CONCRETE PAVEMENT
CPTP
TECHNOLOGY PROGRAM

TechBrief

Performance-Related Specifications for Portland Cement Concrete Pavements

This TechBrief discusses the development and application of performance-related specifications (PRS) for the construction of portland cement concrete pavements. It provides a background summary of the basis for and early experiences with PRS, including a brief description of the PaveSpec software. This is followed by a summary of PRS trial implementations and experiences in three States: Tennessee, Florida, and Wisconsin.

INTRODUCTION

Performance-related specifications (PRS) are an outgrowth of current end-result, quality assurance (QA) specifications (Kopac 2002). In highway construction, PRS are defined as specifications for key materials and construction quality characteristics that have been demonstrated to correlate significantly with long-term pavement performance (Chamberlin 1995). PRS include sampling and testing procedures for acceptance quality characteristics along with acceptance or rejection criteria. A major feature of PRS is the development of rational pay adjustments based on the projected performance of the pavement.

The Federal Highway Administration (FHWA) has been promoting the development and implementation of PRS since the 1980s. A working PRS was developed in the mid-1990s and was later employed on projects in Iowa, Kansas, Missouri, and New Mexico as a shadow specification. In 2000, the Indiana Department of Transportation (DOT) constructed a project in which the PRS served as the governing specification. Since 2004, additional field trials have been conducted in Tennessee, Florida, and Wisconsin as well as in a second project in Indiana. As more agencies and contractors become familiar with the PRS methodology, the approach is expected to lead to higher quality work, more cost-effective and innovative construction methods, and, ultimately, longer lasting roads.

PRS BACKGROUND

Basis and Concepts

The current PRS approach for portland cement concrete (PCC) pavements is based on an innovative approach that uses measured acceptance quality characteristics (AQCs)—such as strength, slab thicknesses, and initial smoothness—to predict future pavement performance through mathematical relationships (Darter et al. 1993; FHWA 1999). Pavement performance is quantified in terms of key distresses (e.g., cracking, faulting, spalling) and

The Concrete Pavement Technology Program (CPTP) is an integrated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, CPTP's primary goals are to reduce congestion, improve safety, lower costs, improve performance, and foster innovation. The program was designed to produce user-friendly software, procedures, methods, guidelines, and other tools for use in materials selection, mixture proportioning, and the design, construction, and rehabilitation of concrete pavements.

www.fhwa.dot.gov/pavement/concrete

U.S. Department of Transportation
Federal Highway Administration

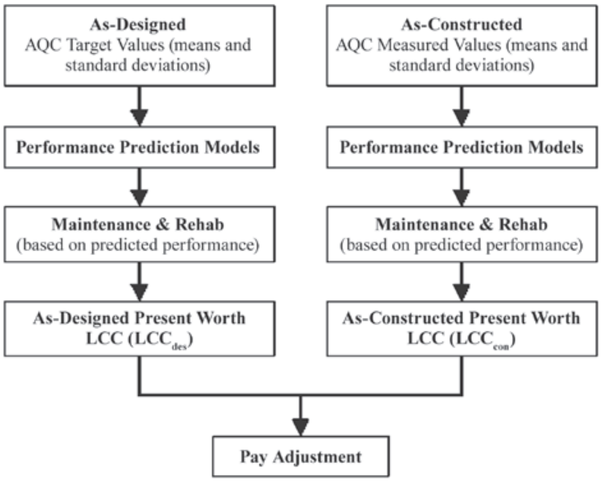

Figure 1. Overview of the performance-related specification approach (Evans, Darter, and Egan 2005).

smoothness over time and is related to the future maintenance, rehabilitation, and user costs of the pavement (FHWA 1999). This link between measured AQCs and the future life-cycle costs (LCCs) of the pavement provides the ability to develop rational and fair contractor pay adjustments that depend on the as-constructed quality delivered for the project, when compared to the as-designed quality (FHWA 1999). Figure 1 illustrates this concept.

A detailed description of some of the key features of the PRS approach is provided below (Darter et al. 1993; Hoerner and Darter 1999; FHWA 1999):

- Consideration of multiple AQCs. The current PRS estimates pavement material and construction quality in terms of five AQCs (or any combination thereof): strength, slab thickness, air content, initial smoothness, and consolidation around dowels. In this approach, tradeoffs can occur (i.e., better quality for one AQC can offset poor quality in another AQC).
- Inclusion of both AQC mean and variability. Under the PRS approach, the predicted pavement performance is a function of both the AQC means and standard deviations. This is an improvement over traditional QA specifications, which typically specify only the mean or a percentage within limits that does not correlate well with performance.
- Definition of as-designed (target) quality. Agencies are required to define their desired quality in terms of AQC means and standard deviations, which should reflect the level of quality for which the agency is willing to pay 100 percent. Under the PRS approach, the contractor earns incentives or disincentives depending on the values of the AQC means and standard deviations that are produced.
- In-situ measurement of as-constructed quality. Because the PRS approach is based on the LCC of the as-constructed pavement, direct in situ sampling from the completed pavement is highly desirable.
- Mathematical performance prediction models. Pavement performance is predicted over time in terms of four distress indicators: transverse joint faulting and spalling, transverse fatigue cracking, and International Roughness Index.
- Prediction of future LCCs based on predicted performance. During the simulation of as-designed and as-constructed performance over time, the future maintenance and rehabilitation (M&R) costs are also simulated by applying an agency-selected M&R plan. The result of this step is a prediction of the most likely LCCs for both the as-designed and as-constructed pavements.
- Rational contractor pay adjustment based on predicted as-designed and as-constructed LCCs. By using the predicted LCC as the one overall quality characteristic for both the as-designed and as-constructed pavements, the final contractor pay adjustment can be determined rationally as a function of the two predicted costs. The PRS equation for determining the contractor pay factor is shown in equation 1.

$$PF = 100 * (BID + [LCC_{DES} - LCC_{CON}]) / BID \quad \text{(Eq. 1)}$$

where:

PF = Pay adjustment factor expressed as the percentage of the bid price.
BID = Contractor's bid price.
LCC_{DES} = As-designed life-cycle cost.
LCC_{CON} = As-constructed life-cycle cost.

This approach produces positive pay adjustments to encourage the contractor to provide high-quality products, but also produces negative pay adjustments to protect the highway agency from overpaying for low-quality work.

Software

PaveSpec 3.0 is the current software required to demonstrate the PRS approach outlined above. This software allows an agency to define a PRS and then conduct the following operations (Hoerner et al. 2000):

- Simulation of performance of as-designed and as-constructed pavement lots.
- Application of user-defined M&R plans to translate estimated M&R activities into future expected LCCs.
- Development of pay factor curves that are functions of both AQC average and standard deviation.
- Computation of contractor lot pay factors (pay adjustments) based on actual measured AQC test results.

The PaveSpec software was developed for the Microsoft Windows environment. The software and a comprehensive User's Guide are available for download at the FHWA site http://www.fhwa.dot.gov/pavement/pccp/pavespec.

Early PRS Experience

After the development and refinement of the PRS in the mid-1990s, shadow field trials were conducted in four states: Iowa in 1996, and Kansas, Missouri, and New Mexico in 1997 (Kopac 2002). The objectives of these collective field trials were to demonstrate the procedure, verify the effectiveness of the draft PRS specification, identify potential problem areas, and determine the specification's reasonableness (Hoerner et al. 1999).

Although the PRS were not the governing specifications on these four initial field trials, the projects did provide valuable information on the practical application of the PRS, including guidance on the necessary lot and sublot sizes, on appropriate sampling and testing frequencies, and on the general start-to-finish development and application of a PRS specification (Hoerner et al. 1999). Furthermore, it was demonstrated that the sampling and testing required by the PRS specification did not take more time or effort than the testing required under the current specifications (Kopac 2002). Finally, it was realized that a practical cap was needed on all PRS pay factors as the computed PRS pay factors for the trial lots at the field trial locations (which were computed for demonstration purposes only) were often high. PRS-based pay factors at the Iowa site were computed as high as 168 percent due to an extra 1 in. (25.4 mm) of thickness provided by the contractor. Pay factors at the other three sites ranged from 105.8 to 118.4 percent of bid price before a cap was applied (Hoerner et al. 1999).

In 2000, the first field trial where the PRS was the governing specification was constructed on a 1.5-mi (2.4-km) segment of I-465 in Indianapolis (Kopac 2002; Graveen et al. 2004). An agency representative indicated that the specifications provided a basis for rational acceptance and/or price adjustment decisions, and that the specification was well received by the contractors involved in the project (Kopac 2002). The researchers on this project noted that valuable information was gained in many areas including selecting AQC target inputs, construction quality and consistency, and the application and limitations of nondestructive testing (Kopac 2002). Lessons learned from this first project were used by Indiana to fine-tune their PRS approach in preparation for future trial PRS projects.

RECENT PRS IMPLEMENTATION PROJECTS

Since 2004, several highway agencies, in cooperation with the FHWA, have continued work on the application and implementation of PRS on highway construction projects. The recent experiences of three such projects are summarized below.

I-65, Nashville, Tennessee (Evans, Darter, and Egan 2005)

In 2004, the Tennessee DOT (TDOT) conducted a trial evaluation of PRS on a 3.5-mi (5.6-km) section of I-65 in Nashville. The pavement design for the 10-lane facility called for a 13-in. (330-mm) jointed plain concrete pavement (JPCP) on a 4-in. (102-mm) permeable asphalt-treated base, with doweled joints placed at 15-ft (4.6-m) intervals. The project was actually constructed under existing TDOT specifications, but PRS data collection activities were performed on the two outer lanes in both the northbound and southbound directions.

Table 1. Target and Actual Quality Characteristic Values for the I-65, Nashville, Project

	Target		Actual	
Quality Characteristic	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Slab thickness, in.	13.0	0.5	13.1	0.16
28-day compressive strength, lbf/in^2	4,500	500	4,967	224
Profile index, in./mi*	7.0	1.0	4.5	0.64

* As measured by the Rainhart profilograph with a 0.1-in. (2.5-mm) blanking band.
1 in. = 25.4 mm; 1 lbf/in^2 = 6.89 kPa; 1 in./mi = 15.8 mm/km

For this project, TDOT selected slab thickness, 28-day PCC compressive strength, and initial smoothness (based on profile index with a 0.1-in. [2.5-mm] blanking band) as the AQCs for use in the PRS. Sampling and testing plans were developed for each of these factors, and historical construction data were reviewed to identify appropriate target means and standard deviations. The PaveSpec software was used to generate pay factor curves for the specific project conditions.

PRS data from 14 lots (in both directions) were collected and analyzed. Table 1 summarizes the target and actual values for each of the quality characteristics. In all cases, the actual mean and standard deviation values were superior to the target values. Figure 2 provides a summary of the pay factors for the project, including the individual pay factors for each quality characteristic and the total pay factor. The average pay factor was 106.5 percent for the northbound lots and 105.2 percent for the southbound lots, indicating that the contractor significantly exceeded the target quality.

The trial PRS appeared to work very well, and both TDOT and contractor officials were supportive of constructing future projects under a full, governing PRS. Several key recommendations came out of the trial project, including the need for more rapid feedback on test results and pay factors and the establishment of maximum values for quality characteristics.

SR 9A, Jacksonville, Florida (Evans et al. 2006)

The Florida DOT (FDOT) developed and implemented a PRS in 2004–2005 on a short (0.25-mi [0.40-km]), six-lane highway construction project on State Route (SR) 9A in southeast Jacksonville. The design pavement was a 12.5-in. (318-mm) JPCP on a 12-in. (305-mm) permeable rigid pavement subgrade material, with transverse doweled joints placed at 16-ft (4.9-m) intervals.

Three AQCs were selected by FDOT for use in the PRS project: slab thickness, 28-day PCC compressive strength, and initial smoothness (based on profile index and a 0.2-in. [5.1-mm] blanking band). Sampling and testing plans were developed for each of these factors based on current FDOT specifications, and recent FDOT project data were reviewed to select appropriate target means and standard deviations for each quality characteristic. The PaveSpec software was used to generate pay factor curves for the specific project conditions based on the LCCs of pave-

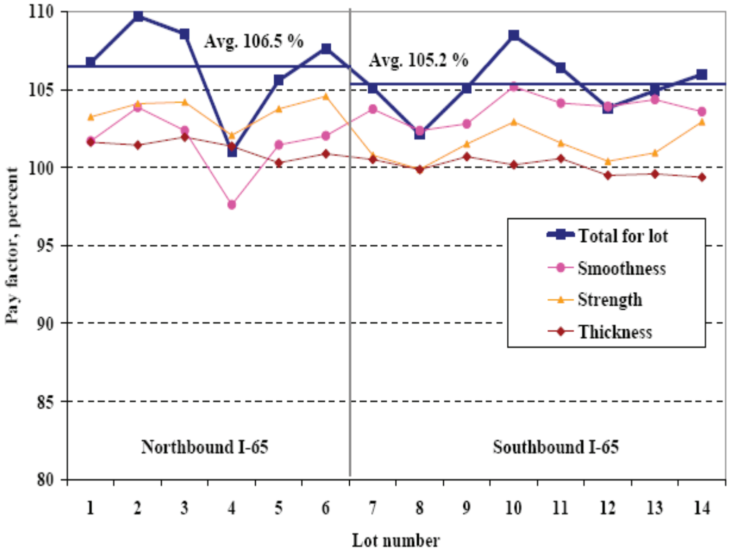

Figure 2. Summary of PRS pay factor results for the I-65, Nashville, project (Evans, Darter, and Egan 2005).

Table 2. Target and Actual Quality Characteristic Values for the SR 9A, Jacksonville, Project

	Target		Actual	
Quality Characteristic	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Slab thickness, in.	12.5	0.5	13.3	0.5
28-day compressive strength, lbf/in^2	4,500	610	5,642	372
Profile index, in./mi*	3.0	1.0	0.96	0.86

* As measured by a California-type profilograph with a 0.2-in. (5.1-mm) blanking band.
1 in. = 25.4 mm; 1 lbf/in^2 = 6.89 kPa; 1 in./mi = 15.8 mm/km

ments with various strength, thickness, and smoothness properties.

Six lots were included in the construction project, with each travel lane in each direction defined as a lot. Table 2 summarizes the overall target and actual values for each of the quality characteristics. In all cases, the actual mean and standard deviation values were superior to the target values. Figure 3 provides a summary of the pay factors for the project, including the individual pay factors for each AQC and the total pay factor. The average overall unconstrained pay factor for the project was 114.8 percent, indicating that the contractor significantly exceeded the target quality. However, during the development of the pay factor curves for the project, FDOT limited the maximum pay factor to 110 percent.

The implementation of the PRS on this project was considered successful. Because the contractor was easily able to meet and exceed the strength requirements, it was recommended that future PRS implementations give more judicious consideration to the selection of both the target strength value and maximum quality level value (i.e., that level of quality at which the pavement is unnecessarily more conservative than the design and above which no further pay increases will be applied). Furthermore, a need was recognized for more timely results on AQC values and pay factors to enable contractors to adjust their operations accordingly.

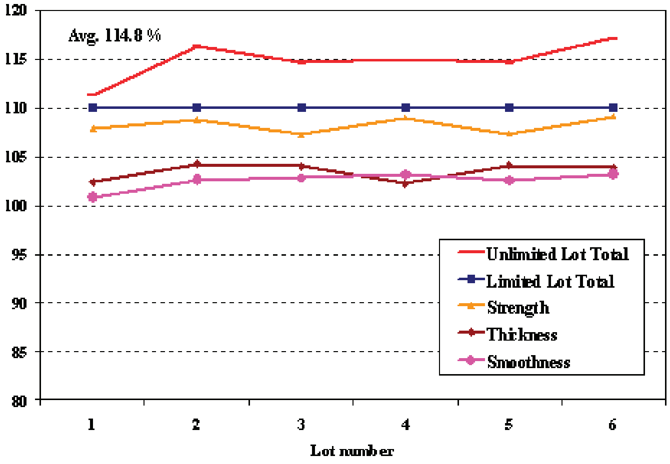

Figure 3. Summary of PRS pay factor results for the SR 9A, Jacksonville, project (Evans et al. 2006).

I-39/I-90/I-94, Madison, Wisconsin (Rao, Smith, and Darter 2007)

In 2006, the Wisconsin DOT (WisDOT) implemented a trial PRS on a project located on a 5-mi (8.1-km) segment of I-39/I-90/I-94 north of Madison. The design for the six-lane facility called for a 12.5-in. (318-mm) JPCP on a 6-in. (152-mm) dense-graded aggregate base, with doweled transverse joints spaced at 18-ft (5.5-m) intervals. The PRS was applied to both the mainline PCC pavement and the PCC shoulders within a 4.2-mi (6.8-km) segment of the project.

WisDOT selected four AQCs for the mainline paving (slab thickness, 28-day compressive strength, air content, and initial pavement smoothness), whereas three AQCs were selected for the PCC shoulders (slab thickness, 28-day compressive strength, and air content). No significant changes in the test methods from the current WisDOT specifications were specified, and the target and standard deviation values for the AQCs were based on a review of historical paving records. The PaveSpec software was used to generate pay factor curves for the specific project conditions based on the LCCs of pavements with various strength, thickness, air content, and smoothness values. The PRS was

Table 3. Target and Actual Quality Characteristic Values for the Mainline Paving of the I-39/I-90/I-94, Madison, Project

	Target		Actual	
Quality Characteristic	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**
Slab thickness, in.	12.5	0.2	12.6	0.19
28-day compressive strength, lbf/in^2	4,500	500	5,313	511
Air content, %	7.0	0.6	6.58	0.35
Profile index, in./mi*	30.0	7.0	21.6	4.2

* As measured by a California-type profilograph with a zero blanking band. 1 in. = 25.4 mm; 1 lbf/in^2 = 6.89 kPa; 1 in./mi = 15.8 mm/km

included as an overriding special provision in the December 2005 letting of the project.

The project included 18 lots for which PRS AQC measurements were obtained. Table 3 summarizes the overall target and actual values for each of the AQCs, and shows that all actual mean and standard deviation values either met or were superior to the target values. Figure 4 provides a summary of the pay factors for the project, including the individual pay factors for each AQC and the total pay factor. The average overall pay factor for the project was 104.9 percent, indicating that the contractor significantly exceeded the target quality.

The trial PRS was judged to have worked very well on this project, with high smoothness and strength levels resulting in significant incentives for the contractor. Several components were noted to be critical to the success of the PRS, most notably the clear definition of sublots and sampling procedures and the selection of appropriate target means and standard deviations for the AQCs. It was further noted that the balance of pay factors between different AQCs should be carefully monitored and adjusted to ensure that contractors do not start favoring one AQC at the expense of another. For future PRS applications, it was recommended that more complex projects (e.g., ramps, staged construction) should be considered.

Summary of Recent PRS Projects

Table 4 summarizes some of the features and results of these three PRS implementation projects. Working under the PRS for each of these projects, the contractor was able to achieve higher-than-specified levels of quality (as measured by the resultant AQC values and the overall pay factors).

SUMMARY

PRS offer a number of potential benefits to highway agencies, perhaps most significantly as a means of effectively specifying desired levels of quality in pavement construction. A number of highway agencies have employed PRS in field trials and have obtained largely positive reactions and results. The evolvement of PRS is expected to continue, with future work looking at, among other things, the development of improved performance models, the incorporation of additional AQCs, and the movement toward in situ and nondestructive acceptance testing procedures (Kopac 2002).

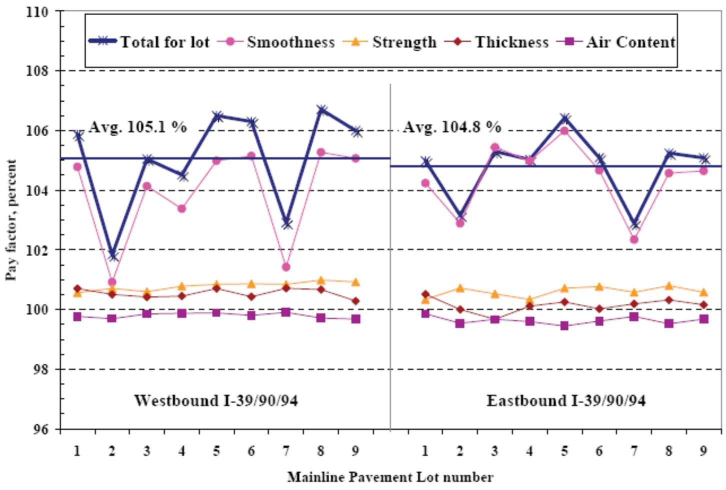

Figure 4. Summary of PRS pay factor results for the mainline paving of the I-39/I-90/I-94, Madison, project (Rao, Smith, and Darter 2007).

Table 4. Features and Results of Recent Performance-Related Specification (PRS) Implementation Projects

Feature/Attribute	I-65 Nashville, Tennessee	SR 9A, Jacksonville, Florida	I-39/I-90/I-94, Madison, Wisconsin
Year built	2004	2004–2005	2006
Total no. of lanes (both directions)	10	6	6
Length, mi	3.5	0.25	4.2
PRS applied to	Outer 2 lanes (both directions)	All lanes (both directions)	All lanes (both directions), including shoulders
Total no. of lots	14	6	18
Lot definition	Min. length = 1,500 ft Max. length = 4,500 ft Width = 1 paving pass (1, 2, or more lanes)	Min. length = 528 ft Max. length = 5,280 ft Width = 1 traffic lane	*For 1-lane paving*: Min. length = 4,224 ft Width = 1 traffic lane *For 2-lane paving*: Min. length = 2,112 ft Width = 2 traffic lanes
Sublot definition	Length = 500 ft Width = 1 paving pass Min. three 500-ft sublots per lot	Length = 250 ft Width = 1 traffic lane	Min. 4 / Max. 8 sublots per lot *For 1-lane paving*: Min. length = 1,056 ft Width = 1 traffic lane *For 2-lane paving*: Min. length = 528 ft Width = 2 traffic lanes
Target thickness / std. dev., in.	13.0 / 0.5	12.5 / 0.5	12.5 / 0.2
Sampling / testing method	AASHTO T148 on retrieved cores	ASTM C42 on retrieved cores	Probes as per WisDOT CMM 4-25-70
No. of samples per sublot	1	2	8 (consisting of 2 replicates)
Actual thickness / std. dev., in.	13.1 / 0.16	13.3 / 0.5	12.6 / 0.19
Target strength / std. dev., lbf / in^2	4,500 / 500	4,500 / 610	4,500 / 500
Sampling / testing method	AASHTO T22/T23 on cylinders at 28 days	ASTM C31/C39 on cylinders at 28 days	AASHTO T22/T23 on cylinders at 28 days
No. of samples per sublot	1 (consisting of 2 replicates)	1 (consisting of 2 replicates)	1 (consisting of 2 replicates)
Actual strength / std. dev., lbf / in^2	4,967 / 224	5,642 / 372	5,313 / 511
Target smoothness / std. dev., in. / mi	7.0 / 1.0	3.0 / 1.0	30.0 / 7.0
Sampling / testing method	Profile index (0.1-in. blanking band) as per ASTM E1274 using Rainhart profilograph	Profile index (0.2-in. blanking band) as per ASTM E1274 using California profilograph	Profile index (zero blanking band) as per ASTM E1274 using California profilograph
No. of samples	Longitudinal trace of each wheelpath per traffic lane per sublot	Longitudinal trace of each wheelpath per sublot	Longitudinal trace of 2 segments of each wheelpath per sublot
Actual smoothness / std. dev., in. / mi	4.5 / 0.64	0.96 / 0.86	21.6 / 4.2
Target air content / std. dev., %	N/A	N/A	7.0 / 0.6
Sampling/testing method	N/A	N/A	AASHTO T152 on same sample used for quality control strength cylinders
No. of samples per sublot	N/A	N/A	1
Actual air content / std. dev., %	N/A	N/A	6.58 / 0.35
Overall pay factor, %	106.5	114.8 (capped at 110)	104.9

1 mi = 1.61 km; 1 ft = 0.305 m; 1 in. = 25.4 mm; 1 lbf/in^2 = 6.89 kPa; 1 in./mi = 15.8 mm/km

REFERENCES

Chamberlin, W. P. 1995. *NCHRP Synthesis of Highway Practice 212: Performance-Related Specifications for Highway Construction and Rehabilitation*. National Research Council, Washington, DC.

Darter, M. I., M. Abdelrahman, P. A. Okamoto, and K. D. Smith. 1993. *Performance-Related Specifications for Concrete Pavements: Volume 1—Development of a Prototype Performance-Related Specification* (FHWA-RD-93-042). Federal Highway Administration, McLean, VA.

Evans, L. D., M. I. Darter, and B. K. Egan. 2005. *Development and Implementation of a Performance-Related Specification – I-65 Tennessee*. FHWA Contract No. DTFH61-03-C-00109. Federal Highway Administration, Washington, DC.

Evans, L. D., K. L. Smith, N. G. Gharaibeh, and M. I. Darter. 2006. *Development and Implementation of a Performance-Related Specification in Florida: State Road 9A (I-295 LEG), Jacksonville*. Draft Final Report. Federal Highway Administration, Washington, DC.

Federal Highway Administration (FHWA). 1999. TechBrief: Guide to Developing Performance-Related Specifications for PCC Pavements (FHWA-RD-99-054). FHWA, McLean, VA.

Graveen, C., J. Weiss, J. Olek, T. Nantung, and V. L. Gallivan. 2004. "The Implementation of a Performance Related Specification (PRS) for a Concrete Pavement in Indiana." Preprint paper, 83rd Annual Meeting of the Transportation Research Board, Washington, DC.

Hoerner, T. E., and M. I. Darter. 1999. *Guide to Developing Performance-Related Specifications for PCC Pavements, Volume I: Practical Guide, Final Report and Appendix A* (FHWA-RD-98-155). FHWA, McLean, VA.

Hoerner, T. E., M. I. Darter, S. M. Tarr, and P. A. Okamoto. 1999. *Guide to Developing Performance-Related Specifications for PCC Pavements, Volume II: Appendix B—Field Demonstrations* (FHWA-RD-98-156). FHWA, McLean, VA.

Hoerner, T. E., M. I. Darter, L. Khazanovich, L. Titus-Glover, and K. L. Smith. 2000. *Improved Prediction Models for PCC Pavement Performance-Related Specifications, Volume I: Final Report* (FHWA-RD-00-130). FHWA, McLean, VA.

Kopac, P. A. 2002. "Making Roads Better and Better." *Public Roads*. July/August 2002, Vol. 66, No. 1. FHWA, McLean, VA.

Rao, S. P., K. L. Smith, and M. I. Darter. 2007. *Development and Implementation of a Performance-Related Specification for a Jointed Plain Concrete Pavement—I-39/90/94 Madison, Wisconsin*. WI/SPR-01-06. Wisconsin Department of Transportation, Madison.

Contact—For information related to concrete pavement, please contact the following:

Federal Highway Administration
Sam Tyson—sam.tyson@dot.gov

CPTP Implementation Team
Shiraz Tayabji, Fugro Consultants, Inc.—stayabji@aol.com

Research—This TechBrief was developed by Kurt D. Smith, P.E., and Todd E. Hoerner, P.E., as part of the Federal Highway Administration's (FHWA's) Concrete Pavement Technology Program Task 65 product implementation activity.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the Resource Centers and Divisions.

Availability—This report is available online at www.fhwa.dot.gov/pavement/pccp/. A limited number of copies are available from the Research and Technology Product Distribution Center, HRTS-03, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD 20706 (phone: 301-577-0818; fax: 301-577-1421).

Key Words—Concrete pavement design, performance-related specifications, quality assurance, pavement performance