Evaluation of Fiber Reinforced Composite Dowel Bars and Stainless Steel Dowel Bars

Solicitation #1176 TPF Studies

Prepared For:

Ohio Department of Transportation
Office of Research and Development
1980 West Broad Street, Second Floor
Columbus, OH 43223

Prepared By:

Applied Pavement Technology, Inc.
115 W. Main Street, Suite 400
Urbana, IL 61801

Principal Investigator:

Roger M. Larson, P.E.
Applied Pavement Technology, Inc.

Original Proposal Submission Date:

May 9, 2008

Revised Proposal Submission Date:

September 3, 2008

Evaluation of Fiber Reinforced Composite Dowel Bars and Stainless Steel Dowel Bars

Proposing Agency:

Applied Pavement Technology, Inc.
115 W. Main Street, Suite 400
Urbana, IL 61801

Principal Investigator:

Roger M. Larson, P.E., Senior Engineer
Applied Pavement Technology, Inc.
7501 Candytuft Court
Springfield, VA 22153
(703) 455-7681
rlarson@appliedpavement.com

Contracting Officer:

Kathryn A. Zimmerman, P.E., President
Applied Pavement Technology, Inc.
115 W. Main Street, Suite 400
Urbana, IL 61801
(217) 398-3977
kzimmerman@appliedpavement.com

Original Proposal Submission Date:

May 9, 2008

Revised Proposal Submission Date:

September 3, 2008

3. TABLE OF CONTENTS

LIST OF TABLES

4. STATEMENT OF THE PROBLEM

Introduction

Dowel bars are placed across transverse joints at the mid-depth of portland cement concrete (PCC) slabs to provide load transfer from one slab to the next. This reduces the development of significant structural distresses in jointed concrete pavements (JCP), such as pumping, faulting, and corner breaks. Numerous field studies have clearly shown that doweled JCP designs perform far better than nondoweled JCP designs ((Darter et al. 1985; Smith et al. 1990; Smith et al. 1998; Selezneva, Jiang and Tayabji 2000; FHWA 2004a). Consequently, the use of dowel bars is recommended for nearly all JCP, except those exposed to low traffic levels (Smith and Hall 2001).

Conventional JCP designs use smooth, round steel dowel bars commonly conforming to AASHTO M31 or ASTM A615. The design of the dowel bar system is a function of the anticipated traffic levels and varies somewhat from agency to agency. Most commonly the dowels are 1.25 to 1.5 inches in diameter and 18 in long, and are placed at mid-depth of the slab at 12-in spacings along the length of the transverse joint. A fusion-bonded coating of epoxy on the steel dowel bar is the industry standard for corrosion protection.

Although dowel bars are effective in improving JCP performance, there is concern that corrosion of steel dowel bars is diminishing the service lives of some JCP projects. For example, the Minnesota Department of Transportation (Mn/DOT) has found that in 16 years or less the standard epoxy-coated dowels currently used have corroded to about one-third of their original diameter (Mn/DOT 2000). Evidence from other highway agencies suggests that corrosion of epoxy-coated dowels may be severe enough within 7 to 15 years to cause joint lockup or cracking of the concrete around the dowel due to expansive forces of the corrosion byproducts (Porter and Braun 1997). Because of this potential for compromising pavement performance, and in light of the Federal Highway Administration's (FHWA's) current initiative on longer life pavement designs, it is critical that more durable and economical materials be found for dowels in both new and rehabilitated JCP designs.

In 1996, the FHWA launched Test and Evaluation Project 30 (TE-30), *High Performance Concrete Pavement* (HPCP), which is exploring the applicability of innovative PCC pavement design and construction concepts, including the use of alternative dowel bars (Smith 2001; FHWA 2006). Several projects featuring alternative dowel bars have been constructed under that program. The field projects constructed under the TE-30 program that incorporate alternative dowel bars now range in age from about 7 to 10 years (although the Detroit I-75 European Demonstration Project is now 15 years old).

The Highway Innovative Technology Evaluation Center (HITEC) has developed an evaluation plan for the assessment of 1.5-in diameter fiber reinforced polymer (FRP) composite and Type 304 stainless steel dowels at 12-in spacing in that program, as well as the laboratory evaluation of the dowel materials themselves (Porter and Braun 1997; HITEC 1998). Under a HITEC and pooled funds effort, a draft Interim Report summarizing Phase I evaluations and recommending activities for phase II was developed (Larson and Smith 2005a). However, funding for that effort was discontinued and no agreement was reached on continuing the proposed Phase II effort. A summary (Larson and Smith 2005b) of alternative dowel bars for JCP is also available.

This proposal describes Applied Pavement Technology, Inc.'s (APTech's) approach to assist the Ohio Department of Transportation in administering the pooled funds project to complete Phase II of the project initially undertaken by HITEC. **This proposal will be limited to updating the draft Interim Report based on input from the Technical Panel, defining the work needed to evaluate the performance of the various projects for a total**

of 10 years, and developing a final report documenting the results of the HITEC Evaluation Plan Final Version dated May 8, 1998, as modified. Table 2 of the HITEC Final Evaluation Plan summarizes the Test Specifications for FRP and for Type 304 stainless steel dowels, which will be the only material types evaluated under this study except that 1.5-in diameter epoxy-coated dowels will be used as the control. In addition, only dowels spaced at 12 in will be considered as part of this effort due to the limitations in funding.

The draft *Interim Report* will be updated to reflect comments of the Technical Panel within the scope of this limited effort and document the current status of the projects. It will include a summary of which materials have adequate available test results (and a summary of those results), which materials are currently available for testing, and what additional samples need to be obtained. It will also include a summary of any additional monitoring, testing and analysis, and evaluation needed to determine the performance of these projects for a total of 10 years so this project can be successfully completed. Key project data will be entered into a spreadsheet for storage. A draft Final Report will be prepared. A final Technical Panel meeting will be held to present the results of the evaluations and discuss the draft final report, and then a Final Report will be prepared.

References

Darter, M. I., J. M. Becker, M. B. Snyder, and R. E. Smith. 1985. *Portland Cement Concrete Pavement Evaluation System–COPES.* NCHRP Report 277. Transportation Research Board, Washington, DC.

Federal Highway Administration (FHWA). 2004. *Key Findings from LTPP Analysis 2000-2003.* Final Report HRT-04-032. Federal Highway Administration, Washington, DC.

Federal Highway Administration (FHWA). 2006. *High Performance Concrete Pavements: Technical Summary of Results from Test and Evaluation Project 30.* FHWA-IF-06-032. Federal Highway Administration, Washington, DC.

Highway Innovative Technology Evaluation Center (HITEC). 1998. *HITEC Evaluation Plan for Fiber Reinforced Polymer Composite Dowel Bars and Stainless Steel Dowel Bars.* Final Version. Highway Innovative Technology Evaluation Center, Civil Engineering Research Foundation, Washington, DC.

Larson, R. M. and K. D. Smith. 2005a. *Evaluation of Alternative Dowel Bar Materials.* Interim Report. Highway Innovative Technology Evaluation Center, Civil Engineering Research Foundation, Washington, DC.

Larson, R. M. and K. D. Smith. 2005b. "Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements." *Proceedings*, 8th International Conference on Concrete Pavements, Denver, CO.

Minnesota Department of Transportation (Mn/DOT). 2000. *2000 Minnesota Road Research Calendar.* Minnesota Department of Transportation, St. Paul, MN.

Porter, M. L. and R. L. Braun. 1997. *Preliminary Assessment of the Potential Use of Alternative Materials for Concrete Highway Pavement Joints.* Technical Report. Iowa State University, Ames, IA.

Selezneva, O., J. Jiang, and S. D. Tayabji. 2000. *Preliminary Evaluation and Analysis of LTPP Faulting Data—Final Report.* FHWA-RD-00-076. Federal Highway Administration, McLean, VA.

Smith, K. D., D. G. Peshkin, M. I. Darter, A. L. Mueller, and S. H. Carpenter. 1990. *Performance of Jointed Concrete Pavements, Volume I: Evaluation of Concrete Pavement Performance and Design Features.* FHWA-RD-89-136. Federal Highway Administration, McLean, VA.

Smith, K. D., M. J. Wade, D. G. Peshkin, L. Khazanovich, H. T. Yu, and M. I. Darter. 1998. *Performance of Concrete Pavements, Volume II: Evaluation of Inservice Concrete Pavements.* FHWA-RD-95-110. Federal Highway Administration, McLean, VA.

Smith, K. D. 2001a. *Status of High Performance Concrete Pavements.* FHWA-IF-01-025. Federal Highway Administration, Washington, DC.

Smith, K. D. and K. T. Hall. 2001. *Concrete Pavement Design Details and Construction Practices—Technical Digest.* Reference Manual for NHI Course 131060. National Highway Institute, Arlington, VA.

5. OBJECTIVES OF THE STUDY

The project continues the evaluation and monitoring work that has been conducted on the use of alternative dowel bar materials, with the following specific research objectives:

- To assess the constructibility, placement verification, environmental qualities and performance capabilities of FRP 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.
- To consider the comparative performance and service life costs of these alternative materials and epoxy coated mild steel for use in dowel bars.

6. BACKGROUND AND SIGNIFICANCE OF WORK

Background

The use of steel dowel bars to transfer forces across sawed or formed transverse joints from one concrete 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. However, a common problem is the corrosion of the steel dowels, especially in states which use salt for snow and ice control. Corrosion can lead to a reduction in the diameter of the dowel bar in the joint area to the point where the dowel bar will fail in shear when loaded, resulting in faulting of the pavement slab. The corrosion can also "lock" the dowel bar into the concrete, preventing slab movement due to temperature changes and leading to slab cracking. In the mid-1970s, State DOT began to require steel dowel bars be coated with epoxy or other materials to prevent corrosion. Epoxy-coated dowels have become the standard for most states, but recently some agencies have been investigating the use of alternative dowel materials. Although the corrosion resistance of some of these alternative materials have been well documented in laboratory examinations, other performance characteristics remain to be fully evaluated, particularly in representative field installations and over meaningful time periods.

A program to evaluate two alternative dowel bar materials, stainless steel and fiber reinforced polymer (FRP), was initiated in 1998 by the Highway Innovative Technology Evaluation Center (HITEC). Initial field installations of FRP and stainless steel dowel bars began in 1996 in conjunction with the FHWA *High Performance Concrete Pavement* (TE-30) project, at which time projects were completed in four States (Iowa, Illinois, Ohio, and Wisconsin) (see Table 6-1). The projects were being evaluated under the May 9, 1998 HITEC evaluation plan. A draft interim report detailing the construction and early performance of the test sections was submitted in March 2005. However, prior to completion of the evaluation, the contract was terminated with the now defunct HITEC. This research shall complete the work initiated by HITEC.

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, although the interest in the use of alternative dowel bar suggests that there is at least the perception of a problem. Another factor driving the interest in alternative dowel bars is the movement towards long-life concrete pavements (design lives of 40, 50, or even 60 years), which would require dowel bars with proven longevity. Until better nationwide data are available, each agency will have to evaluate their pavement performance to determine if corrosion 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, and so on).

Table 6-1. HITEC projects evaluating alternative dowel bar materials.

Project/ Location	Date Built	Type of Load Transfer Devices	Dowel Diameter
Illinois 1 I-55 SB, Williamsville	1996	Epoxy-coated dowels	1.5 in
		FRP composite dowels (*RJD Industries, Inc.*)	1.5 in
Illinois 2 Route 59, Naperville	1997	Epoxy-coated dowels	1.5 in
		FRP composite dowels (*RJD Industries, Inc.*)	1.5 in 1.75 in
		FRP composite dowels (*Corrosion Proof Products, Inc.*)	1.5 in
		FRP composite dowels (*Glasforms, Inc.*)	1.5 in
Illinois 3 U.S. 67 WB, Jacksonville	1999	Epoxy-coated dowels	1.5 in
		FRP composite dowels (*RJD Industries, Inc.*)	1.5 in
		FRP composite dowels (*Strongwell Corporation*)	1.5 in
		FRP composite dowels (*Creative Pultrusions, Inc.*)	1.5 in
		FRP composite tubes filled with cement grout (*Concrete Systems, Inc.*)	2 in
		Type 316L stainless steel clad dowels (*Stelax Industries, Inc.*)	1.5 in
Illinois 4 Route 2 NB, Dixon	2000	FRP composite tubes filled with cement grout (*Concrete Systems, Inc.*)	2 in
		Type 316L stainless steel tubes filled with cement grout	1.5 in 1.75 in
		Type 316L stainless steel clad dowels (*Stelax Industries, Inc.*)	1.5 in 1.75 in
Iowa 2 U.S. Route 65, Des Moines	1997	Epoxy-coated dowels	1.5 in
		FRP composite dowels (*Hughes Brothers, Inc.*) (203- and 305-mm [8- and 12-in] spacings)	1.88 in
		FRP composite dowels (*RJD Industries, Inc.*) (203- and 305-mm [8- and 12-in] spacings)	1.5 in
		Solid stainless steel dowels (Type 316L?) (203- and 305-mm [8- and 12-in] spacings)	1.5 in
Ohio 2 U.S. Route 50, Athens	1997/1998	Epoxy-coated dowels	1.5 in
		FRP composite dowels (*RJD Industries, Inc.*)	1.5 in
		Stainless steel (type 304) tubes filled with cement grout	1.5 in
Wisconsin 2 WI 29, Owen	1997	Epoxy-coated dowels (5 layout configurations)	1.5 in
		FRP composite dowels (*RJD Industries, Inc.*)	1.5 in
		FRP composite dowels (*Creative Pultrusions, Inc.*)	1.5 in
		FRP composite dowels (*Glasforms, Inc.*)	1.5 in
		Type 304L solid stainless steel dowels (*Avesta Sheffield, Inc.*) (2 layout configurations)	1.5 in
		Type 304L stainless steel tubes filled with cement grout (*Damascus Bishop Tube Company*)	1.5 in
Wisconsin 3 WI 29, Hatley	1997	Epoxy-coated dowels (2 configurations)	1.5 in
		FRP composite dowels (*Strongwell Corporation*)	1.5 in
		FRP composite dowels (*Glasforms, Inc.*)	1.5 in
		FRP composite dowels (*Creative Pultrusions, Inc.*)	1.5 in
		FRP composite dowels (*RJD Industries, Inc.*)	1.5 in
		Type 304L solid stainless steel dowels (*Slater Steels, Inc.*)	1.5 in

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. 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 (proposed 10-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). Other research provides considerable information on these options based on lab testing and field evaluation studies (GangaRao 2004). A study at the University of Manitoba 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). A recent University of Minnesota evaluation suggests looking at 2-in diameter FRP dowels to have similar performance to 1.5-in epoxy-coated 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 projects with unstabilized permeable bases or poor quality subgrades. It is suggested that these criterion be considered for this evaluation.

The results of coring on the U.S. 50 project near Athens, Ohio became available in November 2004, and revealed no significant distress on the FRP materials. However, the cores of the epoxy-coated dowels and the concrete-filled Type 304 stainless steel tubes 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 are also available. Load history data was collected but not analyzed. Appendix C of the HITEC draft interim report 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 Ohio project, which may have contributed to the delaminations in the concrete near the dowel bars. The updated version of the model used earlier information from the instrumented dowels on the Ohio 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). Poor subgrade support was reported as the probable cause of poor performance of FRP dowels in West Virginia.

A report documenting the performance of alternative concrete pavement designs (including the use of alternative dowel bar materials) in Wisconsin is available. The results from that study suggest that the performance of the sections with alternative dowel bar materials are not performing substantially better than conventional epoxy-coated dowels and thus may not be cost effective (Crovetti 2006).

On a project in Iowa, 4-in diameter cores of the FRP dowels showed no distress (Cable and Porter 2003). Although the photo in the 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 were not 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; Porter and Pierson 2007).

Absorptivity of the FRP composite material is another concern. Some limited research (Bian 2003; Gupta 2004) has been conducted on this topic.

It should be noted that reviews of monitoring data from other HPCP projects raise similar concerns about low LTEs. For example, in a project in Michigan, both the European section (variably spaced 1.25-in, plastic-coated dowels) and the control section (1.25-in epoxy-coated mild steel dowels at 12-in spacing) exhibited LTEs less than 70 percent (Buch, Lyles, and Becker 2000; Weinfurter, Smiley, and Till 1994). Similarly, a project in Kansas has a number of epoxy-coated steel dowel sections with LTEs of 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 2004). 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.

Review of Recent Literature

Since the original HITEC 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 report on the HPCP projects (FHWA 2006) contains 16 dowel bar or related projects including a much larger range of variables. As provided in the HITEC Letter Agreement, the focus of the HITEC draft Interim Report was 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 for the focus projects are included in Appendix D of the HITEC draft Interim Report. A summary of the status of alternative dowel bars is available (Larson and Smith 2005b).

The major emphasis of the HITEC draft Interim Report was 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.

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 recent Caltrans report (Bian, Harvey, and Ali 2006) documents construction and testing of retrofitted dowel bar test sections. Retrofitted joints and transverse cracks with three and four epoxy-coated steel dowels, four hollow steel dowels, and four fiber-reinforced polymer dowels per wheelpath were tested. Three dowels per wheelpath performed substantially worse than sections with four dowels per wheelpath. Joint performance was better with four epoxy-coated steel dowels per joint. HVS results show that for each of the DBR alternatives, the LTE was not substantially affected by heavy HVS loading and that the slabs failed by fatigue cracking before LTE dropped substantially. FWD testing showed the sensitivity of deflections and LTE to dowel type, number of dowels per wheelpath, and slab temperatures based on the FWD measurements.

A study using APT testing 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) has been completed at the University of Minnesota. A recent synthesis prepared for the Wisconsin Rigid Pavements Technical Oversight Committee discusses dowel bar size and spacing in Europe and the U.S. (CTC and Associates 2007). It includes a summary of the 2006 FHWA scan of long-life pavements in Europe and Canada, some more recent technical guidance on dowel bars in general, and updated information on the Iowa FRP research and the results of University of Minnesota Minne-Alf study.

References

Bian, Y. 2003. *Test Plan for Laboratory Work on Dowel Durability and Mechanical Properties.* Caltrans Partnered Pavement Research Center, University of California, Davis, CA.

Bian, Y., J. T. Harvey, and A. Ali. 2006. *Construction and Test Results on Dowel Bar Retrofit HVS Test Sections 556FD, 557FD, 558FD, and 559FD: State Route 14, Los Angeles County at Palmdale.* UCPRC-RR-2006-02. California Department of Transportation, Sacramento, CA.

Buch, N., R. Lyles, and L. Becker. 2000. *Cost Effectiveness of European Demonstration Project: I-75 Detroit.* Report No. RC-1381. Michigan Department of Transportation, Lansing, MI.

Cable, J. K., and M. L. Porter. 2003. *Demonstration and Field Evaluation of Alternative Portland Cement Concrete Pavement Reinforcement Materials.* Final Report, Iowa DOT Project HR-1069. Iowa Department of Transportation, Ames, IA.

Cable, J. K., M. L. Porter, and R. J. Guinn. 2003. *Field Evaluation of Elliptical Fiber Reinforced Polymer Dowel Performance.* Construction Report, DTFH61-01-X-00042, Project #5. Federal Highway Administration, Washington, DC.

Crovetti, J. A. 2006. *Cost Effective Concrete Pavement Cross Sections.* WI/SPR-03-05. Wisconsin Department of Transportation, Madison, WI.

CTC and Associates, LLC. 2007. *Alternative Dowel Bar Size and Placement in Concrete Pavements.* Transportation Synthesis Report. Wisconsin Department of Transportation, Madison, WI.

Federal Highway Administration (FHWA). 2004. *Key Findings from LTPP Analysis 2000-2003.* Final Report HRT-04-032. Federal Highway Administration, Washington, DC.

Federal Highway Administration (FHWA). 2006. *High Performance Concrete Pavements: Technical Summary of Results from Test and Evaluation Project 30.* FHWA-IF-06-032. Federal Highway Administration, Washington, DC.

GangaRao, H. 2004. *Evaluation of Jointed Plain Concrete Pavements (JPCP) with FRP Dowels*. Draft Final Report. West Virginia University and Federal Highway Administration, Washington, D.C., in press.

Gupta, R. 2004. *Diffusion in GFRP Under Hygrothermal and pH Variations*. Draft Final Report. West Virginia University and Federal Highway Administration, Washington, DC.

Hansen, W., Peng, Y., and Smiley, D. L. 2004. *Qualify Transverse Cracking in PCC Pavement from Loss of Slab-Base Contact*. Final Report RC-1453. Michigan Department of Transportation, Lansing, MI.

Larson, R. M. and K. D. Smith. 2005b. "Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements." *Proceedings*, 8th International Conference on Concrete Pavements, Denver, CO.

Melhem, H. 1999. *Accelerated Testing for Studying Pavement Design and Performance*. FHWA-KS-99-2. Federal Highway Administration, Topeka, KS.

Murison, S. 2004. *Evaluation of Concrete-Filled GFRP Dowels for Jointed Concrete Pavements*. MS Thesis. University of Manitoba, Winnipeg, Manitoba, Canada.

Murison, S., A. Shalaby, and A. Mufti. 2005. "Concrete-Filled Glass Fibre Reinforced Polymer (GFRP) Dowels for Load Transfer in Jointed Rigid Pavements." *Proceedings*, TRB 2005 Annual Meeting, Transportation Research Board, Washington, DC.

Odden, T. D., M. B. Snyder, and A. E. Schultz. 2003. *Performance Testing of Experimental Dowel Bar Retrofit Designs Part I – Initial Testing*. Final Report MN-RC 2004-17A, Minnesota Department of Transportation, St. Paul, MN.

Popehn, N. A., A. E. Schultz, and M. B. Snyder. 2003. *Performance Testing of Experimental Dowel Bar Retrofit Designs: Part 2 – Repeatability and Modified Designs*. Final Report MN-RC 2004-17B. University of Minnesota and Minnesota Department of Transportation, St. Paul, MN.

Porter, M. and N. Pierson. 2007. "Laboratory Evaluation of Alternative Dowel Bars for Use in Portland Cement Concrete Pavement Construction." *Transportation Research Record 2040*. Transportation Research Board, Washington, DC.

Weinfurter, J. A., D. L. Smiley, and R. D. Till. 1994. *Construction of European Concrete Pavement on Northbound I-75 --Detroit, Michigan*. Research Report R-1333. Michigan Department of Transportation, Lansing, MI.

Wojakowski, J. 1998. *High Performance Concrete Pavement*. Report No. FHWA-KS-98/2. Kansas Department of Transportation, Topeka, KS.

7. BENEFITS

In a number of field studies, dowel bars have been shown to significantly reduce faulting and significantly increase the transverse joint load transfer efficiency. For roadway facilities subjected to moderate to heavy truck applications, dowel bars are essential to the long-term performance of the concrete pavement. Thus, it is imperative that steps be taken to ensure that the dowel bars will remain effective over the life of the pavement. With the current emphasis on long-life pavements (40 to 60 years or more), it becomes even more critical to ensure that durable, long-lasting materials are being used.

Because of some concerns of the long-term corrosion resistance of conventional epoxy-coated materials, there has been considerable interest in determining the suitability of alternative dowel bars long-term performance. If it can be demonstrated that these materials can be effective, expected benefits include avoiding early rehabilitation or reconstruction, providing a smoother ride for a longer period of time, and reducing fatalities and serious injuries due to undesirable roughness.

8. ANTICIPATED RESEARCH RESULTS AND DELIVERABLES

As indicated in the preceding sections of this proposal, the results of this research will provide improved guidance on the possible use of alternative dowel bar materials to provide satisfactory joint performance for the full service life of the concrete pavement without detrimental corrosion or deterioration. This guidance will be based on the extended minimum 10-year performance evaluation period proposed and an evaluation of the cost effectiveness of the alternative materials compared with standard epoxy-coated dowels. This guidance should be of value to the participating states and to other states where reduced service lives due to corrosion and other joint deterioration is a significant problem. The updated annotated literature search will document research on other variations of alternative dowel bar material types and spacing which may affect performance and/or cost effectiveness.

During the conduct of this study, the following deliverables will be prepared:

- The draft Interim Report and revised evaluation plan will be updated based on input from the Technical Panel within 7 months of the notice to proceed. An electronic copy of the updated annotated literature survey will also be provided.
- Quarterly Reports will be submitted to ODOT electronically to research@dot.state.oh.us within 1 month of the end of each quarter (March 31, June 30, September 30, and December 31). These reports will provide a summary of the work conducted during the most recent quarter, including a progress schedule depicting the project progress, a comparison of actual versus estimated expenditures, and an estimated percentage of the completed work on the research project. The report will also provide an outline of the work to be accomplished during the next quarter, the implementation of any work items, a description of any problems encountered along with recommended solutions, a listing and explanation of any equipment purchased, and details of any meetings or significant contacts with ODOT or other project contributors.
- Eight (8) copies of a two- to four-page executive summary and eight (8) copies of the draft final report, along with an electronic version of each, will be submitted to ODOT no later than 120 days prior to the project completion date. The final report will document the entire research effort and will also contain guidelines on the use of alternative dowel bar materials.
- Two-hundred and twenty (220) copies of the executive summary and sixty-five (65) copies of the approved final report will be submitted to ODOT by the contract completion date. Two electronic versions of the approved final report and approved executive summary (in both Microsoft Word and Adobe PDF) will also be submitted.

9. WORK PLAN

Introduction

This section describes APTech's work approach for the conduct of this project. The anticipated work effort is proposed to be conducted under seven work tasks.

Work Approach

Task 1: Revise Draft Interim Report

APTech will first provide the HITEC draft Interim Report (dated March 31, 2005) to the Technical Panel for their review and comments. During this review period, APTech will update the annotated bibliography and the summary of the literature review to reflect recent research results. Once review comments are received from the panel, APTech will revise the draft Interim Report to address the panel's comments (as well as comments generated from the Task 2 video/web conference), and will develop an evaluation plan to document the 10-year performance evaluation of the selected projects and to provide recommendations on the use of the various alternative dowel bar materials in the draft Final Report. As part of this task, APTech will attend a project start-up meeting in Columbus.

Task 2: Conduct Initial Video/Web Conference with Technical Panel

After the Technical Panel has reviewed the draft Interim Report (and possibly the updated summary of the literature review), a video conference or web conference will be conducted to obtain panel input on the draft Interim Report, to obtain status reports by the participating states on their individual evaluation project(s), to provide information on the updated literature review, and to develop a specific approach, including additional testing and analysis of the 10 year field performance data, to close out the project. The Interim Report will be revised and distributed along with the Updated Evaluation Plan and updated annotated literature review within 3 months of the initial conference to complete the Task 1 effort.

Task 3: Execute the Revised Evaluation Plan

Once the revised evaluation plan is approved, the participating states will perform the specified field testing, data collection, and performance evaluations of their respective experimental field sites. This will be conducted over an approximate 2-year period, and the results of the field testing and evaluation will be summarized and included in the draft and final reports. The specific projects that will be included in this study are:

- Illinois 1 (I-55 SB, Williamsville)
- Illinois 2 (Route 59, Naperville)
- Illinois 3 (U.S. 67 WB, Jacksonville)
- Iowa 2 (U.S. Route 65, Des Moines)
- Ohio 2 (U.S. Route 50, Athens)
- Wisconsin 2 (WI 29, Owen)
- Wisconsin 3 (WI 29, Hatley)

During this extended time period when the participating states are collecting data, APTech will participate in one annual technical project review session in Columbus.

Task 4: Prepare Draft Final Report

Based on the information and results collected by the participating highway agencies, APTech will prepare a draft final report. This report will be similar to that developed under task 1, but will be expanded with the results and findings from the field work conducted under task 3. In addition, a 2- to 4-page draft Executive Summary will be included. These documents will be submitted to ODOT and to the members of Technical Panel at least 30 days prior to the panel meeting to be conducted under task 5 (and 120 days before the project completion date). A proposed outline for the draft final report is provided in Table 9-1.

Table 9-1. Proposed outline for draft Final Report.

Chapter	Major Headings
1. Introduction	1.1 Original HITEC Mission and Purpose 1.2 Alternative Dowel Bar Materials Evaluated 1.3 Overview of Report
2. Literature Review	2.1 Performance Issues 2.2 Types and Characteristics of Alternative Dowel Bars 2.3 Applications and Performance of Alternative Dowel Bars 2.3.1 New Construction 2.3.2 Rehabilitation (limited discussion)
3. Overview of Field Sites	3.1 Illinois (3 sites) 3.2 Iowa 3.3 Ohio 3.4 Wisconsin (2 sites)
4. Updated Testing Results (by field site)	4.1 Field Installations 4.1.1 Design data 4.1.2 Construction data 4.1.3 Performance data 4.1.4 Operations data, annual 4.2 Laboratory Evaluations 4.3 Nondestructive testing 4.4 Summary of Results
5. Summary and Recommendations	
References	
Appendices	

Task 5: Host Technical Panel Meeting in Chicago

Under this task, a Technical Panel meeting will be held in either Chicago (near O'Hare International Airport) or Columbus. The results of the field testing, analysis, and performance evaluations conducted by the participating highway agencies will be discussed, along with the draft final report conclusions and recommendations. This meeting is also assumed to serve as the project wrap-up meeting.

Task 6: Prepare Final Report

Based on the input from the Technical Panel, APTech will prepare the project final report in accordance with ODOT requirements and guidelines. Ultimately, sixty-five (65) copies of the final report and two-hundred and twenty (220) copies of the executive summary will be delivered to ODOT by the contract ending date, along with electronic versions of each document .

Task 7: Provide Quarterly Progress Reports

Throughout the duration of the project, quarterly reports will be prepared and submitted within 30 days of the completion of each calendar quarter (March 31, June 30, September 30, December 31). These reports will be prepared in accordance with the ODOT formatting guidelines.

10. RECOMMENDED IMPLEMENTATION PLAN

The implementation plan for this project is described below, following the format specified in ODOT's *Research Proposal Formatting and Submission Guidelines*. As noted in those guidelines, these are only preliminary concepts, and the actual implementation activities will be refined as the project is carried out.

a. Products. At the conclusion of this research effort, APTech will provide ODOT with a final report that provides: a) summary of the performance of the experimental alternative dowel materials after a minimum of 10 years of highway traffic; b) recommendations for use of alternative dowel bar materials in new construction, rehabilitation, or pavement preservation projects c) recommendations regarding the cost effectiveness of the alternative dowel bar materials; and d) recommendations for any additional research or project monitoring.

b. Audience. The primary audience for the results of this research is pavement designers, researchers, and administrators responsible for developing guidelines for cost-effective pavement designs.

c. Impediments to Implementation. Two possible impediments to implementation are perceived. The first is that there is limited documentation of the extent of the dowel bar corrosion problem in the U.S., which will make many highway agencies unwilling to spend their limited funding on more costly dowel bar materials; the second is the uncertainty of the cost-effectiveness of alternative dowel bar materials for various jointed concrete pavement applications.

d. Institutions and Individuals to Lead Implementation. Within ODOT, the Office of Pavement Engineering must assume a lead role in working to implement the findings from this research. The pooled fund Technical Panel should promote implementation of study findings in their respective states.

e. Implementation Activities. One possible formal implementation activity is the conduct of a web conference to promote the findings of the study. Another implementation activity is the presentation of study findings at state-level conferences (such as the Ohio Transportation Engineering Conference), national conferences such as the Transportation Research Board, and other regional or industry workshops. Such endeavors will help provide more widespread recognition of the research findings not only within Ohio but to other interested highway agencies as well

f. Criteria for Evaluating Implementation Progress and Consequences. The primary measure of the success of the implementation process is monitoring the number of states who modify their concrete pavement joint designs to implement the research findings on performance and cost-effectiveness of alternative dowel bar materials.

g. Costs of Implementation. The cost of more corrosion resistant dowel materials depends on the size, shape and spacing of the various alternative materials selected for implementation. The increased construction cost for standard placement of FRP composite dowels are estimated at $31,325 per 4-lane mile (18.5 ft joint spacing) and about $400,000 for standard placement of solid stainless steel dowels compared to epoxy coated steel dowels. If dowel bar inserters are used for the stainless steel dowels, the increased construction cost would be about $180,000 (1997-1999 Wisconsin Test Section Construction). This increased construction cost may be justifiable based on the FHWA initiative for longer life (40 years or more) pavements.

11. ITEMIZED BUDGET

The estimated cost to conduct this research effort is $54,000. Table 11-1 provides a breakdown of the estimated project costs presented in ODOT's proposal budget form, with a description of each cost item provided below.

Salaries and Wages

The labor hours assigned to each team member is based on the perceived level of effort and on the perceived level of expertise required for each task. The base hourly labor rates are current (2008) labor rates and serve as the foundation for all direct labor cost calculations. However, a separate line item has been included to account for anticipated APTech salary increases in the future years of the contract. It is the practice of APTech to provide labor rate escalations on a calendar year basis; the amount of these escalations are based on both cost-of-living and merit, and typically ranges from 3 to 6 percent. For purposes of this proposal, a labor escalation rate of 3 percent has been assumed (consisting of both cost-of-living and merit adjustments) and is shown as a line item in Table 11-1. This labor escalation factor is applied only to that direct labor that occurs in calendar year 2009 and beyond.

Fringe Benefit Rate

A fringe benefit rate of 55 percent is applied to all APTech direct labor costs.

Subcontractors

Three technical advisory panel members are included as part of this project: Mr. Andy Gisi, Kansas DOT; Ms. Irene Battaglia, Wisconsin DOT, and Mr. Mark Gawedzinski, Illinois DOT. These members will be attending a 1-day project meeting under task 5, and will require travel monies to attend that meeting. The derivation of the travel costs for the technical panel members is shown in Table 11-2.

Table 11-2. Derivation of task 5 travel costs for Technical Panel members.

Cost Item	Panel Member Travel for Task 5		
	Andy Gisi, KDOT	Irene Battaglia, WisDOT	Mark Gawedzinski, IDOT
Trip Length, days	2	2	2
Airfare	$641	$0	$0
Rental Car and Gas	$0	$180	$180
Lodging ($88/nite)	$88	$88	$88
Per Diem ($31/day)	$47 (@75% for travel day)	$47 (@75% for travel day)	$47 (@75% for travel day)
Ground Transp. and Parking	$60	$20	$20
TOTAL	**$836**	**$335**	**$335**

Travel

Under this project, project team travel is anticipated to occur under three tasks: task 1, for the project start-up meeting; task 3, for a technical project review session; and task 5, for the Technical Panel meeting (considered the project wrap-up meeting). Each meeting will consist of 2 days of travel, with the task 1 and task 3 meetings held in Columbus, and the task 5 meeting held in either Chicago or Columbus. Mr. Larson and Mr. Smith will attend each of the meetings, and the derivation of their travel costs is provided in Table 11-3. Travel costs are based on ODOT requirements, specifically a per diem rate of $31/day (of which only 75% of that is allowed on a travel day), and a lodging rate of $80/day (increased by 10% to $88/day to account for room taxes).

Table 11-3. Derivation of travel costs for APTech staff members.

Cost Item	APTech Staff Travel		
	Task 1 (Start-Up Meeting)	Task 3 (Annual Review Meeting)	Task 5 (Panel Meeting)
Trip Length, days	2	2	2
Travelers	2 (Larson and Smith)	2 (Larson and Smith)	2 (Larson and Smith)
Airfare	**$0**	**$0**	**$450** (Larson)
Rental Car and Gas	**$360** (for 2 rental cars)	**$360** (for 2 rental cars)	**$180** (Smith)
Lodging ($88/nite)	**$176** (1 nite for 2 travelers)	**$176** (1 nite for 2 travelers)	**$176** (1 nite for 2 travelers)
Per Diem ($31/day)	$93 (2 days, 2 travelers@75%)	$93 (2 days, 2 travelers@75%)	$93 (2 days, 2 travelers@75%)
Ground Transp. and Parking	**$40**	**$40**	**$80**
TOTAL	**$669**	**$669**	**$979**
GRAND TOTAL	**$2,317**		

Supplies

An estimate of $225 is made for shipping and communication costs over the duration of the project.

Equipment

No capital equipment is required for the conduct of this project.

Printing

A printing cost of $744 is included for the production of the Executive Summary Report and the Final Report. This cost is derived as follows:

- Executive Summary Report: 4 pages x $0.07/page x 220 copies = $62
- Final Report: 150 pages x $0.07/page x 65 copies = $682

Costs for the production of the revised interim report (assumed eight copies) and the draft final report and draft executive summary (assumed eight copies of each) are ignored in the development of the APTech cost estimate.

Indirect Costs

An indirect cost rate of 130 percent is applied to all APTech direct labor costs (salary and wages).

Fees

A fixed fee of 7 percent is applied to the total burdened APTech labor costs (direct labor + fringe + indirect); a 5 percent fee is applied to other direct costs (travel + supplies + printing).

Other Expenses

No other expenses are anticipated for the conduct of this project.

Total Project Cost

The total cost for this project is estimated to be $54,000.

Table 11-1. Final proposal budget form.

Project Title: *Evaluation of Fiber Reinforced Composite Dowel Bars and Stainless Steel Dowel Bars*
RFP Number: Pooled Funds Solicitation # 1176 TPF Studies
Proposing Agency: Applied Pavement Technology, Inc.
Principal Investigator: Roger M. Larson, P.E.
Co-Principal Investigator: Kurt D. Smith, P.E.
Project Duration: 36 months

	ODOT Funding	Organizational Cost Sharing	Total Project
SALARIES & WAGES Specify number of hours to be worked and hourly rate for each individual below. Salaries & Wages may be shown as a percentage of a total salary. In this case, the percentage of the salary to be paid and the total salary for each individual must be listed. The same unit, hours or percent, must be used for all personnel in all sections of the final proposal budget form.			
PI Roger Larson, P.E. (168 hours at base rate $58.32/hr)	$9,798	$0	$9,798
Co-PI Kurt Smith, P.E. (104 hours at base rate $54.73/hr)	$5,692	$0	$5,692
Others (Specify Role & Name)			
SUBTOTAL, UNESCALATED LABOR	**$15,490**	**$0**	**$15,490**
Labor Escalation (3% of anticipated 2009 & 2010, & 2011 labor)	$568	$0	$568
SUBTOTAL, SALARY & WAGES	**$16,058**	**$0**	**$16,058**
FRINGE BENEFITS (fixed 55% of APTech Direct Labor)			
55% of Salary and Wages Subtotal	$8,832	$0	$8,832
SUBTOTAL, FRINGE BENEFITS	**$8,832**	**$0**	**$8,832**
SUBTOTAL, SALARY & WAGES AND FRINGE BENEFITS	**$24,890**	**$0**	**$24,890**
SUBCONTRACTORS A copy of the subcontractor's budget must be attached. Reimbursement to Contractor for Subcontractor performance is subject to state accounting guidelines as is the Contractor.			
Subcontractors 3 State DOT Advisory Panel Members –Andy Gisi, Kansas DOT –Irene Battaglia, Wisconsin DOT –Mark Gawedzinski, Illinois DOT)	 $836 $335 $335	 $0 $0 $0	 $836 $335 $335
SUBTOTAL, SUBCONTRACTORS	**$1,506**	**$0**	**$1,506**

	ODOT Funding	Organizational Cost Sharing	Total Project
TRAVEL Must be in accordance with current state guidelines. Available on-line at: http://www.obm.ohio.gov/mppr/travel.asp			
In-State Travel (Destination within Ohio) Provide destination, purpose, total mileage, total # of days, total # of meals, total # of trips, names of individual(s) traveling.	$0	$0	$0
Out-of-State Travel (Prior approval required) Provide destination, purpose, total mileage, total # of days, total # of meals, total # of trips, names of individual(s) traveling.	$0	$0	$0
SUBTOTAL, TRAVEL	**$0**	**$0**	**$0**
SUPPLIES (and Shipping) Provide details if over 5% of total budget.			
SUBTOTAL, SUPPLIES	**$225**	**$0**	**$225**
EQUIPMENT At least 2 quotes for each piece of equipment must be attached. (See equipment policy–Section 4.4–for details and exceptions. List all items separately. Time at which the purchase shall be made must be states (e.g., at project initiation, within first five months, etc.)			
SUBTOTAL, EQUIPMENT	**$0**	**$0**	**$0**
PRINTING Provide a breakdown of charges including, charge per page, # of pages, total # of copies, binding charges, etc.			
Quarterly Reports	$0	$0	$0
Interim Reports (if applicable)	$0	$0	$0
Draft Final Report	$0	$0	$0
Exec. Summary (*4 pages@0.07/pg * 220 copies*)	$62	$0	$62
Final Report (*150 pages@0.07/pg * 65 copies*)	$682	$0	$682
SUBTOTAL, PRINTING	**$744**	**$0**	**$744**

	ODOT Funding	Organizational Cost Sharing	Total Project
INDIRECT COSTS 130% of Salary and Wages Subtotal	$20,875	$0	$20,875
FEES			
7% of Burdened Labor Costs (Direct Labor+Fringe+Indirect)	$3,204	$0	$3,204
5% of Other Direct Costs (Subs+ Supplies + Printing+TechTrans)	$239	$0	$239
Technology Transfer	$2,317	$0	$2,317
SUBTOTAL, INDIRECT COSTS AND FEES	**$26,635**	**$0**	**$26,635**
OTHER EXPENSES Any project expense which does not fall into another category. Provide detailed explanation of the expense and applicable breakdown of costs. List individually by category			
List individually by category			
SUBTOTAL, OTHER EXPENSES	**$0**	**$0**	**$0**
TOTAL PROJECT COST	**$54,000**	**$0**	**$54,000**

12. WORK TIME SCHEDULE

APTech's proposed project schedule for completing the tasks outlined in Section 9, *Work Plan*, is provided in Table 12-1. The overall project duration is 36 months, which includes 3-month period for ODOT to review the draft final report.

Table 12-1. Proposed project schedule.

Work Task	MONTH																																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1. Revise Int. Report	M																																			
2. Video/Web Conference																																				
3. Collect Data																			M																	
4. Draft Report																																				
5. Panel Meeting																																		M		
6. Final Report																																				
7. Quarterly Reports				X			X			X			X			X			X			X			X			X			X			X		

M = Meeting with ODOT

13. APPENDICES

Appendix A. Facilities

Appendix B. Qualifications of Research Team

Appendix C. Other Commitments of the Research Team

Appendix D. Resumes

APPENDIX A. FACILITIES

APTech performs its engineering operations out of four office locations: Champaign, Illinois; Essex, Vermont; Downers Grove, Illinois (a suburb of Chicago); and Reno, Nevada. The combined office lease space is over 15,000 ft^2.

APTech owns several pieces of equipment used as part of its pavement evaluation and construction inspection services. This includes a Dynatest 8081 heavyweight model falling weight deflectometer (FWD), a nondestructive testing device used in both the routine and specialized testing of highway and airfield pavements. This state-of-the-art device is capable of applying loadings to a pavement that are similar in magnitude and duration to those produced by moving wheel loads, including those of even the heaviest aircraft.

APTech also owns and operates a trailer-mounted material sampling device that can be used to obtain core and auger samples of the pavement and subsurface layers. Using diamond-tipped core barrels of various sizes, core samples up to 24 inches long and with diameters ranging from 3 to 12 inches can be obtained. The mast of the apparatus is omni-directional, meaning it can be used to obtain cores from walls and low ceilings as well as pavements. Samples obtained by the device can be tested in a number of ways to determine layer thickness, unit weight, strength, stiffness, and other intrinsic material properties. The auger apparatus provides a means of obtaining samples of all unbound layer materials that exist below the pavement surface. The samples can be obtained up to a depth of 10 feet. Tests can then be performed on the extracted samples to determine moisture content, gradation, densities, CBRs, and overall material classification.

APTech also owns a Dynamic Cone Penetrometer (DCP), a simple device used to obtain in situ subgrade strength measurements in conjunction with a coring program. Other testing equipment owned by APTech includes a pachometer (a device that is used to locate and measure depths to steel embedded in concrete), a digital faultmeter, an air meter, slump cones, and bean and cylinder moldings. Several of APTech's engineers and technicians are certified construction inspectors.

APTech has developed an extensive library database that consists of nearly 10,000 publications from each of its four offices, and includes reports from the FHWA, the FAA, the NCHRP, the Transportation Research Board (TRB), various State highway agencies, as well as numerous conference proceedings. APTech also has easy access to the University of Illinois library system, which houses one of the largest public libraries in the nation.

These facilities and equipment are currently available and will be available throughout the duration of this research project. No other facilities or equipment are needed for the conduct of this research project.

APPENDIX B. QUALIFICATIONS OF RESEARCH TEAM

Introduction

APTech is a pavement engineering firm that provides a full range of services to Federal, state, local, and private agencies. These services include pavement management, research, technology transfer, and pavement design and evaluation. Established in 1994, APTech's senior staff has over 150 years of combined experience providing quality pavement engineering services and products to clients around the world.

The research team proposed for this study consists of several prominent pavement practitioners and researchers. The team is led by Mr. Roger Larson, a Senior Engineer at APTech and a nationally known pavement engineer. He will be assisted by Mr. Kurt Smith. Brief summaries of the qualifications of the APTech team members are presented in the next section, with detailed resumes found in appendix D.

Project Team Members

Mr. Roger M. Larson, P.E., will serve as the Principal Investigator on this project, overseeing all of the work efforts and coordinating with the Ohio DOT. Mr. Larson joined APTech in 2002 after a distinguished 41-year career with the Federal Highway Administration (FHWA). He is nationally and internationally recognized in pavement circles for his background in concrete pavement design, performance, construction, and rehabilitation.

Throughout his 41-year career with FHWA, Mr. Larson was actively involved in a variety of highway projects involving planning, design, construction, and maintenance activities. During the last 18 years with the organization, he focused more on concrete pavement design, construction, and rehabilitation issues. He is extremely knowledgeable of all aspects of concrete pavement design and construction, and is cognizant of major concrete pavement research initiatives currently being conducted in the United States and in other countries.

Since joining APTech in 2002, Mr. Larson has participated in a number of activities. He has served as Principal Investigator on a study assessing alternative dowel bars for the American Society of Civil Engineering's (ASCE's) Highway Innovative Technology Evaluation Center (HITEC), and prepared a state-of-the-practice summary document. He has also participated in the development and delivery of several training courses, including concrete pavement design, concrete pavement rehabilitation, overlay design, and preventive maintenance. He is also contributing on the support contract for FHWA's Concrete Pavement Technology Program (CPTP), in which he is assisting in the presentation of workshops and in the preparation of technical briefs.

Based on Mr. Larson's background on pavement characteristics, including friction, texture, and noise, he is currently Principal Investigator on ODOT State Job 134323, *Relationship between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations*. He has been a national leader in this area for the last decade, advocating effective surface texturing techniques that produce improved surface friction and reduced noise emissions as part of a comprehensive pavement design. Mr. Larson was Chairman of the *PCC Pavement Surface Texturing Technical Working Group* in the 1990s that was comprised of FHWA, State, and industry representatives, and co-authored the group's Final Report in 1996. Prior to retiring from FHWA, he served as the English-speaking secretary of the PIARC Technical Committee (C-1) on pavement surface characteristics. Mr. Larson has also served on the technical panel overseeing the NCHRP projects on noise (documented in Synthesis 258) and friction (documented in Synthesis 291), and recently has authored papers and made formal presentations on pavement friction- and texture-related topics at the NASA Tire/Runway Friction Workshop (2003), the Symposium on Pavement Surface Characteristics (2004), the International Friction Conference (2005), the 8th International Concrete Pavement Conference (2005), and the 1st National Workshop on Pavement Preservation (2005). Mr. Larson also served on the Project Advisory Committee for the Midwest Regional University Transportation Center friction research that was recently completed.

Mr. Kurt D. Smith, P.E., will serve as the Co-Principal Investigator and Project Manager. Mr. Smith earned his B.S. and M.S. degrees in Civil Engineering from the University of Illinois and has over 22 years of experience in the areas of pavement design, evaluation, and rehabilitation. He is a Program Director at APTech, where he oversees the research and training segment of the firm and actively manages several projects while serving as an advisor and technical analyst on others. For example, Mr. Smith recently served as the Principal Investigator on an FHWA research study on the cost-effectiveness of concrete pavement design features, and also served as the Co-Principal Investigator on two recent FHWA studies, one on the effect of joint sealing on pavement performance and one developing guidelines for the repair and rehabilitation of concrete pavements. Currently, he is serving as a Co-Principal Investigator on an FHWA study providing technical support for FHWA's Concrete Pavement Technology Program (CPTP) and as a Principal Investigator on an FHWA study documenting the application of the falling weight deflectometer in the mechanistic-empirical pavement design process. In addition, Mr. Smith is serving as Co-Principal Investigator on the ODOT State Job 134323, *Relationship between Skid Resistance Numbers Measured with Ribbed and Smooth Tire and Wet-Accident Locations.*

APPENDIX C. OTHER COMMITMENTS OF THE RESEARCH TEAM

The APTech team members that have been assembled for this research effort have sufficient time available to commit to this project. Table C-1 below summarizes the current percent time commitments for the APTech project team members for the years 2008 through 2011, broken out by either *project work obligations* or *administrative/managerial commitments*. As observed from this table, all proposed APTech team members have the necessary time available to actively participate in the subject project.

Table C-1. Current time commitments of APTech team members.

Team Member	Project Role	Type of Obligation	Time Commitment			
			2008	2009	2010	2011
Roger Larson	Principal Investigator	**Project Work**				
		OH Friction Study (State Job 134323)	5%	0%	0%	0%
		FHWA Concrete Pavement Technology Program	5%	5%	0%	0%
		Administrative*	5%	5%	5%	5%
Kurt Smith	Co-Principal Investigator	**Project Work**				
		OH Friction Study (State Job 134323)	5%	0%	0%	0%
		FHWA Concrete Pavement Technology Program	20%	20%	0%	0%
		FHWA FWD Study	15%	15%	0%	0%
		National Highway Institute Training Courses	10%	10%	10%	10%
		IPRF Airfield Pavement Study	5%	5%	0%	0%
		Administrative*	15%	15%	15%	15%

* Administrative time includes items such as company management, personnel management, and business development.

APPENDIX D. RESUMES

Roger M. Larson, P.E.

Kurt D. Smith, P.E.

ROGER M. LARSON, P.E.
PRINCIPAL INVESTIGATOR

EDUCATION

M.S., Civil Engineering, University of Minnesota, 1966

B.S., Civil Engineering, South Dakota State University, 1961

PROFESSIONAL REGISTRATION

Professional Engineer, Minnesota, No. 8444

PROFESSIONAL AFFILIATIONS

- Life Member, American Society of Civil Engineers
- Member, National Society of Professional Engineers
- Past Member, American Concrete Institute
- Transportation Research Board
  - Past Member, Committee A2B04, *Pavement Rehabilitation*
  - Member, Committee AFD50, *Rigid Pavement Design*
  - Past Liaison Member, NCHRP Project 1-34D, Pavement Subsurface Drainage
  - Past Panel Member, NCHRP Synthesis topic 38-15, "Falling Weight Deflectometer Usage"

PROFESSIONAL SUMMARY

In January 2002, Mr. Larson joined Applied Pavement Technology, Inc. (APTech) as a Senior Engineer after a distinguished 41-year career with the Federal Highway Administration (FHWA). He is nationally and internationally recognized in pavement circles for his background in concrete pavement design, performance, construction, and rehabilitation, and brings that experience to APTech as a principal investigator and technical advisor on research projects and as an instructor for various training courses.

Throughout his 41-year career with the FHWA, Mr. Larson was actively involved in projects involving highway research, planning, design, and construction and maintenance activities, and served in progressively responsible positions. During his last 18 years with the organization, he managed the research, development, and implementation of improved pavement design, construction, maintenance, and performance evaluation procedures.

Among some of his specific accomplishments at the FHWA are his update to the FHWA general pavement design policy (23CFR626 Non-regulatory Supplement), and the development of programs to implement Strategic Highway Research Program (SHRP), Asphalt and Concrete Pavement Research, and Long Term Pavement Performance (LTPP) results. He also successfully promoted retrofitted load transfer devices to implement earlier FHWA research. This effort resulted in the industry-funded development of equipment to construct multiple slots for retrofitted dowel bar installations which are now used routinely in about half the States.

Mr. Larson was also responsible for the preparation and approval of initial study design and follow-up monitoring of three major FHWA contract research projects conducted to review the performance of existing experimental jointed and continuously reinforced concrete pavements at the national level. These studies provided significant insight into concrete pavement performance characteristics and behavior, and led to improvements in current design and construction techniques. Throughout his career, Mr. Larson has also provided major input into almost a dozen National Cooperative Highway Research Program (NCHRP) pavement design syntheses of highway practice that have been published, and managed FHWA nationally coordinated research program activities for studies in flexible pavements, rigid pavements, and/or truck/pavement interaction.

In addition, Mr. Larson managed or assisted in the development of implementation guidelines, manuals, syntheses of practice, state-of-the-art summaries and national highway pavement-related training courses. For example, he assisted in the preparation of the 1986 and 1993 American Association of State Highway and Transportation Officials (AASHTO) pavement design guides, as well as in the preparation of the 1998 AASHTO Design Supplement. Furthermore, he was a member of the NCHRP panel for Project 1-37A, which guided the development of the 2002 pavement design guide that is based on mechanistic-empirical procedures which is now being adopted by the various States.

Mr. Larson has also directed three FHWA tri-regional workshops on concrete pavement rehabilitation, four international conferences on concrete pavement design and rehabilitation, and various pavement design and rehabilitation workshops and meetings. During his employment with the FHWA, Mr. Larson received many outstanding performance ratings, letters of commendation, and awards recognizing special accomplishments related to highway research, development, and implementation.

Mr. Larson has extensive experience in experimental design and pavement analysis and has served on oversight panels for various FHWA, SHRP, Highway Innovative Technology Evaluation Center (HITEC), and NCHRP pavement research projects. He is active in various American Concrete Institute (ACI), American Society of Civil Engineers (ASCE), National Society of Professional Engineers (NSPE), NCHRP, and Transportation Research Board (TRB) activities. He recently represented the FHWA as the English-speaking secretary of the PIARC World Road Association Committee C-1 on Surface Characteristics.

Mr. Larson has also been a national leader in the area of tire-pavement noise and pavement texturing for over a decade, advocating effective surface texturing techniques that produce improved surface friction and reduced noise emissions. While with the FHWA, he co-authored a technical report on pavement-tire noise and safety, and has been a strong advocate of integrating surface texture and noise considerations as part of a comprehensive pavement design process.

Since joining APTech, Mr. Larson has served as a consultant on several projects and has been very active in technology transfer. He has served nationwide as an instructor on topics such as concrete pavement design, concrete pavement rehabilitation, concrete overlays, and pavement preventive maintenance, and previously served as the Principal Investigator for a HITEC project documenting the performance of alternative dowel bars. He is on the Implementation Team for FHWA's Concrete Pavement Technology Program (CPTP). He has been active in promoting improved PCC surfacing texturing to reduce noise and maintain desirable texture/friction properties to preserve safety.

In 1983, he successfully completed the 6-week Pavement Management Course at the University of Texas in Austin. In April 2002, Mr. Larson received a Distinguished Engineer Award from South Dakota State University.

REPRESENTATIVE EXPERIENCE

- Co-Principal Investigator for the FHWA, providing technical support for FHWA's Concrete Pavement Technology Program (CPTP). Mr. Larson was responsible for the preparation of a detailed status report and giving a number of technical presentations as part of the CPTP Implementation Team.
- Principal Investigator on the Ohio Department of Transportation Study to find skid number relationships between ribbed and smooth tires and to evaluate the effect of macrotexture on wet weather and rear end crashes. Mr. Larson is responsible for conducting a literature review and an experimental design for this project.
- Instructor for the National Highway Institute (NHI) training course, *PCC Pavement Evaluation and Rehabilitation.*
- Instructor for the *Pavement Evaluation, Design and Rehabilitation* course for the Oklahoma ASCE.
- Instructor for the FHWA project *PCC Overlays: State of the Practice.*
- Instructor for the presentation of *Pavement Evaluation and Rehabilitation* training course for ASCE.
- Instructor for the NHI training course, *Pavement Preservation: Selecting Pavements for Preventive Maintenance.*
- Instructor for the NHI training course, *Concrete Pavement Design Details and Construction Practices.*
- Project Engineer for the FHWA project, *Long-Term Pavement Performance Data Analysis.*
- Project Engineer for the update and revisions to the ASCE *Low Volume Roads Pavement Design Guide.*
- Principal Investigator for the HITEC project, *Evaluation of Alternative Dowel Bar Materials.*
- Co-chair for the FHWA pavement and bridge deck Thin Bonded Overlay & Surface Laminates Technical Working Group.
- FHWA Program Manager for the Special Demonstration Project SP204, Retrofit Load Transfer.
- FHWA Program Manager responsible for the technical development of ten NHI highway engineering training courses.
- Participant on numerous FHWA Pavement Design and Rehabilitation Team Reviews at the request of the States and the FHWA Division offices.
- Assistant planning and research engineer involved in pavement research, design, and management activities in the FHWA Minnesota Division Office.

SELECTED PUBLICATIONS AND PRESENTATIONS

Larson, R. M. 2006. *CPTP Project and Product Status and PCC Pavement Joint Design.* Presentations at Northwest ACPA Conference in Stevenson, Washington.

Larson, R.M. 2006. *Overview of Friction Testing in the US and Abroad.* Presentation at the PA Annual Concrete Conference in Grantsville, PA.

Larson, R. M. 2005. *Overview of Friction Testing in the US and Abroad.* Presentation at ACPA Annual Tech Day, Indian Wells, CA.

Zimmerman, K.A. and R. M. Larson. 2005. *Improving Safety as Part of a Pavement Preservation Program.* TR E-Circular #78, Roadway Pavement Preservation 2005, Transportation Research Board, Washington, D.C.

Larson, R.M. 2005. *Using Friction and Texture Data to Reduce Traffic Fatalities, Serious Injuries, and Traffic Delays.* Proc., International Conference on Surface Friction, Christchurch, New Zealand, May 1-4, 2005.

Larson, R.M., L. Scofield, and J. Sorenson. 2005. *Providing Durable, Safe, and Quiet Highways. Proceedings*, 8th International Conference on Concrete Pavements, International Society for Concrete Pavements, Colorado Springs, CO, August 14-18, 2005.

Larson, R.M. and K.D. Smith. 2005. *Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements. Proceedings*, 8th International Conference on Concrete Pavements, International Society for Concrete Pavements, Colorado Springs, CO, August 14-18, 2005.

Larson, R.M., L. Scofield, and J.B. Sorenson. 2004. *Pavement Functional Surface Characteristics*. Preprint CD-ROM, SURF 2004, 5th Symposium on Pavement Surface Characteristics. Toronto, Ontario, Canada.

Larson, R.M., L. Scofield, and J.B. Sorenson. 2003. "Research Frontiers in Pavement Preservation." *TR News Number 228*. Transportation Research Board, Washington, D.C.

Zimmerman, K.A., K.D. Smith, T.E. Hoerner, M.J. Wade, and R.M. Larson. 2003. *A Guide for the Design and Maintenance of Low-Volume Roads*. ASCE/FHWA.

Hoerner, T.E., K.D. Smith, R.M. Larson, and M.E. Swanlund. 2003. "Current Practices of PCC Pavement Texturing." *Transportation Research Record 1860*. Transportation Research Board, Washington, D.C.

Larson, R.M. 1999. *Innovations in Load Transfer Restoration*, PIARC World Road Congress.

Larson, R.M., D. Peterson, and A. Correa. 1998. *Retrofit Load Transfer, Special Demonstration Project SP-204*. FHWA-SA-98-047. Federal Highway Administration, Washington, D.C.

Larson, R.M. and B.O. Hibbs. 1997. *Tire Pavement Noise and Safety Performance*. 6th International Purdue Conference on Concrete Pavement Design and Materials for High Performance. Purdue University, West Lafayette, IN.

Hibbs, B.O. and R.M. Larson. 1996. *Tire Pavement Noise and Safety Performance—PCC Surface Texture Technical Working Group*. FHWA-SA-96-068. Federal Highway Administration, Washington, D.C.

Larson, R.M. and S.D. Tayabji. 1994. *Performance of Continuously Reinforced Concrete Pavements*. 3rd International Workshop on the Design and Evaluation of Concrete Pavements. Vienna, Austria.

Larson, R.M., S. Vanikar, and S. Forster. 1993. Summary Report—*U. S. Tour of European Concrete Highways (U.S. TECH), Follow-up Tour of Germany and Austria*. FHWA-SA-93-080. Federal Highway Administration, Washington, D.C.

Guo, H., R.M. Larson, and M.B. Snyder. 1993. *A Nonlinear Mechanistic Model for Dowel Looseness in PCC Pavements*. 5th International Conference on Concrete Pavement Design and Rehabilitation. Purdue University, West Lafayette, IN.

Larson, R.M. 1990. *The Need for Dowel Bars in Jointed Concrete Pavements*. 2nd International Workshop on the Design and Evaluation of Concrete Pavements. CROW, The Netherlands.

Kelleher, K. and R.M. Larson. 1989. *The Design of Plain Doweled Jointed Concrete Pavement*. 4th International Conference on Concrete Pavement Design and Rehabilitation. Purdue University, West Lafayette, IN.

Larson, R.M. and D. Freund. 1987. *Microcomputer Applications in Pavements*. ASCE Conference, Microcomputers in Transportation.

KURT D. SMITH, P.E.
PROGRAM DIRECTOR

EDUCATION

M.S., Civil Engineering, University of Illinois, 1985

B.S., Civil Engineering, University of Illinois, 1983

PROFESSIONAL REGISTRATION

Professional Engineer, Illinois (1989)

PROFESSIONAL AFFILIATIONS

- American Society of Civil Engineers
- Transportation Research Board
  - Member, Committee AFD50, *Rigid Pavement Design*
  - Member, Committee AFD70, *Pavement Rehabilitation*
- American Concrete Institute
  - Member, Committee 325, *Concrete Pavements*
- International Society for Concrete Pavements

PROFESSIONAL SUMMARY

Mr. Smith has over 23 years of experience in the areas of pavement design, evaluation, and rehabilitation. He has led nationwide studies on pavement performance and pavement rehabilitation effectiveness and has also conducted numerous pavement evaluation projects requiring the assessment of the structural adequacy of the existing pavement and the development of appropriate rehabilitation strategies. Taken together, these activities have provided Mr. Smith with a keen understanding of pavement behavior and performance.

Mr. Smith has been employed with Applied Pavement Technology, Inc. (APTech) since 1996 and is currently a Program Director and Principal. Mr. Smith oversees the research and training segment of the firm and actively manages several projects while serving as an advisor and technical analyst on others. For example, Mr. Smith is currently serving as the Principal Investigator on a Federal Highway Administration (FHWA) study on the use of deflection data in mechanistic pavement design applications. He is also serving as a Co-Principal Investigator or Principal Investigator on three major pavement research initiatives: an FHWA project providing technical support to the agency's Concrete Pavement Technology Program (CPTP); a South Dakota Department of Transportation (SDDOT) project evaluating the new mechanistic-empirical pavement design guide; and an Ohio Department of Transportation study on the use of smooth and ribbed tires for measuring pavement surface friction.

In recent years, Mr. Smith has also served as the Principal Investigator on an FHWA research study evaluating the cost-effectiveness of concrete pavement design features and as the Co-Principal Investigator on two other FHWA studies: one developing guidelines for the repair and rehabilitation of concrete pavements and another developing guidelines for assessing materials-related distress in concrete pavements. He also assisted in the development of local road surfacing criteria for the South Dakota DOT and in the development of a low-volume roads design guide and related training class for the American Society of Civil Engineers (ASCE).

Mr. Smith has also made significant contributions to the area of technology transfer. For example, he has served as the Principal Instructor for the presentation of several National Highway Institute (NHI) training courses, including *Concrete Pavement Design Details and Construction Practices, Portland Cement Concrete (PCC) Pavement Distress Evaluation and Rehabilitation, Hot Mix Asphalt Pavement Evaluation and Rehabilitation,* and *Geotechnical Aspects of Pavements*. Furthermore, he assisted in the development of the pavement preservation series for the NHI that includes *Pavement Preservation: The Preventive Maintenance Concept*, and serves as an instructor for that course and for one titled *Pavement Preservation: Selecting Pavements for Preventive Maintenance*. He also helped develop the other two courses in this series: *Pavement Preservation: Design and Construction of Quality Preventive Maintenance Treatments* and *Pavement Preservation: Integrating Pavement Preservation Practices and Pavement Management*. Because of his demonstrated teaching skills, Mr. Smith is recognized by the NHI as a certified instructor. Taken together, this training course exposure has provided Mr. Smith with an awareness of the design and rehabilitation practices of many transportation agencies, as well as many of the issues and obstacles that they encounter on a daily basis.

Mr. Smith also serves as a technical analyst on many of APTech's airfield pavement evaluation projects, and has conducted analyses on airfield pavement projects at Calgary International Airport, Edmonton International Airport, Syracuse International Airport, Pittsburgh International Airport, O'Hare International and Midway Airport. In addition, Mr. Smith has conducted numerous airfield pavement inspections and evaluations, including statewide airport pavement inspection projects in Virginia, Iowa, and Illinois, and numerous pavement evaluation and rehabilitation studies at Bangor (Maine) International Airport, Lubbock (Texas) International Airport, Wood County (West Virginia) Airport, Southeast Iowa Regional Airport, and Lexington (Kentucky) Bluegrass Airport.

Mr. Smith is also an active participant in the airfield pavement research activities of the Innovative Pavement Research Foundation (IPRF). For example, he served as the Co-Principal Investigator on two IPRF studies, one on *Innovative Testing Standards for Acceptance Criteria for Concrete Pavement*, which investigated the use of alternative testing methods for assessing concrete pavement strength and thickness, and one on *Concrete Mixes and Pavement Construction for Deicing Facilities*, which evaluated the effects of aircraft deicing agents on concrete pavements. He also assisted on the IPRF airfield pavement study *Practices for Accelerated Airfield Concrete Pavement Rehabilitation and Reconstruction*, which documented the "best practices" of "fast track" concrete pavement construction at airfields.

Prior to joining APTech, Mr. Smith spent 11 years with ERES Consultants, Inc. (ERES), serving in various capacities within the research segment of the firm. During his tenure at ERES, Mr. Smith contributed to many national pavement research studies, developing strong technical and project management skills. Mr. Smith served as a Principal Investigator on several prominent research studies and worked his way from an associate research engineer to the position of Vice President of Research, where he was responsible for the overall technical and administrative management of the firm's research division. While associated with ERES Consultants, Mr. Smith served as Principal Investigator on an FHWA-sponsored study entitled *Performance Evaluation of Experimental Rigid Pavements*, a study evaluating the performance of concrete pavements and providing improved guidance on concrete pavement design and construction. Also, Mr. Smith served as Principal Investigator on an NCHRPsponsored study entitled *Smoothness Specifications for Pavements*, a study in which the effect of initial pavement smoothness on overall pavement performance was investigated, and served as Principal Investigator for two other research studies (the FHWA project *Development of a Prototype Performance-Related Specifications for PCC Pavements*, and the NCHRP study *Performance of Subsurface Pavement Drainage*). He also served as Co-Principal Investigator on an FHWA research study (*Physical and Mechanical Properties of PCC Recycled Aggregate Concrete*) evaluating the effect of recycled coarse aggregate on concrete pavement performance and on another FHWA research study that developed a prototype performance specification for concrete pavement construction (*Performance-Related Specifications for Portland Cement Concrete: Laboratory Test Development and Accelerated Test Planning*).

In addition to the above projects, Mr. Smith has been involved with a number of other projects that have provided him with a strong background in pavement design, construction, and performance. From 1986–1990, Mr. Smith was a Co-Principal Investigator on an FHWA-sponsored research study evaluating the performance of 95 concrete pavement sections throughout the country. From 1988–1991, Mr. Smith was Project Manager on a study for the Arizona Department of Transportation that evaluated 30 pavement sections in the Phoenix Urban Corridor and resulted in the recommendation of various design changes. Mr. Smith also served as Project Manager on an FHWA-sponsored study, *Concrete Joint Sawing Operations*, in which he developed guidelines for concrete joint sawing activities and early loading criteria. Finally, Mr. Smith also assisted in the development of all three versions of DARWin, the American Association of State Highway and Transportation Officials' (AASHTO) computer software program for the design of pavement structures.

Mr. Smith also contributed to the Strategic Highway Research Program (SHRP) research initiatives conducted in the late 1980s and early 1990s. He was the primary author of the original *Distress Identification Manual*, and assisted in the development of the original *Data Collection Guide*, both of which were produced in 1987.

Mr. Smith also played key roles on the SHRP H-105 and H-106 research studies on materials and methods for pavement maintenance activities, as well as the SHRP C-206 study that assembled all of the SHRP concrete research results and produced various implementation packages.

Mr. Smith regularly attends transportation conferences and seminars where he frequently makes technical presentations. In 1989, Mr. Smith was awarded the Eldon J. Yoder Outstanding Paper Award for his paper *Effect of Design Features on Concrete Pavement Performance* at the Fourth International Conference on Concrete Pavement Design and Rehabilitation (with co-authors D. Peshkin, M. Darter, and A. Mueller). Mr. Smith also received this award in 1993 at the Fifth International Conference on Concrete Pavement Design and Rehabilitation as a co-author (with Paul Okamoto and Pete Nussbaum) on the paper *Guideline Recommendations for Timing Contraction Joint Sawing of PCC Highway Pavements*.

REPRESENTATIVE EXPERIENCE

Pavement Research

- Senior Engineer on the IPRF study *Materials-Related Distress and Projected Pavement Life—Concrete Airfield Pavements in Colorado*.
- Senior Engineer on the FHWA study *Local Calibration of the MEPDG using Pavement Management Systems*.

- Co-Principal Investigator on the Illinois Department of Transportation study *Performance of HMA Overlays in Illinois.*
- Principal Investigator on the FHWA study *Using Falling Weight Deflectometer Data with Mechanistic-Empirical Design and Analysis.*
- Co-Principal Investigator on the Ohio Department of Transportation Study to determine skid number relationships between ribbed and smooth tires.
- Co-Principal Investigator to provide technical support for the FHWA's Concrete Pavement Technology Program (CPTP).
- Co-Principal Investigator for the evaluation of alternative dowel bar materials for the Highway Innovative Technology Evaluation Center (HITEC).
- Co-Principal Investigator on the IPRF pavement study *Concrete Mixes and Pavement Construction for Deicing Facilities.*
- Co-Principal Investigator on the South Dakota DOT study *Mechanistic-Empirical Pavement Design Guide Implementation Plan.*
- Co-Principal Investigator on the FHWA Task 65 project *Technology Transfer, Deployment, and Delivery Services for the Concrete Pavement Technology Program.*
- Co-Principal Investigator on the FHWA Task 9 project *Cost Effectiveness of Sealing Transverse Contraction Joints in Concrete Pavements.*
- Co-Principal Investigator on the IPRF pavement study *Innovative Testing Standards for Acceptance Criteria for Concrete Pavement.*
- Senior Engineer on the IPRF airfield pavement study *Practices for Accelerated Airfield Concrete Pavement Rehabilitation and Reconstruction.*
- Principal Investigator on the FHWA project *Concrete Overlays: State of the Practice.*
- Principal Investigator on the FHWA project *Incremental Costs and Performance Benefits of Various Features of Concrete Pavement.*
- Co-Principal Investigator for a project to develop objective criteria that can be used to assist in making pavement surfacing decisions for local roads in South Dakota.
- Co-Principal Investigator for a joint FHWA/ASCE project developing a pavement design and maintenance guide for low-volume roads.
- Co-Principal Investigator on the FHWA project Repair and Rehabilitation of Concrete Pavements.
- Senior Engineer on the ASCE's Civil Engineering Research Foundation (CERF) study on the use of alternative dowel bars in concrete pavements.
- Principal Investigator on the American Concrete Pavement Association (ACPA) project *Fatigue Models for Concrete Airfield Pavement Design.*
- Senior Engineer on the technical assistance contract for the FHWA's Long-Term Pavement Performance (LTPP) program.
- Technical Consultant for the South Dakota DOT project *Investigation of Long-Term Effects of Magnesium Chloride and Other Concentrated Salt Solutions on Pavement and Structural Portland Cement Concrete.*
- Principal Investigator on the FHWA project *Technical Reports on Pavement Topics.*
- Principal Investigator on the FHWA project *High-Performance Concrete Pavements.*
- Co-Principal Investigator, NCHRP Project 4-20C *Aggregate Tests Related to the Performance of Concrete Pavements.*
- Co-Principal Investigator on the FHWA project *Detection, Analysis, and Treatment of Materials-Related Distress in PCC Pavements.*

- Technical Consultant, Iowa Department of Transportation project HR-1066, *Evaluation of Mixing Time vs. Concrete Consistency and Consolidation.*
- Principal Investigator on the FHWA project *Performance Evaluation of Experimental Rigid Pavements—Data Collection and Analysis.*
- Principal Investigator on NCHRP Project 1-31 *Smoothness Specifications for Pavements.*
- Principal Investigator on NCHRP Project 1-34 *Performance of Subsurface Pavement Drainage.*
- Principal Investigator on the FHWA project *Development of Prototype Performance-Related Specifications for PCC Pavements.*
- Co-Principal Investigator on the FHWA project *Physical and Mechanical Properties of Recycled PCC Aggregate Concrete.*
- Co-Principal Investigator on the FHWA project *Performance-Related Specifications for PCC: Laboratory Test Development and Accelerated Test Planning.*
- Co-Principal Investigator on the FHWA study *Performance/Rehabilitation of Rigid Pavements.*
- Project Manager on the FHWA project *Concrete Joint Sawing Operations.*
- Project Manager on the Arizona DOT project *Concrete Pavement Design and Rehabilitation.*
- Project Engineer on SHRP Project H-105 *Innovative Materials and Equipment for Pavement Surface Repairs.*
- Project Engineer on SHRP Project H-101 *Pavement Maintenance Effectiveness.*
- Project Engineer on the SHRP H-106 project *Innovative Materials Development and Testing.*
- Project Engineer on the SHRP C-206 project *Optimization of Highway Concrete Technology.*
- Project Engineer on the SHRP H-107A project *Fabrication and Testing of Maintenance Equipment Used for Pavement Surface Repairs.*
- Co-Principal Investigator on the FHWA study *Pressure Relief Joints and Other Joint Rehabilitation Techniques.*
- Project Engineer for the FHWA project *Technical Support for the Long Term Pavement Monitoring (LTM) Program.*
- Project Engineer for the implementation of the FHWA/SHRP project *Development of Strategic Highway Research Program, LTPP Program.*

Training Courses and Manuals

- Senior Engineer for the National Concrete Pavement Technology Center project developing a *Guide for Concrete Overlay Solutions.*
- Principal Investigator for the National Concrete Pavement Technology Center training course on PCC Rehabilitation and Maintenance.
- Co-Principal Investigator for a joint FHWA/ASCE project developing a training course on the design and maintenance of low-volume paved roads.
- Contributing author on the development of a manual on *Integrating Materials and Construction Practices for Durable Concrete Pavements.*
- Principal Instructor for the NHI training course *PCC Pavement Evaluation and Rehabilitation.*
- Principal Instructor for the NHI training course *Concrete Pavement Design Details and Construction Practices.*
- Co-Principal Investigator for the development of NHI training course *Pavement Preservation: Design and Construction of Quality Preventive Maintenance Treatments.*
- Co-Principal Investigator for the development of NHI training courses on *PCC Pavement Distress Evaluation and Rehabilitation* and *HMA Pavement Distress Evaluation and Rehabilitation.*

- Principal Investigator on the revisions to the *Technical Digest* and NHI training course, *Concrete Pavement Design Details and Construction Practices.*
- Principal Investigator for the development of an interactive CD-ROM on the NHI training course *Concrete Pavement Design Details and Construction Practices.*
- Principal Investigator for the development of a *Technical Digest* and NHI training course *Concrete Pavement Design Details and Construction Practices.*
- Project Engineer and Instructor for the NHI training course *Pavement Preservation: the Preventive Maintenance Concept.*
- Instructor for the NHI training course *Pavement Preservation: Selecting Pavements for Preventive Maintenance.*
- Project Engineer and Instructor for the NHI training course *Techniques for Pavement Rehabilitation.*
- Project Engineer and Instructor for the NHI course *AASHTO Design Procedures for New Pavements.*
- Project Engineer and Instructor for the NHI course *Pavement Analysis and Design Checks.*
- Instructor for the NHI course *AASHTO Overlay Design Procedures.*
- Project Engineer and Instructor for the NHI training course *Pavement Design—Principles and Practices.*
- Project Engineer for the rewrite of the Minnesota DOT *Geotechnical and Pavement Manual.*

Airport Evaluation, Design, and Management

- Senior Engineer on the analysis of Runway 13-31 at Amarillo (Texas) International Airport.
- Senior Project Engineer for the analysis of the apron pavements at Pittsburgh International Airport.
- Senior Project Engineer for the analysis of pavements at Lexington (Kentucky) Bluegrass Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Taxiway A and associated connectors at Syracuse Hancock International Airport.
- Senior Project Engineer for the analysis of pavements at Southeastern Iowa Regional Airport.
- Senior Project Engineer for the statewide airport pavement management system in Illinois.
- Senior Project Engineer for the analysis of pavements at Edmonton International Airport.
- Senior Project Engineer for the analysis of pavements at Calgary International Airport.
- Senior Project Engineer for the pavement evaluation of Runway 15–33 at Bangor (Maine) International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Runway 3–21, Wood County (West Virginia) Airport.
- Senior Project Engineer for the pavement evaluation of the 10 largest airports in Iowa.
- Senior Project Engineer for the pavement evaluation of Runway 17R–35L at Lubbock (Texas) International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Taxiway P at O'Hare International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Taxiway S at O'Hare International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Taxiway F at O'Hare International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Taxiway M at O'Hare International Airport.

- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Taxiway T at O'Hare International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Runway 4L at O'Hare International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Runway 4R at O'Hare International Airport.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Runway 14L at O'Hare International Airport.
- Senior Project Engineer for the evaluation of B777 aircraft on O'Hare's primary runways.
- Senior Project Engineer for the pavement evaluation and design of rehabilitation for Runway 4R at Midway Airport.
- Senior Project Engineer for the update of pavement management systems for O'Hare International Airport and Midway Airport.
- Senior Project Engineer for the statewide airport system evaluation in Virginia.

Roadway Pavement Evaluation

- Project Manager on the field testing and evaluation of two county highways in Champaign County, Champaign, Illinois.
- Project Manager for the evaluation of Archer Elevator Road in Springfield, Illinois.
- Project Manager on the falling weight deflectometer testing of pavements at Cooper Nuclear Power Station in Brownville, Nebraska.
- Senior Engineer on a study for the North Carolina DOT evaluating the performance of a bonded concrete overlay.
- Senior Engineer for the evaluation and rehabilitation design of Green Street and Lincoln Avenue, Urbana, Illinois.
- Senior Engineer on the evaluation of Highway 140, Modoc Billy Creek Fish Hole Creek, Oregon.
- Senior Engineer on the evaluation of county highway, Logan County, Illinois.
- Project Manager for the evaluation and rehabilitation design of Wright Street and Fifth Street, Champaign, Illinois.
- Principal Investigator for the conduct of a probabilistic life-cycle costs analysis of pavement design alternatives for the I-25 Southeast Corridor in Denver, Colorado.
- Senior Project Engineer for the evaluation of Parking Lots B and C at O'Hare International Airport.
- Senior Project Engineer for the evaluation of Parking Lot F at O'Hare International Airport
- Senior Project Engineer for the pavement evaluation of Bessie Coleman Road at O'Hare International Airport.
- Senior Project Engineer for the pavement evaluation of the recirculation Road at O'Hare International Airport.
- Senior Project Engineer for the Delaware Department of Transportation Concrete Pavement Performance Reviews.
- Senior Project Engineer for the evaluation of the East–West Tollway, Chicago.
- Senior Project Engineer for the evaluation of the Indian Nation Toll Road, Oklahoma.
- Senior Project Engineer evaluating the effect of PCC shoulders and widened lanes for the Colorado Department of Transportation.
- Project Engineer for the evaluation of PCC pavement joint deterioration on I-88.

Computer Program Development

- Principal Investigator for the FHWA project to develop a computer program for computing *Incremental Costs and Performance Benefits of Various Features of Concrete Pavement.*
- Project Engineer for the AASHTO project to create and revise the DARWin pavement design software (versions 1.0, 2.0, 3.0).
- Senior Project Engineer for the development of a pavement condition forecasting program for the National Park Service.

SELECTED PUBLICATIONS

Van Dam, T. J., K. R. Peterson, L. L. Sutter, and K. D. Smith. 2008. "Durability of Concrete Pavements Used for Aircraft Deicing Facilities." Preprint Paper. Transportation Research Board.

Smith, K. 2007. *Early Entry Sawing of Portland Cement Concrete Pavements*. Federal Highway Administration.

Smith, K. 2007. *Conventional Fast Track Paving and Repair*. Federal Highway Administration.

Smith, K. and E. Skok. 2007. "A Historical Look at Interstate Highway System Pavements in the North Central Region." Transportation Research E-Circular E118. Transportation Research Board.

Wolters, A., K. Smith, and C. Peterson. 2007. "Evaluation of Rubblized Pavement Sections in Michigan." Preprint Paper. Transportation Research Board.

Nazarian, S., D. Yuan, K. Smith, F. Ansari, and C. Gonzalez. 2006. *Acceptance Criteria of Airfield Concrete Pavement Using Seismic and Maturity Concepts*. Innovative Pavement Research Foundation.

Van Dam, T. J., K. R. Peterson, K. D. Smith, L. L. Sutter, D. G. Peshkin, and R. G. Alger. 2006. *Design and Construction of Concrete Pavement for Aircraft De-icing Facilities*. Innovative Pavement Research Foundation.

Nazarian, S., D. Yuan, K. Smith, and J. Bruinsma. 2006. "Demonstration of Seismic and Maturity Testing Technologies at Aurora Municipal Airport." *Proceedings, 2006 ASCE Airfield and Highway Pavements Conference*. American Society of Civil Engineers.

Taylor, P. C., S. H. Kosmatka, G. F. Voigt, M. E. Ayers, A. Davis, G. J. Fick, J. Gajda, J. Grove, D. Harrington, B. Kerkhoff, C. Ozyildirim, J. M. Shilstone, K. Smith, S. M. Tarr, P. D. Tennis, T. J. Van Dam, and S. Waalkes. 2006. *Integrated Materials and Construction Practices for Concrete Pavement: A State of the Practice Manual*. Federal Highway Administration.

Larson, R. and K. Smith. 2005. "Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements." *Proceedings, Eighth International Conference on Concrete Pavements*. Colorado Springs, CO.

Tayabji, S., K. Smith, and S. Tyson. 2005. "U.S. Concrete Pavement Technology— Current Practices, Future Directions." *Proceedings, 6th International Congress on Global Construction*. Dundee, Scotland.

Tyson, S. S., K. D. Smith, S. D. Tayabji, and R. M. Larson. 2005. "The Concrete Pavement Technology Program (CPTP) — Promoting High-Performance Concrete Pavements." *Proceedings, Seventh International Symposium on Utilization of High-Strength/High-Performance Concrete*, Special Publication 228, American Concrete Institute.

Liu, J., D. Zollinger, S. Tayabji, and K. Smith. 2005. *Application of Reliability Concept in Concrete Pavement Rehabilitation Decision Making*. Transportation Research Record 1905, Transportation Research Board.

Smith, K. D., K. A. Zimmerman, and F. N. Finn. 2004. "The AASHO Road Test: Living Legacy for Highway Pavements." *TR News*, Number 232. Transportation Research Board.

Hoerner, T. E., K. D. Smith, and J. E. Bruinsma. 2004. *Incremental Costs and Performance Benefits of Various Features of Concrete Pavement Design Features*. Federal Highway Administration.

Liu, J., D. G. Zollinger, S. D. Tayabji, and K. Smith. 2004. *SAPER: Tool for Selecting Concrete Pavement Repair and Rehabilitation Treatments*. Transportation Research Board Preprint Paper.

Zollinger, D. G., S. D. Tayabji, and K. Smith. 2003. *Repair and Rehabilitation of Concrete Pavements, Volume I – Executive Summary and Key Rehabilitation Considerations*. Federal Highway Administration.

Zollinger, D. G., S. D. Tayabji, K. Smith, and J. Liu. 2003. *Repair and Rehabilitation of Concrete Pavements Volume II – Guidelines for Pavement Condition Assessment and Evaluation.* Federal Highway Administration.

Zollinger, D. G., S. D. Tayabji, and K. Smith. 2003. *Repair and Rehabilitation of Concrete Pavement Volume III – Summary of Pavement Rehabilitation Techniques and Strategy Development.* Federal Highway Administration.

Liu, J., D. G. Zollinger, S. D. Tayabji, and K. Smith. 2003. *Repair and Rehabilitation of Concrete Pavements Volume IV. Strategic Analysis of Pavement Evaluation and Repair (SAPER).* Federal Highway Administration.

Smith, K. and J. Roesler. 2003. *Review of Fatigue Models for Concrete Airfield Pavement Design.* American Society of Civil Engineers Airfield Specialty Pavement Conference.

Zimmerman, K., K. Smith, T. Hoerner, M. Wade, and R. Larson. 2003. *A Guide for the Design and Maintenance of Paved Low-Volume Roads.* American Society of Civil Engineers.

Folliard, K. and K. Smith. 2003. *Aggregate Tests for Portland Cement Concrete Pavements: Review and Recommendations.* National Cooperative Highway Research Program.

Hoerner, T., K. Smith, R. Larson, and M. Swanlund. 2003. *Current Practice of PCC Texturing.* Transportation Research Record 1860, Transportation Research Board.

Smith, K., J. Roesler, and J. Naughton. 2002. *Review of Fatigue Models for Concrete Airfield Pavement Design.* American Concrete Pavement Association.

Smith, K., H. Yu, and D. Peshkin. 2002. *Portland Cement Concrete Overlays: State of the Technology Synthesis.* Federal Highway Administration.

Smith, K. *High Performance Concrete Pavements: Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements.* 2002. Federal Highway Administration.

Hoerner, T. and K. Smith. *PCC Pavement Texturing: Effects on Tire-Pavement Noise and Surface Friction.* 2002. Federal Highway Administration.

Smith, K. and K. Hall. 2002. *Concrete Pavement Design Details and Construction Practices.* National Highway Institute.

Hoerner, T., K. Smith, H. Yu, D. Peshkin, and M. Wade. 2002. *PCC Pavement Evaluation and Rehabilitation.* National Highway Institute.

Grogg, M., K. Smith, S. Seeds, T. Hoerner, D. Peshkin, and H. Yu. 2002. *HMA Pavement Evaluation and Rehabilitation.* National Highway Institute.

Van Dam, T., L. Sutter, K. Smith, M. Wade, and K. Peterson. 2002. *Guidelines for Detection, Analysis, and Treatment of Materials-Related Distress in Concrete Pavements, Volume 1: Final Report.* Federal Highway Administration.

Van Dam, T., L. Sutter, K. Smith, M. Wade, and K. Peterson. 2002. *Guidelines for Detection, Analysis, and Treatment of Materials-Related Distress in Concrete Pavements, Volume 2: Guidelines, Description and Use.* Federal Highway Administration.

Sutter, L., K. Peterson, T. Van Dam, K. Smith, and M. Wade. 2002. *Guidelines for Detection, Analysis, and Treatment of Materials-Related Distress in Concrete Pavements, Volume 3: Case Studies Using the Guidelines.* Federal Highway Administration.

Sutter, L., K. Peterson, T. Van Dam, and K. Smith. 2002. *Using Epifluorescence Optical Microscopy to Identify Causes of Portland Cement Concrete Distress: Case Study.* Transportation Research Record 1798, Transportation Research Board.

Grogg, M. and K. Smith. 2001. *PCC Pavement Smoothness: Characteristics and Best Practices for Construction.* Federal Highway Administration.

Zollinger, D., K. Smith, and S. Tayabji. 2001. "A Framework for Repair and Rehabilitation Treatment Selection for Portland Cement Concrete Pavements." *Proceedings, Seventh International Conference on Concrete Pavements.* Orlando, FL.

Smith, K. and M. Swanlund. 2001. "Status of High-Performance Concrete Pavements Constructed under the FHWA's TE-30 Program." *Proceedings, Seventh International Conference on Concrete Pavements.* Orlando, FL.

Wade, M., D. Peshkin, K. Smith and H. Yu. 2001. "Estimating Remaining Life of Airfield Pavements." *Proceedings, ASCE Airfield Pavement Specialty Conference.*

Smith, K. 2001. *Status of High Performance Concrete Pavements.* Federal Highway Administration.

Zimmerman, K., K. Smith, and M. Grogg. 2000. *Applying Economic Concepts from a LCCA to a Pavement Management Analysis.* Transportation Research Board.

Smith, K. and K. Zimmerman. 2000. *Probabilistic Life Cycle Cost Analysis of Pavement Design Alternatives for the I-25 Southeast Corridor Project, Denver, Colorado.* Colorado Asphalt Pavement Association.

Smith, K. and K. Hall. 1999. *Concrete Pavement Design Details and Construction Practices.* National Highway Institute.

Peshkin, D., K. Smith, K. A. Zimmerman, and D. N. Geoffroy. 1999. *Pavement Preventive Maintenance.* Course #13154. National Highway Institute, Federal Highway Administration.

Seeds, S. B., N. C. Jackson, J. Ziegler, D. G. Peshkin, K. D. Smith, M. G. Wade, J. A. Epps, E. D. Moody, and T. V. Scholz. 1998. *Techniques for Pavement Rehabilitation, Sixth Edition.* National Highway Institute.

Smith, K., M. Wade, H. Yu, and M. Darter. 1997. "Design Considerations for Improved JPCP Performance." *Proceedings, Sixth International Purdue Conference on Concrete Pavement Design and Materials for High Performance.* Purdue University.

Khazanovich, L., M. Darter, and K. Smith. 1997. "Transverse Crack Deterioration Model for JRCP." *Proceedings, Sixth International Purdue Conference on Concrete Pavement Design and Materials for High Performance.* Purdue University.

K. Smith, T. Hoerner, and M. Darter. 1997. "Effect of Initial Pavement Smoothness on Future Smoothness and Pavement Life." *Transportation Research Record 1570.* Transportation Research Board.

Smith, K., H. Yu, M. Wade, D. Peshkin, and M. Darter. 1996. *Performance of Concrete Pavements, Volume I—Field Investigation.* FHWA-RD-94-177. Federal Highway Administration.

Smith, K., M. Wade, D. Peshkin, L. Khazanovich, H. Yu, and M. Darter. 1996. *Performance of Concrete Pavements, Volume II—Evaluation of Inservice Concrete Pavements.* FHWA-RD-95-110. Federal Highway Administration.

Yu, H., M. Darter, K. Smith, J. Jiang, and L. Khazanovich. 1996. *Performance of Concrete Pavements, Volume III—Improving Concrete Pavement Performance.* FHWA-RD-95-111. Federal Highway Administration.

Wade, M., K. Smith, H. Yu, M. Darter, and C. Weinrank. 1996. *Performance of Concrete Pavements, Volume IV—Appendixes.* FHWA-RD-95-112. Federal Highway Administration.

Smith, K. L, K. D. Smith, L. Evans, T. Hoerner, M. Darter, and J. Woodstrom. 1996. *Smoothness Specifications for Pavements.* National Cooperative Highway Research Program.

Wade, M., G. Cuttell, J. Vandenbossche, H. Yu, K. Smith, and M. Snyder. 1996. *Performance of Concrete Pavements Containing Recycled Concrete Aggregate.* FHWA-RD-96-164. Federal Highway Administration.

Darter, M., T. Hoerner, K. Smith, P. Okamoto, and P. Kopac. 1996. "Development of a Prototype Performance-Related Specification for Concrete Pavements." *Transportation Research Record 1544.* Transportation Research Board.

Wade, M., K. Smith, H. Yu, and M. Darter. 1995. "Monitoring of European Concrete Pavements." *Transportation Research Record 1478.* Transportation Research Board.

Yu, H., K. Smith, and M. Darter. 1995. *Field and Analytical Evaluation of the Effects of Tied PCC Shoulder and Widened Slabs on Performance of JPCP.* Colorado Department of Transportation.

Whiting, D., M. Nagi, P. Okamoto, T. Yu, D. Peshkin, K. Smith, M. Darter, J. Clifton, and L. Kaetzel. 1994. *Optimization of Highway Concrete Technology.* SHRP-C-373. Strategic Highway Research Program.

H. Yu, D. Peshkin, K. Smith, M. Darter, D. Whiting, and H. Delaney. 1994. *Concrete Pavement Rehabilitation—Users Manual.* SHRP-C-412. Strategic Highway Research Program.

Smith, K., T. Yu, and M. Darter. 1993. *A Performance Evaluation of PCC Pavements Constructed on Permeable Bases.* FHWA-SA-94-045. Western States Drainable PCC Pavement Workshop.

Okamoto, P., P. Nussbaum, and K. Smith. 1993. "Guideline Recommendations for Timing Contraction Joint Sawing of PCC Highway Pavements." *Proceedings, Fifth International Conference on Concrete Pavement Design and Rehabilitation.* Volume 2. Purdue University.

Darter, M., M. Abdelrahman, P. Okamoto, and K. Smith. 1993. *Performance-Related Specifications for Concrete Pavements, Volume I—Development of a Prototype Performance-Related Specifications.* FHWA-RD-93-042. Federal Highway Administration.

Darter, M., M. Abdelrahman, T. Hoerner, M. Phillips, K. Smith, and P. Okamoto. 1993. *Performance-Related Specifications for Concrete Pavements, Volume II—Appendixes.* FHWA-RD-93-043. Federal Highway Administration.

Okamoto, P., C. Wu, S. Tarr, M. Darter, and K. Smith. 1993. *Performance-Related Specifications for Concrete Pavements, Volume III—Appendixes.* FHWA-RD-93-044. Federal Highway Administration.

Darter, M., K. Smith, and K. Hall. 1992. "Concrete Pavement Backcalculation Results from Field Studies." *Transportation Research Record 1377.* Transportation Research Board.

Smith, K., T. Wilson, M. Darter, and P. Okamoto. 1992. "Analysis of Concrete Pavements Subjected to Early Loading." *Transportation Research Record 1370.* Transportation Research Board.

Okamoto, P., P. Nussbaum, K. Smith, M. Darter, T. Wilson, C. Wu, and S. Tayabji. 1991. *Guidelines for Timing Contraction Joint Sawing and Earliest Loading for Concrete Pavements, Volume I—Final Report.* FHWA-RD-91-079. Federal Highway Administration.

Okamoto, P., P. Nussbaum, K. Smith, M. Darter, T. Wilson, C. Wu, and S. Tayabji.. *Guidelines for Timing Contraction Joint Sawing and Earliest Loading for Concrete Pavements, Volume II—Appendix.* FHWA-RD-91-080. Federal Highway Administration.

Smith, K. and L. Evans. 1991. *Field/Laboratory Evaluation of Concrete Joint Resealing Materials.* Third World Congress on Joint Sealing and Bearing Systems for Concrete Structures. Toronto, Ontario, Canada.

Smith, K., D. Peshkin, and M. Darter. 1991. "Performance of Concrete Pavements with Permeable Base Courses." *Proceedings, XIXth World Road Congress, Permanent International Association of Road Congresses.* Marrakech, Morocco.

Peshkin, D., K. Smith, and M. Darter. 1991. "Evaluation of Concrete Pavements Exhibiting Long-Term Performance." *Proceedings, XIXth World Road Congress, Permanent International Association of Road Congresses.* Marrakech, Morocco.

Smith, K. D., D. G. Peshkin, and M. I. Darter. 1991. *Concrete Pavement Design Manual.* Northwest Concrete Pavement Seminar.

Darter, M., K. Smith, and D. Peshkin. 1991. *Field Calibrated, Mechanistic-Empirical Models for Jointed Concrete Pavements.* Transportation Research Board.

Smith, K., D. Peshkin, A. Mueller, E. Owusu-Antwi, and M. Darter. 1991. *Evaluation of Concrete Pavements in the Phoenix Urban Corridor, Volume I—Final Report.* FHWA-AZ91-264-I. Arizona Department of Transportation.

Peshkin, D., K. Smith, G. James, L. Evans, and M. Darter. 1991. *Evaluation of Concrete Pavements in the Phoenix Urban Corridor, Volume II—Appendices.* FHWA-AZ91-264-II. Arizona Department of Transportation.

Darter, M. and K. Smith. 1990. *Design of Joints to Control Faulting.* 6th International Symposium on Concrete Roads. Madrid, Spain.

Smith, K., D. Peshkin, and M. Darter. 1990. *Considerations in the Design of Jointed Concrete Pavements.* 6th International Symposium on Concrete Roads. Madrid, Spain.

D. Peshkin, A. Mueller, K. Smith, and M. Darter. 1990. *Structural Overlay Strategies for Jointed Concrete Pavements, Volume III—Performance Evaluation and Analysis of Thin Bonded Concrete Overlays.* FHWA-RD-89-144. Federal Highway Administration.

Smith, K., D. Peshkin, M. Darter, A. Mueller, and S. Carpenter. 1990. *Performance of Jointed Concrete Pavements, Volume I—Evaluation of Concrete Pavement Performance and Design Features.* FHWA-RD-89-136. Federal Highway Administration.

Smith, K., A. Mueller, M. Darter, and D. Peshkin. 1990. *Performance of Jointed Concrete Pavements, Volume II—Evaluation and Modification of Concrete Pavement Design and Analysis Models*. FHWA-RD-89-137. Federal Highway Administration.

Smith, K., D. Peshkin, M. Darter, and A. Mueller. 1990. *Performance of Jointed Concrete Pavements, Volume III—Summary of Project Findings*. FHWA-RD-89-138. Federal Highway Administration.

Smith, K., D. Peshkin, M. Darter, A. Mueller, and S. Carpenter. 1990. *Performance of Jointed Concrete Pavements, Volume IV—Appendix A, Project Summary Reports and Summary Tables*. FHWA-RD-89-139. Federal Highway Administration.

Smith, K., D. Peshkin, M. Darter, A. Mueller, and S. Carpenter. 1990. *Performance of Jointed Concrete Pavements, Volume V—Appendix B, Data Collection and Analysis Procedures*. FHWA-RD-89-140. Federal Highway Administration.

Mueller, A., D. Peshkin, K. Smith, and M. Darter. 1990. *Performance of Jointed Concrete Pavements, Volume VI—Appendix C, Synthesis of Concrete Pavement Design Methods and Analysis Models, and Appendix D, Summary of Analysis Data for the Evaluation of Predictive Models*. FHWA-RD-89-141. Federal Highway Administration.

Smith, K., D. Peshkin, M. Darter, and A. Mueller. 1990. "Effect of Design Features on Concrete Pavement Performance." *Proceedings, 4th International Conference on Concrete Pavement Design and Performance*. Purdue University.

Peshkin, D., A. Mueller, K. Smith, and M. Darter. 1990. "An Eleven-Year Evaluation of Arizona's Prestressed Pavement." *Proceedings, 4th International Conference on Concrete Pavement Design and Performance*. Purdue University.

Snyder, M., K. Smith, and M. Darter. 1989. "Evaluation of Pressure Relief Joint Installations." *Transportation Research Record 1215*. Transportation Research Board.

Peshkin, D., K. Smith, M. Darter, and C. Arnold. "Performance Evaluation of Experimental Pavement Designs at Clare, Michigan." *Transportation Research Record 1227*. Transportation Research Board.

Carpenter, S. H., M. I. Darter, A. L. Mueller, M. B. Snyder, K. D. Smith, and K. T. Hall. 1987. *Pavement Design—Principles and Practices*. FHWA/NHI Training Course Notebook. Federal Highway Administration.

Rauhut, J.B., M. Darter, R. Lytton, P. Jordahl, M. Gardner and K. D. Smith. 1988. *Data Collection Guide for the Long-Term Pavement Performance Studies*. Strategic Highway Research Program.

Smith, K., M. Darter, J. B. Rauhut, and K. Hall. 1987. *Distress Identification Manual for the Long Term Pavement Performance (LTPP) Studies*. Strategic Highway Research Program.

Smith, K., M. Snyder, M. Darter, M. Reiter, and K. Hall. 1987. *Pressure Relief and Other Joint Rehabilitation Techniques*. FHWA/RD-88/111. Federal Highway Administration.

SELECTED PRESENTATIONS

Concrete Pavement Designs on the Original Interstate System, American Concrete Institute Spring Conference Session 120, Atlanta, GA, April 2007.

Concrete Pavement Bases, 2007 Indiana ACPA Workshop, Indianapolis, IN, February 2007.

Concrete Pavement Design, 2007 Indiana ACPA Workshop, Indianapolis, IN, February 2007.

The AASHO Road Test: A Look Back, FHWA Pavement and Material Technology Transfer Workshop, Utica, IL, August 2006.

Long-Life Concrete Pavements, Virginia Concrete Conference, Richmond, VA, March 2006.

Subgrades and Bases for Concrete Pavements, 2006 Indiana ACPA Workshop, Indianapolis, IN, February 2006.

Pavement Lessons from 50-Year-Old Interstate System: North Central Region, Transportation Research Board Annual Meeting, Washington, DC, January 2006.

Concrete Kicks on Route 66, American Concrete Institute Fall Meeting, Kansas City, KS, November 2005.

Long-Life Concrete Pavements, Nevada Infrastructure Concrete Workshop, Reno, NV and Las Vegas, NV, November 2005.

FHWA Study of Sealed and Unsealed Joints, Nevada Infrastructure Concrete Workshop, Reno, NV and Las Vegas, NV, November 2005.

Evaluating Costs and Benefits of Concrete Pavement Design Features, American Concrete Pavement Association Annual Meeting, Marco Island, FL, December 2004.

Concrete Pavement Joint Design, Nevada Infrastructure Concrete Workshop, Las Vegas, NV, and Reno, NV, November 2004.

Thin and Ultra-Thin Whitetopping: Design, Construction, and Repair, Nevada Infrastructure Concrete Workshop, Las Vegas, NV and Reno, NV, November 2004.

Design and Construction of PCC Overlays, American Concrete Institute Workshop, Lansing, MI, November 2, 2004.

Materials-Related Distress in Airfield Pavements, American Concrete Institute Fall Meeting, San Francisco, CA, October 2004.

FHWA's High Performance Concrete Pavement Program, Ohio Department of Transportation High Performance Concrete Pavement Workshop, Nelsonville, OH, June 2004.

Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements, Midwest Concrete Consortium Spring Meeting, Madison, WI, April 2004.

Firsts in Concrete Pavement Design and Construction, American Concrete Institute Spring Meeting, Washington, DC, March 2004.

Concrete Pavement Durability Studies, American Concrete Institute Spring Meeting, Washington, DC., March 2004.

Concrete Overlays, Fifth Pennsylvania Concrete Conference, Harrisburg, PA, 2004.

FHWA/ACI Training Initiative on Concrete Overlays, Transportation Research Board Annual Meeting, Washington, DC., January 2004.

Incremental Cost and Performance Benefits of Various Features of Concrete Pavements, Transportation Research Board Annual Meeting, Washington, DC, January 2004.

Incremental Cost and Performance Benefits of Various Features of Concrete Pavements, Transportation Research Board Committee for Research on Improved Concrete Pavements, Woods Hole, MA, 2003.

Evaluating the Costs and Benefits of Various Design Features, American Concrete Pavement Association Mid-Year Meeting, Chicago, IL, 2003.

Evaluating the Costs and Benefits of Various Design Features, Southeast Concrete Alliance Network (SCAN) Forum, Raleigh, NC, 2003.

Alternative Dowel Bars for Load Transfer in Jointed Concrete Pavements, Transportation Research Board Annual Meeting, Washington, DC, 2003.

PCC Overlays: State of the Practice, American Concrete Institute Fall Meeting, Phoenix, AZ, October 2002.

Use of Concrete in Late 19th Century and Early 20th Century Road Building in the U.S., American Concrete Institute Spring Meeting, Detroit, MI, April 2002.

Portland Cement Concrete Overlays, American Concrete Institute Spring Meeting, Philadelphia, PA, March 2001.

Field Survey and Sampling Procedures for MRD-Affected Pavements, Transportation Research Board Annual Meeting, Washington, DC., January 7–11, 2001.

Probabilistic Life Cycle Cost Analysis of Pavement Design Alternatives for the I-25 Southeast Corridor Project, Denver, Colorado, Workshop on Reconstructing the Southeast Corridor, Denver, CO, April 14, 2000.

Pavement Design, Montana Department of Transportation Training Workshop, April 13–16, 1998.

AASHTO Pavement Design Procedures, Federal Highway Administration Workshop, Washington, DC, March 2, 1998.

An Overview of Performance-Related Specifications for Concrete Pavements, Federal Highway Administration Innovative Contracting Workshop, Philadelphia, PA, May 7–9, 1996.

Evaluation of Inservice Concrete Pavements, Ohio/Kentucky American Concrete Pavement Association Annual Workshop, Columbus, OH, March 27–28, 1996.

Smoothness Specifications for Pavements, American Concrete Pavement Association Annual Meeting, Marco Island, FL, November 28–December 2, 1995.

Highlights of FHWA Pavement Performance Study, American Concrete Pavement Association CPR Workshop, Chicago, IL, November 8–9, 1995.

On the Effects of Initial Pavement Smoothness, Road Profile User's Group Annual Meeting, October 3–5, 1995.

Smoothness Specifications for Pavements, Federal Highway Administration Region 4 Quality Management Workshop, February 15–17, 1995.

A Performance Evaluation of PCC Pavements Constructed on Permeable Bases, Transportation Research Board Annual Meeting, Washington, D.C., 1994.

An Evaluation of Concrete Pavement Designs in the Phoenix Urban Corridor, Transportation Research Board Annual Meeting, Washington, D.C., 1993.

Concrete Pavement Joints, Missouri/Kansas American Concrete Pavement Association Concrete Paving Workshop, March 4–5, 1992.

Analysis of Concrete Pavements Subjected to Early Loading, American Society of Civil Engineers, 1991.

Performance-Related Specifications for Concrete Pavements, Federal Highway Administration Region 5 QA/QC Workshop, December 9–11, 1991.

Joint Spacing Guidelines for Jointed Plain Concrete Pavements, Transportation Research Board, 1990, (with M. Darter, and D. Peshkin).

Concrete Pavement Design, Northwest Concrete Pavement Seminar, 1990.

Evaluation of Pressure Relief Joint Installations, Transportation Research Board, 1987.