LTEs can be evaluated. The full load history on the last drop at each location is recommended to aid the evaluation.

It currently appears unlikely than an interim guide on the use of alternative dowel bar materials can be developed and included in the HITEC Final Report. This is too complex an issue with too little performance data currently available to make long term performance predictions. However, with an extended evaluation period for all the projects included in the HPCP program and the evaluation of other research recently completed or underway, this should be possible at the end of the 10-year evaluation period.

Summary and Recommendations

The Final Report for this effort should provide specific recommendations for monitoring the HPCP alternative dowel bar material projects for another 5 years. In addition, a summary of testing results (and detailed test procedures) to date should be included. It also appears that a reanalysis of available FWD data should be performed to determine if and how the deflection and load transfer efficiency data can be used to provide better design and material selection criteria for both new construction and rehabilitation/pavement preservation projects. In particular, the load history should be evaluated to see if it can explain the cause of the low load transfer efficiencies on many of the projects.

Specific recommendations are as follows:

1. States should be encouraged to take 6-in diameter cores of 10 to 12 representative projects ranging between 15 and 30 years of age and constructed with epoxy-coated mild steel dowels to verify the probable effect of corrosion (and the frequency of occurrence of horizontal delaminations in the concrete at the dowel bar level) on long-term concrete pavement performance in their State so cost effectiveness can be better evaluated. FWD testing should be performed to select the dowels to be cored and to aid the analysis of any distresses observed during examination of the cores.

2. States should consider monitoring the HPCP alternative dowel projects for a minimum of 10 years. It appears that at least this length of time is needed to develop and verify performance prediction models which can incorporate the effect of different material types, sizes, and spacing. Coring (6-in diameter) of representative alternative dowel bar materials should be given high priority. FWD testing (including the load history) over the selected dowels on both the approach and leave side of the joints should be conducted prior to coring to help evaluate the reason for the low LTEs.

3. Failure criterion for evaluating field performance of alternative dowel materials should be developed. Most current studies report satisfactory performance although some transverse joint load transfer efficiencies are 70 percent or less in 5 years or less. To provide useful comparative information, the FWD testing must be done at lower temperatures when the joints are not locked up. It is suggested that the failure criterion for projects with up to 5 years of performance data include: transverse joint load transfer efficiencies of 85 percent or less and/or differential deflections at the joints of more than 5 mils. In addition, the maximum deflection ,which is indicative of joint base/subbase/subgrade support, should also be included for information and possible use. It is suggested that a maximum normalized deflection under a 9,000 pound load of 10 mils be considered as evidence of poor base support at the joint. Once the failure criterion is developed, the expected performance of the various projects should be re-evaluated.

4. The high cost of solid FRP or stainless steel dowels is a major obstacle to their more widespread use. Additional evaluation of other less expensive alternatives, such as mortar-filled tubes, should be considered. However, it is expected that PCC pavements with expected lives of 40 to 60 years can be constructed for an additional cost of 3 to 5 percent which is very reasonable. It has been reported that there is a problem with availability of capacity to fill FRP or stainless steel tubes with mortar. Also, there are not sufficient quantities of stainless steel clad mild steel dowel bars available for more widespread use. These problems must be addressed if these lower cost alternative materials prove to provide satisfactory long-term performance.

5. Constructibility issues of fastening dowels to baskets or verifying accurate placement by either baskets or dowel bar inserters must be addressed. The MIT Scan 2 device is reported to work well for verifying placement of epoxy-coated dowels but has not demonstrated the ability to verify placement with the alternative dowel bar materials being evaluated.

6. Based on the field monitoring data available, it appears that the 1.5-in diameter FRP dowels being evaluated will not provide satisfactory long-term performance. Alternative material combinations, closer spacing, and/or larger sizes appear to be required and should be evaluated.

7. A more comprehensive study of the cause of the low joint load transfer efficiency of epoxy coated dowels on the HPCP and LTPP projects should be undertaken. The epoxy coated dowel control sections on this more limited HITEC evaluation generally have minimum load transfer efficiencies greater than 85 percent and with differential deflections less than 5 mils which is the proposed failure criterion for this study.

8. The annotated bibliography should be updated to reflect the most recent alternative dowel bar materials research including accelerated pavement testing studies in the field or in the laboratory.

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Appendix A

HITEC Evaluation Plan for

Fiber Reinforced Polymer Composite Dowel Bars

and

Stainless Steel Dowel Bars

Final Version
May 8, 1998

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	David Graves, New York Department of Transportation
	Roger Green, Ohio Department of Transportation
	Joseph Hannon, California Department of Transportation
	Roger Larson, Federal Highway Administration
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ABSTRACT

This plan has been prepared at the request of two Highway Innovative Technology Evaluation Center (HITEC) applicants. It documents a procedure developed to provide an objective evaluation of Fiber Reinforced Polymer (FRP) Composite Dowel Bars and Stainless Steel Dowel Bars.

These products are used to transfer loads across sawed or formed transverse joints from one concrete pavement slab to another. Presently, steel dowel bars with various coatings are used to transfer these loads, but as they age corrosion problems have become evident causing joint problems. The products under consideration in this HITEC evaluation are intended to have similar load transfer characteristics without the corrosion problems. The conventional epoxy-coated mild steel dowel will serve as the control for this study.

The goal of this evaluation is to provide potential users (material, structural, highway, and construction engineers, etc.) with objective design, material, construction, and performance information needed to make an informed assessment of these systems for particular engineering applications.

During execution of this plan existing field installations will be inspected, removed, and tested; laboratory testing will be completed; and new dowel bars will be installed and monitored for a time period of up to five years.

The overall evaluation, including field activity, will take place over a five to six year period.

1.0 INTRODUCTION

1.1 HITEC Mission and Process

The Highway Innovative Technology Evaluation Center was established by the Civil Engineering Research Foundation through a grant from the Federal Highway Administration to encourage and expedite the introduction of new innovative technologies to the highway program, particularly from the private sector and the entrepreneur who might not otherwise seek to penetrate the diverse and difficult highway market.

Applications for evaluation of technologies are screened for suitability by HITEC and, if accepted, Panels are formed to design and monitor the implementation of an evaluation plan to assess the performance of the technology in its highway application. The objective of the evaluation is to provide potential users of an applicant's technology with sufficiently-comprehensive information to permit them to make at least preliminary decisions about including the technology in their programs.

1.2 Alternative Materials for Dowel Bars in Concrete Pavement Joints

The use of steel dowel bars to transfer loads across sawed or formed transverse joints from one concrete pavement slab to another while permitting expansion and contraction movements of the concrete, has been a basic design practice in most U. S. state departments of transportation for many decades.

As the U. S. highway system ages, however, doweled pavement joints have shown many problems. (1) A common problem is the corrosion of the steel dowels which causes the bars to be "frozen" into place in the surrounding concrete, thus "locking" the joint and transferring the slab movement stresses to the concrete where cracking and spalling and eventually joint faulting may occur producing an unsatisfactory serviceability level for the pavement.

To address the corrosion problem, experimentation has been performed in the field and laboratory using various coatings, from asphalt cement to epoxy resins, applied to the steel dowels. Also, alternative materials have been used to manufacture dowels that are corrosion resistant in the concrete matrix. While the resistance to corrosion for some alternative materials has been well documented in laboratory examinations, other performance characteristics affecting service life remain to be fully evaluated, particularly in representative field installations and over meaningful time periods.

With the foregoing common objective, two applicants offering different alternative dowel materials separately requested evaluation but agreed to participate concurrently in a joint program of field installations, laboratory tests, observations and evaluations.

1.3 Products to be Evaluated

1.3.1 Epoxy-Coated Mild Steel Dowels

Epoxy-coated mild steel dowels are the standard of practice for concrete pavement joints for most departments of transportation today. As such, they will be used as the "control" material against which the alternative materials will be evaluated in this experiment. Samples of epoxy-coated mild steel dowels will be tested and included as the control in all laboratory and field tests delineated in the following experiment plan for evaluation of Fiber Reinforced Polymer (FRP) and Stainless Steel dowels.

1.3.2 Fiber Reinforced Polymer (FRP) Composite Dowel Rods

The Composites Institute, New York, New York, made application to HITEC for the evaluation of "*a new generation of FRP composite dowel rods and installation methods for new construction and repair of concrete highways."* The FRP Composites are defined by the Composites Institute as: " A matrix of polymeric material that is reinforced by fibers or other reinforcing material." FRP composite constituents include resins (polymers), fiber reinforcements, fillers, and additives.

The Composites Institute (CI) is the largest division of the Society of the Plastics Industry, Inc.(SPI). The CI trade association is the collective and leading voice of the composites industry, with more than 375 member companies. Formed in 1945, CI continues to be the foremost association supporting the use of composites in construction and civil infrastructure. The Market Development Alliance (MDA) consists of broad-based CI membership representing suppliers, fabricators, processors, and consultants of the composites industry. It acts as the coordinating body for CI's generic pre-competitive market development activities, including development and commercialization of new composites and application for the civil infrastructure. The MDA has focused committees on marine/waterfront piling system, structural shapes, concrete repair, FRP composite bridges, and the newly formed Composite Dowel Bar Team. There are a number of FRP projects underway in fields related to highways and structures, including:

- an Army Pier restoration in Oakland, California
- a cable stayed suspension foot bridge in Perthshire, Scotland
- a repaired I-95 prestressed concrete bridge beam in West Palm Beach, Florida
- polymer concrete parapet panels used on the Pennsylvania Turnpike and Allegheny Bridge, and
- a composite wrap to repair structural columns on FDR Drive in New York City.

The FRP Composite Dowel Bar Project is the newest focus of the MDA with 17 members committed and four or five others expected to participate in its support.

1.3.3 Stainless Steel (ASTM T304) Dowel Bars

An additional application for evaluation was made by the Specialty Steel Industry of North America for the evaluation of *"Stainless Steel (ASTM T304) dowel bars as load transfer devices in concrete highway joints."*

Stainless Steel is a corrosion-resistant material due to the presence of chromium and other alloying elements that create an impenetrable barrier to oxidation. The composition of Stainless Steel can be controlled to provide corrosion resistance in different environments. T304 is designed to resist corroding in high chloride-bearing concretes such as coastal areas or where there is extensive use of de-icing salts during winter snow storms.

Stainless Steel bars can be fabricated as:

- solid bars of full-section Stainless Steel,
- stainless clad bars with a core of mild steel or other material and a bonded Stainless Steel outer layer,
- Stainless Steel hollow pipes, and
- Stainless Steel pipes, filled with concrete or other materials.

While Stainless Steel has been in commercial use since the 1920s, initial costs have deterred its use in highway applications until more recent recognition of the importance of life-cycle costs and extended service life. Current highway projects and field programs reflecting a renewed interest in Stainless Steel include:

- a Michigan DOT bridge deck (built in 1984) using Stainless Steel reinforcing bars for one-half and epoxy-coated steel for the other,
- a New Jersey bridge deck (1984) using stainless-clad reinforcing bars,
- Stainless Steel dowel bars on Maryland Highway 97 in the late 1980s,
- adoption of Stainless Steel specifications for concrete reinforcing bars by the British Standards Institute, and
- Stainless Steel reinforcing projects planned by the Oregon DOT, the New Jersey Turnpike Authority, and the Ontario Ministry of Transport.

2.0 SCOPE OF EVALUATION

2.1 Performance Issues

Applications to be considered in the field evaluations include the use of the alternative dowel bars in two types of joints.

2.1.1 Transverse contraction joints in concrete pavements

Pavement joints are constructed in new pavements to accommodate one or more of several movements. While the new concrete is curing, the hydration process causes the pavement mass to contract or shrink and the presence of transverse contraction joints at strategic longitudinal intervals, generally 12 to 20 foot, prevents the development of random cracks in the slab. Cured and mature pavement slabs respond to changes in ambient temperature and radiant heat from the sun by expanding and contracting. These movements are accommodated in part by the doweled joints where at least one end of each of the embedded dowel bars is treated with a debonding agent and is free to slide longitudinally within the concrete.

Problems occur when the mild steel dowels corrode. The oxidized surface of the dowel expands and locks the dowel into the surrounding concrete, thus transferring any longitudinal movement stresses to the concrete which fails in tension or shear. The failure process, once begun, is progressive as the cracked concrete admits moisture, the corrosion of the dowels increases, the concrete disintegrates further, and the joint weakens and eventually faults. In current practice, mild steel dowels are usually epoxy coated to prevent or reduce corrosion.

2.1.2 Transverse expansion joints in concrete pavements

Adjacent to structures and at other strategic locations where pressure from adjacent pavement slabs could be highly damaging, expansion joints are constructed with a full-depth formed opening width of up to 7.5 centimeters or 3 inches, filled with a preformed compressible material. The dowels in expansion joints are fitted with hollow caps to provide a recess into which they can slide as the expansion joint closes. The primary functional difference between contraction and expansion joints is the need for the dowel to span a greater space between slabs for load transfer when an expansion joint is open.

The same failure mechanism occurs in expansion joints as in contraction joints. Corroded and locked dowels may transfer compressive stresses to the concrete which may result in crushing or shear failures at the joint or damage to adjacent structures or facilities.

2.1.3 Positioning dowels

Methods used in positioning the dowels in field installations in new concrete pavement construction include the use of wire baskets to position dowel bars or the use of mechanical inserters. Regardless of the placement method, a critical consideration is the accuracy of the dowel position in the joint. The dowel must be aligned horizontally with the centerline of the pavement, vertically with the longitudinal profile of the pavement, at an elevation that is mid-point in the pavement slab thickness, and approximately centered longitudinally on the sawed or formed joint opening. Where pavement joints are skewed rather than perpendicular to the pavement centerline, the positioning of the dowels must remain parallel to the centerline and profile. In any of the alignment requirements, a misaligned dowel can "lock" the joint and transfer stresses to the concrete just as a corroded dowel may do.

Quality control in the construction of joints requires the ability to verify the accuracy of the dowel placement in the finished concrete matrix. Ground penetrating radar (GPR) is the most promising non-destructive technology for this process but its applicability for FRP bars is still unproven and its effectiveness may be diminished in wet, uncured concrete. The use of taggants may be required for the detection of FRP bars by the GPR or by other metal-detecting devices.

2.2 Overview of Evaluation Plan

The evaluation plan is designed to limit the variables to the dowel materials and to limit the materials to a selected few offered by the applicant materials industries.

The dowels from the Composites Institute to be evaluated will be glass-fiber reinforced polymer (FRP), meeting approximately the performance specifications for mild steel dowels except in the bending modulus. Dowels will be approximately 18 inches in length and 1.5 inches minimum diameter.

Dowels from the Specialty Steel Industry of North America, will be T304 Stainless Steel solid or hollow pipe filled with concrete or other materials. Dowels will be approximately 18 inches in length and 1.5 inches in diameter.

Conventional epoxy-coated mild steel dowels will serve as the control for this study.

The Evaluation Plan will consist of three parts as described in the following sections.

2.2.1 Literature Review

Valuable testing work has been done on non-corrosive dowel bars by the Engineering Research Institute at the Iowa State University and by the Federal Highway Administration. Highway structures have been constructed in the U. S., Canada, and overseas using alternative materials for concrete reinforcement and/or for structural members. Experimental projects using non-corrosive dowel bars in concrete pavements have been completed in Illinois, Connecticut, Wisconsin, Ohio and Arkansas. The Ohio Department of Transportation has accepted the FRP dowel bars as an alternative to epoxy coated steel for the repair of doweled joints. The records and reports of these laboratory and field activities and others will be reviewed, synthesized and incorporated in the evaluation report. (See the brief Bibliography at the end of this plan report.)

Environmental issues will be addressed to determine if there is documentation in the literature or manufacturer's records that the dowels are free from hazardous materials in the manufacturing process or product. Information on the potential for recycling of used bars or by-products of the manufacturing process will be sought also.

2.2.2 Field Installations

The principle thrust of the HITEC evaluation will be in the observation and testing of field installations completed or planned by various state departments of transportation. Construction of new or rehabilitated concrete pavements with joints using alternative materials for dowels has been completed in some participating highway agencies and others are planned for the next construction season. Five states, Illinois, Iowa, Kansas, Ohio, and Wisconsin will participate in these field installations under the FHWA initiative, *TE-30, High Performance Rigid Pavements (HPRP).*

The participating states, in some cases, also may conduct additional experiments with other alternative materials and designs under TE-30, but the HITEC program will be confined to the evaluation of FRP and Stainless Steel dowels installed in standard joint designs using bond-breakers as recommended by the manufacturers providing the dowels.

Initial monitoring of the HITEC test sections will be performed by the highway agency immediately upon completion and curing of the installations and at six month intervals for the first 18 months of service life. Annual monitoring by the highway agency will continue thereafter, for a total period of five years. In addition to pavement condition observations using the Strategic Highway Research Program (SHRP) protocol, load transfer will be measured using falling weight deflectometers (FWD) and verification of dowel positions will be determined using NDT methods such as ground penetrating radar (GPR). If these methods prove to be inadequate, cores may be required to determine dowel bar positions and orientation in the experiment installations.

A second and concurrent part of the field installation program will be the joint condition assessment, deflection testing, and the coring of "old" FRP and Stainless dowels from concrete pavement joint repair installations made in Ohio in 1985 on I-77 in Guernsey County, and FRP dowels installed in 1983 in Ohio on

State Route 7 in Belmont County. Cores and full-length dowels to be cut from the Ohio pavements will be used in the laboratory investigations.

The third and final part of the field program will be the removal and laboratory evaluation, at the conclusion of the five-year observation period, of sample cores and full-length dowels from the alternative materials dowel joints placed as a part of this experiment.

2.2.3 Laboratory Investigations

On laboratory samples of the dowel bars and laboratory concrete castings, tests will be conducted on dowel fatigue, dowel debonding or pull out stress, dowel durability and load transfer capability using dowel shear tests. The laboratory shall design and propose fatigue testing subject to the approval of the Panel. The 1983 and 1985 Ohio section cores and dowels and those taken from the experiment sections at the end of five years, will be inspected and tested for all forms of degradation and performance as outlined in the following evaluation plan.

3.0 EVALUATION PLAN

3.1 Objectives

The objectives of the evaluation are:

- To assess the constructability, placement verification, environmental qualities and performance capabilities of Fiber Reinforced Polymer dowels and Stainless Steel dowels to perform the load transfer and joint movement requirements in concrete pavement joints for the full service life of the pavement without detrimental corrosion or deterioration; and
- To consider the comparative performance and service-life costs of these alternative materials and epoxy-coated mild steel for use in dowel bars.

3.2 Field Installations

Dowels will be supplied by the applicants for the field and laboratory tests in compliance with the state specifications for dowel dimensions and installation methods in each of the participating state departments of transportation. The sponsoring agencies are encouraged to select project sites so that different types of joints are constructed (i.e. expansion, contraction, and/or repair).

Dowel installations will be designed to meet standard size, positioning, and joint design requirements for epoxy-coated mild steel doweled joints so that the performance data will reflect the alternative dowel materials, not alternative joint designs. Epoxy-coated mild steel doweled joints will also serve as the control for all comparisons.

The field installations to be made in the participating states will include the use of FRP and/or Stainless Steel dowels meeting the minimum dimensions of 18 inches in length and 1.5 inches in diameter. Installations will be by baskets or by inserters as defined by project specifications for joint construction in each state. The planned installations are delineated in *Table 1, Summary of Plan Schedule, Sites, and Tests for Field Program.*

In addition, previous installations of FRP Dowels will be extracted and tested per the testing program described below. At a minimum, the dowels from the Ohio projects shall be removed. Dowels from other previous installations may also be added to the evaluation.

Information to be recorded for each field installation project will include the following:

3.2.1 Design data

- Location: route and milepost or section.
- New construction, or rehabilitation.
- Design traffic: ESALS
- Roadway location: tangent, curve, grade, cut/fill.
- Type of joint: contraction, expansion.
- Joint design: position, spacing, sealant used (if any).
- Dowel: size, material (manufacturer's specifications), debonding agent.

- Dowel basket or insertion details and specifications.
- Pavement design: subgrade soil, subbase, base, slab thickness, mix design, reinforcement.

3.2.2 Construction Data

- Manufacturer of dowels.
- Date and weather conditions during construction.
- As-built pavement, joint design, and concrete strength data.
- Base and subbase classifications and conditions
- Materials, equipment, and labor costs for the joint(s) construction (if available).
- Observations regarding the constructability, ease of handling, quality control, and other dowel-related factors.
- Dowel placement verification using Ground Penetrating Radar (GPR) or other method to determine dowels positions in constructed joints.

3.2.3 Performance Data

Immediately before opening to traffic, at six-month intervals over the first 18 months, and annually for the remainder of the 5-year period:

- FWD measurements of load transfer.
- Faulting measurements.
- Joint condition (spalling, cracking, crushing, etc.,) observations using the SHRP protocol
- Joint sealant condition.
- Pavement roughness (Mays Number, IRI, or other, but preferably IRI)

3.2.4 Operations Data, Annual

- Weather data: temperature range, freeze-thaw cycles.
- Traffic data and axle loading estimates developed and accumulated throughout the observation period.
- Joint sealing practices, materials and cleaning-resealing frequency.
- Snow and ice control practices, salt and abrasive applications and frequency during observation period.

3.3 Laboratory Evaluations

A series of tests and analyses, listed in *Table 2, Test Specifications for FRP and Stainless Steel Dowels*, will be performed in one or more laboratories (selected by HITEC with the advice of the Panel) to supplement the field investigations and to permit accelerated loadings and exposure through simulations of field conditions. Three types of laboratory information will be used in the evaluation:

1) Laboratory samples and castings of fabricated specimens using new, original tests,
2) Cores and full length dowels of each material type taken from the field test sites and subjected to laboratory examination and performance testing,

3) Manufacturer's and other accredited laboratory tests and analyses of dowel bar physical properties, and manufacturer's certification that dowel materials, manufacturing processes, and products meet all current Federal environmental requirements.

3.3.1 Laboratory Tests

The following tests will be performed in selected laboratories using the FRP dowels and the Stainless Steel dowels supplied by the manufacturers.

Where accredited laboratories have already performed the specified tests on sample dowels that meet the same identical specification as the dowels provided for field installations, the HITEC Panel may waive the repetition of those tests and incorporate the already available test data in the evaluation.

In any event, the dowels tested in the laboratory for this evaluation must be identical to those provided for the field evaluation program. In general, the laboratory portion of the evaluation plan includes the following items:

- Physical property test data (to be furnished by applicants),
- Durability test data,
- Fatigue testing to simulate repeated truck loading,
- Elemental isopescu shear strength test,
- Debonding and pullout tests,
- Limited durability tests of full-length cut outs of: (a) previously-installed dowel bars (Ohio), and (b) the five-year experimental joints, and
- Correlation of laboratory specimens with field measurements and behavior.

Each of the laboratory tests are shown in Table 2 and described in the following sections.

3.3.1.1 Physical Property Tests

The material properties of modulus of elasticity, tensile strength, coefficient of thermal expansion, porosity and elongation characteristics should be determined by the Applicants for the alternative material dowels (in accredited laboratories) and reported to the Evaluation Panel for each type of dowel bar to be evaluated in the field and laboratory program.

3.3.1.2 Elemental Isopescu Shear Strength Tests

Elemental tests will be used to determine the shear strengths of the dowel bars of the alternative materials. These tests use full-size dowel bars embedded in blocks of concrete and subjected to pure shear isolated from moments and other forces.

The tests provide a means of determining the shear strength of the dowel. In addition, the tests provide a means of determining the informal contact modulus properties for a more theoretical determination of the force distribution along the dowel length. Three tests of each alternative material should be performed.

3.3.1.3 Debonding and Pullout Tests

Since dowel bars are not designed to be subjected to axial forces and are designed to slip in the pavement joints, the dowels must not bond with the concrete in the joint. Pull-out (debonding) tests with and without bond breakers are needed to show that the alternative material dowel bars pull out freely from the concrete. The surface roughness, dowel bar materials, and the concrete material properties should be varied for tests through the range of conditions expected in highway pavement joints. A standard pullout test is indicated in Table 2. However, the test configuration or size of specimen should be large enough so as to not allow the resisting load to be located close to the zone of influence of the pullout (bond) forces of the dowel bar. Three tests of each material and parameter should be performed.

3.3.1.4 Durability Tests

Durability tests are needed for each selected alternative material dowel bar and previously installed dowel bars. Since corrosion is a potential problem of mild steel dowel bars, the alternative materials should be investigated for possible degradation due to corrosive environments.

Potential deleterious environmental conditions may cause different reactions for different alternative materials. Corrosive chloride ions and acids may affect Stainless Steel, where high alkalinity moisture conditions may affect FRP materials. Each of these potential degrading conditions needs to be tested in the laboratory using the Owens Corning test protocol described in the Appendix. The tests should include submersed specimens in a bath, followed by shear strength tests to measure any potential decline of the dowel bars performance. Three specimens should be tested for each selected environmental condition for each alternative material.

3.3.1.5 Testing of Previously-Installed Dowel Bars

Full-length dowels for each material cut out of the 1980s installations in Ohio sections and the five-year-old experiment sections installed under the HITEC program should be subjected to the durability tests. Other installations as deemed appropriate may also be removed. Dowel bars that were installed in Ohio in 1985-86 and at the end of five years in each of the cooperating states, dowel bars on the experiment sections will be removed following pavement condition surveys by coring three sections of each alternative dowel material for observation and limited durability tests. In addition, three full-length dowels of each alternative material will be cut out. The departments of transportation will perform the coring. Cutting out the full-length dowels will be arranged by HITEC in coordination with the departments. The dowels will be subjected to flexural bend strength tests and compared to original (new) dowel strength values. The dowels will be observed for signs of deterioration due to the loads and environment. Also, durability tests will be performed.

4.0 REPORTING

4.1 Laboratory-Field Coordination

The field and laboratory data will be recorded by the participating state agencies (under FHWA TE-30) and selected laboratories (under HITEC contracts) and collected by a HITEC representative on a quarterly basis for further analysis by the Evaluation Panel and publication as warranted.

The HITEC effort is intended to augment and compliment the individual state evaluation projects and the FHWA initiative, while striving to establish consistency in data collection and reporting systems wherever possible.

In order to provide meaningful correlation of the field and laboratory tests described in the foregoing sections, a coordination consultant will be retained by HITEC to represent the Panel and work with the participating agencies and laboratories by visiting each of the laboratories and field test sites, obtaining samples of the products used in each of the sites, coordinating the testing of the field and lab samples, assembling the tabulation of data, assisting the Panel in performing independent analyses of the laboratory and field test results, and participating in the preparation of reports of the results obtained from the laboratory and field determinations.

4.2 Reports

A quarterly progress report will be issued to update all parties involved until the completion of the HITEC evaluation.

A stand-alone report will be published by HITEC at the conclusion of the initial 18 month observation period and a final complete report will be published following the end of a five year monitoring period. The 18 month report will cover:

- Experiment design and construction data
- Dowel placement verification
- Field construction observations
- Initial load transfer performance
- Initial joint condition observations
- All completed laboratory analyses.

The five year complete report will cover:

- An executive summary of the 18 month report
- Joint condition and dowel performance data for the full five year period
- All laboratory test results and analyses
- An analysis of potential life cycle costs for the alternative dowel materials, as compared to epoxy-coated mild steel dowels.

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Table 1
Summary of Plan, Schedule, Sites and Tests for Field Program
FRP and Stainless Steel Dowel HITEC Evaluation
March 26, 1999

Location	Timing	Materials	Sites/Sizes	Tests/ Observations
ILLINOIS	1997	FRP	5 sections: 1@450' 2@225'; 2@150'	Construction costs & features FWD load transfer Faulting
	1998	Stainless & FRP	7 Sections 5 @ 150' 2 @ 450'	Dowel position check Concrete cracks & spalls Traffic loading data
IOWA	1997	Stainless & FRP	FRP- 4 sections: 2 @450'; 2 @ 100' Stainless- 2 sections 1 @ 220'; 1 @ 520'	Construction costs & features FWD load transfer Faulting Dowel position check Concrete cracks & spalls Traffic loading data
KANSAS	10/01/97	FRP	106 joints constructed over a length of 1600' 24 joints were FRP	Construction costs & features FWD load transfer Faulting Dowel position check Concrete cracks & spalls Traffic loading data
OHIO	10/16/97	Stainless & FRP	6 joints, ea mat'l	Construction features FWD load transfer
	Spring '98	Stainless & FRP	6 joints, ea mat'l	Faulting Dowel position check Concrete cracks & spalls Traffic loading data
	Fall '97	Stainless & FRP	1983 & 1985 Installations	FWD tests at joints GPR dowel position verification Inspection of joint conditions

				Core 3 dowels, each mat'l and cutout 3 full dowels, each mat'l at each site
WISCONSIN	Fall '97	Stainless & FRP	2 Sections @ 600' ea with chairs for placement	Construction costs & features FWD load transfer Faulting GPR dowel position check Concrete cracks & spalls Traffic loading data
	Fall '97	Stainless & FRP	2 @ 4000' ea with DBI for placement	Construction costs & features FWD load transfer Faulting GPR dowel position check Concrete cracks & spalls Traffic loading data
Each Experiment Section	After 5 years	Stainless & FRP	As installed	FWD tests at joints Inspection of joint conditions Core 3 dowels, each mat'l Cutout 3 full dowels, each mat'l at each site

Note: Epoxy-coated mild steel dowels will serve as the control on all projects.

Table 2

Tests Specifications for FRP and Stainless Steel Dowels
FRP and Stainless Steel Dowel HITEC Evaluation
March 26, 1999

Type of Test	Specifications/Standards	Number of Specimens	Notes
TESTS PERFORMED ON NEW FRP BARS			
Elasticity	Elasticity can be obtained from tensile strength tests below	Open	Data to be furnished by the suppliers.
Thermal Expansion	ASTM D696/D3386	Open	Data to be furnished by the suppliers.
Longitudinal			
Transverse			
Tensile Strength	ASTM D3916/D638	Open	Data to be furnished by the suppliers.
Porosity	ASTM D570	Open	Data to be furnished by the suppliers.
Shear	ASTM D4255/D4255M	Open	Data to be furnished by the suppliers.
Elemental Isopescu Shear	ASTM D2344	3 per material	
Pull-Out	AASHTO T253 & ASTM A775	3 per material	
Durability & Fatigue	Owens Corning Protocol (modifying ASTM D4255/D4255M and ASTM D4476)	3 per material	See Appendix for most recent version.
Flexural	ASTM D790	3 per material	

Appendix B—HITEC Panel List
Dowel Bar Pavement Joints
9/29/03

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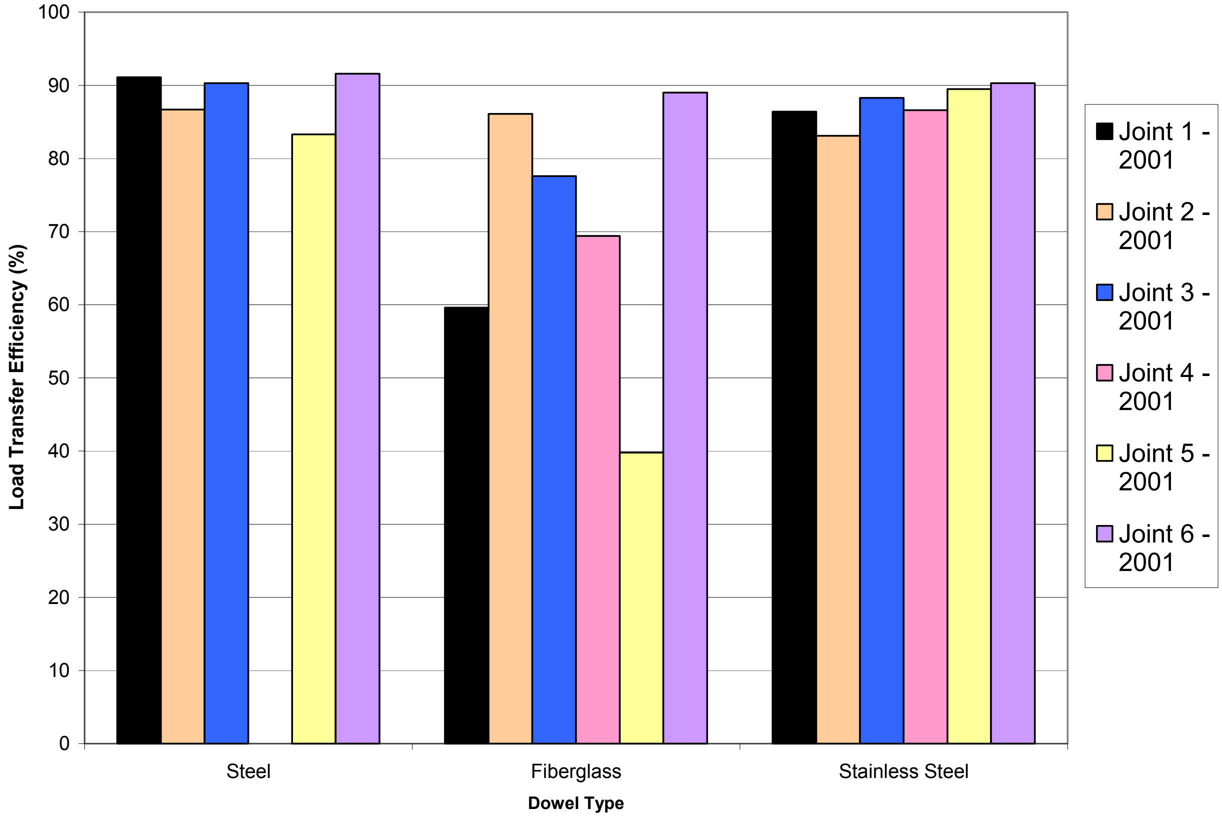
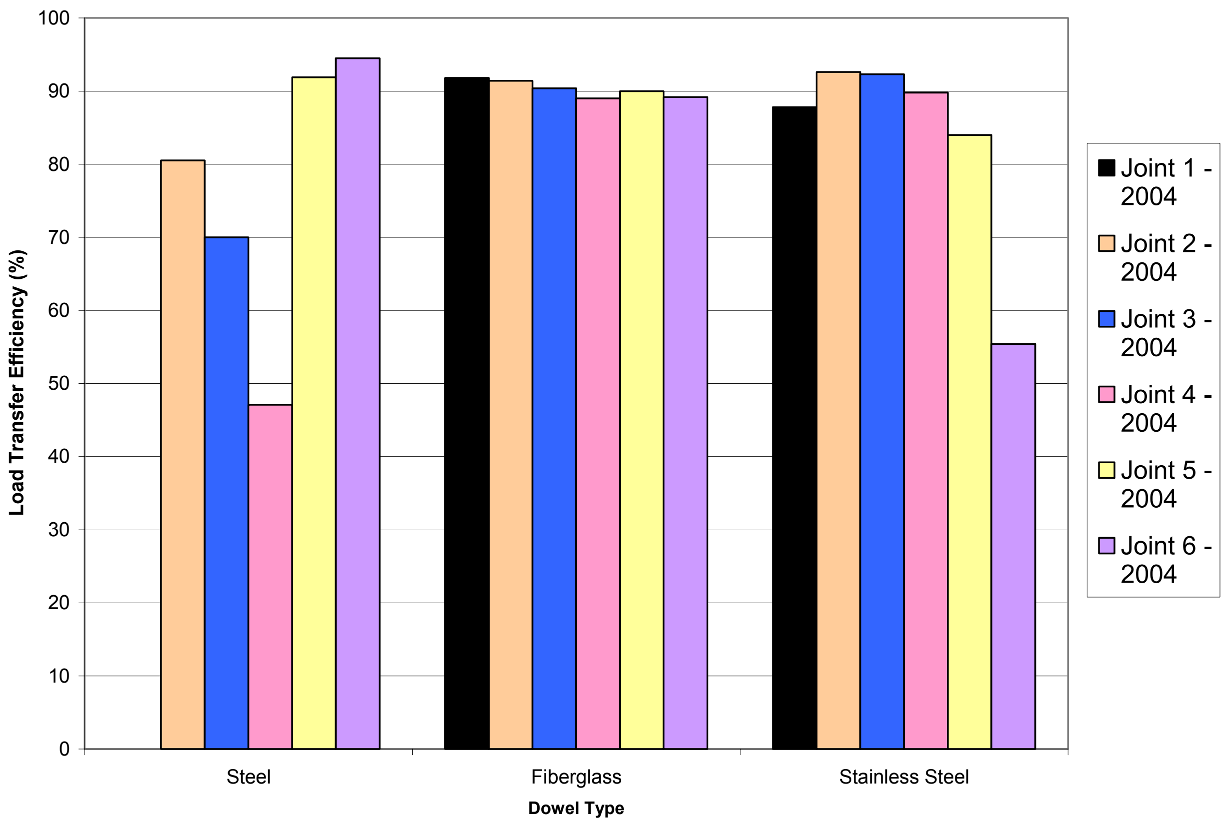
Appendix C—OH 2 Core Photos and 2001 and 2004 FWD Data








100
90
80
70
60
50
40
30
20
10
0
Load Transfer Efficiency (%)
Steel
Fiberglass
Stainless Steel
Dowel Type
Joint 1 - 2001
Joint 2 - 2001
Joint 3 - 2001
Joint 4 - 2001
Joint 5 - 2001
Joint 6 - 2001


100
90
80
70
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40
30
20
10
0
Load Transfer Efficiency (%)
Steel
Fiberglass
Stainless Steel
Dowel Type
Joint 1 - 2004
Joint 2 - 2004
Joint 3 - 2004
Joint 4 - 2004
Joint 5 - 2004
Joint 6 - 2004

Appendix D—Detailed Project Status Reports

(Source: Draft FHWA July 30,2004 Updated HPCP Summary Report – QES 2004)

CHAPTER 27. OHIO 1, 2, AND 3 (U.S. Route 50, Athens)

Introduction

Under the TE-30 program, the Ohio Department of Transportation (ODOT) constructed three experimental pavement projects on U.S. 50, approximately 8 km (5 mi) east of the city of Athens (see figure 45). The projects incorporate a variety of experimental design features, including high-performance concrete mixtures utilizing ground granulated blast furnace slag (GGBFS) (Ohio 1), alternative dowel bar materials (Ohio 2), and alternative joint sealing materials (Ohio 3) (Ioannides et al. 1999; Sargand 2000; Hawkins et al. 2000). Although each project was funded separately under the TE-30 program, they are all located on the same section of roadway and share many of the same design and construction attributes, as well as the same traffic and environmental loadings; therefore, these projects are all described together in this chapter.

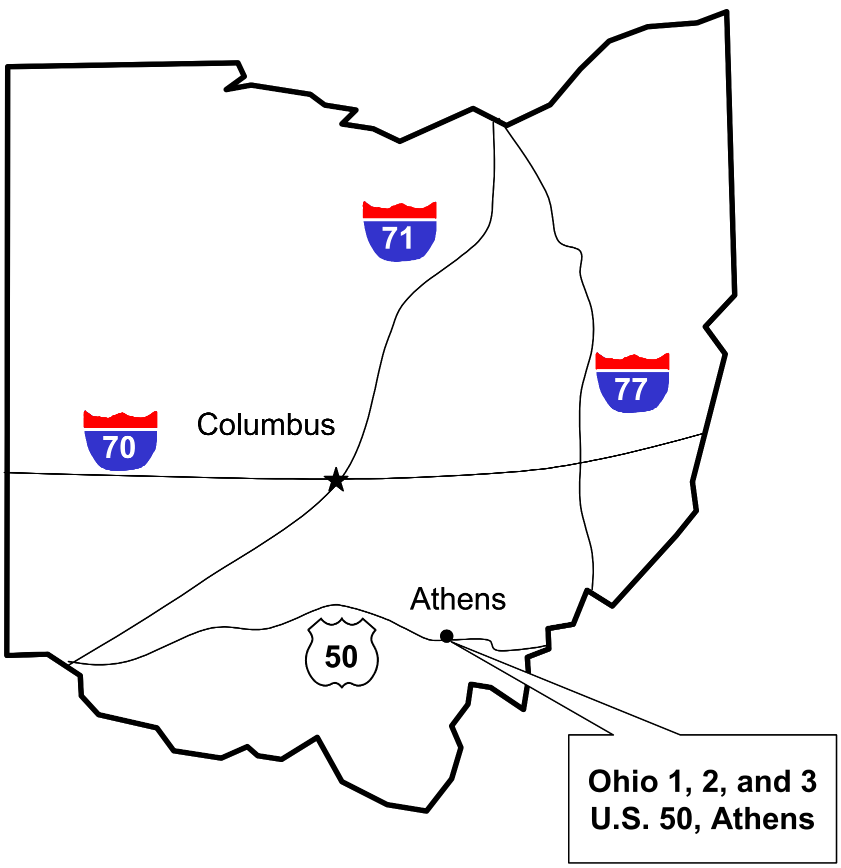

Figure 45. Location of OH 1, 2, and 3 projects.

Study Objectives

The study objectives for the overall U.S. 50 pavement project may be broken out by each specific study. For OH 1, the evaluation of GGBFS, the primary objective is to evaluate the effectiveness of GGBFS as a partial cement replacement in PCC pavements. The expectation of adding GGBFS to a concrete mix is increased workability, increased durability, and increased long-term strength.

For OH 2, the evaluation of alternative dowel bar materials, the general purposes of the study are to evaluate dowel response under a variety of loading and environmental conditions and to compare the measured responses of different types of dowel bars (Sargand 2000). Specific objectives include the following (Sargand 2000):

- Instrument standard steel and fiberglass dowels for the monitoring of strain induced by curing, changing environmental conditions, and applied dynamic forces.
- Record strain measurements periodically over time to determine forces induced in the dowel bars during curing and during changing environmental conditions.
- Record strain measurements in the dowel bars as dynamic loads are applied with the FWD.
- Evaluate strain histories recorded for the in-service pavement.

For OH 3, the evaluation of joint sealing materials, the objectives are to (Ioannides et al. 1999):

- Assess the effectiveness of a variety of joint sealing practices employed after the initial sawing of joints, and to examine their repercussions in terms of reduced construction times and life-cycle costs.
- Identify those materials and procedures that are most cost effective.
- Determine the effect of joint sealing techniques on pavement performance.

Project Design and Layout

General Design Information

The U.S. 50 project is a 10.5-km (6.5-mi) segment of highway that was reconstructed and expanded to a new four-lane divided facility. The eastbound lanes of the project were constructed in the fall of 1997, and the westbound lanes were constructed in the fall of 1998 (Ioannides et al. 1999).

The 20-year design traffic loading for this pavement is approximately 11 million ESAL applications. The subgrade over the project site is predominantly a silty clay material (Ioannides et al. 1999).

The cross-sectional design for the projects is a 254-mm (10-in) JRCP placed over a 102-mm (4-in) open-graded base course. The open-graded base course in the eastbound direction is a "New Jersey" type nonstabilized base, whereas the open-graded base course in the westbound direction is a "Iowa" type nonstabilized base (Ioannides et al. 1999). A 152-mm (6-in) crushed aggregate subbase is located beneath the open-graded bases, and is topped with a bituminous prime coat to prevent migration of fines into the open-graded layers (Ioannides et al. 1999). Table 21 provides the actual project gradations for these materials. A 102-mm (4-in) underdrain was placed at both the outside and inside edges of the pavement to collect infiltrated moisture from the open-graded bases (Ioannides et al. 1999).

Table 21. Comparison of actual base and subbase gradations used on Ohio U.S. 50 project.

Sieve Size	Total Percent Passing		
	New Jersey Open-Graded Base (EB)	**Iowa Open-Graded Base (WB)**	**Crushed Aggregate Subbase (EB/WB)**
2 in			100
1½ in	100		
1 in		100	
#8	12	30	25
#16	6	19	18
#30	4	15	14
#40	4	12	13
#50	4	9	12
#100	3	6	10
#200	3.2	5.6	9.8

The slabs are reinforced with smooth welded wire fabric (WWF) to control random cracking (Sargand 2000). Wire style designation W8.5 x W4—6x12 was specified, meaning that the longitudinal wires have a cross sectional area of 54.8 mm^2 (0.085 in^2) and are spaced 152 mm (6 in) apart, and the transverse wires have a cross-sectional area of 25.8 mm^2 (0.04 in^2) and are spaced 305 mm (12 in) apart. This style designation translates to a longitudinal steel content of 0.14 percent.

The transverse joints are spaced at fixed 6.4-m (21-ft) intervals and contain 38-mm (1.5-in) diameter, 457-mm (18-in) long, epoxy-coated dowel bars on 305-mm (12-in) centers (Sargand 2000). However, some of the joints within the alternative dowel bar project contain either fiberglass dowels or stainless steel tubes filled with concrete (Sargand 2000). Transverse joints were sealed with a preformed compression sealant except for the joints within the joint sealant project. The longitudinal centerline joint is tied with 16-mm (0.62-in) diameter, 760-mm (30-in) long, deformed bars spaced at 760-mm (30-in) intervals (Ioannides et al. 1999).

Plain concrete shoulders were paved separately from the mainline pavement. These were tied to the mainline pavement using 16-mm (0.62-in) diameter, 76-mm (30-in) long, deformed tie bars. The outside shoulder is 3 m (10 ft) wide and the inside shoulder is 1.2 m (4 ft) wide (Ioannides 1999).

Project Layout Information

As described previously, the U.S. 50 project actually includes three projects, one evaluating GGBFS, one evaluating alternative dowel bar materials, and one evaluating joint sealant materials. In addition, a control section that does not contain GGBFS is located at the western end of the project. The general layout of these projects is shown in figure 46. More detailed information on each project is provided in the following sections.

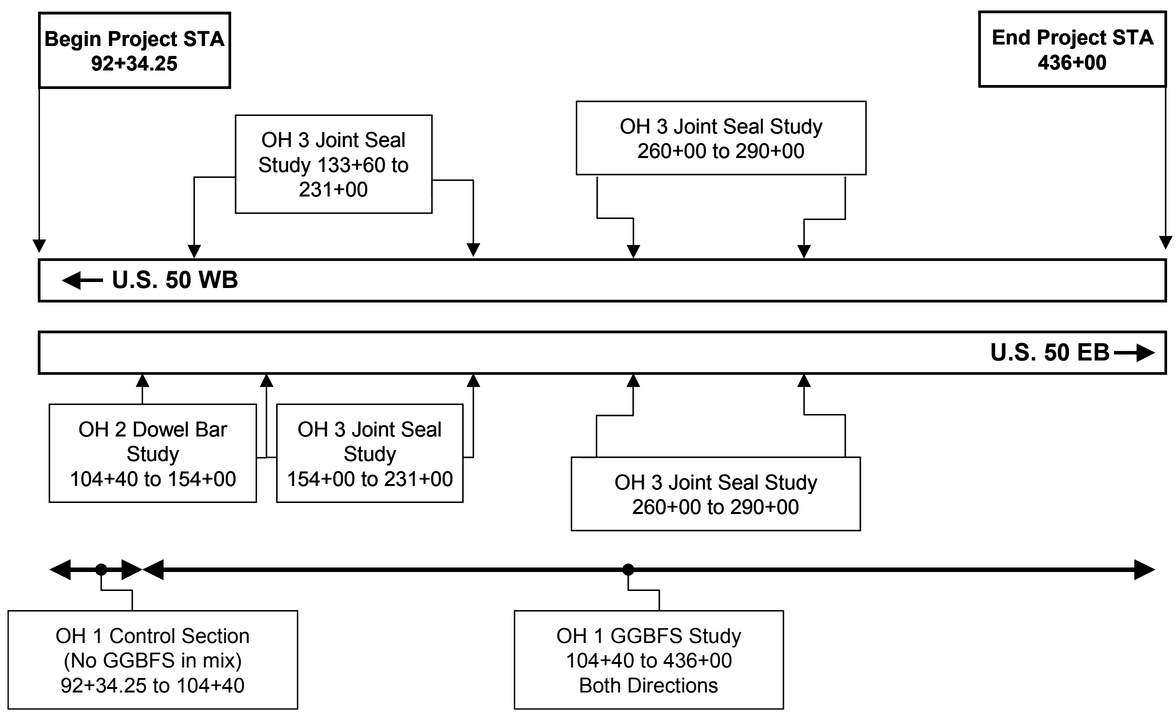

Figure 46. Layout of experimental projects on Ohio U.S. 50.

OH 1, Evaluation of Ground Granulated Blast Furnace Slag

The entire 10.5-km (6.5-mi) length of the U.S. 50 project was constructed using a high-performance concrete mix. The mixture consists of a Type I cement with GGBFS replacing 25 percent of the cement (Sargand 2000). An AASHTO #8 gravel (0.13 mm [0.5 in] top size) was used for the coarse aggregate and a natural sand was used for the fine aggregate (Sargand 2000). A w/c of 0.44 was used in the mix design. The complete PCC mix design is shown in table 22.

Table 22. Concrete pavement mix design used on Ohio U.S. 50 project.

PCC Mix Design Component	Quantity
Natural Sand	1437 lb/yd^3
AASHTO #8 Aggregate	1374 lb/yd^3
Type I Cement	412 lb/yd^3
Water	236 lb/yd^3
GGBFS	138 lb/yd^3
Water Reducer	11 oz/yd^3
Air Entraining Agent	16.5 oz/yd^3
Design Air	8%
Design Slump	3 in

Samples from the concrete mix used in the actual paving operation were tested in the laboratory and showed a 28-day compressive strength of 27.6 MPa (4000 lbf/in^2) and a 28-day modulus of rupture of 2.76 MPa (400 lbf/in^2) (Sargand 2000). The 28-day static modulus of elasticity was 25.92 GPa (3,760,000 lbf/in^2) (Sargand 2000).
As previously mentioned, a control pavement section that does not contain GGBFS in the concrete mix is located at the western end of the project, between stations 92+35.4 and 104+40. Other than the mix design, the design of the control section is the same as the GGBFS section.

OH 2, Evaluation of Alternative Dowel Bars

Three types of dowel bars were used in the dowel bar project: epoxy-coated steel dowel bars, fiberglass dowel bars (manufactured by RJD Industries, Inc.), and stainless steel tubes filled with concrete. The diameter of the steel and fiberglass dowels bars is 38 mm (1.5 in), while the stainless steel tubes have an outer diameter of 38 mm (1.5 in) and an inner diameter of 34 mm (1.35 in) (Sargand 2000). All bars are 457 mm (18 in) long.

Most of the U.S. 50 project contains conventional epoxy-coated steel dowel bars. However, three specific test sections, each incorporating one of the load transfer devices under study, were set up near the western-most limits of the project in the eastbound direction to instrument dowel response and to compare the performance of the different load transfer devices. Each test section is made up of six consecutive joints, with the middle two joints containing instrumented dowel bars (see figure 47). The concrete-filled stainless steel bars were not instrumented because the thin wall thickness did not permit the necessary installation operation to protect the lead wires of the gages (Sargand 2001).

Three dowel bars within each joint are instrumented. The instrumented bars are located at distances of 152 mm (6 in), 762 mm (30 in), and 1980 mm (78 in) from the outside edge of the pavement, as shown in figure 48 (Sargand 2000). Each instrumented dowel bar contained a uniaxial strain gauge on the top and the bottom of the bar, and one 45-degree rosette on the side. The uniaxial gauges measure environmental and dynamic strains while the rosette gauges measure only dynamic strains (Sargand 2000).

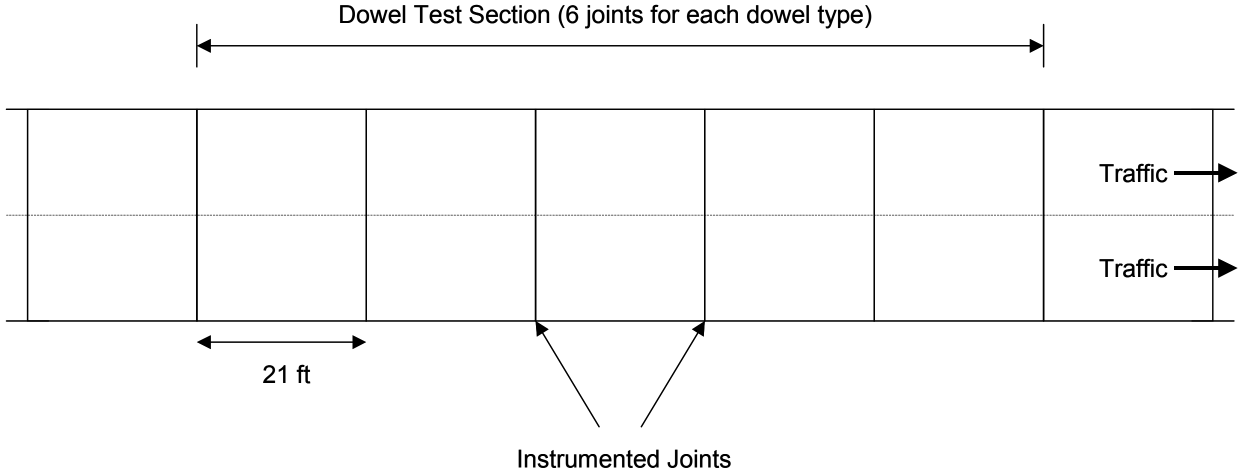

Figure 47. Layout of dowel test sections on Ohio U.S. 50 project.

Two thermocouple units were also installed near each instrumented joint to measure temperatures in the concrete slab. One unit housed three sensors that measure temperatures at depths of 102, 178, and 254 mm (4, 7, and 10 in) from the surface of the slab, and the second unit consists of a single sensor measuring temperatures at a depth of 25 mm (1 in) below the surface of the slab (Sargand 2000).

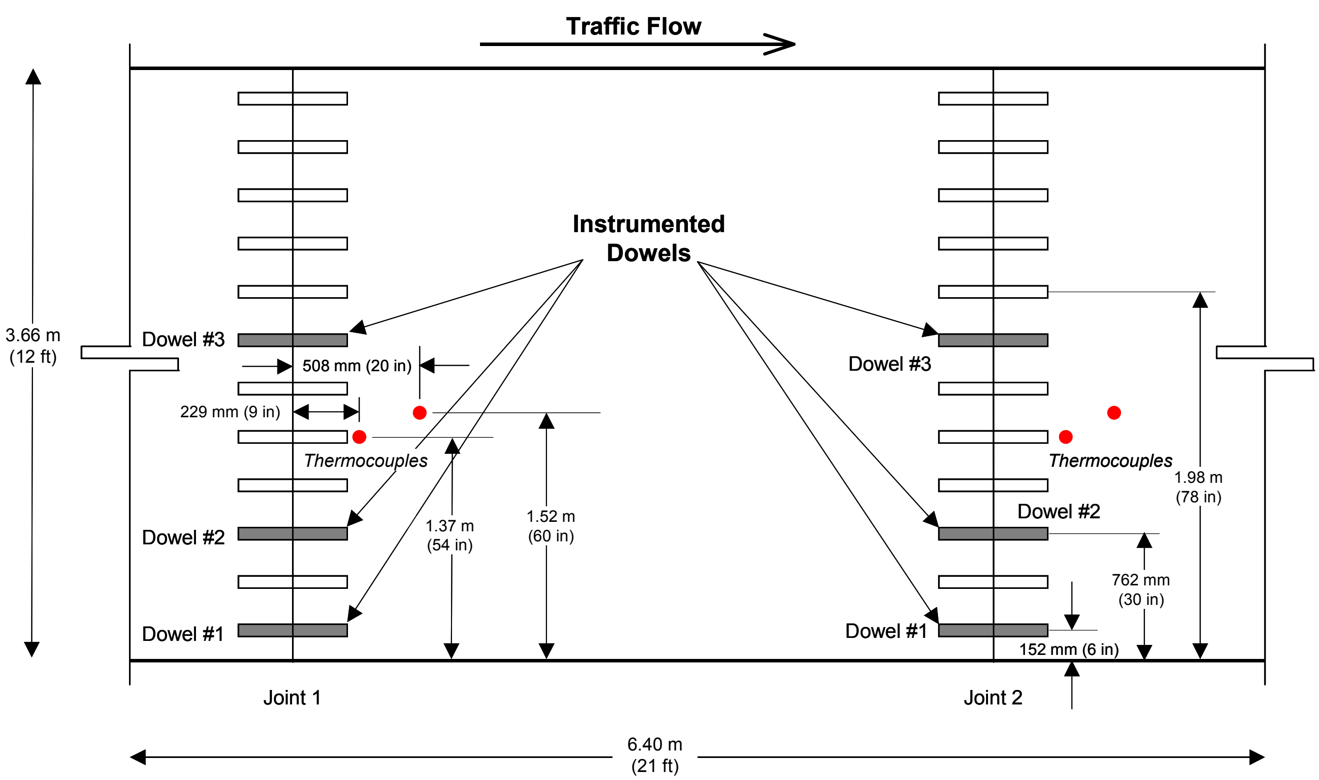

Figure 48. Dowel instrumentation layout for Ohio U.S. 50 project (Sargand 2000).

OH 3, Evaluation of Joint Sealing Materials

The joint sealant evaluation is conducted in selected segments of both the eastbound and westbound directions of U.S. 50. A total of nine different joint sealants are evaluated (including four silicone sealants, two hot-poured sealants, and three compression seals), each of which is installed in a unique joint channel configuration. In addition, several pavement sections containing no sealant are included in the study.

Table 23 summarizes the location of the different sealant materials in each direction, as well as the joint channel configuration (see figure 49) used for each material (Hawkins, Ioannides, and Minkarah 2000). The westbound sections each represent replicate sealant sections of those in the eastbound lanes, with the exception of the Watson Bowman WB-687 in the eastbound lanes, which was replicated using the Watson Bowman WB-812 in the westbound lanes (Ioannides et al. 1999). The eastbound lanes were sealed in October and November of 1997, whereas the westbound lanes were sealed in December 1998 (silicone and compression seals) and April 1999 (hot-poured sealants) (Ioannides et al. 1999).

State Monitoring Activities

The Ohio DOT, in conjunction with researchers from several state universities, monitored the performance of these pavements for 5 years. Annual condition surveys and profile measurements were conducted, along with special FWD testing on the instrumented joints. In addition, detailed joint sealant evaluations following SHRP procedures were performed annually on a selected samples of each sealant material.

Table 23. Sealant materials used in joint sealant study on Ohio U.S. 50 project (Hawkins, Ioannides, and Minkarah 2000).

Sealant Material	Sealant Type	Begin Station	End Station	Joint Configuration	Section Length, ft	No. of Joints
Eastbound Direction						
TechStar W-050	Preformed	154+00	160+00	5	600	29
No Sealant	—	160+00	166+00	6	600	29
Dow 890-SL	Silicone	166+00	172+00	3	600	29
Crafco 444	Hot-Pour	172+00	188+00	1	1600	76
Crafco 903-SL	Silicone	188+00	194+00	1	600	29
Watson Bowman WB-687	Preformed	194+00	200+00	5	600	27
Crafco 902 Silicone	Silicone	200+00	206+00	1	600	29
Crafco 903-SL	Silicone	206+00	213+00	4	700	33
Dow 890-SL	Silicone	213+00	219+00	4	600	29
No Sealant	—	219+00	225+00	2	600	28
Delastic V-687	Preformed	225+00	231+00	5	600	29
Crafco 221	Hot-Pour	260+00	266+00	1	600	29
Dow 890-SL	Silicone	266+00	272+00	1	600	28
Dow 888	Silicone	272+00	284+00	1	1200	57
Dow 888	Silicone	284+00	290+00	1	600	29

Westbound Direction						
TechStar W-050	Preformed	133+60	139+60	5	600	29
No Sealant	—	139+60	166+00	2	2640	126
Dow 890-SL	Silicone	166+00	172+00	3	600	29
Crafco 221	Hot-Pour	172+00	188+00	1	1600	76
Crafco 903-SL	Silicone	188+00	194+00	1	600	29
Crafco 903-SL	Silicone	194+00	200+00	1	600	29
Dow 890-SL	Silicone	200+00	206+00	1	600	28
Crafco 444	Hot-Pour	206+00	213+00	1	700	33
Dow 888	Silicone	213+00	219+00	1	600	28
Delastic V-687	Preformed	219+00	225+00	5	600	29
Watson Bowman WB-812	Preformed	225+00	231+00	5	600	28
Dow 888	Silicone	260+00	266+00	1	600	29
Crafco 903-SL	Silicone	266+00	272+00	4	600	28
Dow 890-SL	Silicone	272+00	284+00	4	1200	57
No Sealant	—	284+00	290+00	6	600	29

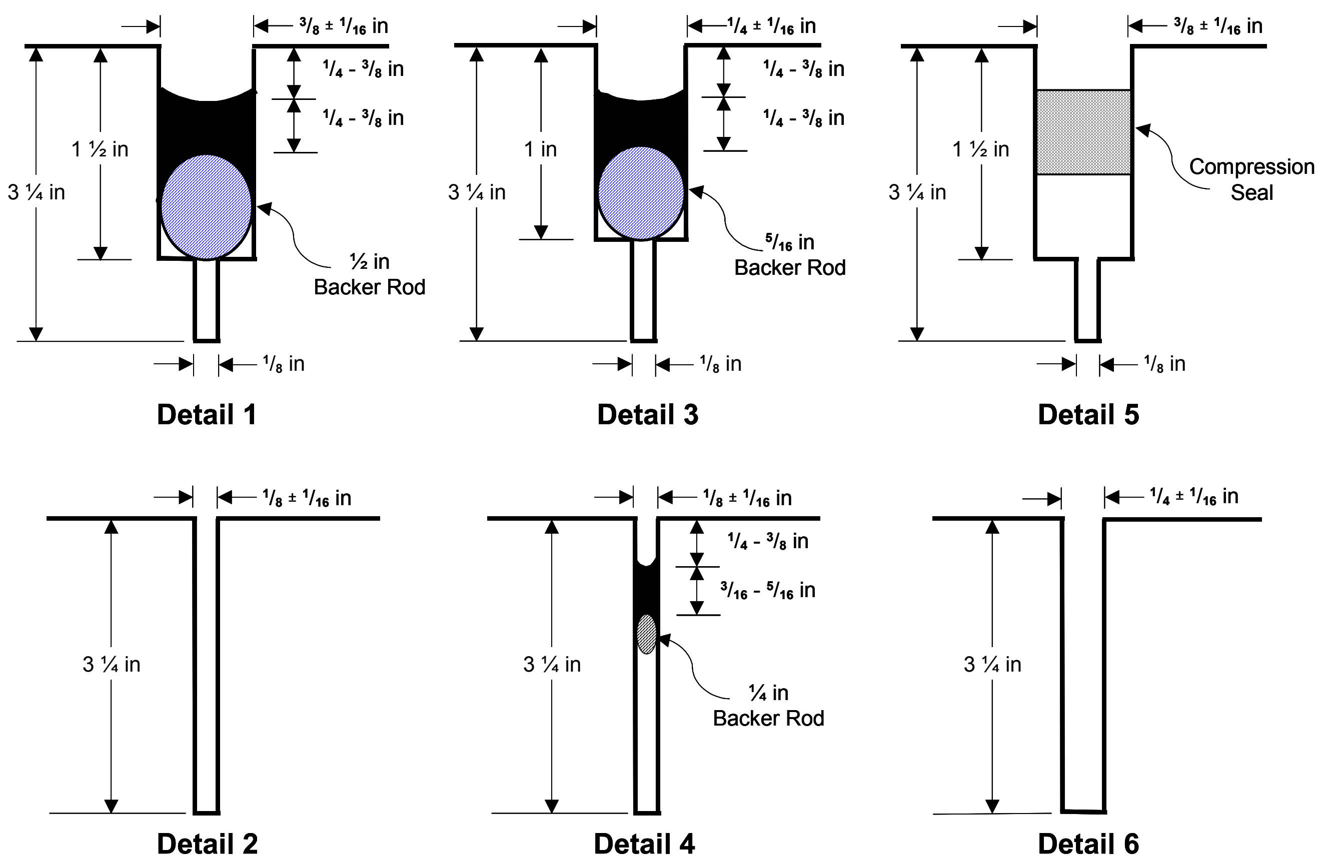

Figure 49. Joint channel configurations used in sealant study on Ohio U.S. 50 project (Hawkins, Ioannides, and Minkarah 2000).

Results/Findings

Performance results are available in the final reports for these sections. This information is presented in the following sections for each specific study.

OH 1, Evaluation of Ground Granulated Blast Furnace Slag

The final report, *Application of High Performance Concrete in the Pavement System, Structural Response of High Performance Pavements*, March 2002 provides the results from this study. Several factors related to the performance of the HPC pavement containing 25 percent GGBFS have been evaluated with the following results.

- Temperature gradients generated between the top and bottom of concrete slabs during the cure period can have a significant impact on the development of early cracks. HPC pavement sections placed in October, 1997 experienced gradients of 10 degrees C, and developed cracking within eighteen hours of placement. One HPC and one standard pavement section placed in October, 1998 experienced gradients of only 5 degrees C, and did not develop cracking. The higher temperature gradient in 1997 resulted from a cold front shortly after placement.

- Large values of strain recorded with the vibrating wire strain gages and maturity measurements indicated that the HP 1 and HP 2 sections could be expected to crack, as was observed in the field. HP 3 constructed one year later of the same concrete mix but during a period of warmer weather did not develop cracks. In this case, both strain and maturity data collected in the field indicated a low probability of cracking.

- Results from HIPERPAV also suggested that sections HP 1 and HP 2 would crack, while HP 3 would not. Predicted strength curves were calculated for the placements, in addition to those provided by the standard HIPERPAV prediction model.

- Section HP 3 had less initial warping than did section SP (standard ODOT paving concrete). Sections HP 1 and 2 developed cracking, precluding effective curling measurement of these slabs.

Based on the laboratory results and field data obtained in this study, the following conclusions were derived (Sargand 2002):

- Temperature gradients generated between the surface and bottom of concrete slabs during the curing process can have a significant impact on the formation of early cracks.
- Section HP3 had less initial warping than did section SP constructed with standard ODOT class C concrete.
- FWD data indicated that, under similar loading conditions, the HP3 section experienced slightly less deflection at joints than the SP section.
- With limited data available, it was suggested that the moisture in the base at sealed and unsealed joints was similar. In some cases, however, moisture under sealed conditions

was observed to be slightly higher, indicating that joint seals might trap moisture under the pavement.

- During FWD tests the deflection at sealed joints was generally higher than at unsealed joints.

OH 2, Evaluation of Alternative Dowel Bars

An analysis of the strains in both the fiberglass and steel dowel bars under environmental and dynamic loading was conducted (ORITE 1998; Sargand 2000; Sargand 2001). Major findings from that analysis include (Sargand 2000; Sargand 2001):

- In addition to transferring dynamic load across PCC pavement joints, dowel bars serve as a mechanism to reduce the curling and warping of slabs due to curing and temperature and moisture gradients in the slabs.

- Steel and fiberglass dowels both experienced higher moments from environmental factors than from dynamic loading. The dynamic bending stresses induced by a 56.9 kN (12,800 lb) load were considerably less than the environmental bending stresses induced by a 3 ^{o}C (5.4 ^{o}F) temperature gradient.

- Steel bars induced greater environmental bending moments than fiberglass bars.

- Significant stresses were induced by steel dowel bars early in the life of this pavement as it cured late in the construction season under minimal temperature and thermal gradients in the slab. Concrete pavements paved in the summer under more severe conditions may reveal even larger environmental stresses.

- Both types of dowels induced a permanent bending moment in the PCC slabs during curing, the magnitude of which is a function of bar stiffness.

- Curling and warping during the first few days after concrete placement can result in large bearing stresses being applied to the concrete around the dowels. This stress may exceed the strength of the concrete at that early age and result in some permanent loss of contact around the bars.

- Steel bars transferred greater dynamic bending moments and vertical shear stresses across transverse joints than fiberglass bars of the same size.

Given these findings, it is concluded that the effects of environmental cycling and dynamic loading both must be included in the design and evaluation of PCC pavement joints (Sargand 2001). Because of the high bearing stresses that can be generated in concrete surrounding dowel bars, this parameter should be considered in dowel bar design, especially during the first few days after placement of concrete (Sargand 2001).

It is noted that these results are based on the analysis of the instrumented steel and fiberglass dowel bars only. The stainless steel tubes were not instrumented for the reason stated earlier.

OH 3, Evaluation of Joint Sealing Materials

The results from this experiment, through the 2001 performance evaluation have resulted in several observations (Ioannides et al. 1999; Hawkins, Ioannides, and Minkarah 2000):

- The silicone and hot-poured sealants in the eastbound lanes are in fair to poor condition, typically suffering from full-depth adhesion failure.

- The worst of the sealed sections were those with a narrow joint width of 3 mm (0.12 in). In these installations, the sealant material had overflowed and run onto the pavement surface.

- There is a significant difference in the performance of the same joint seal materials from EB (constructed in '97) and WB (constructed in '98). This difference is attributed to improvements in installation temperatures, experience, and equipment.

- The joints in this experiment were cleaned only by water- and air-blasting, even when the sealant manufacturers recommended sand blasting. This suggests that some of the adhesion loss may be due to an inadequate cleaning process.

- Both the Watson Bowman and the Delastic compression seals have performed by far best overall in both directions. In the WB direction, the silicones have performed best, but were poor in the EB. The performance of the hot pour materials is very different, being far better in WB in general. However, the Crafco 221 material did relatively well in one EB test section. The TechStar compression seal, however, has developed significant adhesion failure and has sunk into the joint.

- The compression seals have performed by far best overall in both directions. In the WB direction, the silicones have performed best, but were poor in the EB. The performance of the hot pour materials is very different, being far better in WB in general. However, the Crafco 221 material did relatively well in one EB test section.

- Hot pour material appears to have performed better when installed within the manufacturer's recommended temperature range. No specific temperature range is recommended for the silicone materials.

- Roughness measurements made using PSI, IRI, and Mays meter do not provide any conclusive trends relating to pavement performance.

- Assessment of joint seal efficiency has little relationship to pavement condition, at this time. It is recommended to reseal the EB sites, except for the two compression seals for continued performance monitoring.

- The Techstar W-050 material performed poorly in both directions, and is considered unsuitable for pavement applications.

- Currently, the unsealed sections seem to have more spalling, corner, and midslab cracking distress than others, although there is no conclusive pavement performance related trends as yet.

A summary of estimated joint sealant costs on this project is provided in table 24 (Ioannides et al. 1999). These costs are based solely on the material costs themselves and do not include the costs of backer rods, adhesives, or labor.

Table 24. Summary of sealant costs on Ohio U.S. 50 project (Ioannides et al. 1999).

Material	Unit Cost	Estimated Cost/Joint
Dow 890-SL	$48.00/gal	$12.27
Crafco 903-SL	$36.00/gal	$9.50
Dow 888	$42.00/gal	$10.74
Crafco 902	$39.00/gal	$9.97
Crafco 444	$10.50/gal	$2.68
Crafco 221	$0.25/lb	$0.64
Watson Bowman WB-812	$1.03/ft	$43.26
Watson Bowman WB-687	$0.72/ft	$30.24
Delastic V-687	$0.66/ft	$27.72
TechStar V-050	$8.65/ft	$363.30

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CHAPTER 11. IOWA 2 (U.S. Route 65, Des Moines)

Introduction

The Iowa Department of Transportation's second TE-30 project consists of an evaluation of alternative dowel bar materials and spacings. The experimental project was constructed in 1997 on the U.S. 65 Bypass near Des Moines (Cable and McDaniel 1998b). Figure 17 shows the location of this project.

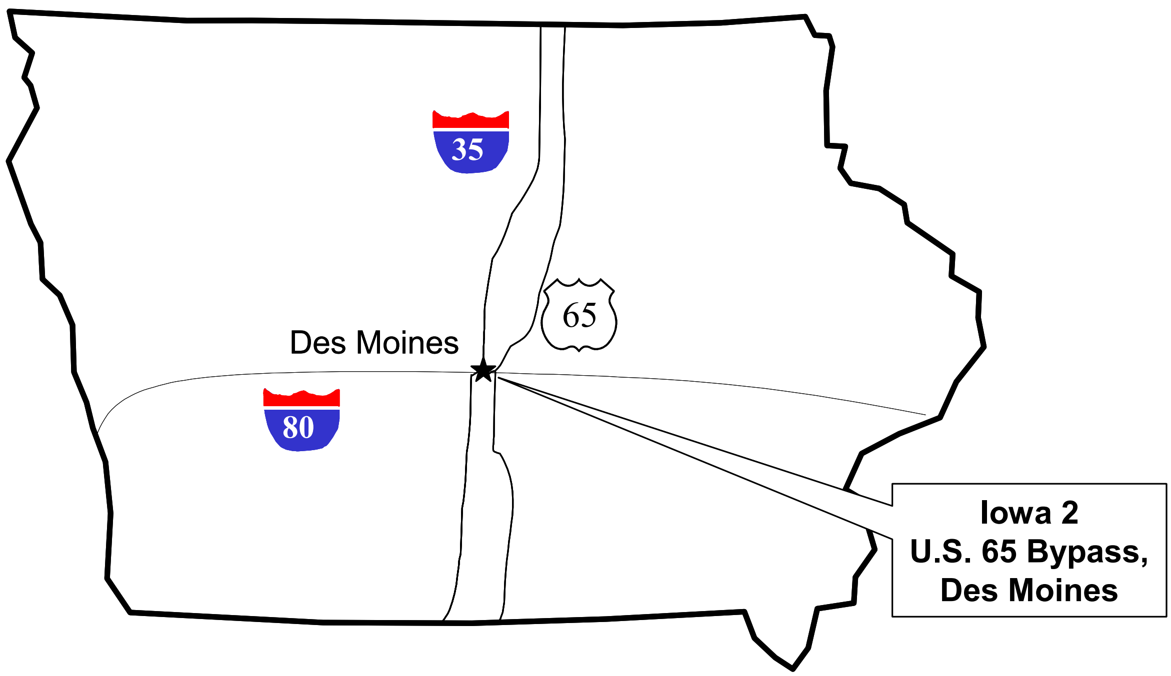

Figure 17. Location of IA 2 project.

Study Objectives

Because of the susceptibility of steel dowel bars to corrosion, the Iowa DOT has expressed interest in the use of alternative dowel bar materials to provide load transfer across transverse joints in concrete pavements. Therefore, one of the goals of this project is the comparative study of concrete pavement joints containing fiber reinforced polymer (FRP) dowel bars, stainless steel dowel bars, and conventional epoxy-coated steel dowel bars under the same design criteria and field conditions (Cable and McDaniel 1998b). Another goal of the project is the investigation of the transverse joint load transfer characteristics of alternative dowel bar spacings (Cable and McDaniel 1998b). This evaluation is a 5-year study being performed through the combined efforts of the Iowa Department of Transportation and the Iowa State University.

Project Design and Layout

This project was constructed in 1997 on the northbound lanes of the U.S. 65 Bypass near Des Moines. The basic design for the project is a 305-mm (12-in) JPCP on a 152-mm (6-in) granular base course (Cable and McDaniel 1998b). Transverse joints are located at 6.1-m (20-ft) intervals and are skewed 6:1 in the counterclockwise direction (Cable and McDaniel 1998b). Both transverse and longitudinal joints are sealed with a hot-poured sealant. Number 5 tie bars, 914 mm (36 in) long and spaced at 762-mm (30-in) intervals, were mechanically inserted by the paver across the longitudinal centerline joint (Cable and McDaniel 1998b).

The shoulder for the JPCP is a 203-mm (8-in) asphalt concrete (AC) layer, paved 2.4 m (8 ft) wide on the outside edge and 1.6 m (6 ft) on the inside edge (Cable and McDaniel 1998b). Longitudinal subdrains are located under the outside shoulder and adjacent to the edge of the outside driving lane (Cable and McDaniel 1998b).

Four different load transfer systems are included in the study: a fiber composite dowel bar manufactured by Hughes Brothers, a fiber composite dowel bar manufactured by RJD Industries, a Type 316L solid stainless steel dowel bar, and a conventional epoxy-coated steel dowel bar (Cable and McDaniel 1998b). The Hughes Brothers dowel bar is 48 mm (1.88 in) in diameter, whereas the other dowel bars are 38 mm (1.5 in) in diameter. The required diameters for the alternative dowel bars were determined from laboratory testing and experimental research performed by the manufacturers (Cable and McDaniel 1998b).

A standard spacing of 305 mm (12 in) was used for each load transfer system included in the study. In addition, sections were constructed using a spacing of 203 mm (8 in) for the alternative dowel bar materials. The experimental design matrix for this project is shown in table 9, and the layout of the test sections is shown in figure 18. The dowel bar spacing configurations used on this project are illustrated in figure 19.

Table 9. Experimental design matrix for IA 2.

	305-mm (12-in) JPCP 6.1-m (20-ft) Joint Spacing (skewed)			
	203-mm (8-in) Dowel Spacing		**305-mm (12-in) Dowel Spacing**	
	38-mm (1.5-in) Diameter Dowel	**48-mm (1.88-in) Diameter Dowel**	**38-mm (1.5-in) Diameter Dowel**	**48-mm (1.88-in) Diameter Dowel**
Fiber Composite Dowel Bars (*Hughes Brothers)*		Section 1 (440 ft)		Section 2 (417 ft)
Fiber Composite Dowel Bars (*RJD Industries)*	Section 3 (100 ft)		Section 4 (80 ft)	
Stainless Steel Dowel Bars	Section 5 (222 ft)		Section 6 (556 ft)	
Epoxy-Coated Steel Dowel Bars			Section 8 (477 ft)	

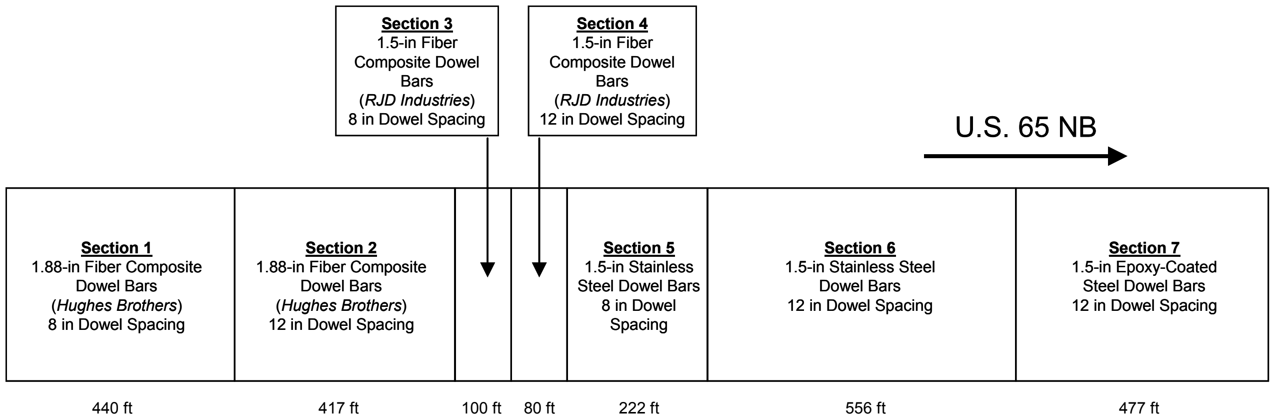

Figure 18. Layout of IA 2 project.

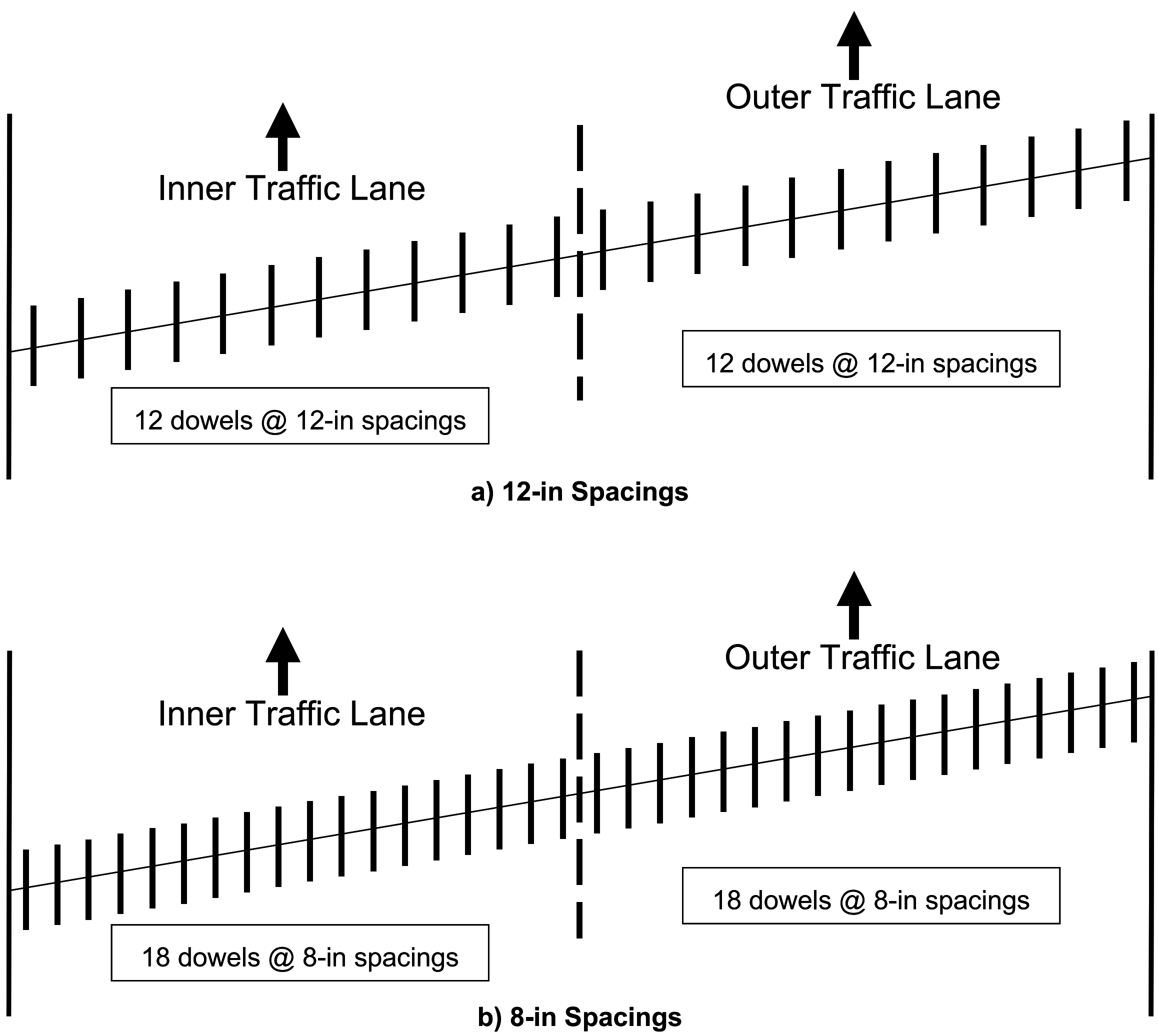

Figure 19. Illustration of dowel bar spacing configurations on IA 2.

Fiber composite tie bars were also provided by the fiber composite dowel bar manufacturers for installation in their respective test sections. However, these fiber composite tie bars had a tendency to "float" to the top of the surface during or immediately after their placement (Cable and McDaniel 1998b). This was attributed to either an incompatibility of the automatic tie bar inserter to the smaller diameter of the fiber composite tie bars or to the lighter weight of the fiber composite bars themselves (Cable and McDaniel 1998b). After several bars surfaced in succession, the epoxy-coated steel tie bars were used on the remainder of the project.

State Monitoring Activities

The performance of these test sections was monitored under a 5-year monitoring program (from the Fall of 1997 through the Spring of 2003) being conducted jointly by the Iowa DOT and the Iowa State University (Cable and Porter 2003). The following monitoring activities were conducted (Cable and Porter 2003):

- Visual distress survey using LTPP procedures. As part of these surveys, joint openings were monitored using PK nails placed along joints in each section, and joint faulting was measured using a Georgia Digital Faultmeter.

- Deflection testing using a Dynatest Falling Weight Deflectometer (FWD). Within each section, deflection testing was performed at three joints and at three center slab locations per lane. Testing was performed twice a year, once in March or April (to represent a "weak" foundation condition) and once in August or September (to represent a "strong" foundation condition).

In addition, ground penetrating radar (GPR) was used to establish the location (depth and orientation) of dowel bars and tie bars (Cable and Porter 2003). At the end of 5 years, selected joints in each section were cored and the condition of each dowel bar type was inspected (Cable and Porter 2003).

Preliminary Results/Findings

During the construction of the project, several items were noted to be of importance to future installations of alternative dowel bars in concrete pavements (Cable and McDaniel 1998b):

- The original method of securing the fiber composite and stainless steel dowel bars to the basket was inadequate. To address this, plastic zip ties were fastened around each basket brace loop and end of dowel to hold them in place. Any excess tie length was cut or turned down to prevent surface finishing problems.

- The placement of the stainless steel dowels required three to five people to handle the baskets. Future use of stainless steel dowels will require "x" braces welded to the basket to prevent side sway and collapse during handling.

- Nails were attached to the bottom of the fiber composite tie bars to facilitate their location using both cover meters and GPR.

- As stated previously, the fiber composite tie bars, placed using the automatic tie bar inserter on the paver, were susceptible to "floating" to the surface. If this is a continuing problem, the placement of these bars in tie bar baskets or the use of conventional epoxy-coated tie bars may be required.

Final Results/Findings

Project test sections were tested twice a year, beginning in the Fall of 1997, with the final tests in the Spring of 2002. Testing could not be performed in the fall of 2000. The results of the FWD testing were interpreted through calculating load transfer efficiency. The results of the load transfer analysis are illustrated in *figure 20* (Cable and Porter 2003). In *figure 20*, the dowel bars are labeled according to their material and spacing: standard epoxy (std. epoxy), stainless steel (S.S.), fiber composite (FRP). *Figure 21* displays the overall average faulting over the period of research (Cable and Porter 2003). *Figure 22* illustrates the changes in joint openings over the research period (Cable and Porter 2003). Visual surveys of this project resulted in only minor corner cracking being noted immediately after construction. There are no visible signs of pavement distress that can be associated with joint reinforcement or typical highway loading over the five years of surveys (Cable and Porter 2003).

The following summaries and conclusions have been reached based on the data gathered during the study (Cable and Porter 2003):

- All dowel materials tested are performing equally in terms of load transfer, joint movement, and faulting over the five-year analysis period.

- Stainless steel dowels do provide load transfer performance equal to or greater than epoxy-coated steel dowels in this study on the average over five years.

- FRP dowels of the sizes tested in this research should be spaced no greater than 8 inches (203 mm) apart to gain load transfer performance at the same level as epoxy-coated steel dowels at 12-inch (305 mm) spacing.

- No deterioration due to road deicers was found on any of the dowel materials retrieved in the 2002 coring operation.

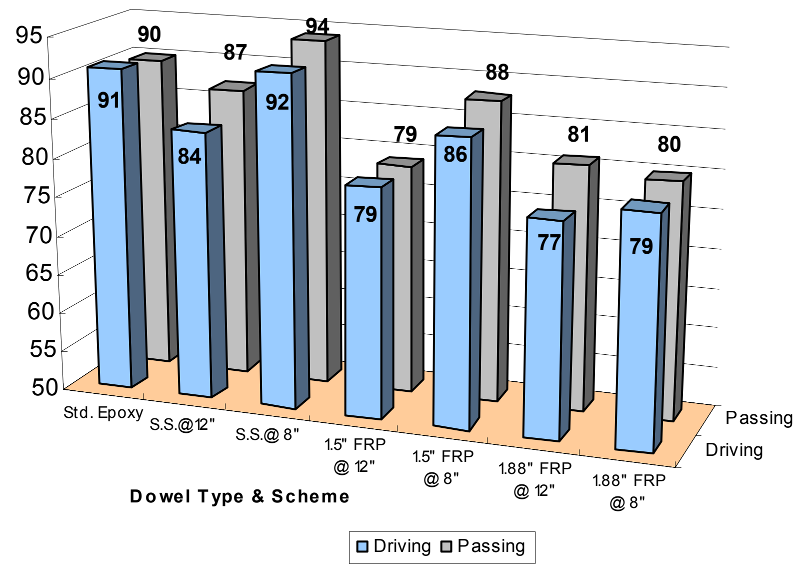

Figure 20. Average Load Transfer Efficiency

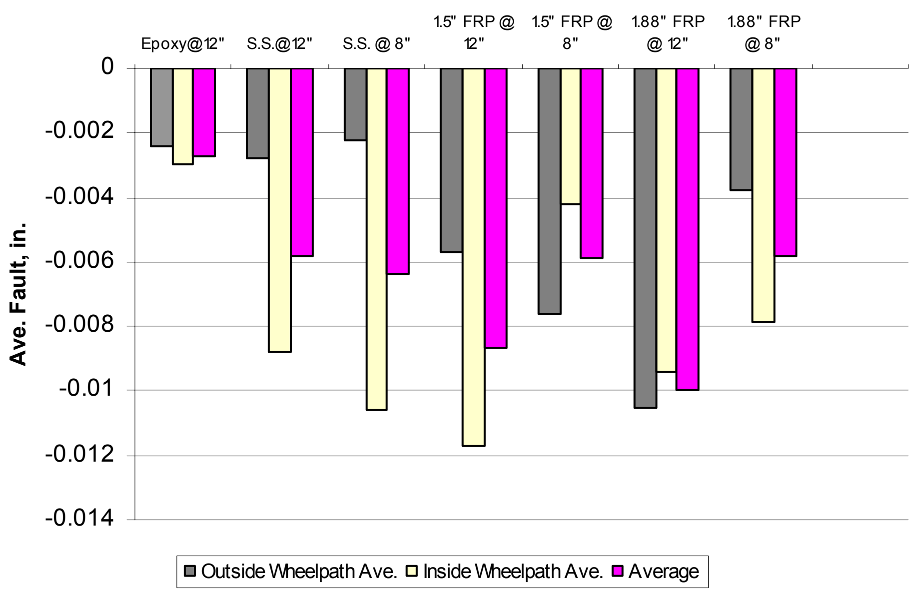

Figure 21. Average Faulting Over Research Period

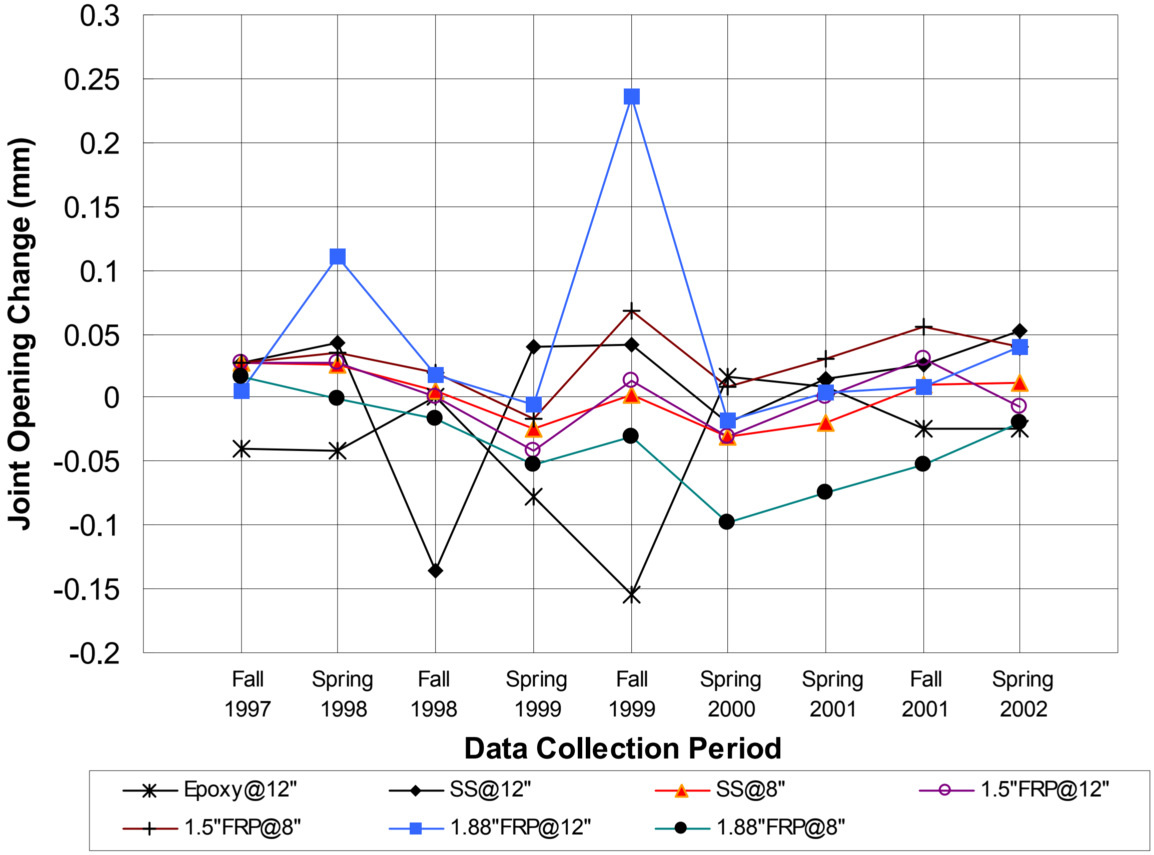

Figure 22. Joint Opening Trends

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CHAPTER 36. WISCONSIN 2 (Highway 29, Owen) AND WISCONSIN 3 (Highway 29, Hatley)

Introduction

In the summer of 1997, WisDOT constructed two experimental concrete pavement projects on Highway 29 to investigate the constructibility and cost effectiveness of alternative concrete pavement designs (Crovetti 1999; Crovetti and Bischoff 2001). Constructed with partial funding from the TE-30 program, one project (designated WI 2) is located in the eastbound lanes of Highway 29 between Owen and Abbotsford, while the other project (designated WI 3) is located in both lanes of Highway 29 between Hatley and Wittenberg (see figure 60). The WI 3 test sections are also part of FHWA's ongoing Strategic Highway Research Program (SHRP) study. Because of the similarities and complementary design of these two projects, they are considered together in this chapter.

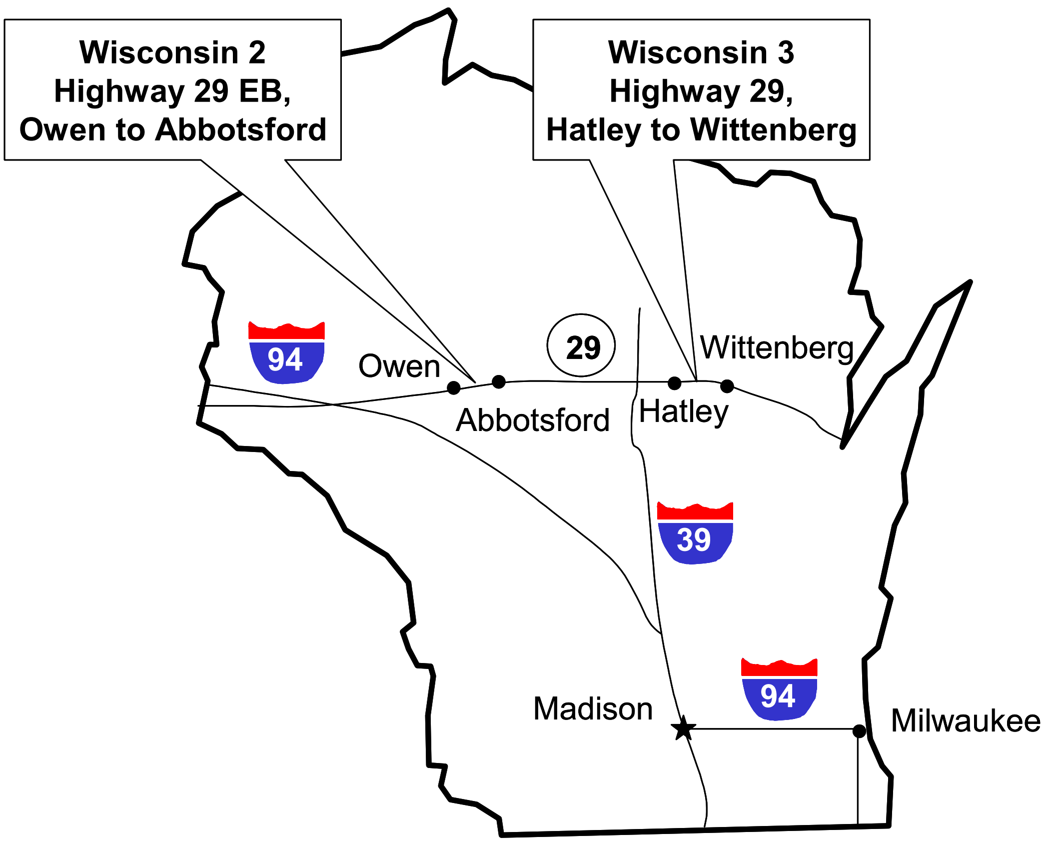

Figure 60. Location of WI 2 and WI 3 projects.

Study Objectives

The overall objective of these projects is to evaluate the constructibility and cost-effectiveness of alternative concrete pavement designs (Crovetti 1999). Among the different concrete pavement designs and design features being investigated in these projects are (Crovetti 1999):

- Reduced number of dowel bar across transverse joints.
- Alternative dowel bar materials for transverse joint load transfer.
- Variable thickness pavement cross section.

Project Design and Layout

Wisconsin 2

The WI 2 project is located only in the eastbound lanes of Highway 29. It was constructed in September 1997 and includes both alternative dowel bar materials and alternative dowel bar layouts (Crovetti 1999; Crovetti and Bischoff 2001):

- Alternative Dowel Bar Materials
  - Standard epoxy-coated steel dowel bars.
  - Solid stainless steel dowel bars, manufactured by Avesta Sheffield.
  - Fiber-reinforced polymer (FRP) composite dowel bars, manufactured by Glasforms.
  - FRP composite dowel bars, manufactured by Creative Pultrusions.
  - FRP composite dowel bars, manufactured by RJD Industries.
  - Stainless steel tubes filled with mortar, manufactured by Damascus Bishop.

- Alternative Dowel Bar Layouts
  - Standard dowel layout (dowels spaced at 305-mm [12-in] intervals).
  - Alternative dowel layout 1 (three dowels in each wheelpath).
  - Alternative dowel layout 2 (four dowels in outer wheelpath, three in all other wheelpaths).
  - Alternative dowel layout 3 (four dowels in outer wheelpath, three in all other wheelpaths, one dowel at outer edge).
  - Alternative dowel layout 4 (three dowels in all wheelpaths, one dowel near outer edge).

The alternative dowel bar layouts are illustrated in figure 61. These layouts were selected to reduce dowel bar requirements while still maintaining standard placement locations used in Wisconsin (Crovetti 2001).

The nominal pavement design for these pavement sections is a 275-mm (11-in) JPCP with skewed variable joint spacing of 5.2-6.1-5.5-5.8 m (17-20-18-19 ft) (Crovetti 1999). The dowel bars were 38 mm (1.5 in) in diameter and were placed using an automated dowel bar inserter (DBI). The transverse joints were left unsealed.

The pavement was constructed over existing base materials that were salvaged from the in-place structure, including 230 mm (9 in) of existing dense-graded, crushed aggregate subbase and 125 mm (5 in) of existing dense-graded, crushed aggregate base. An additional 50 mm (2 in) of new dense-graded aggregate base was placed prior to the PCC paving.

Figure 62 shows the approximate layout of the eleven test and two control sections included in the WI 2 project, using the section nomenclature adopted by the researchers. Nominal 161-m (528-ft) long pavement segments generally consisting of twenty-nine joints were selected from within each test section for long term monitoring (Crovetti 1999). Table 30 provides the experimental design matrix for the project.

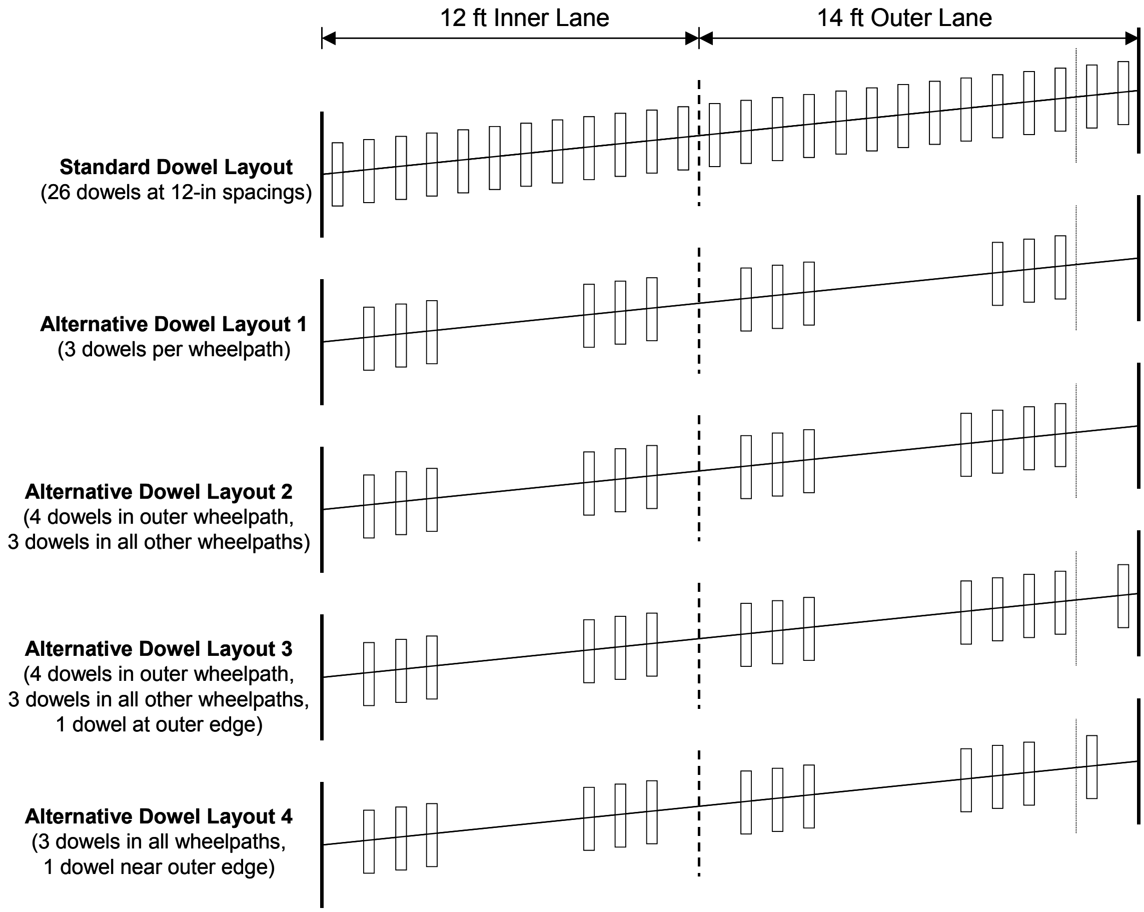

Figure 61. Alternative dowel bar layouts used on WI 2.

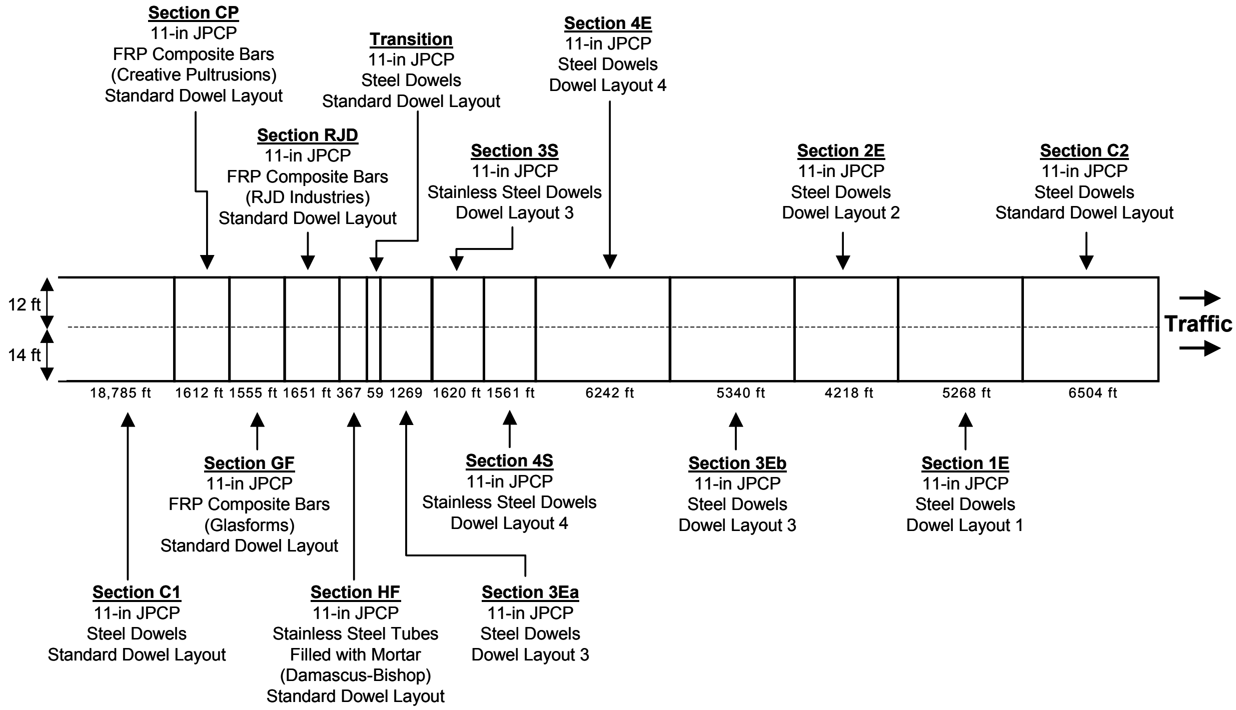

Figure 62. Approximate layout of WI 2 test sections.

Table 30. Experimental design matrix for WI 2.

	11 in JPCP 17-20-18-19 ft Joint Spacing				
	Standard Dowel Layout	**Alternative Dowel Layout 1**	**Alternative Dowel Layout 2**	**Alternative Dowel Layout 3**	**Alternative Dowel Layout 4**
Standard Epoxy-Coated Steel Dowels	Section C1 Section C2	Section 1E	Section 2E	Section 3Ea Section 3Eb	Section 4E
Solid Stainless Steel Dowels *(Avesta Sheffield)*				Section 3S	Section 4S
FRP Composite Dowel Bars *(Creative Pultrusions)*	Section CP				
FRP Composite Dowel Bars *(Glasforms)*	Section GF				
FRP Composite Dowel Bars *(RJD Industries)*	Section RJD				
Stainless Steel Tubes Filled with Mortar *(Damascus-Bishop)*	Section HF				

Wisconsin 3

The westbound lanes of the WI 3 project were constructed in June 1997, whereas the eastbound lanes were constructed in October 1997 (Crovetti 1999). The project includes the evaluation of a variable thickness cross section, an alternative dowel bar layout, and alternative dowel bar materials. The variable thickness cross section uses a 275 mm (11 in) thickness at the outside edge of the outer lane that then tapers to a thickness of 200 mm (8 in) at the far edge of the inner lane (see figure 63). The goal is the more efficient use of materials in areas subjected to greater traffic loading, resulting in more cost-effective designs.

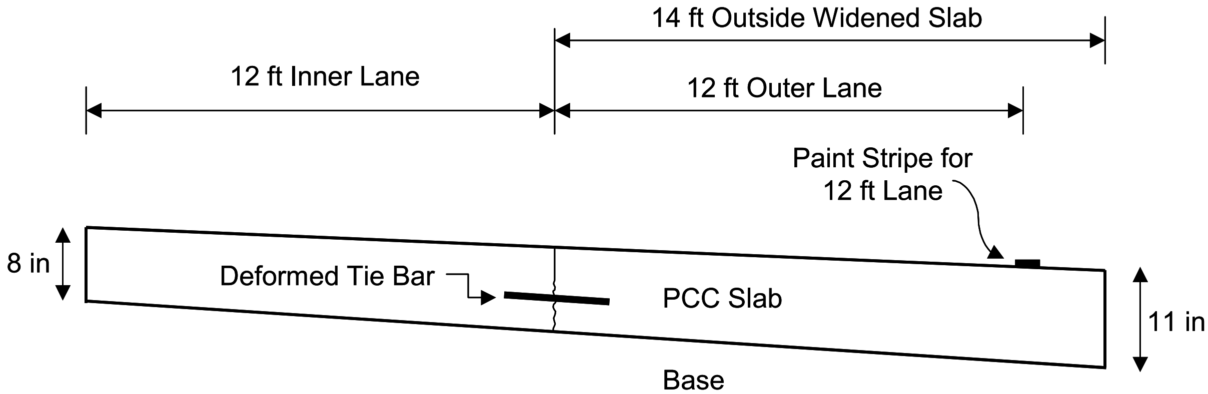

Figure 63. Variable cross section used on WI 3.

The following alternative dowel bar materials are also included on the WI 3 project (Crovetti 1999):

- Standard epoxy-coated dowel bars.
- FRP composite dowel bars, manufactured by MMFG.
- FRP composite dowel bars, manufactured by Glasforms.
- FRP composite dowel bars, manufactured by Creative Pultrusions.
- FRP composite dowel bars, manufactured by RJD Industries.
- Solid stainless steel dowel bars, manufactured by Slater Steels.

The nominal pavement design for these pavement sections is a 275-mm (11-in) JPCP with a uniform joint spacing of 5.5 m (18 ft). However, as previously described, one section has a variable thickness cross section, varying from 275 mm (11 in) for the outer lane, and then tapering to 203 mm (8 in) at the edge of the inner lane. The pavement rests on a 150-mm (6-in) crushed aggregate base course, and the transverse joints contain 38-mm (1.5-in) diameter dowels and are not sealed.

A total of six sections are included in the WI 3 project. The approximate layout of the WI 3 sections being monitored is shown in figure 64. All dowel bars were placed on baskets prior to paving (Crovetti 2001). It is noted that within the section incorporating various FRP composite dowel bars (Section FR), some of the composite dowel bars were improperly distributed between the 3.7-m (12-ft) and 4.3-m (14-ft) baskets, resulting in different manufacturers' bars being placed across some of the inner and outer traffic lanes (Crovetti 1999). The location of the different manufacturers' dowel bars is shown by lane in the blowup illustration in figure 64.

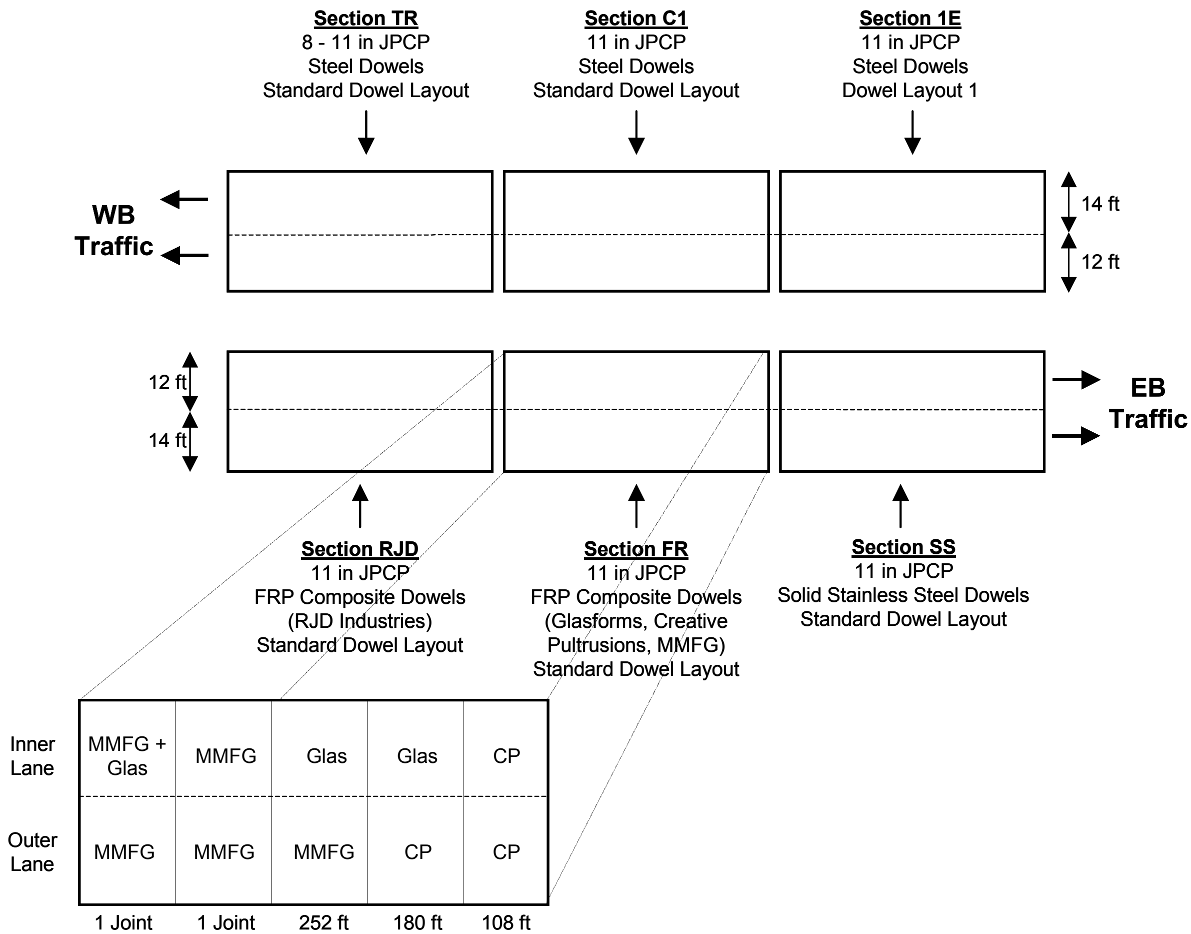

Figure 64. Approximate layout of WI 3 monitoring sections.

The experimental design matrix for the WI 3 project is shown in table 31. Most of the dowel materials are placed in the standard dowel layout, although one section is placed in alternative dowel layout 1. As previously mentioned, all of these sections are included in the SHRP study, and the SHRP code is provided in table 31 for each section.

Table 31. Experimental design matrix for WI 3.

	11-in JPCP 18-ft Joint Spacing		**8- to 11-in JPCP 18-ft Joint Spacing**
	Standard Dowel Layout	**Alternative Dowel Layout 1**	**Standard Dowel Layout**
Standard Epoxy-Coated Steel Dowels	Section C1 (SHRP 550259)	Section 1E (SHRP 550260)	Section TR (SHRP 550263)
Solid Stainless Steel Dowels *(Slater Steels)*	Section SS (SHRP 550265)		
FRP Composite Bars *(MMFG, Glasforms, Creative Pultrusions)*	Section FR (SHRP 550264A)		
FRP Composite Dowel Bars *(RJD Industries)*	Section RJD (SHRP 550264B)		

State Monitoring Activities

WisDOT, in conjunction with Marquette University, is monitoring the performance of these pavement test sections. These monitoring activities include (Crovetti 1999; Crovetti and Bischoff 2001):

- Dowel bar location study—conducted 2 months after construction.
- FWD testing—conducted immediately prior to paving, immediately after paving, and after 6 and 12 months of trafficking.
- Distress surveys—conducted immediately after paving and after 6 and 12 months of trafficking. The distress surveys are being conducted over a nominal 161-m (528-ft) pavement segment selected from within each test section.
- Ride quality surveys—conducted using a pavement profiler and measured on the sections after approximately 1 and 3 years of service.

Continued monitoring of these sections, in the form of FWD testing, distress surveys, and ride quality surveys, will continue through 2004 (Crovetti and Bischoff 2001).

Preliminary Results/Findings

Even though these sections are only 3 years old, some significant findings have been revealed through their early monitoring. These findings are described in the following sections by type of monitoring activity.

Construction Monitoring

A dowel bar inserter (DBI) was used during the construction of WI 2. The DBI easily accommodated the various types of dowel bar materials used in the study, and the DBI also accommodated the various dowel layout patterns with minimal disruption to the paving operations (Crovetti 1999).

Dowel Bar Location Study

With the purpose of determining the depth, longitudinal position, and transverse position of each dowel bar, a dowel bar location study was performed on the WI 2 project 2 months after construction using an impact echo device (Crovetti 1999). A summary of the results from the study are provided in table 32 (Crovetti 1999). Generally, it appears that the dowel bars are slightly deeper than the mid-depth of the slab (140 mm [5.5 in]), and that some vertical skewing of the dowels occurred across the joint. It should be noted that dowel depth data were inconclusive for the stainless steel tubes and the solid stainless steel dowels, and that the device could not provide exact longitudinal and transverse positions of each dowel end (Crovetti 1999).

Table 32. Summary of dowel bar location study results from WI 2 (Crovetti 1999).

Test Section	No. of Joints Tested	Average Depth, West Side of Joint, in	Average Depth, East Side of Joint, in	Average Depth Variation, in
C1 (epoxy-coated steel dowel)	1	6.04	5.86	0.18
CP (FRP composite dowel)	2	6.17	5.97	0.21
GF (FRP composite dowel)	5	6.12	6.00	0.47
RJD (FRP composite dowel)	7	6.04	6.05	0.20

FWD Testing

FWD testing has been conducted several times since the construction of these test sections. Table 33 summarizes the backcalculated k-value and concrete elastic modulus, as well as the total joint deflection (defined as the sum of the deflections from both the loaded and unloaded sides of the joint) obtained from the FWD testing (Crovetti 1999). Generally, the test results are fairly consistent over time, although greater variability was noticed in the June 1998 tests for both directions, presumably because of higher slab temperature gradients (Crovetti 1999). Apparent increases in total joint deflections may be due to FWD testing conducted in the early morning when upward slab curling is likely.

Table 33. Summary of FWD test results for WI 2 and WI 3 projects (Crovetti 1999).

Property	WI 2			WI 3				
	EB lanes			EB lanes			WB lanes	
	Oct 97	Jun 98	Nov 98	Oct 97	Jun 98	Nov 98	Jun 98	Nov 98
Dynamic k-value, $lbf/in^2/in$	312	255	254	364	324	324	255	222
PCC Elastic Modulus, lbf/in^2	3,560,000	3,870,000	4,820,000	3,970,000	5,990,000	6,060,000	5,290,000	6,130,000
Total 9000-lb Joint Deflection, mils	8.96	7.77	8.18	6.70	5.56	8.48	6.23	7.11

Transverse joint load transfer efficiencies were also measured on all test sections using the FWD. Figure 65 illustrates the average transverse joint load transfer for the outermost wheelpath of the WI 2 project, while figure 66 illustrates the average transverse joint load transfer for the outermost wheelpath of the WI 3 project (Crovetti 1999). For WI 2, the late season tests (October 1997 and November 1998) indicate significantly reduced LTE in the composite doweled sections and in dowel layout 1 as compared to the control sections (Crovetti 1999). However, LTE measured in the summer do not indicate any significant differences within the test sections, probably because of the increased aggregate interlock brought about by the closing of the joints due to the warmer temperatures (Crovetti 1999).

For WI 3, figure 66 shows that the FRP composite dowel sections and dowel layout 1 experience a reduction in LTE in the November 1998 test results; there is also a slight reduction in the LTE of the stainless steel section (Crovetti 1999). However, LTE measured in June 1998 do not indicate any significant differences between the test sections.

Distress Surveys

Distress surveys were conducted for both WI 2 and WI 3 in June and December 1998. Some joint distress (spalling, chipping, and fraying of the transverse joints) was observed and is primarily attributable to the joint sawing operations that dislodged aggregate particles near the joint faces (Crovetti and Bischoff 2001). However, this joint spalling has not yet progressed to the point to be considered as low severity based on the Wisconsin DOT Pavement Distress guidelines (Crovetti and Bischoff 2001). Other than the minor joint spalling, no transverse faulting, slab cracking, or other surface distress has been observed to date (Crovetti and Bischoff 2001).

Ride Quality Surveys

Figure 67 presents the average international roughness index (IRI) measurements in the outer lane of the WI 2 and WI 3 pavement sections (Crovetti and Bischoff 2001). These measurements were recorded in the summer of 1998 and the winter of 2000. Although there is some variability in the data, most of the test sections are performing comparably to the control sections (Crovetti and Bischoff 2001).

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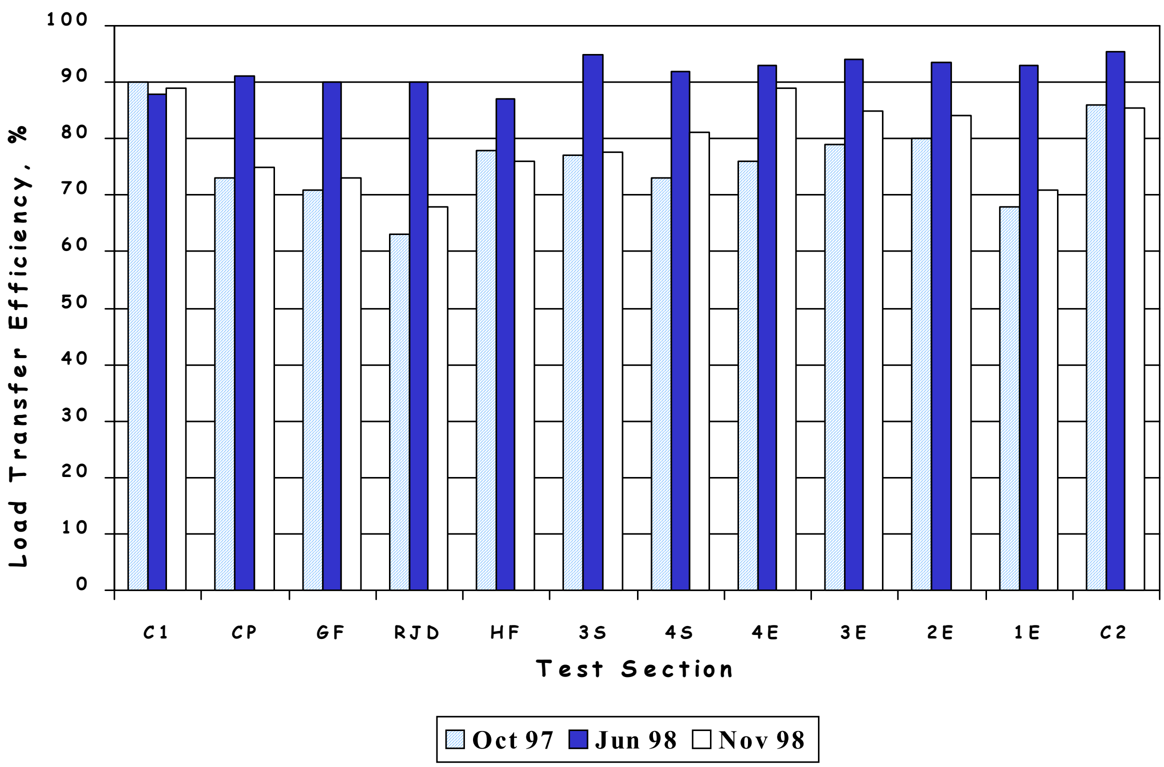

Figure 65. Transverse joint load transfer for outermost wheelpath on WI 2 (Crovetti 1999).

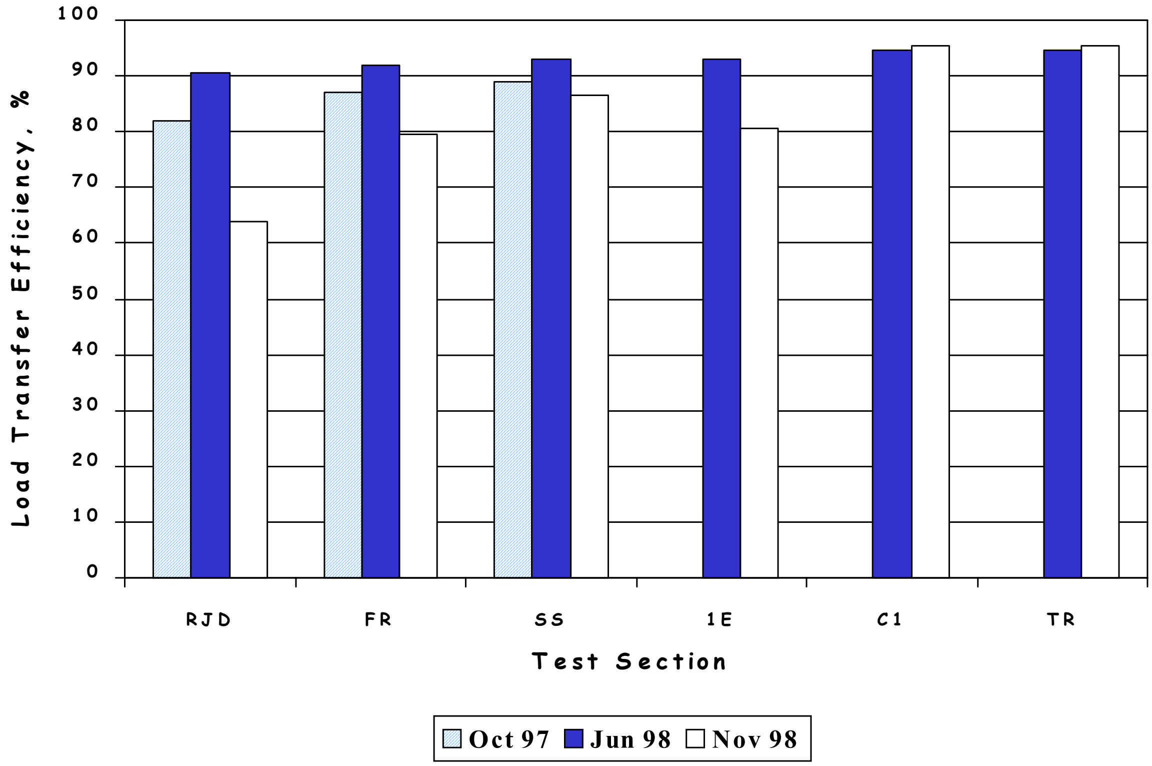

Figure 66. Transverse joint load transfer for outermost wheelpath on WI 3 (Crovetti 1999).

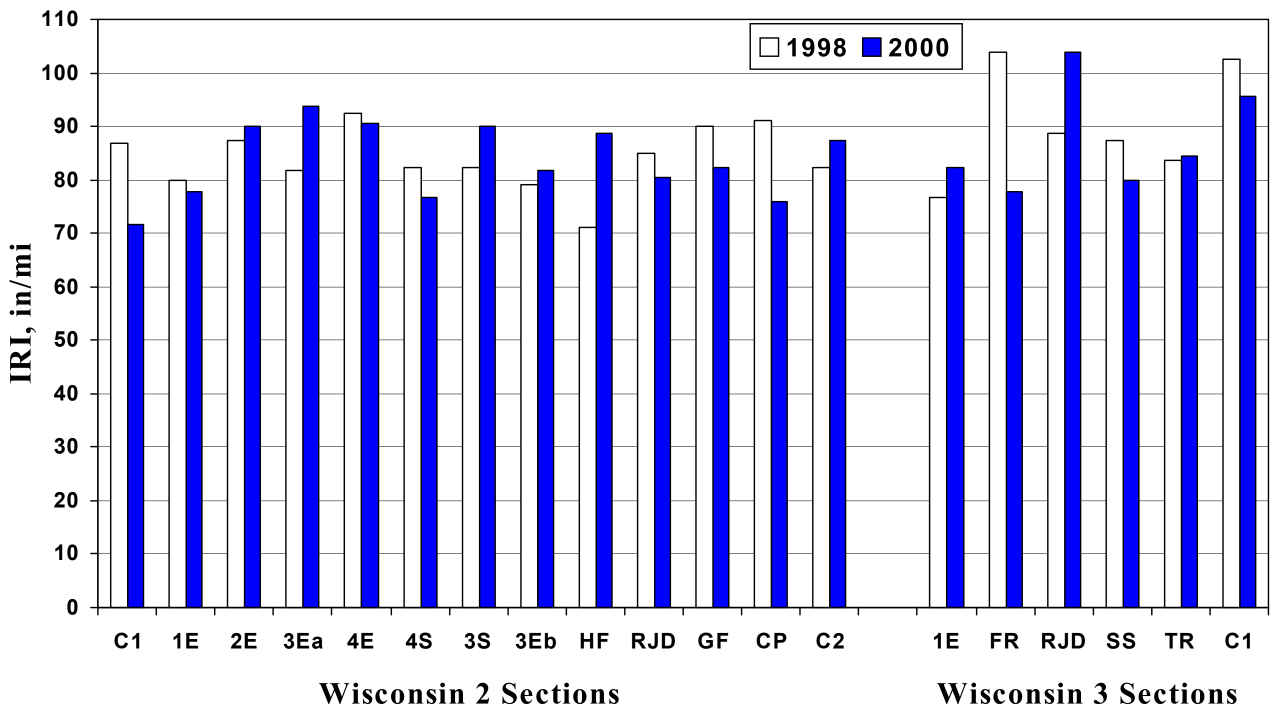

Figure 67. Average IRI values in the outer traffic lanes of WI 2 and WI 3 pavement sections (Crovetti and Bischoff 2001).

References

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CHAPTER 5. ILLINOIS 1 (I-55 SB, Williamsville)

Introduction

This project was the first constructed by the Illinois Department of Transportation (IDOT) to evaluate alternative dowel bars for use in jointed concrete pavements. Constructed in 1996, the project is located on the exit ramp of a weigh station in the southbound direction of I-55 (milepost 107) near Williamsville, just north of Springfield (see figure 2). Although not a TE-30 project, it did serve as a springboard for future IDOT projects evaluating alternative dowel bars under the TE-30 program.

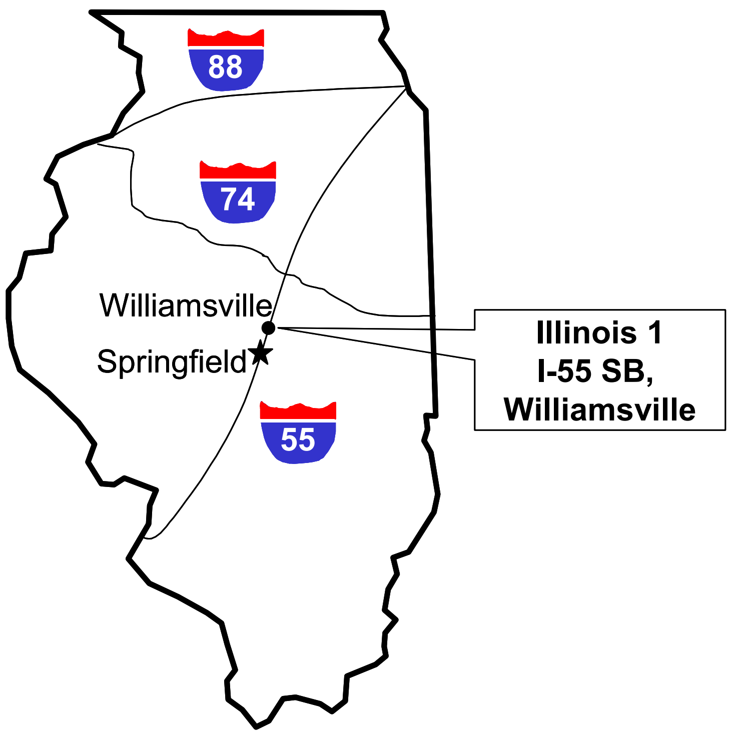

Figure 2. Location of IL 1 project.

Study Objectives

On most concrete pavements, steel dowel bars are used at transverse joints to provide positive load transfer between adjacent slabs. However, even if epoxy coated, these dowel bars are susceptible to corrosion, which can create locked or "frozen" joints that can spall and crack the concrete, significantly reducing the service life of the pavement. The purpose of this study, therefore, is to compare the performance of non-corrosive type 'E' fiberglass and polyester dowels to the performance of conventional epoxy-coated dowel bars in a side-by-side field evaluation project.

Project Design and Layout

This project was constructed in 1996 and consists of a 280-mm (11.25-in) slab placed on a 100-mm (4-in) bituminous aggregate subbase (BAM) (Gawedzinski 2000). In accordance with IDOT practices at the time, the jointed concrete pavement was constructed as a hinge-joint design, in which conventional doweled transverse joints are spaced at 13.7-m (45-ft) intervals and intermediate "hinge" joints containing tie bars are placed at 4.6-m (15-ft) intervals between the doweled joints (see figure 3); this pavement is essentially a jointed reinforced design with the reinforcing steel concentrated at locations where the pavement is expected to crack. The hinge joints contain number 6 epoxy-coated tie bars, 900-mm (36-in) long and placed at 450-mm (18-in) intervals across the joint (Gawedzinski 2000). Preformed compression seals (32-mm [1.25-in] wide) are placed in the doweled transverse joints and a hot-pour joint seal placed in the tied hinge joints (Gawedzinski 2000).

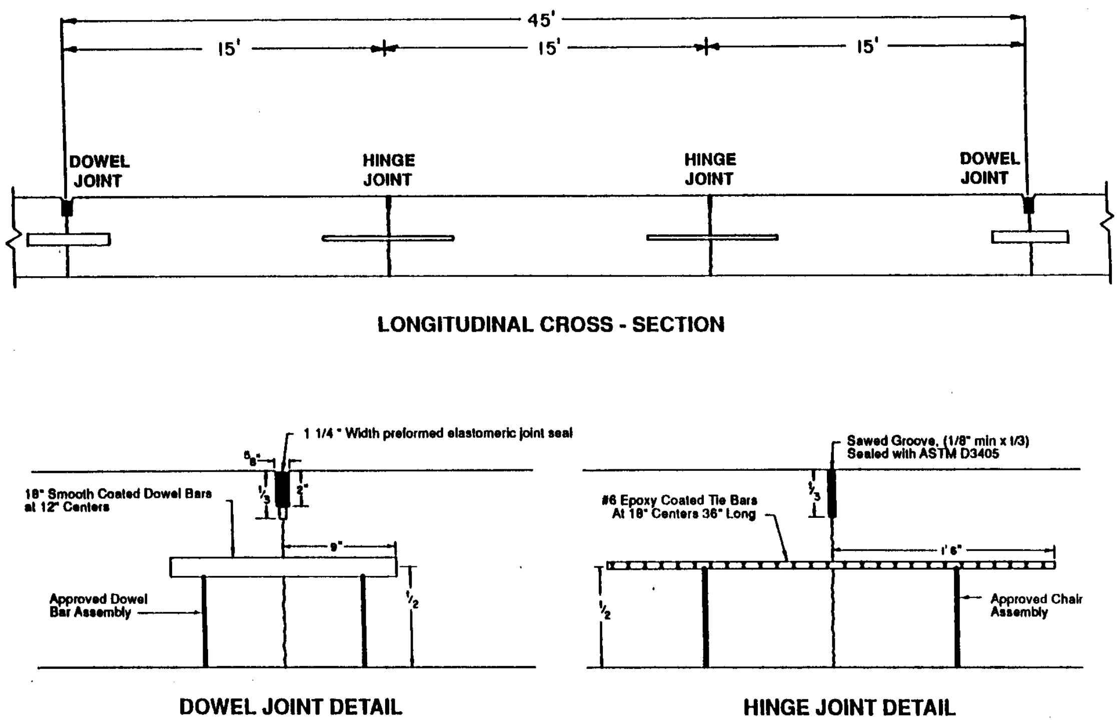

Figure 3. Illinois DOT hinge joint design (IDOT 1989).

The pavement was paved 4.9-m (16-ft) wide, and a 3.0-m (10-ft) tied portland cement concrete (PCC) shoulder was placed adjacent to the mainline exit ramp. The shoulders were tied using number 6 epoxy-coated tie bars, 900-mm (36-in) long and placed at 750-mm (30-mm) intervals (Gawedzinski 2000).

A total of seven joints (excluding hinge joints) are included in the project, the layout of which is shown in figure 4. The first two regular transverse joints of the project contain conventional epoxy-coated steel dowel bars (38-mm [1.5-in] diameter). The next four regular transverse joints contain type 'E' fiberglass and polyester bars (38-mm [1.5-in] diameter and 450-mm [18-in] long). The fiberglass and polyester resin bars were manufactured by RJD Industries of Laguna Hills, CA. The final regular transverse joint in the project contains conventional epoxy-coated steel dowel bars.

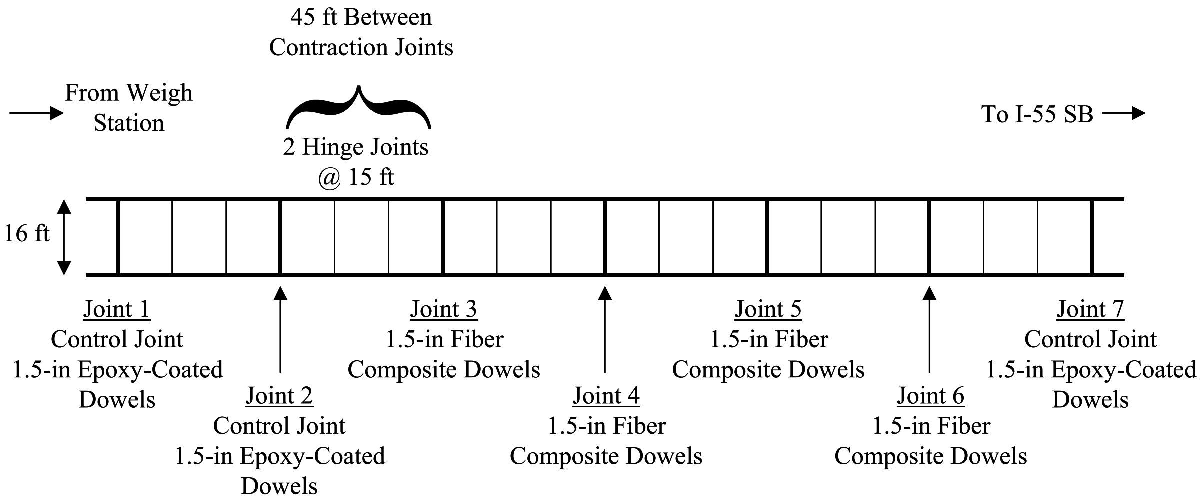

Figure 4. Layout of IL 1 project.

State Monitoring Activities

IDOT collects traffic data from the sorter scale located at the entrance ramp of the weigh station. Traffic totals from the period from September 1996 to September 1999 are summarized in table 2 (Gawedzinski 2000).

Table 2. Traffic data for IL 1 (September 1996 to September 1999) (Gawedzinski 2000).

Truck Type	Number of Vehicles	Accumulated 18-kip ESAL Applications
Single-Unit Trucks	95,623	31,324
Multiple Unit Trucks	1,860,542	3,056,458
TOTALS	1,956,165	3,087,783

All seven joints in the project are evaluated at least semi-annually by IDOT to assess their performance. This evaluation consists of both distress surveys and nondestructive testing using the falling weight deflectometer (FWD). Results from the FWD testing program are plotted in figures 5 and 6 (Gawedzinski 2000). Figure 5 shows the load transfer across each of the seven joints as a function of time, whereas figure 6 shows the maximum joint deflection measured at each joint as a function of time.

A gradual decrease in overall load transfer efficiency is observed in figure 5, with the conventional steel dowel bars consistently showing higher levels of load transfer then the fiber composite bars. But, as seen in figure 6, the largest deflection is consistently shown by one of the conventional doweled joints, although the other two conventional doweled joints show consistently low deflections. However, for both load transfer types, the load transfer efficiency is still relatively high and the magnitude of the joint deflections relatively low.

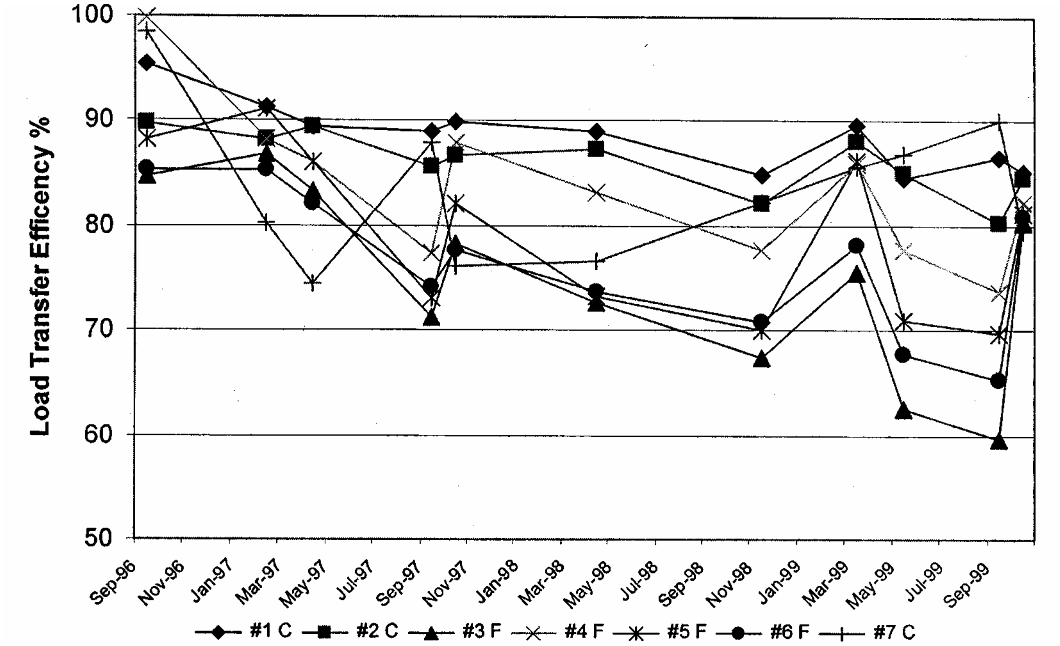

Figure 5. Load transfer efficiency on IL 1 (Gawedzinski 2000).

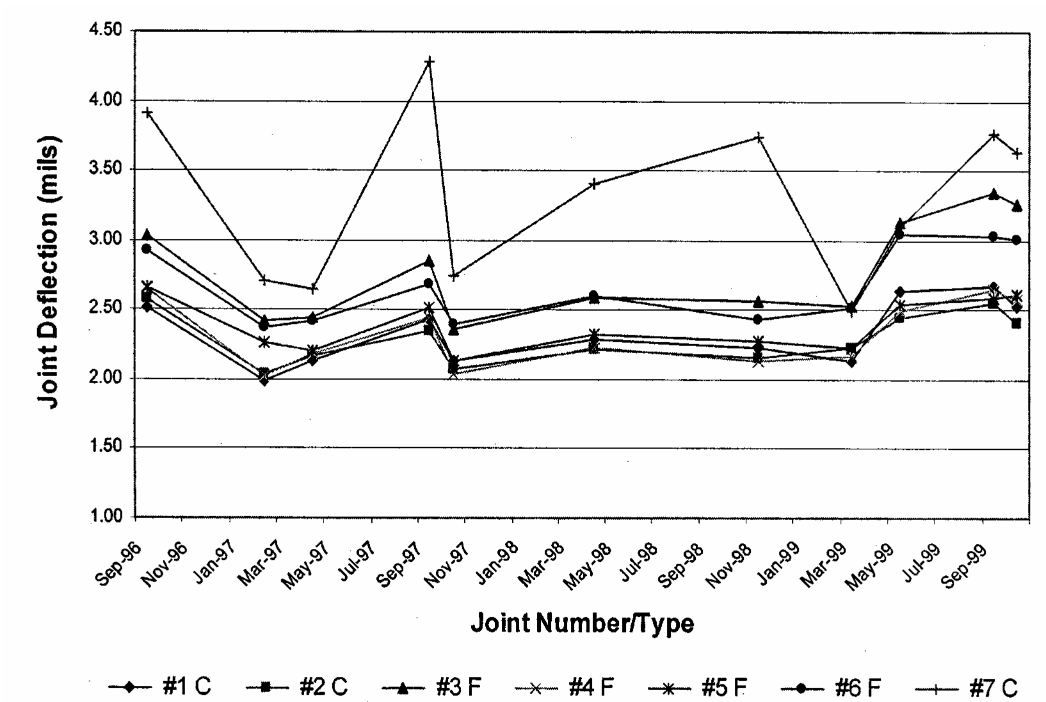

Figure 6. Maximum joint deflections on IL 1 (Gawedzinski 2000).

Preliminary Results/Findings

After about 4 years of service, this project is performing well. None of the joints is exhibiting any signs of distress. IDOT will continue monitoring the project to assess the relative performance of the different dowel bar types.

Interim Project Status, Results & Findings

Truck data continues to be gathered from the sorter scale installed in the entrance ramp of the weigh station. Equivalent Single Axle Loads (ESALs) were computed using scale vendor software and standard IDOT design coefficients. Reported ESAL counts are lower than actual applied ESALs due to the failure of the hard drive on the sorter scale computer for a 13½ month period of time from January 23, 2002 to March 13, 2003. ESAL counts for the missing period of time were projected using the truck data previously gathered from the scale and manual counts obtained from scale operators. Cumulative ESAL estimates are provided in table 3 (Gawedzinski 2004).

Table 3. Cumulative ESALs as of the Day of FWD Testing (Gawedzinski 2004).

Date	Cumulative ESALs
09/26/96	1519.7
2/18/97	292,817.5
4/22/97	485,194.8
9/23/97	1,047,809.7
10/28/97	1,167,329.0
4/27/98	1,637,109.1
11/17/98	2,173,905.1
3/24/99	2,525,120.4
5/13/99	2,719,695.7
9/28/99	3,114,261.8
10/6/99	3,164,730.8
4/13/00	3,710,619.8
6/14/01	5,704,438.6
10/11/01	6,487,023.9
4/17/02	7,551,381.9
10/3/02	8,666,353.0
4/16/03	9,719,309.1
6/11/30	9,841,810.9
10/2/03	10,075,492.5
10/24/03	10,103,714.9

Visual observations of the joints show no obvious signs of pavement distress; neither faulting nor spalling was evident at any of the seven joints. The original construction had the joints sealed with a preformed elastomeric joint seal material compressed into a 5/8" thick saw cut. Over time, the preformed elastomeric joint material has been pushed deeper into the saw cut, especially in the wheel paths. Load Transfer Efficiency Percentage (LTE %) and joint deflection values were determined for each of the seven pavement joints. The average values were determined from deflections measured as simulated 4, 8, and 12 kip loads were applied to the pavement on the approach and leave sides of the joints. The joints were tested at both inner and outer wheel paths and at the center of the lane for a total of 18 tests per joint.

Figure 7 (Gawedzinski 2004) provides a summary of the LTE % versus ESALs, as measured over time. Figure 8 (Gawedzinski 2004) provides a graph of average pavement temperature at a four inch depth verses LTE %.

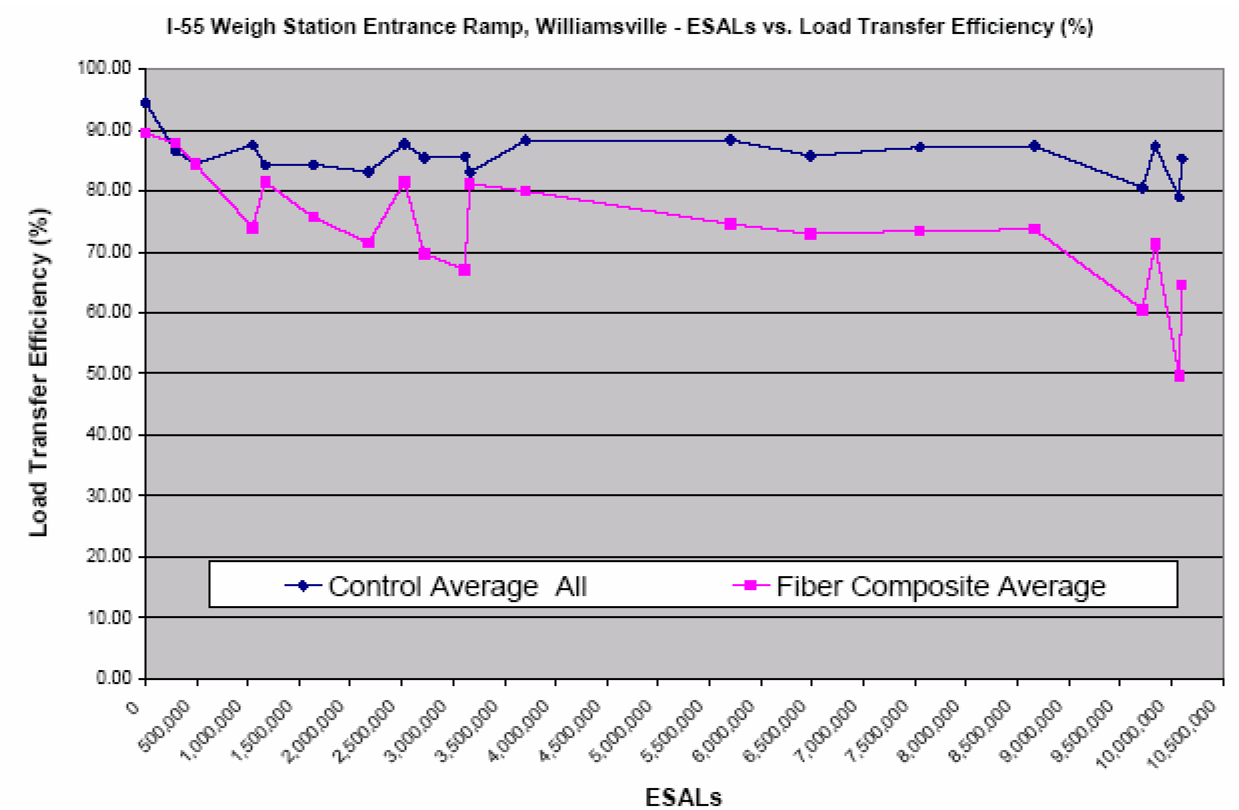

Figure 7. Load Transfer Efficiency vs ESALs (Gawedzinski 2004).

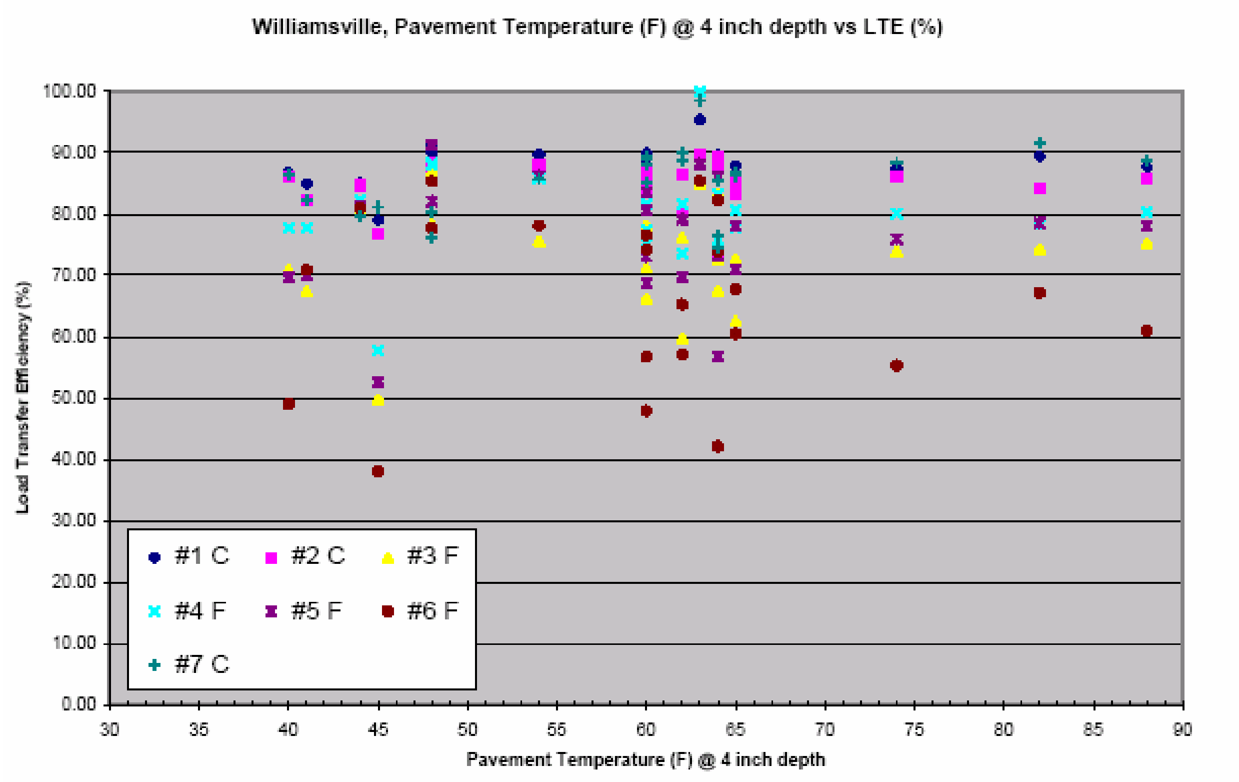

Figure 8. Load Transfer Efficiency vs Pavement Temperature (Gawedzinski 2004).

Current Observations (Gawedzinski 2004)

Williamsville is the oldest TE-30 test site in Illinois, at 7½ years, and over 10.1 million ESALs. The joints at Williamsville show very little sign of distress or damage. The preformed elastomeric joint seal is still intact showing only that it is deeper in the joints under the wheel paths. Overall, only very minor spalling is displayed at the joints; however, it is not known if this was due to damage during the cutting of the original saw cuts or if it has occurred over time. Evaluation of the FWD data indicate that, on average, the fiber composite dowel bars perform somewhat less effectively than the carbon steel control dowel bars. Graphs showing the individual joint performance show that changes in deflection and LTE% are related to the "overall pavement system" performance, rather than changes in individual joint performance. Dips and spikes in deflection and LTE % are similar to some degree for all of the joints, rather than the joints behaving individually. More frequent FWD testing is planned for the Williamsville site in order to evaluate what causes this response for the bars. Data show LTE% and joint deflection do not appear to be affected by changes in pavement temperature. It is unknown what the moisture content is at the dowel bar/joint interface and how much the moisture content effects LTE% and joint deflections.

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CHAPTER 6. ILLINOIS 2 (Route 59, Naperville)

Introduction

The first TE-30 project constructed in Illinois is located in the southbound lanes of Illinois Route 59 between 75th and 79th Streets, just east of Naperville, a suburb of Chicago (see figure 7). This is IDOT's second project evaluating alternative dowel bar materials, and was constructed in 1997 as part of the reconstruction and widening of Illinois Route 59 (Gawedzinski 2000).

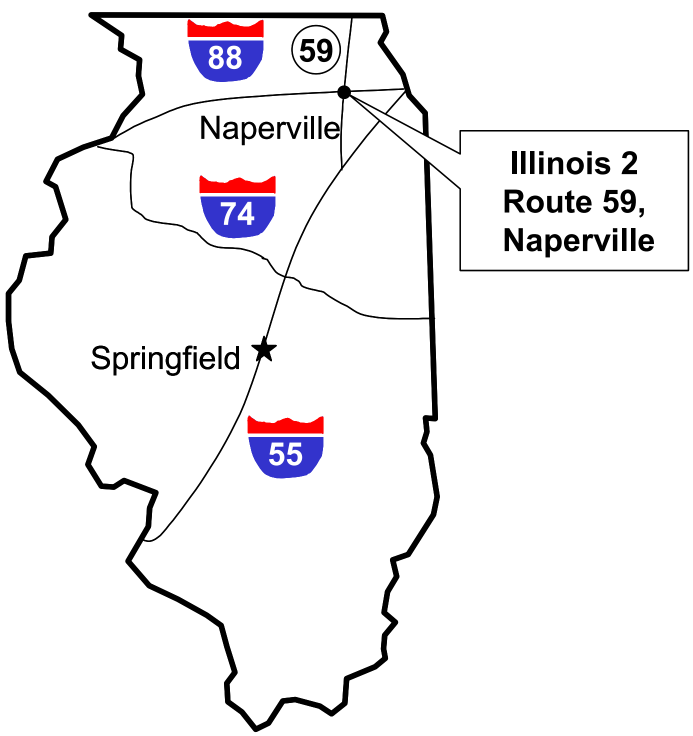

Figure 7. Location of IL 2 project.

Study Objectives

The purpose of this project is to continue IDOT's investigation into alternative dowel bar materials by comparing the performance of IDOT's standard steel dowel bars to several different types of alternative dowel bars (Gawedzinski 2000). This project essentially expands on the IL 1 study by incorporating additional alternative dowel bars from several other manufacturers.

Secondary objectives of the study include an evaluation of different transverse joint reservoir designs and a comparison of different traffic counters. Transverse joint reservoir designs include a standard transverse joint configuration containing preformed joint seals, narrow-width joints containing a hot-poured sealant, and narrow-width joints left unsealed. The traffic counters included in the project are conventional loop detectors/piezo electric axle sensors and a new device that measures traffic-induced changes to the earth's magnetic field (Gawedzinski 2000).

Project Design and Layout

This project was constructed in 1997 and consists of a 255-mm (10-in) slab placed on a 305-mm (12-in) aggregate base course (Gawedzinski 2000). A porous granular embankment subgrade (PGES) material meeting the gradation shown in table 3 is located beneath the aggregate base course (Gawedzinski 1997).

Table 3. Gradation of PGES crushed stone material.

Sieve Size	Percent Passing
150 mm (6 in)	97 ± 3
100 mm (4 in)	90 ± 10
50 mm (2 in)	45 ± 25
75 µm (#200)	5 ± 5

Pavement designs for the experimental sections consist of both hinge-joint designs and all-doweled designs. As described for IL 1, the hinge-joint design contains conventional doweled transverse joints spaced at 13.7-m (45-ft) intervals and intermediate "hinge" joints containing tie bars at 4.6-m (15-ft) intervals between the doweled joints (see figure 3). The hinge joints contain number 6 epoxy-coated tie bars, 900-mm (36-in) long and placed at 450-mm (18-in) intervals across the joint. The all-doweled designs have transverse joints spaced at 4.6-m (15-ft) intervals and contain dowel bars across every joint. The project has three lanes in the southbound direction (total width of 10.8-m [36-ft]), with the inside and center lanes paved together and the outside lane paved later. A tied curb and gutter was placed adjacent to both the inside and outside lanes.

In addition to pavement design, another variable being evaluated under the study is type of load transfer device. The following five load transfer devices are included (Gawedzinski 1997; Gawedzinski 2000):

- Conventional 38-mm (1.5-in) diameter epoxy-coated steel dowel bars conforming to ASTM M227.
- 38-mm (1.5-in) diameter polyester and type E fiberglass dowel bars, manufactured by RJD Industries.
- 44-mm (1.75-in) diameter polyester and type E fiberglass dowel bars, manufactured by RJD Industries.
- 38-mm (1.5-in) diameter polyester and type E fiberglass dowel bars, manufactured by Corrosion Proof Products, Inc.
- 38-mm (1.5-in) diameter epoxy resin and type E fiberglass dowel bars, manufactured by Glasforms, Inc.

Joint width and joint sealant are other variables that are being evaluated under the study. Two of the sections were constructed with 16-mm (0.62-in) wide transverse joints; these were used on the hinge-joint designs only, and were sealed with preformed elastomeric joint seals conforming to AASHTO M220 (Gawedzinski 2000). The other six sections were constructed with narrow 3-mm (0.12-in) transverse joints; five of these were sealed with a hot-poured sealant conforming to ASTM D3405 and one section was left unsealed (Gawedzinski 1997).

The layout of the sections is presented in figure 8. This figure summarizes the main features included in each of the sections. The experimental design matrix for this project is shown in table 4.

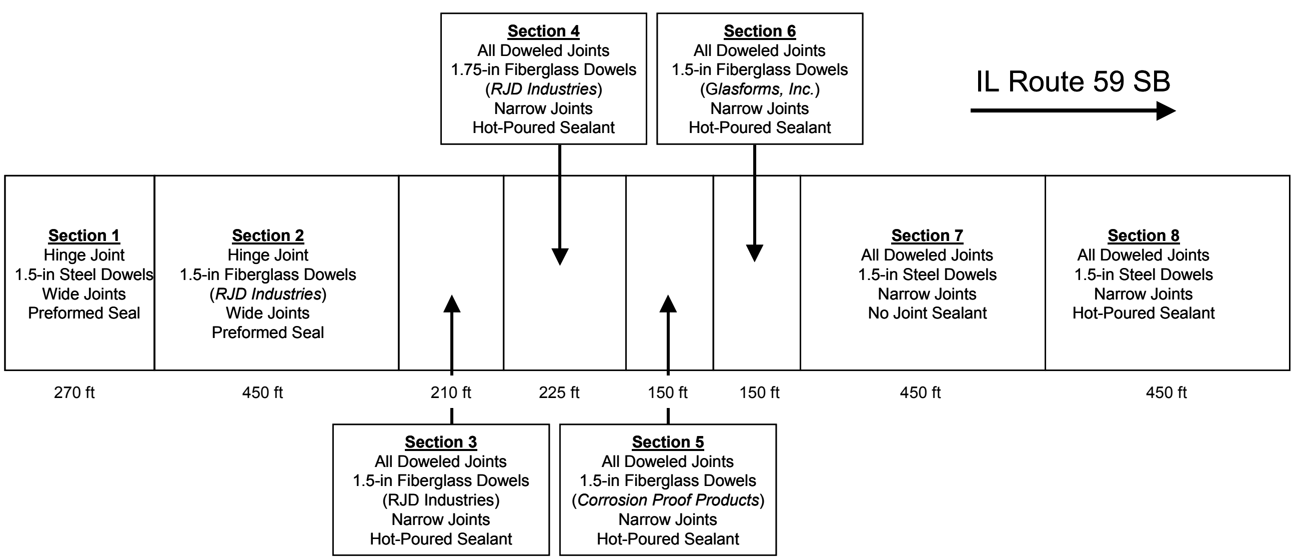

Figure 8. Layout of IL 2 project.

State Monitoring Activities

IDOT collects traffic data for the three southbound lanes and the three northbound lanes using the following devices:

- Peek 241 traffic classifier.
- Nu-Metrics Groundhog® traffic sensors.

The Peek 241 uses traditional traffic loop detectors placed in the subbase, with piezo electric axle sensors installed in channels sawed in the surface of the pavement (Gawedzinski 1997). The Groundhog® uses changes in the earth's magnetic field to classify vehicles, and requires only a 178-mm (7-in) diameter hole cored in the new pavement to install the device. However, problems were encountered with the Groundhog® device and therefore no comparisons between the devices are possible (Gawedzinski 2000).

Table 4. Experimental design matrix for IL 2.

	JRCP Hinge-Joint Design 45-ft Joint Spacing			**JPCP All-Doweled Joints 15-ft Joint Spacing**		
	Preformed Seal (wide joints)	**Hot-Poured Sealant (narrow joints)**	**No Sealant**	**Preformed Seal (wide joints)**	**Hot-Poured Sealant (narrow joints)**	**No Sealant**
38-mm (1.5-in) Epoxy-Coated Steel Dowel Bars	Section 1 (270 ft long, 6 doweled joints)				Section 8 (450 ft long, 30 doweled joints)	Section 7 (450 ft long, 30 doweled joints)
38-mm (1.5-in) Polyester and Type E Fiberglass Dowel Bars (*RJD Industries*)	Section 2 (450 ft long, 10 doweled joints)				Section 3 (210 ft long, 14 doweled joints)	
44-mm (1.75-in) Polyester and Type E Fiberglass Dowel Bars (*RJD Industries*)					Section 4 (225 ft long, 15 doweled joints)	
38-mm (1.5-in) Polyester and Type E Fiberglass Dowel Bars (*Corrosion Proof Products, Inc.*)					Section 5 (150 ft long, 10 doweled joints)	
38-mm (1.5-in) Epoxy-Resin and Type E Fiberglass Dowel Bars (*Glasforms, Inc.*)					Section 6 (150 ft long, 10 doweled joints)	

Traffic data for the three experimental southbound lanes are summarized in table 5 (Gawedzinski 2000). These data are for the period of September 25, 1997 to January 31, 2000. The number of ESALs for each lane was estimated by applying the percentage of vehicles in each lane to the total number of ESALs that were reported for all three traffic lanes (1,515,401).

Table 5. Traffic data for IL 2 (September 25, 1997 to January 31, 2000) (Gawedzinski 2000).

Project Traffic Lane	**Total Number of Vehicles**	**% of All Vehicles**	**Estimated ESALs Based on Vehicle %**
Outside Lane 1	4,687,659	28.6	433,404
Middle Lane 2	6,040,237	36.8	557,668
Center Lane 3	5,689,235	34.6	524,329
TOTALS	16,417,687	100.0	1,515,401

This project is evaluated by IDOT on at least a semi-annual basis. This evaluation consists of both distress surveys and nondestructive testing using the FWD. Results from the FWD testing program are plotted in figures 9 and 10 for sections 1 through 6 only (Gawedzinski 2000). Figure 9 shows the average load transfer for these six test sections as a function of time, whereas figure 10 shows the average maximum joint deflection measured for these six test sections as a function of time.

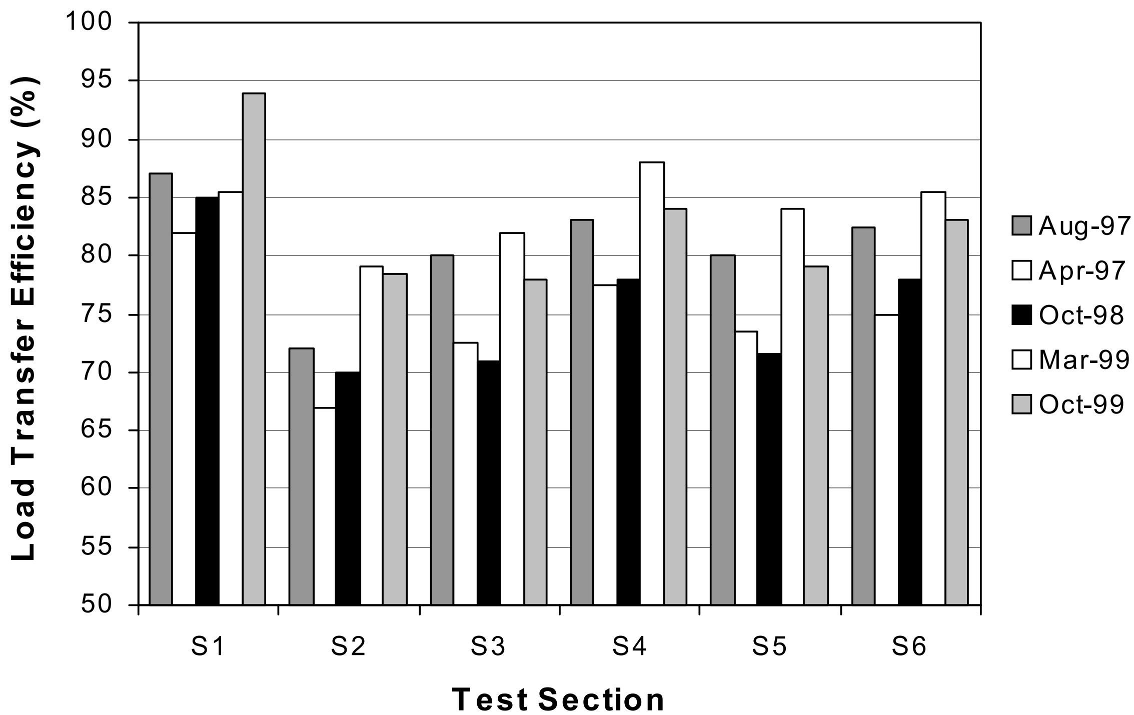

Figure 9. Load transfer efficiency on IL 2 (Gawedzinski 2000).

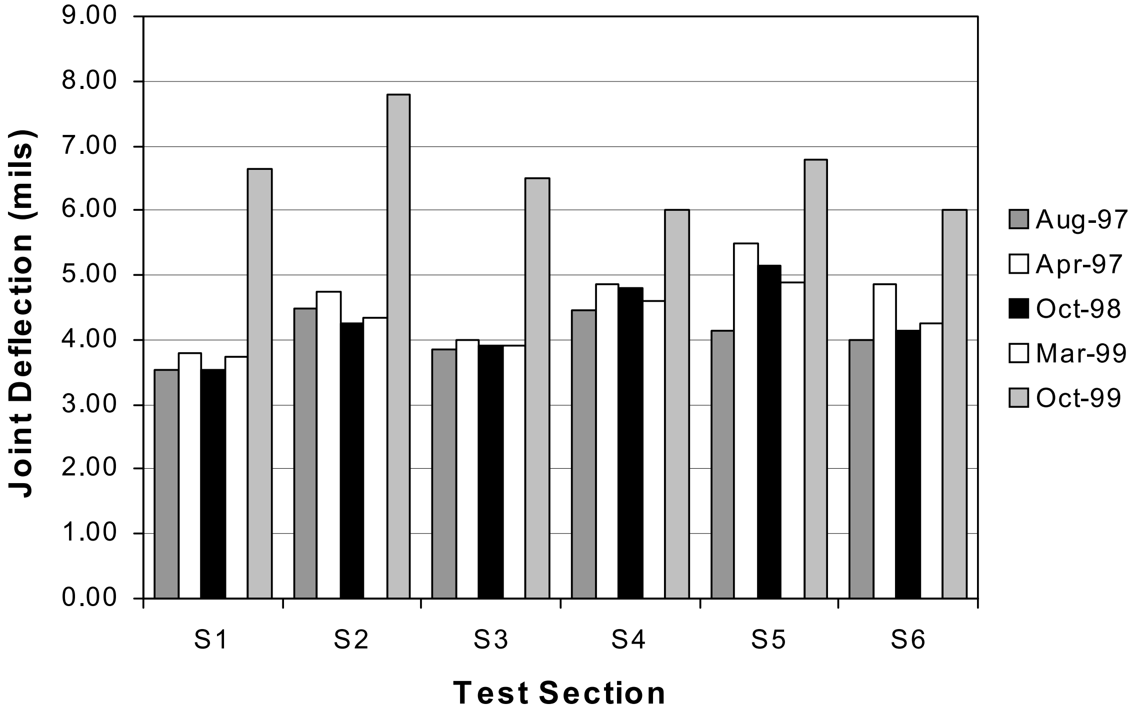

Figure 10. Maximum joint deflections on IL 2 (Gawedzinski 2000).

The best overall load transfer is exhibited by section 1, which contains the conventional steel dowel bars. The other sections all vary from about 70 to 85 percent, but it is interesting to note how the load transfer fluctuates over time, presumably because of the season and the temperature at the time of testing. Figure 10 shows that the maximum deflections for all joints is increasing over time, with the maximum deflection at the most recent testing (October 1999) significantly larger for all six sections than the previous maximum deflection values.

Preliminary Results/Findings

After about 3 years of service, this project is performing well. None of the joints is exhibiting any signs of distress. IDOT will continue monitoring the project to assess the relative performance of the different dowel bar types and of the sealed/unsealed joints.

One issue for consideration in future installations of fiber composite dowel bars is the method used to secure the bar to the basket. During the construction of the middle and inner lanes of this project, it was noted that the fiber composite bars were loose and only partially attached to the upper support wire of the basket (Gawedzinski 1997). A special metal spring clip provided by RJD Industries was ultimately used to secure the dowel bars to the dowel basket and also to provide an additional frictional force to the bar to prevent it from moving as concrete was placed over the basket (Gawedzinski 1997).

Interim Project Status, Results & Findings

Traffic data were obtained using preformed loop detectors and piezo sensors placed in each of the three lanes. The detectors and sensors were wired to a Model 241Traffic Classifier produced by Peek Traffic. In August of 2002, the traffic classifier was replaced with a Road Reporter manufactured by International Traffic Corporation/PAT America, Inc. Daily traffic files are polled periodically and tabulated to provide monthly traffic totals for classification. Standard conversion factors used by the Illinois Department of Transportation are used to convert Single Unit (SU) and Multiple Unit (MU) truck counts to ESALs. In May of 2003, land development work on the properties on the east side of IL 59 resulted in an east-west access road intersecting IL 59 at the location of the traffic classifier loops and piezo sensors. Traffic signals associated with the new road necessitated relocating the traffic classifier site approximately 0.4 miles to the south. Work on relocating the site will be complete in 2004. Cumulative ESAL information for each lane, as reported by the Illinois Department of Transportation (Gawedzinski 2004) are provided in table 6.

FWD tests are currently performed annually across all of the test sections. Certain sections were dropped from the FWD testing for a period of time due to traffic safety issues. These issues were resolved and now FWD results are obtained for both wheel paths and the center of the lane for all three lanes. Visual observations of joint performance are performed periodically, noting any changes in the appearance of the pavement. Results of the FWD tests are provided in figures 11 through 13 for the right, center and left lanes respectively.

Table 6. Traffic data for IL 2 (September 25, 1997 to June 16, 2003) (Gawedzinski 2004).

Date	Cumulative ESALs		
	Right Lane	Center Lane	Left Lane
8/25/97	1,751	4,288	1,008
4/6/98	73,677	146,779	33,118
10/19/98	160,540	306,559	71,363
3/29/99	210,187	412,343	95,277
10/13/99	319,964	614,230	141,165
4/24/00	393,299	761,761	173,867
10/16/00	480,678	909,423	212,076
5/15/01	560,141	981,053	280,037
5/1/02	661,433	1,110,816	326,719
6/16/03	728,208	1,249,667	357,084

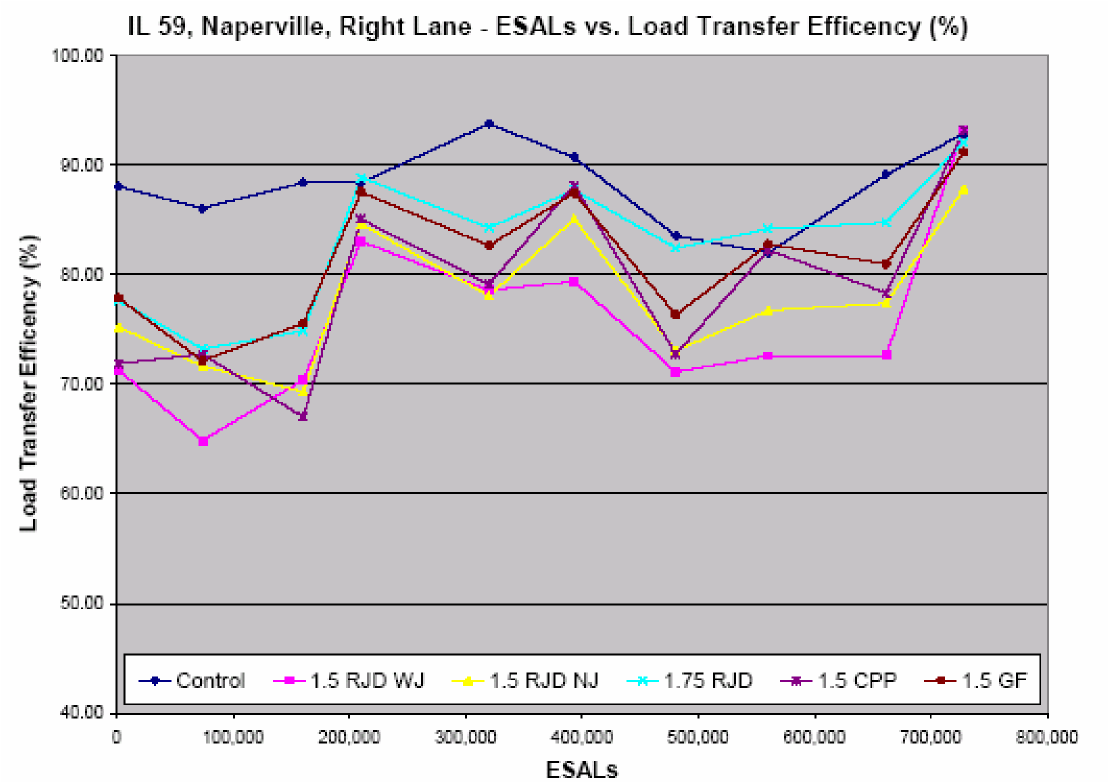

Figure 11. Load Transfer Efficiency vs ESALs for the Right Lane (Gawedzinski 2004).

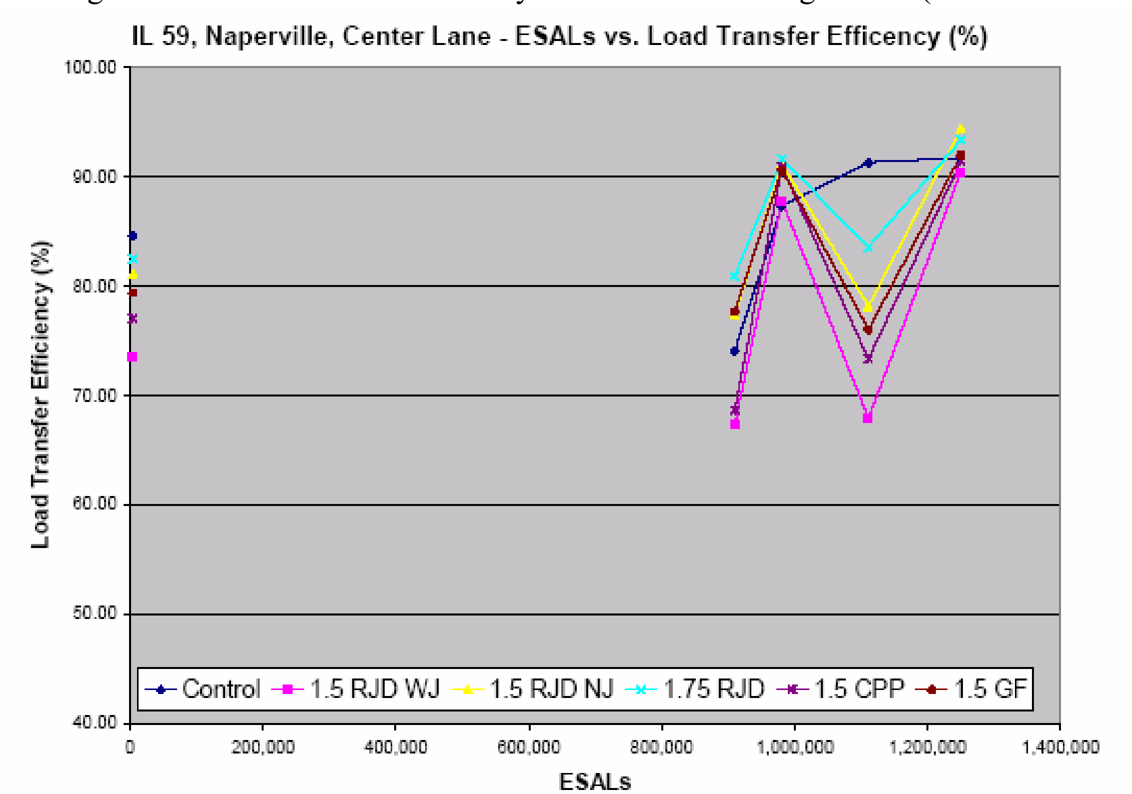

Figure 12. Load Transfer Efficiency vs ESALs for the Center Lane (Gawedzinski 2004).

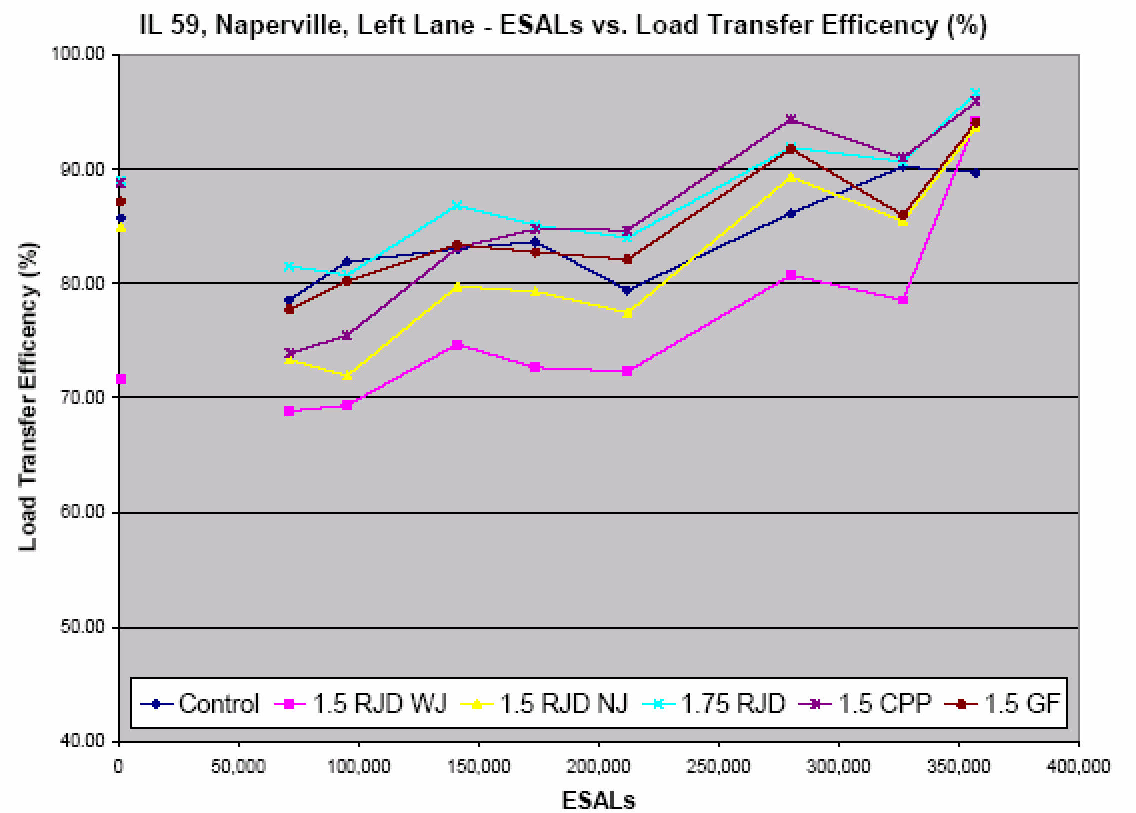

Figure 13. Load Transfer Efficiency vs ESALs for the Left Lane (Gawedzinski 2004).

Current Observations (Gawedzinski 2004)

Evaluation of the joints shows typical behavior of the joints and the joint sealer/filler material with no obvious signs of spalling or faulting. The preformed elastomeric joint sealer remains intact, while the ASTM D-6690 (formerly ASTM D-3405) material is acting more as joint filler in that there are areas across several joints where the material has become disbonded from the pavement, allowing water and incompressibles into the joint.

Observations of the LTE% vs. time and ESALs graphs, as well as the joint deflection vs. time and ESALs graphs, show somewhat consistent behavior for joint deflection, with sections averaging between 3 to 5 mils. LTE% graphs show behavior consistent with a decrease in joint deflection. Figure 14 shows the same type of behavior displayed at the Williamsville, IL test site (Illinois 1). Plots of average values show no relationship between LTE% or joint deflection and average pavement temperature. The control bars (1½" Ø epoxy coated carbon steel) have a higher LTE% and lower joint deflection than any of the fiber composites, but the overall performance of the fiber composite bars appears to be very close to the behavior of the epoxy coated steel control set.

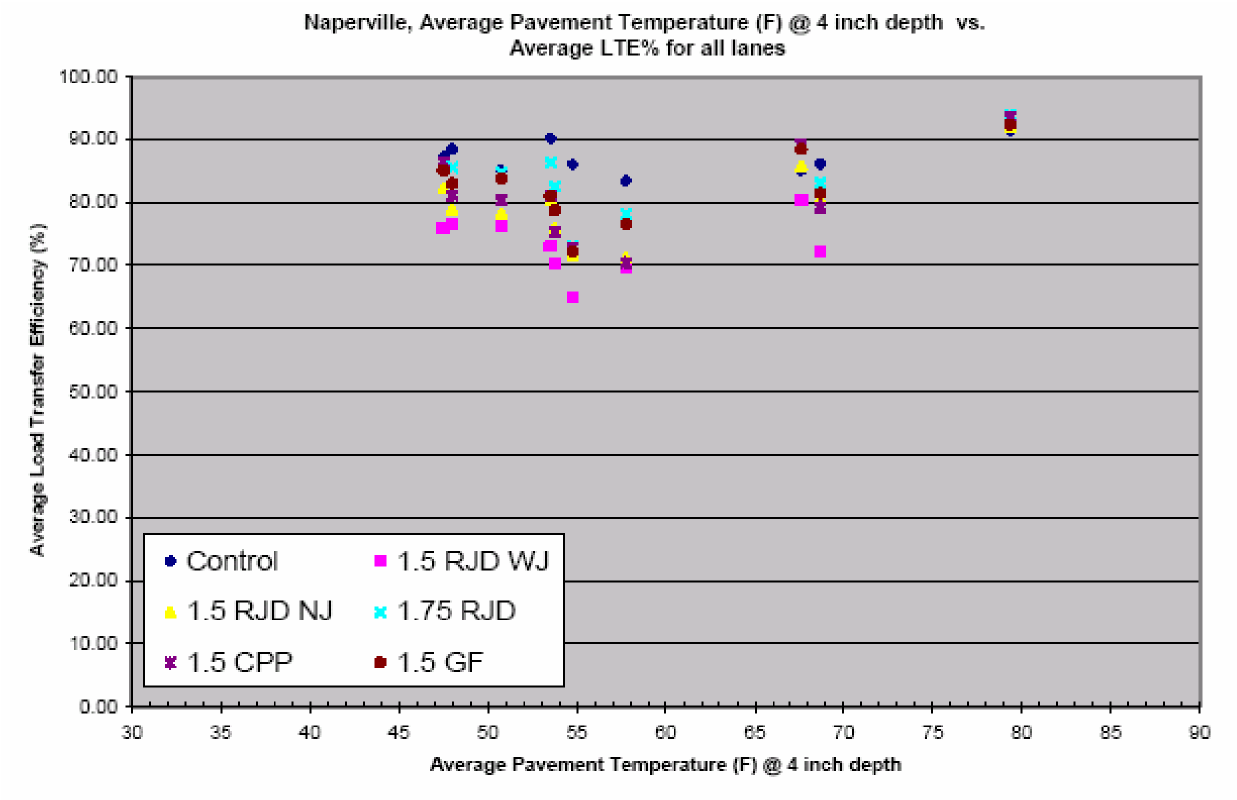

Figure 14. Average Load Transfer Efficiency vs Pavement Temperature for all Lanes (Gawedzinski 2004).

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CHAPTER 7. ILLINOIS 3 (U.S. Route 67, Jacksonville)

Introduction

IDOT's second TE-30 project, and their third evaluating alternative dowel bar materials, is located on the two westbound lanes of U.S. Route 67, west of Jacksonville (see figure 11). This project was constructed in 1999.

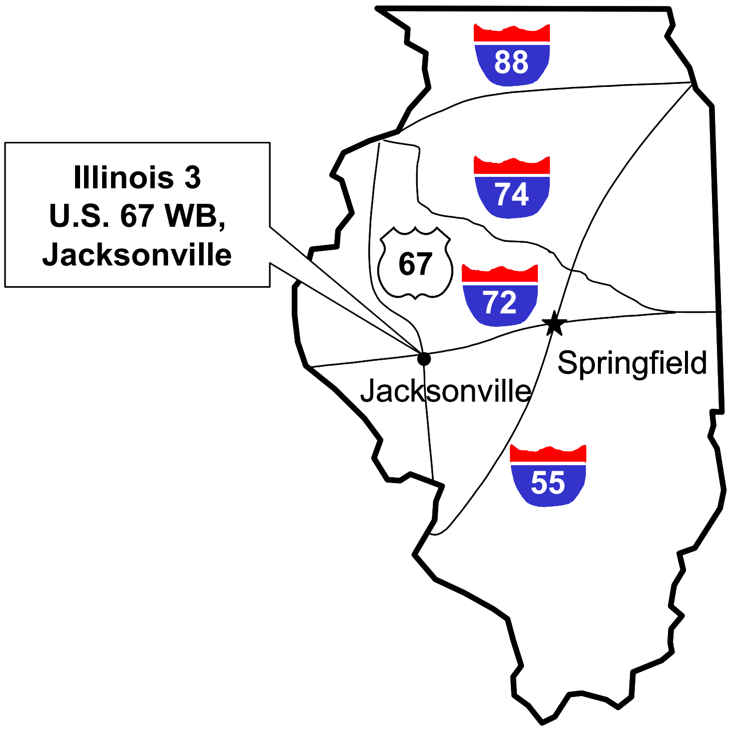

Figure 11. Location of IL 3 project.

Study Objectives

This project continues IDOT's investigation of alternative dowel bar materials and joint sealing effectiveness (Gawedzinski 2000). Several additional fiber composite dowel bars are evaluated in this study that were not included in previous studies, and these comparisons are all done using IDOT's now standard all-doweled jointed plain concrete pavement (JPCP) design. In addition, an unsealed section is included to further investigate the performance of unsealed joints.

Project Design and Layout

Constructed in 1999, the basic pavement design for each section is a 250-mm (10-in) thick JPCP placed on a 100-mm (4-in) cement aggregate mixture (CAM) base course (Gawedzinski 2000). The existing subgrade was stabilized to a depth of 300 mm (11.8 in) with lime (Gawedzinski 2000). Transverse joints are spaced at 4.6-m (15-ft) intervals and tied concrete shoulders are incorporated as part of the construction project.

The project consists of seven test sections evaluating alternative dowel bar materials and unsealed joints. The following load transfer devices are included in the study (Gawedzinski 2000):

- 38-mm (1.5-in) diameter polyester and type E fiberglass dowel bars, manufactured by RJD Industries.
- 38-mm (1.5-in) diameter vinyl ester and type E fiberglass dowel bars, manufactured by Strongwell (Morrison Molded Fiber Glass Company).
- 38-mm (1.5-in) diameter vinyl ester and type E fiberglass dowel bars, manufactured by Creative Pultrusions, Inc.
- Fiber-Con™ dowel bar, manufactured by Concrete Systems, Inc. and consisting of a fibrillated type E fiberglass and polyester resin tube filled with hydraulic cement.
- 38-mm (1.5-in) diameter carbon steel rods clad with grade 316 stainless steel, manufactured by Stelax Industries Inc.
- Conventional 38-mm (1.5-in) diameter epoxy-coated steel dowel bars conforming to ASTM M227.

All but one of the sections was sealed with a hot-poured joint sealant conforming to ASTM D 3405. One section was left unsealed to compare the performance of pavements with unsealed joints to that of sealed joints.

The layout of the sections is presented in figure 12. This figure summarizes the main features included in each of the sections. The experimental design matrix for this project is shown in table 6.

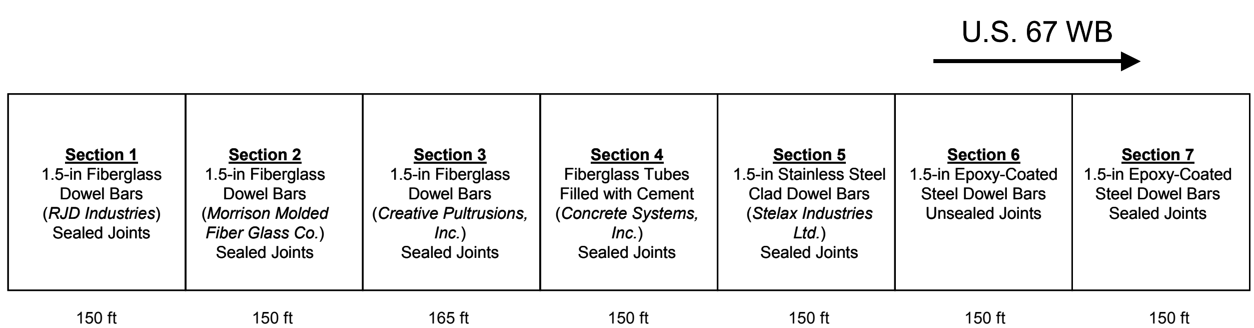

Figure 12. Layout of IL 3 project.

State Monitoring Activities

IDOT installed an automatic traffic recording station at the project site in February 2000. Traffic data are recorded using a Peek series 3000 ADR traffic classifier (Gawedzinski 2000). No traffic data are currently available.

Table 6. Experimental design matrix for IL 3.

	250-mm (10-in) JPCP 4.6-m (15-ft) Joint Spacing	
	Sealed Joints (ASTM D3405)	**Unsealed Joints**
38-mm (1.5-in) diameter polyester and type E fiberglass dowel bars (*RJD Industries*)	Section 1 (150 ft long, 10 joints)	
38-mm (1.5-in) diameter vinyl ester and type E fiberglass dowel bars (*Morrison Molded Fiber Glass Company*)	Section 2 (150 ft long, 10 joints)	
38-mm (1.5-in) diameter vinyl ester and type E fiberglass dowel bars (*Creative Pultrusions, Inc.*)	Section 3 (150 ft long, 11 joints)	
Fiber-Con™ dowel bar, consisting of a fibrillated type E fiberglass and polyester resin tube filled with hydraulic cement (*Concrete Systems, Inc.*)	Section 4 (150 ft long, 10 joints)	
38-mm (1.5-in) diameter carbon steel rods clad with grade 316 stainless steel (*Stelax Industries Inc.*)	Section 5 (150 ft long, 10 joints)	
38-mm (1.5-in) diameter epoxy-coated steel dowel bars	Section 7 (150 ft long, 10 joints)	Section 6 (150 ft long, 10 joints)

Before the pavement was opened to traffic, IDOT conducted FWD testing on the experimental sections in June 1999. Results from the FWD testing program are plotted in figures 13 and 14 (Gawedzinski 2000). Figure 13 shows the average load transfer for the seven experimental sections in both the driving and passing lanes, whereas figure 14 shows the average maximum joint deflection measured for each of the seven experimental sections in both the driving and passing lanes. Although the joint deflections are low, the load transfer efficiencies are not as high as might be expected for a new concrete pavement. These initial FWD results will serve as a baseline for comparison with future testing values.

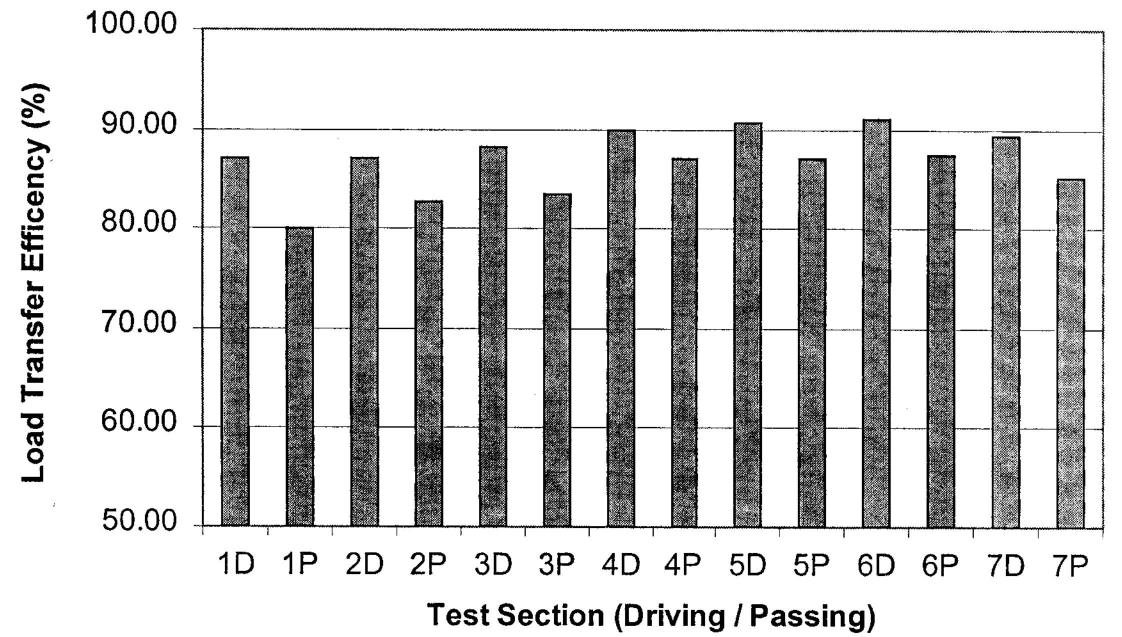

Figure 13. Load transfer efficiency on IL 3 (Gawedzinski 2000).

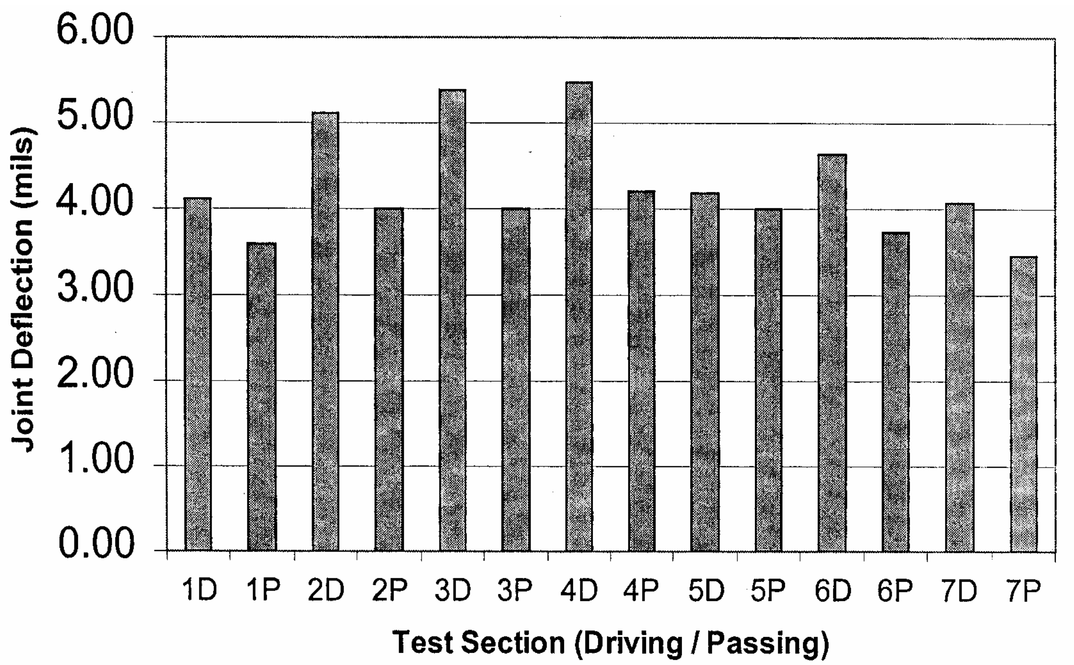

Figure 14. Maximum joint deflections on IL 3 (Gawedzinski 2000).

Preliminary Results/Findings

This pavement is performing well after 1 year of service. None of the joints are exhibiting any signs of distress. IDOT will continue monitoring the project to assess the relative performance of the different dowel bar types and of the sealed/unsealed joints.

Interim Project Status, Results & Findings

FWD tests are conducted semi-annually along with periodic visual observations of joint performance. Traffic data is collected using an ADR 3000, manufactured by Peek Traffic. The data is periodically polled and converted to ESALs using standard IDOT conversion factors. A summary of the cumulative ESALs is provided in table x.

Joints are also periodically observed, to look for signs of joint deterioration or distress. Joints were formed using a thin saw cut and sealed with an ASTM D 6690 (formerly ASTM D 3405) hot pour joint seal material. Problems affecting ride quality became apparent, due to several of the joints being overfilled with the 3405 joint seal material. Subsequent evaluations noted failure of the 3405 joint seal material to maintain a bond with either side of the pavement at the joint.

Table x. Current Traffic for Driving and Passing Lanes (Gawedzinski 2004).

Date	Cumulative ESALs	
	Driving Ln	Passing Ln
6/23/99	0	0
6/27/00	68,604	9,7420
10/10/00	95,413	13,764
4/18/01	160,805	22,940
10/11/01	240,558	34,305
4/18/02	310,034	43,193
10/01/02	372,800	48,871
4/16/03	442,221	54,892
10/21/03	493,053	59,488
11/25/03	504,163	

Current Observations (Gawedzinski 2004)

Several joints were observed where the joint seal material was either missing from the wheel paths, or had been pushed deeper in the joint and was debonded from both sides of the pavement joint. A large amount of small rocks were also compressed into the joint seal material at the joint surface. As with the other sites (IL 1 & IL 2) no obvious signs of joint distress were apparent during the visual observations.

Similar behavior as observed at the older two sites (IL 1 & IL2) is shown in the following figures. The control set (1½" Ø epoxy coated steel), unsealed epoxy coated steel bars, stainless steel cald carbon steel bars, and fibrillated wound fiber composite bars exhibit better LTE% and lower joint deflections than the pultruded fiber composite bars, but do not show excessive joint deflection indicating failure of the joints. Pavement at Jacksonville (IL 3) was constructed on a cement aggregate mixture subbase (CAM2 w/ a minimum of 200 lbs of cement per cubic yard) rather than a granular subbase as in Naperville (IL 2) or a bituminous aggregate mixture subbase (BAM) at Williamsville (IL 1).

An additional FWD test was performed on the driving lane of US 67 in November of 2003 to evaluate the joint deflections which had occurred earlier that year. Testing was not conducted in the passing lanes due to traffic control problems at the time of the November tests. The large shift in average joint deflection vales between the April and October tests necessitated the November retest. More frequent testing is scheduled for 2004.

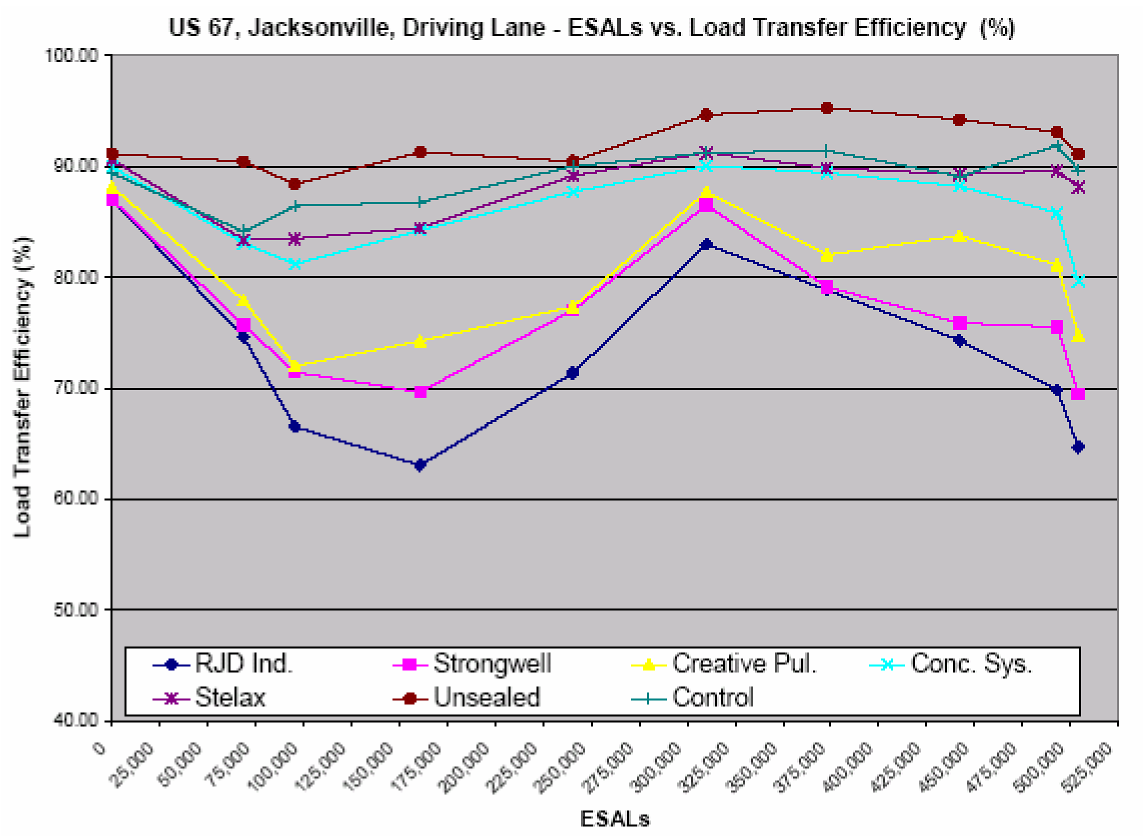

Figure xx. Driving Lane Load Transfer Efficiency vs ESALs (Gawedzinski 2004).

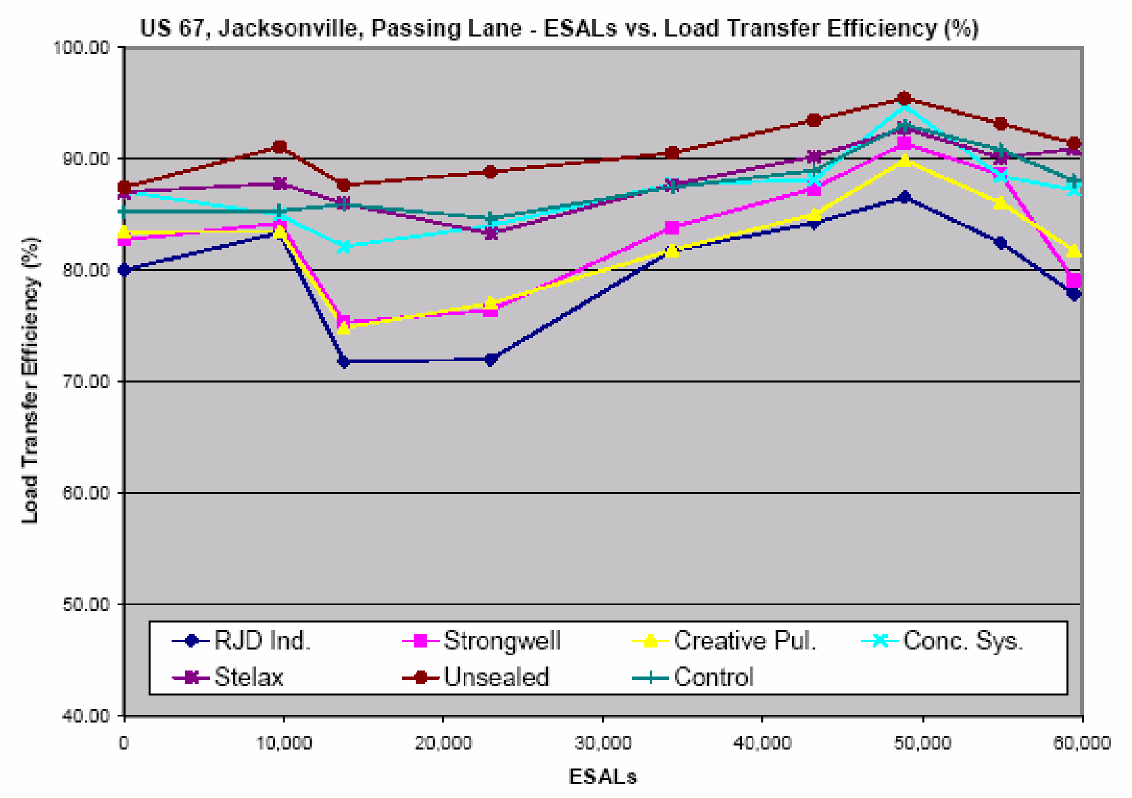

Figure xx. Passing Lane Load Transfer Efficiency vs ESALs (Gawedzinski 2004).

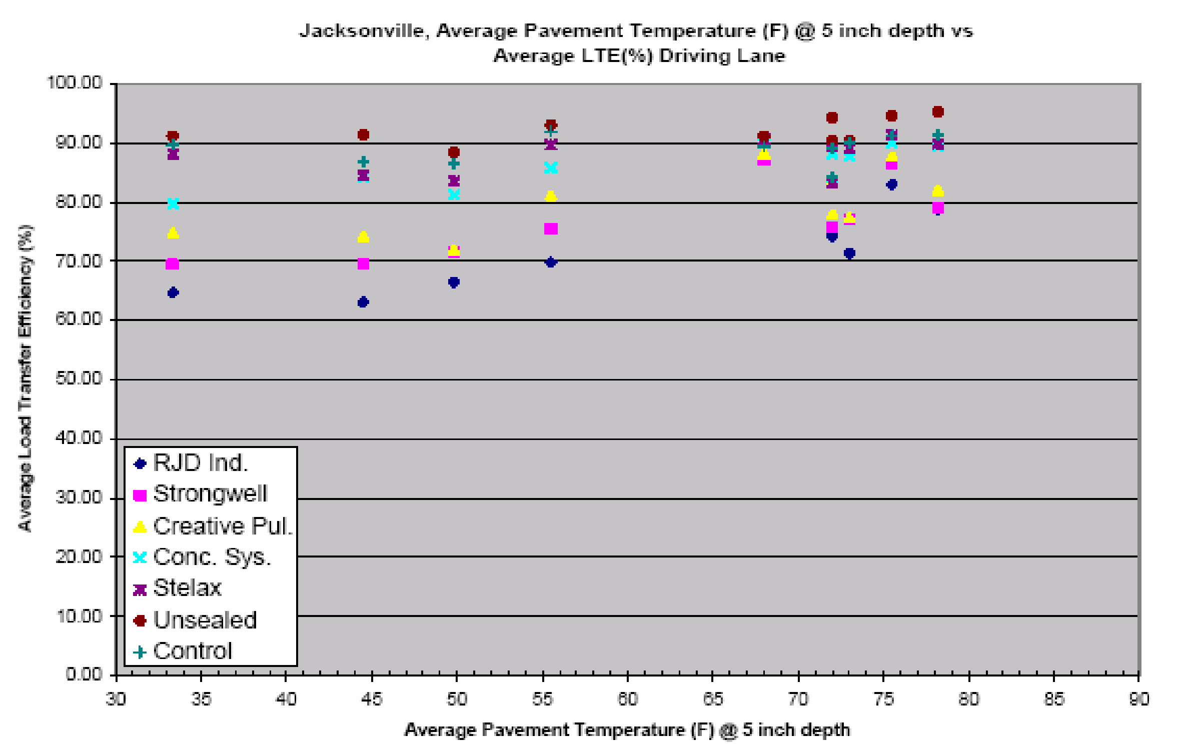

Figure xx. Average Load Transfer Efficiency vs Average Pavement Temperature (Gawedzinski 2004).

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Reference

Gawedzinski, M. 2000. *TE-30 High Performance Rigid Pavements Illinois Project Review*. Illinois Department of Transportation, Springfield, IL.

Gawedzinski, M. 2004. *TE-30 High Performance Concrete Pavements: An Update of Illinois Projects*. Illinois Department of Transportation, Springfield, IL.

CHAPTER 8. ILLINOIS 4 (Route 2, Dixon)

Introduction

A fourth project evaluating alternative dowel bars was constructed by IDOT in the April 2000. The experimental project is located in the driving lane of the northbound direction of Illinois Route 2 in Dixon (see figure 15) where it replaces an existing concrete pavement (Gawedzinski 2000).

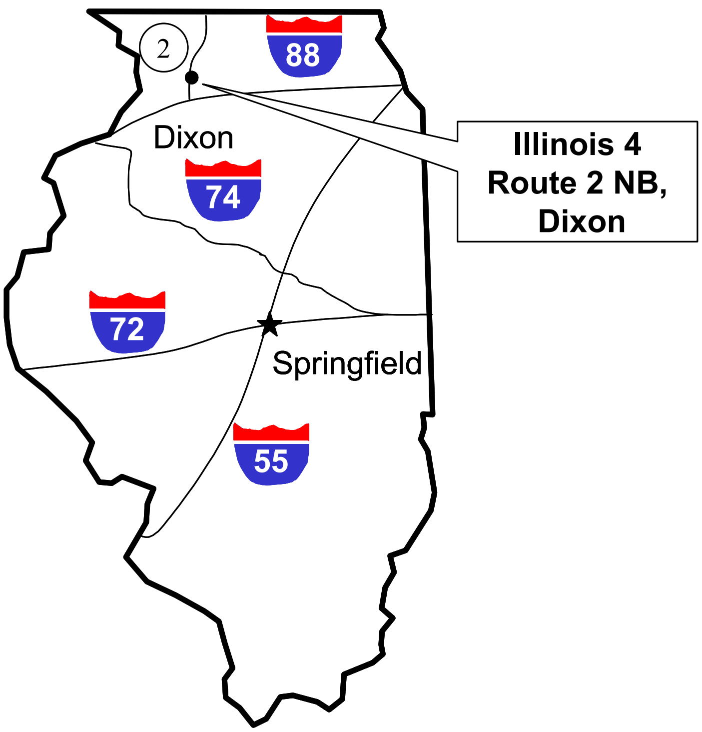

Figure 15. Location of IL 4 project.

Study Objectives

Although not an official TE-30 project, this project carries on IDOT's investigation of alternative dowel bar materials. The alternative dowel bar materials used in the project included stainless steel tubes filled with cement grout, stainless steel clad carbon steel tubes, and fiber composite tubes filled with cement grout. Two different diameters, 38-mm (1.5 in) and 44.5-mm (1.75 in), were used for the stainless steel tubes and for the stainless steel clad dowels. The fiber composite tubes were formed using a pultrusion process and were approximately 50-mm (2 in) in diameter. The pultrusion process produced a much smoother bar, compared to the first generation, fibrillated bars. Additionally two different methods of securing the bars to the baskets, welding and using cable ties, were used in the four sections. Additional construction details are presented in the literature.

Project Design and Layout

The pavement design for each section is a 240-mm (9.5-in) doweled JPCP placed over a 300-mm (12-in) granular base course (Gawedzinski 2000). Transverse joints are spaced at 4.6-m (15-ft) intervals and are sealed with a hot-poured sealant. A tied curb and gutter is placed adjacent to the outer driving lane of the project.

The experimental project consists of five test sections evaluating the following alternative dowel bar materials (Gawedzinski 2000):

- Fiber-Con™ dowel bar, manufactured by Concrete Systems, Inc. and consisting of a pultruded fiber composite tube composed of type 'E' fiberglass and polyester resin and filled with hydraulic cement.
- 38-mm (1.5-in) diameter, 2.76 mm (0.109 in) thick grade 316 stainless steel tube filled with cement grout.
- 44.5-mm (1.75-in) diameter, 2.76 mm (0.109 in) thick grade 316 stainless steel tube filled with cement grout.
- 38-mm (1.5-in) diameter carbon steel rods clad with grade 316 stainless steel, manufactured by Stelax Industries Inc.
- 44.5-mm (1.75-in) diameter carbon steel rods clad with grade 316 stainless steel, manufactured by Stelax Industries Inc.

Conventional load transfer devices are installed in JPCP sections adjacent to the experimental pavement sections.

State Monitoring Activities

Traffic data will be recorded using a Peek series 3000 ADR traffic classifier. IDOT obtained baseline FWD deflection data after the pavement was constructed and will monitor its performance on at least a semi-annual basis.

Interim Project Status, Results & Findings

Data has been collected on a semi-annual basis for the past three years. The cumulative ESALs are provided in table xx. Results of deflection testing are illustrated in the following figures.

Table xx. Data Collection Date and Cumulative ESALs (Gawedzinski 2004).

Date	Cumulative ESALs
8/1/00	0
5/1/01	20,780
10/1/01	50,036
4/25/02	62,701
10/2/02	76,872
4/3/03	93,982
10/3/03	125,533

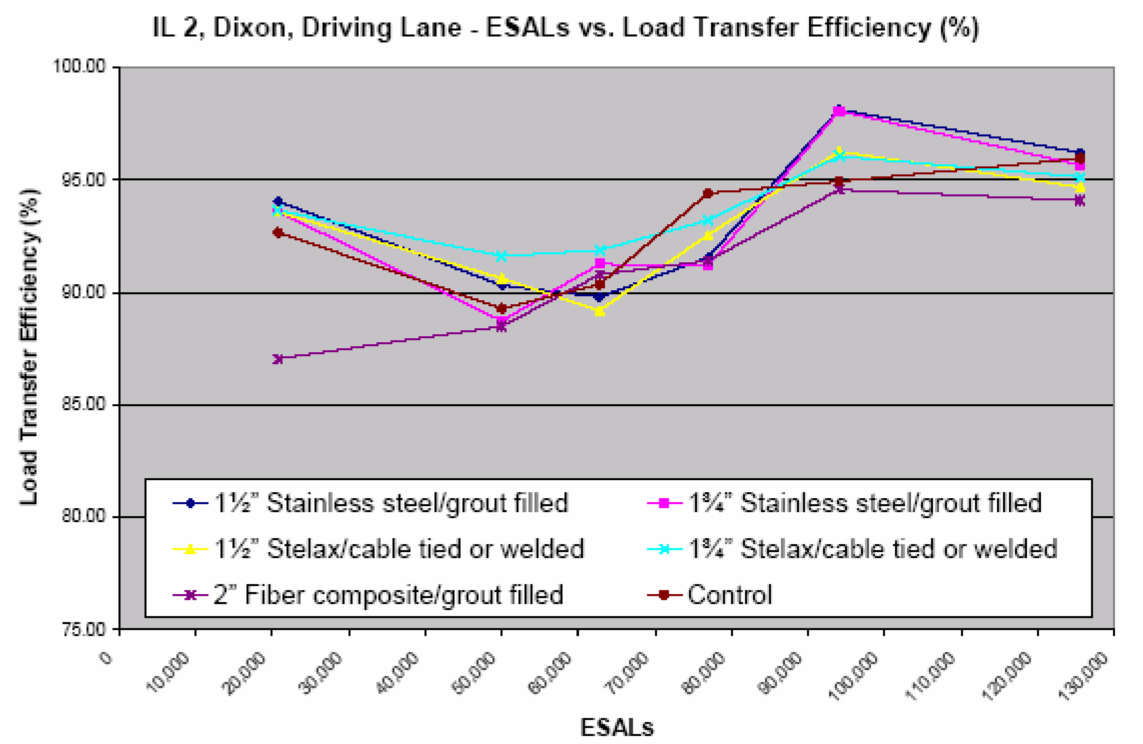

Figure xx. Driving Lane Load Transfer Efficiency vs ESALs (Gawedzinski 2004).

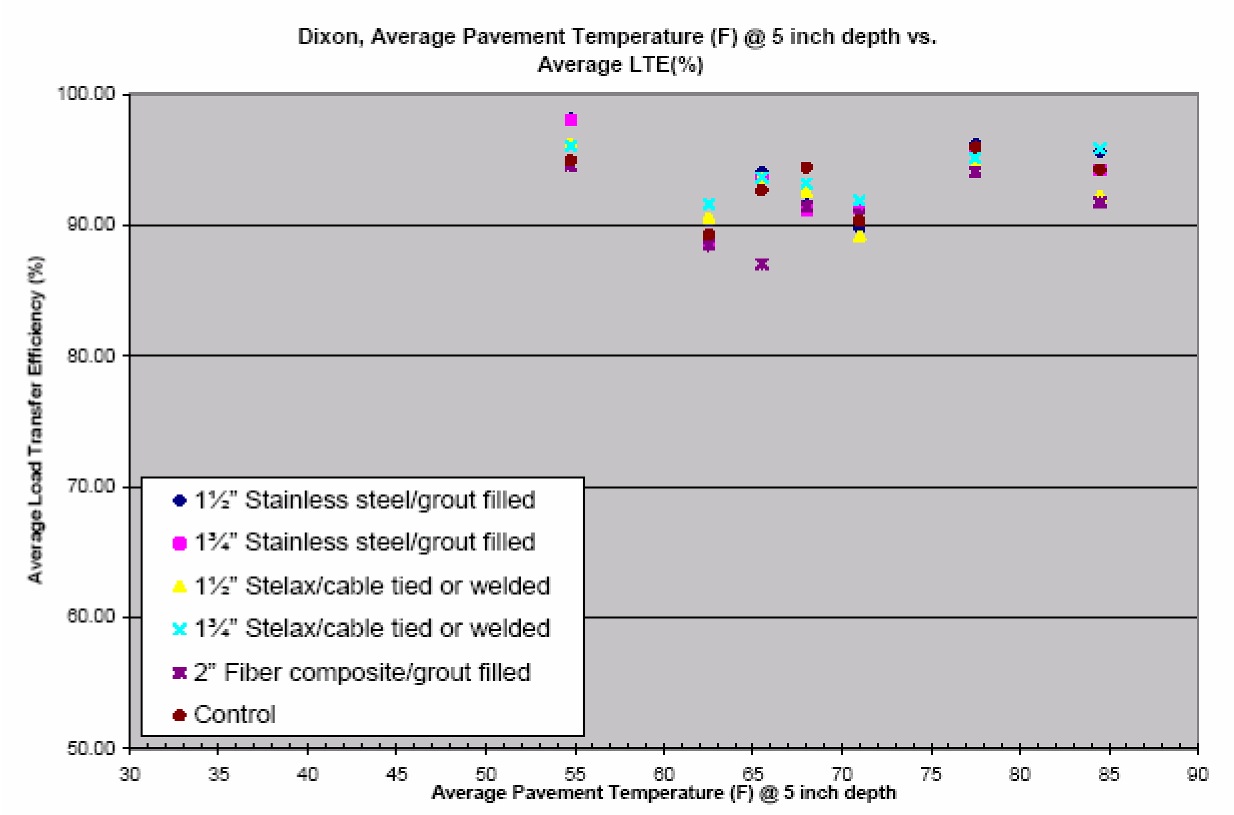

Figure xx. Average Load Transfer Efficiency vs Average Pavement Temperature (Gawedzinski 2004).

Current Observations (Gawedzinski 2004)

At the time of construction, all of the test joints were to remain unsealed. Visual observation of the joints show all of the joints performing well with slight spalling possibly due to the pavement being cut too early. None of the joints show accumulation of incompressible material in the joint or any significant spalling due to the joints "locking up." Additional monitoring will continue. The LTE% and joint deflection graphs show behavior expected with relatively new pavements.

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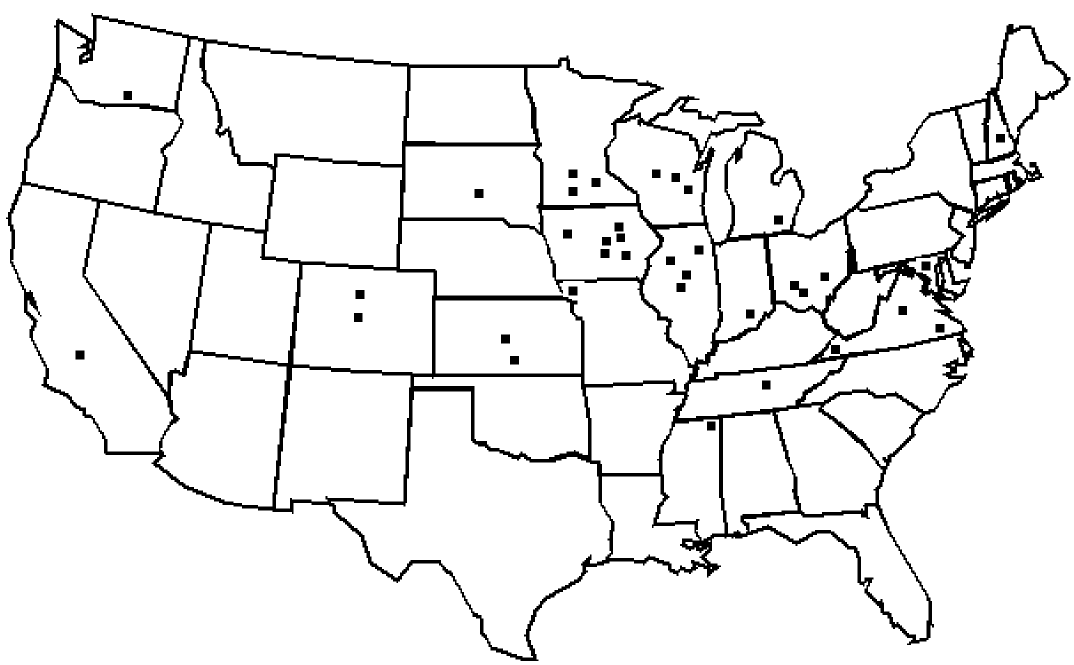
Appendix E
Listing and Location of TE-30 and Related Projects

Project	TE-30?	Pavement Type	Design Features Evaluated	Year Built
California 1	No	PPCP	Precast, Post-tension Concrete Pavement	Pending
Colorado 1	No	UTW	Ultra Thin White-Topping	1996 - 1997
Colorado 2	No	PPCP	Precast Concrete Slabs for Full Depth Repairs	2004
Illinois 1 I-55 SB, Williamsville	No	JRCP	Alternative Dowel Bar Materials	1996
Illinois 2 IL 59, Naperville	Yes	JRCP JPCP	Alternative Dowel Bar Materials Sealed/Unsealed Joints Traffic Counters	1997
Illinois 3 U.S. 67 WB, Jacksonville	Yes	JPCP	Alternative Dowel Bar Materials Sealed/Unsealed Joints	1999
Illinois 4 SR 2 NB, Dixon	No	JPCP	Alternative Dowel Bar Materials	2000
Indiana 1	Yes	JPCP	Construction material factors to reduce curling and warping	2002
Iowa 1a IA 5, Carlisle	Yes	JPCP	PCC Mixing Times on PCC Properties	1996
Iowa 1b U.S. 30, Carroll	Yes	JPCP	PCC Mixing Times on PCC Properties	1996
Iowa 2 U.S. 65 Bypass, Des Moines	Yes	JPCP	Alternative Dowel Bar Materials Alternative Dowel Bar Spacings	1997
Iowa 3 U.S. 151, Linn/Jones	Yes	JPCP	Fly-Ash Stabilization of PCC	2000-2001
Iowa 4 IA 330, Jasper, Story, and Marshall Counties	No	JPCP	Elliptical Steel Dowel Bars	2002
Iowa 5 Iowa 330, Melbourne	No	JPCP	Elliptical Fiber Reinforced Polymer Dowel Bars	2002
Iowa 6 Various Locations	No	Various	Fly-ash Stabilization of Subgrade for PCC Pavements	N/A
Iowa 7	No	Various	Total Environmental Management for Paving (TEMP)	N/A
Kansas 1 K-96, Haven	Yes	JPCP FRCP	Alternative Dowel Bar Materials Alternative PCC Mix Designs (incl. Fiber PCC) Joint Sawing Alternatives Joint Sealing Alternatives Surface Texturing Two-Lift Construction	1997
Kansas 2	Yes	JPCP	Smoothness Monitoring of plastic concrete	2001
Maryland 1 U.S. 50, Salisbury Bypass	Yes	JPCP FRCP	PCC Mix Design Fiber PCC	2001
Michigan 1 I-75 NB, Detroit	No	JRCP JPCP	Alternative Dowel Bar Material Two-Lift Construction Exposed Aggregate Thick Foundation	1993
Minnesota 1 I-35W, Richfield	Yes	JPCP	Alternative Dowel Bars PCC Mix Design	2000
Minnesota 2 Mn/Road Low Volume Road Facility, Albertville	Yes	JPCP	Alternative Dowel Bar Materials Doweled/Nondoweled Joints PCC Mix Design	2000
Minnesota 3 Mn/ROAD, Mainline Road Facility and US 169, Albertville	No	UTW	Application of Ultra-Thin Whitetopping	1997
Mississippi 1 U.S. 72, Corinth	Yes	Resin-Modified Pavement	Alternative PCC Paving Material (Resin-Modified Pavement)	2001
Missouri 1 I-29 SB, Rock Port	Yes	JPCP FRCP	Fiber PCC Slab Thickness Joint Spacing	1998
New Hampshire 1	Yes	N/A	HPCP Definitions	N/A

			“Design Optimization” Computer Program	
Ohio 1 U.S. 50, Athens	Yes	JRCP	PCC Mix Design	1997-1998
Ohio 2 U.S. 50, Athens	Yes	JRCP	Alternative Dowel Bar Materials	1997
Ohio 3 U.S. 50, Athens	Yes	JRCP	Sealed/Unsealed Joints	1997-1998
Ohio 4 US 35, Jamestown	Yes	JPCP	Evaluation of Soil Stiffness using Non-destructive Testing Devices	2001
Pennsylvania 1	Yes	JPCP	Evaluation of HIPERPAV	2004
South Dakota 1 U.S. 83, Pierre	Yes	JPCP FRCP	PCC Mix Design Joint Spacing Doweled/Nondoweled Joints	1996
Tennessee 1	No	JPCP	Implementation of PRS	2004
Virginia 1 I-64, Newport News	Yes	JPCP	PCC Mix Design	1998-1999
Virginia 2 VA 288, Richmond	Yes	CRCP	PCC Mix Design Steel Contents	2000
Virginia 3 U.S. 29, Madison Heights	Yes	CRCP	PCC Mix Design Steel Contents	2000
Wisconsin 1 WI 29, Abbotsford	Yes	JPCP	Surface Texturing	1997
Wisconsin 2 WI 29, Owen	Yes	JPCP	Alternative Dowel Bar Materials Alternative Dowel Bar Spacings	1997
Wisconsin 3 WI 29, Hatley	Yes	JPCP	Alternative Dowel Bar Materials Alternative Dowel Bar Spacings Trapezoidal Cross Section	1997
Wisconsin 4 I-90, Tomah	Yes	JPCP	Alternative Dowel Bar Materials PCC Mix Design	2002
FHWA 1	No	UTW	UTW Repair Techniques	
Various States 1	No	JPCP	Evaluation of magnetic Tomography for Dowel Bar Location (MIT Scan 2)	2003 +

KEY:

JPCP = Jointed Plain Concrete Pavement
JRCP = Jointed Reinforced Concrete Pavement
CRCP = Continuously Reinforced Concrete Pavement
FRCP = Fiber-Reinforced Concrete Pavement
PPCP - Precast Post-tension Concrete Pavement
UTW - Ultra-Thin Whitetopping



Location of TE-30 and related projects.