Development and Implementation of a Performance-Related Specification for SR 9a Florida · FINAL REPORT

PUBLICATION NO. FHWA HIF 09 016

NOVEMBER 2008

U.S. Department of Transportation
Federal Highway Administration

Office of Infrastructure
Office of Pavement Technology
Washington, DC 20590

CONCRETE PAVEMENT TECHNOLOGY PROGRAM

Notice

Quality Assurance Statement

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-HIF-09-016		

4. Title and Subtitle
Development and Implementation of a Performance-Related Specification for SR 9a, Florida: Final Report

5. Report Date
[December 2006]
November 2008

6. Performing Organization Code
ARA Project 10467

7. Authors
L. Evans, K. L. Smith, N. G. Gharaibeh, and M. I. Darter

8. Performing Organization Report No.

9. Performing Organization Name and Address
Applied Research Associates, Inc.
100 Trade Centre Drive, Suite 200
Champaign, IL 61820

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
Florida Dept. of Transportation
State Materials Office
5007 NE 39th Avenue
Gainesville, FL 32609

Federal Highway Administration
Office of Pavement Technology
1200 New Jersey Avenue, SE
Washington, DC 20590

13. Type of Report and Period Covered
Final Report
2003–2006

14. Sponsoring Agency Code

15. Supplementary Notes
FHWA Contacts: Peter Kopac, 202-493-3151, and Sam Tyson, 202-366-1326

16. Abstract

The primary objective of this study was to develop, implement, and evaluate a Level 1 performance-related specification (PRS) for the construction of a jointed plain concrete pavement in the State of Florida. The study included an evaluation of the construction quality levels achieved on recent Florida JPCP projects and the formulation of a Level 1 PRS using the results of the quality evaluation and defined FDOT pavement practices as a basis. The Level 1 PRS defined the sampling and testing requirements for three acceptance quality characteristics (AQCs): thickness, strength, and smoothness. The corresponding performance-based pay factor curves were developed for each AQC. The Level 1 PRS was included as an overriding special provision in the July 2001 letting of the paving project SR 9A (I-295 Leg) in southeast Jacksonville, Florida. Construction of the PRS project took place in 2004–05. Three lanes and tied shoulders were placed in both directions.

AQC measurements obtained from the project were used to compute PRS pay factors and establish pay adjustments for the contractor. The higher-than-target (i.e., higher-than-design) quality levels achieved by the contractor resulted in significant pay increases for the contractor under the PRS. Feedback from FDOT and the contractor indicated that this first PRS implementation in Florida was successful, particularly with respect to the layouts of lots and sublots and quality achieved. Several suggestions were received to improve and streamline the PRS process.

17. Key Words
Performance-related specification (PRS), acceptance quality characteristic (AQC), rejectable quality level (RQL), maximum quality level (MQL), lot, sublot, concrete strength, thickness, smoothness

18. Distribution Statement
Distribution unlimited.
Authorized for public release.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	

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

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CHAPTER 1—INTRODUCTION

This report documents the results obtained from the use of a performance-related specification (PRS) for construction of a section of concrete pavement highway. The construction project is located on SR 9A (I-295 Leg) in southeast Jacksonville, Florida, and was built in 2004–05. The primary objective of this study was to develop, implement, and evaluate a PRS for the construction of jointed plain concrete pavement (JPCP) in the State of Florida. The Federal Highway Administration (FHWA) sponsored the development and implementation of the PRS for this project by Applied Research Associates, Inc., with full cooperation and assistance of the Florida Department of Transportation (FDOT).

BACKGROUND

The PRS methodology builds upon the traditional materials-and-methods specifications or quality assurance (QA) specifications used by State highway agencies, by linking key materials and construction quality characteristics (e.g., strength, thickness, smoothness) with pavement performance and, subsequently, future pavement costs.

The underlying premise of the methodology is that lower or more variable materials and construction quality levels result in reduced pavement performance, which, in turn, requires an agency to spend more money in the future through sooner, more frequent, or more comprehensive maintenance and rehabilitation work. By passing the expected economic consequences of high or low construction quality on to the paving contractor through incentives and disincentives, a more rational approach to construction is achieved, one that promotes the minimization of as-designed and as-constructed life-cycle costs (LCCs) and is more equitable to both the highway agency and the contractor.

Initial development of the PRS methodology can be traced back to the mid 1980s and the work of the New Jersey Department of Transportation (Weed, 1989), which developed comprehensive procedures for deriving acceptance plans and payment schedules based on as-constructed portland cement concrete (PCC) thickness and strength. Using the American Association of State Highway and Transportation Officials (AASHTO) rigid pavement performance equation, the expected difference in performance between a pavement with as-designed and as-constructed quality levels could be computed, with the resulting LCC difference passed on to the contractor.

The first of four FHWA-sponsored studies on PRS for concrete pavements was performed in the late 1980s and resulted in an expansion of the procedure to include surface profile (i.e., smoothness) as a key construction quality attribute (Irick et al., 1990). It also introduced the use of concrete pavement performance models developed in National Cooperative Highway Research Program (NCHRP) Project 1-19.

The second FHWA-sponsored study took place between 1990 and 1993 (Darter et al., 1993a; Darter et al., 1993b; Okamoto, 1993). Under that study, the first demonstration software (PaveSpec 1) of JPCP PRS was developed, and an extensive laboratory testing program was conducted to evaluate various PCC material properties (strength, modulus, air content), inter-strength relationships (e.g., flexural versus compressive strength, core versus cylinder strength), and the effects of entrained air content on spalling.

In the third FHWA PRS study (1994 through 1998) (Hoerner and Darter, 1999; Hoerner et al., 1999a; Hoerner et al., 1999b; Hoerner, 1999), the variability of key materials and construction quality characteristics was investigated. Two new characteristics (air content and consolidation around dowels) and new pavement performance models were evaluated, and several field trials of the prototype PRS were conducted. In addition, version 2.0 of the PaveSpec software program was developed, incorporating many of the results of these undertakings.

Performance model refinement was the primary focus of the final FHWA PRS study, which was conducted between 1998 and 2000 (Hoerner et al., 2000; Hoerner and Darter, 2000). Each of four PRS models (transverse joint faulting, transverse slab cracking, transverse joint spalling, and smoothness) were evaluated, improved, and incorporated into PaveSpec Version 3.0.

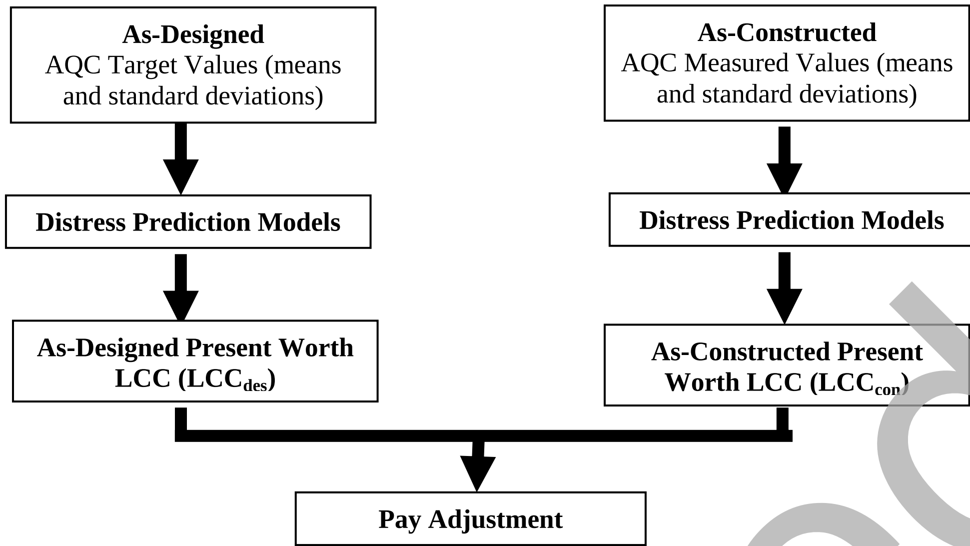
PERFORMANCE-RELATED SPECIFICATION CONCEPT

Specifications that describe how the finished product shall perform over time are described as performance specifications. PRS are defined as QA specifications that describe the desired levels of key materials and construction acceptance quality characteristics (AQCs) (e.g., concrete strength, slab thickness, and initial smoothness) that have been found to correlate with fundamental engineering properties that predict performance (TRB, 2005). PRS are improved QA specifications. Like QA specifications, PRS specify the desired product quality rather than the desired product performance. However, in PRS, when agency engineers specify quality, they know what performance they are specifying.

Another major difference comes from the methods used to determine the overall pay adjustment for a given lot (i.e., the amount of material or construction produced by the same process). Conventional QA acceptance plans use engineering judgment to establish individual AQC pay adjustments (and weighting factors for each) for determining the overall price adjustment for the lot (FHWA, 1997). PRS, however, use mathematical models (taking AQC values into account) to estimate future pavement performance and corresponding LCCs to compute one overall lot price adjustment (Darter et al., 1993a; FHWA, 1997; Hoerner and Darter, 2000).

As illustrated in figure 1, PRS pay adjustments are based on the difference between the LCCs associated with the target (as-designed) pavement and those associated with the as-constructed pavement. AQC target values represent the AQC values or range of values for which a highway agency is willing to pay 100 percent of the contracted unit price for PCC. These AQC targets are used to predict the future performance (using mathematical distress prediction models) and the associated estimated future LCCs defining the as-designed pavement. (Note: The future LCCs consist of those maintenance and rehabilitation costs expected to be incurred by the agency and potential users [user costs may be included by the agency] over a selected analysis period, assuming a given rehabilitation policy.)

The estimated LCCs corresponding to the as-designed AQC quality are then summarized into one overall LCC (LCC_{des}) representing the AQC quality of the as-designed pavement. The as-constructed AQCs are measured at the time of construction and used to predict the future performance and LCCs associated with the as-constructed pavement. The estimated LCCs corresponding to the measured as-constructed AQC quality are then summarized into one overall LCC (LCC_{con}) representing the AQC quality of the as-constructed pavement.



AQC = acceptance quality characteristic; LCC = life-cycle cost; des = as designed; con = as constructed

Figure 1. Basic concepts of life-cycle-cost-based performance-related specification.

An incentive pay adjustment is computed if the as-constructed AQC quality is measured to be better than the agency-specified target values (due to an increase in pavement life, resulting in a corresponding decrease in LCCs). Conversely, a disincentive pay adjustment is computed if the as-constructed AQC quality is measured to be less than the agency-specified target values (due to a decrease in pavement life, resulting in a corresponding increase in LCCs) (Darter et al., 1993a). The amount of the pay adjustment (incentive or disincentive) is determined as a percentage of the bid price using the following equation:

$$PF = 100 * (BID + [LCC_{des} - LCC_{con}]) / BID \qquad \text{Eq. 1}$$

where:
- BID = Contractor's unit price bid for PCC pavements.
- LCC_{des} = As-designed life-cycle cost per unit length.
- LCC_{con} = As-constructed life-cycle cost per unit length.

STUDY OBJECTIVES AND SCOPE

The primary objective of this study was to develop, implement, and evaluate a PRS for the construction of JPCP in the State of Florida. This specification would provide the Florida DOT with a methodology that (a) assures that pavement design assumptions are being fulfilled, (b) promotes high quality construction, and (c) protects the department from poor workmanship. At the same time, the specification would allow the contractor the maximum freedom in deciding how to perform the construction.

Specifically, the contract objectives were the following:

- Develop initial PRS—Review Florida DOT specifications, meet with department personnel to identify a suitable construction project and determine the specific goals for PRS development, develop an initial PRS (complete with pay factor curves) for the selected construction project based on existing department specifications and goals, and develop a final PRS based on revisions requested by department staff.

- Implement final PRS—Educate and inform department personnel on use of the final PRS and provide on-site assistance to department field engineers in the areas of sampling and testing plan layout, AQC test value reporting, and pay factor computations for the selected construction project.

- Evaluate the PRS—Evaluate the effectiveness and performance of the PRS, based on assessments of the level of department and contractor satisfaction with PRS, contractor bidding practices and targeted AQC values, the overall adequacy of the PaveSpec 3.0 software, and the PRS-related pay factors in comparison with those computed using the department's current construction specifications.

- Summarize the project results—Prepare a final report documenting the development, implementation, and evaluation of the PRS.

CHAPTER 2—OVERVIEW OF FLORIDA SR 9A CONSTRUCTION PROJECT

LOCATION

The PRS developed and evaluated in this study was implemented on a relatively short highway construction project located on SR 9A (I-295 Leg) in southeast Jacksonville (see figure 2). As part of a multiyear effort to complete the I-295 loop on the city's east side, this project (Financial Project 209600-1-52-01, State Project No. 72002-3563) involved the construction of 0.420 mi (0.676 km) (2,217 ft [675.7 m]) of six-lane mainline pavement; a 0.169-mi (0.272 km) (894-ft [273 m]) bridge over SR 5 and the Florida East Coast railway; entrance and exit ramps for the SR 5–9A interchange; and various roadside improvements, all occurring between mileposts (MPs) 23.401 and 24.916 (stations 207+00 and 127+00) of SR 9A. As shown in figure 2, the PRS was applied to the PCC mainline pavement (excluding the bridge) located between MPs 24.496 and 24.916 (stations 149+17 and 127+00).

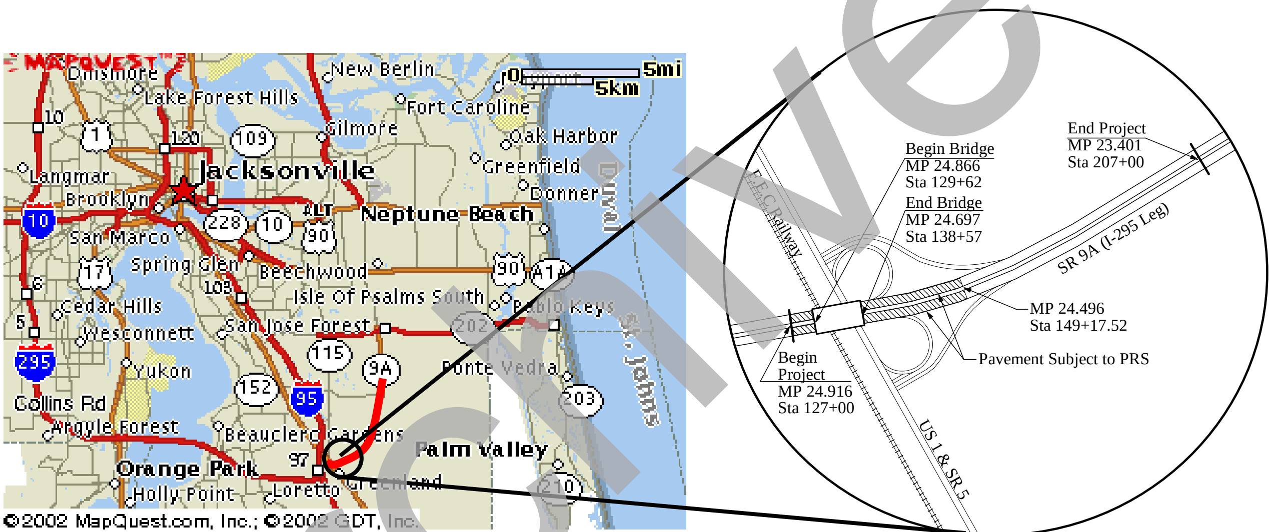


Figure 2. State Road 9A construction project location.

DESCRIPTION

The SR 9A project was let in September 2001 and was awarded to AMEC Civil, LLC, in October 2001. The project letting included provisions and a pre-bid meeting on July 19, 2001, covering the use of the PRS. Following a pre-construction meeting on June 12, 2003, PRS project concrete paving of the northbound mainline occurred on January 8 and 9, 2004. Southbound paving east of the bridge was completed on June 6, 2005.

As seen in figure 3, the geometric design of the mainline pavement consists of three lanes in each direction located between MPs 24.496 and 24.916 (stations 149+17 and 127+00) and a fourth speed-change lane located between MPs 24.613 and 24.916 (stations 143+00 and 127+00). The design includes tie bars for connecting adjacent slabs to one another and for connecting the inside and outside slabs to the concrete shoulders, 8 and 10 ft (2.4 and 3.0 m) wide.

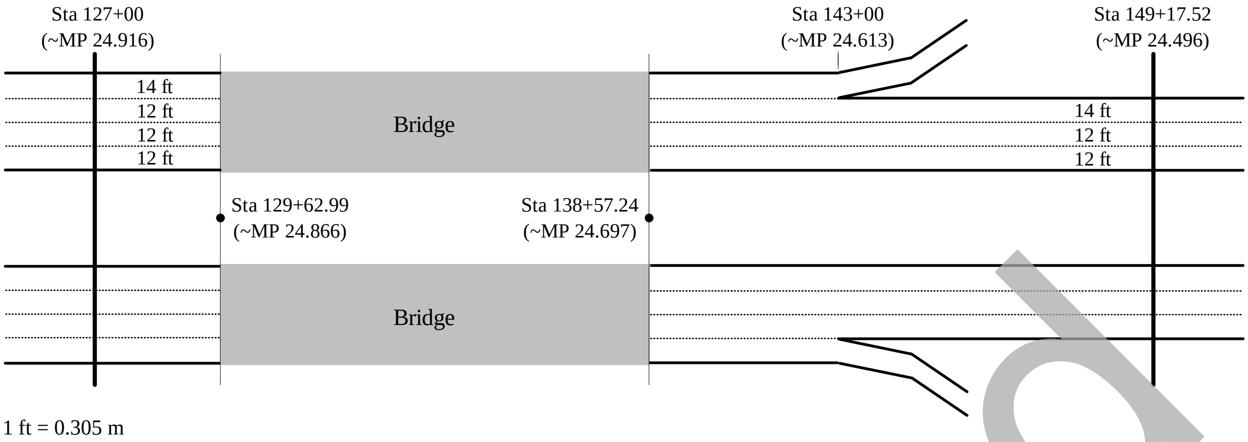


Figure 3. Layout of SR 9A pavement project.

The JPCP design was for PCC 12.5 in. (320 mm) thick with perpendicular, doweled (diameter 1.25 in. [32 mm], spacing 12 in. [304.8 mm]) transverse joints spaced every 16 ft (4.9 m). Dowel baskets were used for the transverse joints. Support for these JPC slabs was to consist of 12 in. (304.8 mm) of permeable rigid pavement subgrade material and 36 in. (915 mm) of select material, placed on constructed embankment. Longitudinal joints were tied using No. 4 steel tie bars spaced at 24 in. (600 mm). These bars were inserted during the paving process. Longitudinal edge drains were included in the design to help remove water from the pavement system.

SR 9A is located in a wet–nonfreeze climate. The mean daily temperature in the area ranges from about 56 °F (13 °C) in January to 83 °F (28 °C) in July (National Oceanic and Atmospheric Administration [NOAA], 1983). The mean annual number of days above 90 °F (32 °C) is approximately 57, while the mean annual number of days below 32 °F (0 °C) is approximately 9. The mean annual precipitation is about 51 in. (1,295 mm).

CHAPTER 3—DEVELOPMENT OF THE PERFORMANCE-RELATED SPECIFICATION

In developing the PRS for the SR 9A project, the latest FHWA procedures (Hoerner and Darter, 1999) and software (PaveSpec 3.0) were used. A level 1 (simplified) specification was chosen to minimize deviation from the department's existing specifications and testing practices and thus provide the best chance possible for successful implementation.

To begin the development process, much information about the department's current specifications and design criteria, construction sampling and testing techniques, pavement performance measures, and typical maintenance and rehabilitation strategies and costs was collected and carefully reviewed. This information, along with data specific to the SR 9A project, was used to create the framework for the specification and provide the necessary inputs to the PaveSpec program, which are provided in appendix A.

This chapter discusses in detail the various types of data collected in the study and how the data were used to develop the SR 9A PRS. It also presents the resulting PRS pay factor curves used in compensating the contractor for the level of quality achieved on the project. The final, binding version of the PRS, in the form of a Technical Special Provision, is provided in appendix B.

SELECTION OF ACCEPTANCE QUALITY CHARACTERISTICS AND AS-DESIGNED QUALITY LEVELS

In the construction of its concrete pavements, the department calls for the inspection and testing of several quality characteristics. Among these characteristics are slump, air content, slab thickness, strength, dowel and tie bar placement, and surface smoothness. For the SR 9A PRS implementation, Florida DOT decided that three of the five AQCs considered by PaveSpec would provide the basis for concrete pavement pay adjustments. These AQCs included slab thickness, 28-day compressive strength, and surface smoothness, as determined using a California-type profilograph with a 0.2-in. (5 mm) blanking band.

To define for each AQC the levels of quality for which the department is willing to pay 100 percent of the bid price (i.e., target values) and the levels it considers unacceptable (minimum and maximum values), the department's applicable concrete specifications (Florida DOT, 2000) and design methodology were examined. In addition, actual AQC data from three nearby concrete paving projects completed in 2000 were obtained and analyzed. The sections below discuss how the gathered information was used to establish as-designed target values (i.e., mean and standard deviation) and corresponding rejectable and maximum quality limits (RQLs and MQLs) for each of the three AQCs included in the PRS.

Slab Thickness

Section 350-16 of the department's 2000 Standard Specifications discusses how slab thickness is measured and evaluated for acceptance. The specification requires that the contractor take cores at randomly selected locations, with each core representing no more than 2,500 yd^2 (2,090 m^2) of pavement area. The department determines the average thickness of pavement from the lengths of all cores taken from the entire job. In this computation, cores measuring more than 0.5 in.

(12.7 mm) greater than the specified thickness are assigned a thickness equal to the specified thickness plus 0.5 in. (12.7 mm).

Areas of pavement found by the department to be deficient in thickness by more than 0.5 in. (12.7 mm) are handled in one of two ways. The first option allows the contractor to remove and replace the deficient area with concrete of the thickness shown in the plans. No compensation is given for the removal and replacement. The second option allows the contractor to leave the deficient pavement in place, but to receive zero compensation for the subject pavement area.

The final pay quantity is determined by multiplying the area of pavement to be paid for by the ratio of the average thickness to the specified thickness. This prorated amount of pavement is then multiplied by the bid unit price for concrete pavement. The final pay quantity is capped, however, by a maximum average of over-thickness of 0.25 in. (6.4 mm).

As discussed in chapter 2, the specified pavement thickness on the SR 9A project is 12.5 in. (317.5 mm). Because the department will not pay for, and may require replacement for, pavement that is more than 0.5 in. (12.7 mm) below the specified thickness, the department's RQL for slab thickness for the SR 9A project is assumed to be 12.0 in. (304.8 mm) (12.5 in. - 0.5 in. [317.5 – 12.7 mm]). This value was deemed appropriate by the department for use in the PRS.

Department specifications indicate that the MQL for thickness for the SR 9A project is 12.75 in. (323.9 mm) (12.50 in. + 0.25 in. [317.5 + 6.4 mm]). No additional bonus money is paid to the contractor for achieving an average thickness for the project greater than 12.75 in. (323.9 mm). For PRS development and implementation, however, the department determined that the MQL should be increased from 12.75 in. (323.9 mm) to 13.5 in. (342.9 mm) to allow for more incentive opportunity.

The logical target mean for thickness for the SR 9A project is represented by the specified thickness of 12.5 in. (317.5 mm). To determine the appropriate standard deviation target, slab thickness data from three previous SR 9A jobs (Financial Projects 20959315201, 20929615201, and 20929315201) were analyzed. These projects represented approximately 21 lane-miles (34 lane-kilometers) of mainline pavement, extending from MP 24.496 northeasterly to MP 20.917. For each project, only the core thickness measurements taken on mainline pavement (specified thickness of 12.5 in. [317.5 mm]) were evaluated.

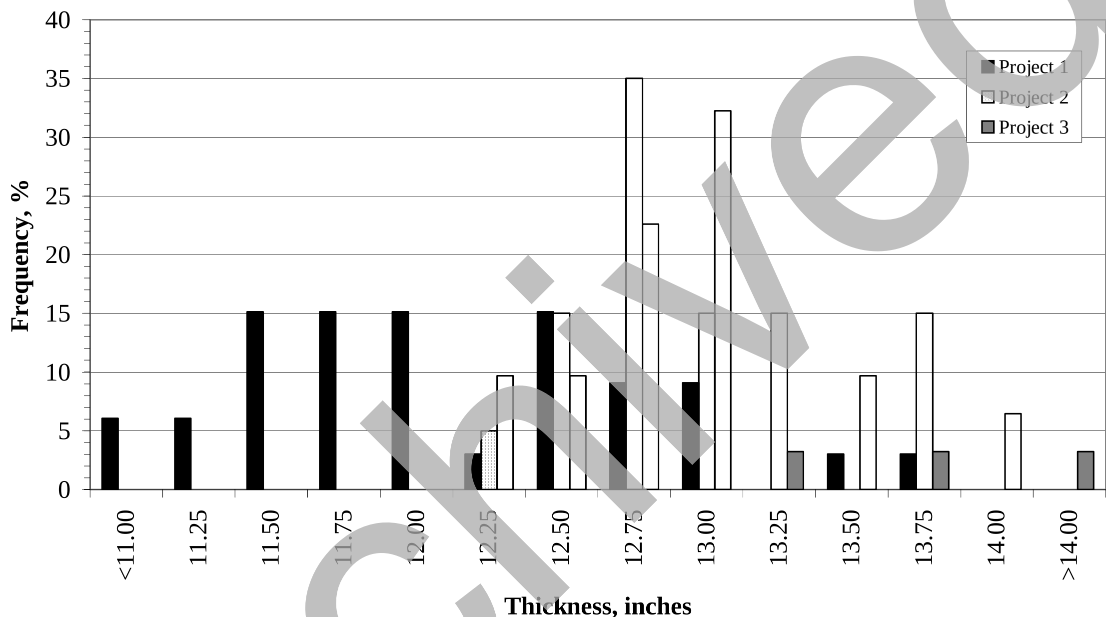
Table 1 provides a statistical breakdown of the measured slab thicknesses for each project, while figure 4 shows the corresponding thickness distributions. Because of the unusually high variation in thickness for project 1, only the data from projects 2 and 3 were considered in establishing the target standard deviation. The weighted average thickness (based on number of independent cores) for these two projects was computed to be 12.67 in. (321.8 mm) and the standard deviation of the pooled variances of thickness was computed to be 0.49 in. (12.5 mm) Based on these results, the department recommended establishing the target standard deviation at 0.50 in. (12.7 mm). These are the target mean and standard deviations for which the department is willing to pay 100 percent bid price.

Table 1. Statistics for Slab Thickness Data From Three Florida Concrete Pavement Projects

Statistic	Project 1	Project 2	Project 3
Number of independent cores	33	20	31
Average, in.	11.99	12.83	12.57
Standard deviation, in.	0.71	0.40	0.54
Coefficient of variation (COV) [a]	0.06	0.03	0.04

1 in. = 25.4 mm

[a] COV = standard deviation/average



1 in. = 25.4 mm

Figure 4. Slab thickness distributions for three Florida concrete pavement projects.

Compressive Strength

Acceptance sampling and testing protocol and requirements for concrete strength are provided in Sections 347-4 and 347-5 of the department's 2000 Standard Specifications. According to the protocol, at least one representative sample of concrete must be obtained from each day's production of each design mix from each production facility. From that sample, the contractor must cast four concrete cylinders, 6 in. (152.4 mm) in diameter by 12 in. (304.8 mm) long. Two of the cylinders must then be tested for compressive strength 7 days after casting, while the other two cylinders must be tested 28 days after casting. For each pair of cylinders tested, the average compressive strength is determined. Concrete below the 28-day minimum compressive strength requirement of 2,700 lbf/in^2 (18.62 MPa) is subject to removal and replacement by the contractor. This strength value represents the department's existing RQL, and the department recommended that it be applied to the SR 9A PRS.

A corresponding MQL for strength was found to not exist. However, based on the department's target for strength and the variability of strength observed in past projects (see discussion below), the department determined that 5,500 lbf/in^2 (37.92 MPa) would be a suitable MQL value for the 9A PRS.

The Florida DOT's current procedure for designing JPCPs is based on the 1993 AASHTO Design Guide. The procedure and the standard design input values used by the department are presented in its 1996 Rigid Pavement Design Manual. In this manual, the design concrete strength is represented by the 28-day modulus of rupture determined through third-point loading. The standard design value is given as 4,400 kPa (638 lbf/in^2). Using the following equation for converting flexural strength to compressive strength, the corresponding 28-day design compressive strength was computed to be 4,510 lbf/in^2 (31.10 MPa):

$$M_{R,28\text{-}day} = 9.5 * (f'_{C,28\text{-}day})^{0.5} \quad \text{Eq. 2}$$

where: $M_{R,28\text{-}day}$ = Estimated modulus of rupture at 28 days, lbf/in^2.
$f'_{C,28\text{-}day}$ = Estimated compressive strength at 28 days, lbf/in^2.

For PRS purposes, the target mean for compressive strength was set at 4,500 lbf/in^2 (31.03 MPa).

Evaluation of 28-day compressive strength data on cylinders tested in the three previous SR 9A projects yielded the strength statistics listed in table 2 and the strength distributions shown in figure 5. Again, because of the unusually high variation in strength for project 1, only the data from projects 2 and 3 were considered in establishing the target standard deviation. The weighted average strength (based on number of pairs of cylinders) for these two projects was computed to be 5,548 lbf/in^2 (38.25 MPa), and the standard deviation of strength was computed from pooled variances to be 610 lbf/in^2 (4,206 kPa). Based on these results, the department recommended establishing the target standard deviation at 610 lbf/in^2 (4,206 kPa). As previously stated, these are the means and standard deviations for which the department is willing to pay 100 percent of bid price.

Table 2. Statistics for Compressive Strength Data From Three Florida Concrete Pavement Project

Statistic	Project 1	Project 2	Project 3
Number of pairs of cylinders	26	45	45
Average, lbf/in^2	5,471	5,419	5,698
Standard deviation, lbf/in^2	833	649	570
Coefficient of variation (COV) [a]	0.15	0.12	0.10

1 lbf/in^2 = 6.89 kPa

[a] COV = standard deviation/average

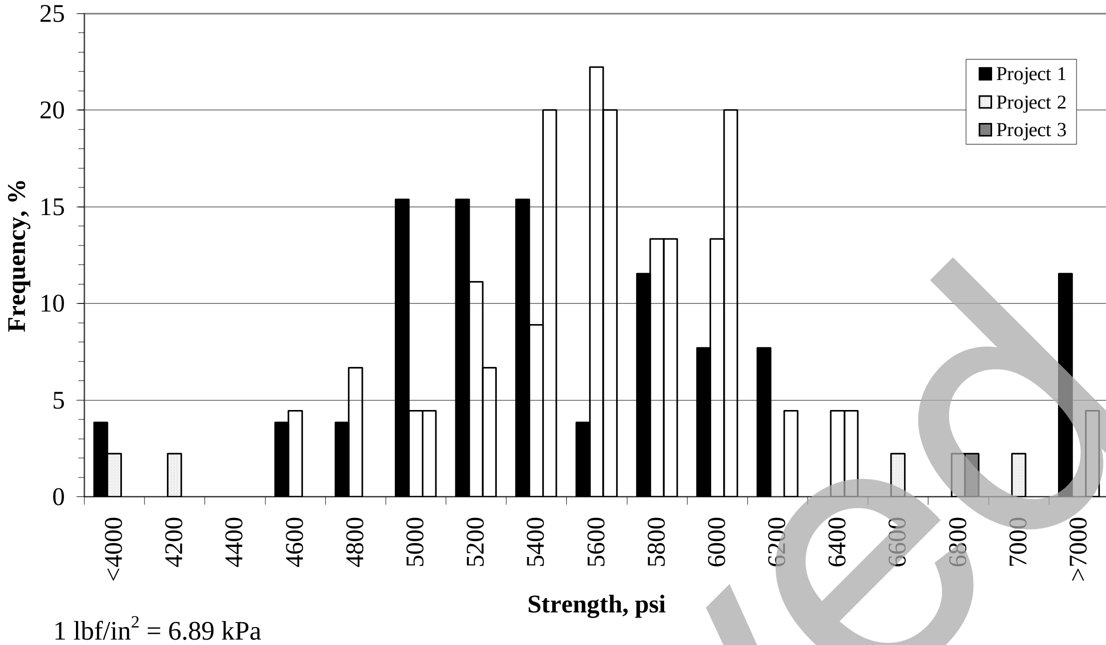


Figure 5. Compressive strength distributions for three Florida concrete pavement projects.

Smoothness

Sections 350-14 and 352-4c of the department's 2000 Standard Specifications describe how concrete smoothness is tested and evaluated for acceptance. The procedure requires that the contractor furnish and operate an electronic California-type profilograph along each wheelpath of each traffic lane longer than 250 ft (76.2 m). The profilograph must be capable of producing profile traces and computing profile index (PI) based on a 0.2-in. (5 mm) blanking band (herein denoted as $PI_{0.2\text{-in}}$).

Profilograph test results are examined by the department's field engineer. Individual high points in excess of 0.3 in. (7.6 mm) per 25-ft (7.6 m) length are identified for grinding, and the average $PI_{0.2\text{-in}}$ for each 0.1-mi (0.16 km) section is computed using the left and right wheelpath $PI_{0.2\text{-in}}$ values. Each 0.1-mi (0.16 km) tangent or slightly curved (centerline radius of curvature ≥ 2,000 ft) (609.6 m) section with an average $PI_{0.2\text{-in}}$ greater than 7 in./mi (111 mm/km) must be corrected by the contractor via grinding. Contract unit price adjustments for smoothness, prior to grinding, are made according to the schedule shown in table 3.

The information in table 3 indicates that the department's RQL and MQL values for smoothness are 7 in./mi (111 mm/km) and 3 in./mi, respectively. These values were deemed appropriate for use in the SR 9A PRS. Table 3 also shows that the DOT's target mean smoothness (prior to grinding) is 5.5 in./mi (87 mm/km), which is the midpoint of the range ($5.0 < PI_{0.2\text{-in}} \leq 6.0$) that corresponds to 100 percent payment. However, because the SR 9A contract was let with the requirement that all concrete pavement be diamond ground and that contractor bid prices for concrete pavement include the cost of grinding, a different target mean was sought for the PRS.

Table 3. Price Adjustment Schedule for Pavement Smoothness
Prior to Grinding (FDOT, 2000)

Average Profile Index (PI) per 0.1-mi Section, in./mi	**Contract Unit Price Adjustments, Percentage of Pavement Unit Bid Price**
$3.0 \leq PI_{0.2\text{-in}}$	103
$3.0 < PI_{0.2\text{-in}} \leq 4.0$	102
$4.0 < PI_{0.2\text{-in}} \leq 5.0$	101
$5.0 < PI_{0.2\text{-in}} \leq 6.0$	100
$6.0 < PI_{0.2\text{-in}} < 7.0$	99
$PI_{0.2\text{-in}} = 7.0$	98
$PI_{0.2\text{-in}} > 7.0$	Corrective work required

1 mi = 1.6 km; 1 in./mi = 16 mm/km

After-grinding smoothness data for the three previous SR 9A jobs were examined for this purpose. Table 4 shows a statistical breakdown of the measured $PI_{0.2\text{-in}}$ values for several 0.1-mi (0.16 km) test segments from each project, while figure 6 shows the corresponding $PI_{0.2\text{-in}}$ distributions. The weighted average $PI_{0.2\text{-in}}$ (based on number of 0.1-mi (0.16 km) test segments) for these three projects was computed to be 2.7 in./mi (42 mm/km), and the pooled standard deviation was computed to be 1.2 in./mi (19 mm/km). Based on these results, the department recommended establishing the PRS target mean at 3.0 in./mi (47 mm/km) and the target standard deviation at 1.0 in./mi (16 mm/km).

Table 4. Statistics for Smoothness ($PI_{0.2\text{-in}}$) Data From Three Florida
Ground Concrete Projects

Statistic	**Project 1**	**Project 2**	**Project 3**
Number of pairs of 0.1-mi sections	33	60	78
Average, in./mi	3.0	2.1	3.0
Standard deviation, in./mi	1.2	1.3	1.2
Coefficient of variation (COV) [a]	0.40	0.65	0.40

1 mi = 1.6 km; 1 in./mi = 16 mm/km
[a]COV = standard deviation/average

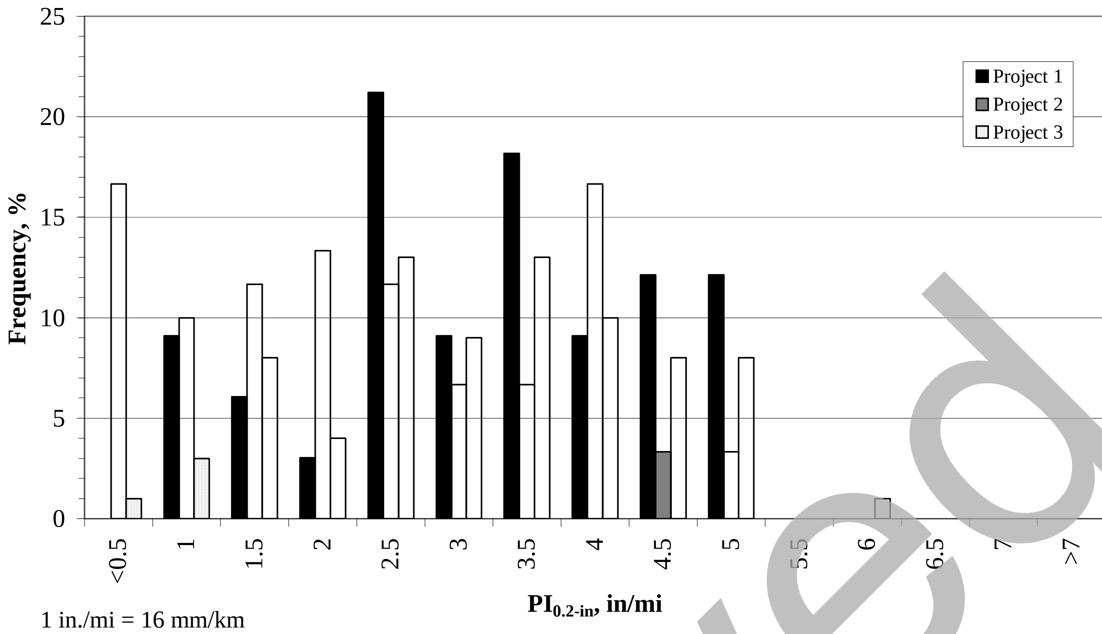


Figure 6. Smoothness distributions for three Florida concrete pavement projects.

SUMMARY OF ACCEPTANCE QUALITY CHARACTERISTICS TARGET VALUES, REJECTABLE QUALITY LEVELS, AND MAXIMUM QUALITY LEVELS

Table 5 summarizes the target means and standard deviations established for each AQC for the SR 9A PRS. It also lists the established RQLs and MQLs for each AQC. These values apply to each lot of concrete pavement.

Table 5. Summary of Target, Rejectable, and Maximum Quality Levels for the SR 9A Performance-Related Specification

Acceptance Quality Level	Lot Target Values		Rejectable Quality Level	Maximum Quality Level
	Mean	Standard Deviation		
Slab thickness, in.	12.5	0.5	12.0	13.5
28-day PCC compressive strength, lbf/in^2	4,500	610	2,700	5,500
PI$_{0.2\text{-in}}$, in./mi	3.0	1.0	5.0	0.0

1 in. = 25.4 mm; PCC = portland cement concrete; 1 lbf/in^2 = 6.89 kPa; PI = profile index; 1 in./mi = 16 mm/km

PAVEMENT PERFORMANCE INDICATORS AND MODELS

The Florida DOT monitors JPCP performance through annual visual distress surveys and ride quality tests. The distress surveys identify the amount and severity level of up to 10 different surface distress types, including slab cracking, joint faulting, and joint spalling, that have developed over time and through the loss of smoothness over time. Smoothness is measured with an inertial profiler and is reported in terms of the International Roughness Index (IRI). The collected distress and smoothness data are entered into the department's pavement management system, which is used to track deterioration rates and predict future conditions and corresponding rehabilitation needs.

For the SR 9A PRS, all four performance indicators—slab cracking, joint spalling, joint faulting, and smoothness—available in PaveSpec 3.0 were selected for predicting pavement service life. In addition, the PaveSpec default performance models linking the three AQCs (thickness, strength, and smoothness) with the four performance indicators were selected for developing the PRS pay factor equations.

CONSTANT INPUT VALUES

Constant inputs represent those PaveSpec parameters that do not differ between as-designed and as-constructed pavements. They include various design, traffic, and climatic parameters, as well as the maintenance and rehabilitation strategies and costs used to compute LCCs and corresponding pay factor amounts.

Table 6 lists the constant input values established for the SR 9A PRS. Many of these values were defined in the contract plans, while others represent standard values given in the department's rigid design manual.

Climatic data were derived from two sources: the NOAA 1983 *Climatic Atlas of the United States*, which includes statistics based on roughly 30 years of U.S. weather data, and the FHWA LTPP database, which includes weather statistics for thousands of test pavements in the United States and Canada. For this latter source, climatic data from three LTPP test sections in the Jacksonville area and covering the last 15 to 20 years were analyzed. The climatic values shown in table 6 represent the best estimates for the SR 9A project.

Table 6. Constant Inputs for PaveSpec 3 Defining the SR 9A Project

Input Parameter	Value	Source
Project Location and Design Information		
Setting	Urban	Contract plans
Functional class	Freeway	Contract plans
Directions	2 (EB, WB)	Contract plans
Lanes per direction	3	Contract plans
Lane widths	12 ft (14 ft outside)	Contract plans
Pavement type	Plain, doweled	Contract plans
Dowel bar diameter	1.25 in.	Contract plans
Joint spacing	16 ft	Contract plans
Shoulder type	Tied PCC	Contract plans
Base type and thickness	48-in. permeable ($5x10^{-5}$ cm/sec)	Contract plans
Transverse joint seal type	Silicone	Florida Department of Transportation (DOT) Rigid Design Manual
Design life	20 years	Florida DOT Rigid Design Manual
Traffic Information		
Initial ADT	28,500 veh/day	Contract plans
Traffic growth rate	2.4% (compound)	Computed from contract plan ADT estimates (18,100 in 1995; 28,500 in 2000; 37,400 in 2010; 45,800 in 2020)
Directional traffic factor	58%	Contract plans
Percent trucks	14%	Contract plans
Percent trucks in outer lane	65%	Florida DOT Rigid Design Manual
Truck load equivalency factor	1.67 ESALs/truck	Florida DOT Rigid Design Manual
Climatic and Materials Information		
Mean annual precipitation	51 in.	U.S. Climatic Atlas (NOAA, 1983), LTPP database (ERES, 2001)
Mean annual days above 90°F	57	U.S. Climatic Atlas (NOAA, 1983), LTPP database (ERES, 2001)
Mean annual air freeze–thaw cycles	18	LTPP database (ERES, 2001)
Mean annual freezing index	0	LTPP database (ERES, 2001)
PCC modulus of elasticity	4×10^6 lbf/in^2	Florida DOT Rigid Design Manual
PCC water/cementitious materials ratio	0.42	Florida DOT Rigid Design Manual
Modulus of subgrade reaction (k)	200 lbf/in^2/in	Florida DOT Rigid Design Manual
% subgrade material passing #200	14%	Florida DOT

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

Maintenance and Rehabilitation Strategies and Costs

The Florida DOT exercises several different options for maintaining and rehabilitating concrete pavements. They include various concrete pavement restoration activities, such as joint resealing, slab replacement, edge drain installation, and diamond grinding, and more extensive measures, such as conventional asphalt concrete (AC) overlays and AC overlays over cracked-and-seated PCC.

Based on discussions with key DOT staff, the following maintenance and rehabilitation activities were established for use in the SR 9A PRS:

Maintenance Plan Summary

- Reseal 50 percent of the transverse joints every 20 years.
- Reseal 50 percent of the longitudinal joints every 20 years.
- Reseal 100 percent of the cracks every 20 years.

Localized Rehabilitation Plan Summary

- If the lot average percent cracked slabs exceeds 10 percent, apply full slab replacement to 100 percent of cracked slabs.
- If the lot average percent spalled joints exceeds 10 percent, apply partial-depth repairs to 100 percent of spalled joints.

Sublot Failure Thresholds

- Consider the sublot failed if the cumulative percent of cracked slabs exceeds 15 percent.
- Consider the sublot failed if the average transverse joint faulting exceeds 0.10 in. (2.5 mm).
- Consider the sublot failed if the IRI exceeds 150 in./mi (2,366 mm/km).
- Consider the sublot failed if the cumulative amount of spalled joints exceeds 30 percent.

If 25 percent of the sublots have failed, apply the global rehabilitation procedures listed in table 7.

Table 7. Global Rehabilitation Activities If 25 Percent of Sublots Are Failed

Global Rehabilitation Activity	**Activities**
Prior to Phase I	Repair 100% of outstanding spalled joints with partial-depth repairs. Repair 100% of outstanding cracked slabs with full slab replacements.
Phase I (diamond grinding)	Assumed Life: 10 years Starting International Roughness Index (IRI): 60 in./mi Ending IRI: 150 in./mi
Phase II (asphalt concrete [AC] overlay)	Assumed Life: 10 years Starting IRI: 60 in./mi Ending IRI: 150 in./mi
Phase III (AC overlay)	Assumed Life: 10 years Starting IRI: 60 in./mi Ending IRI: 150 in./mi
Phase IV (AC overlay)	Assumed Life: 10 years Starting IRI: 60 in./mi Ending IRI: 150 in./mi

1 in./mi = 16 mm/km

Unit Costs

Unit cost data, shown in table 8, were provided by Florida DOT in 2001 dollars. Definitions for the cost items are shown below.

- Joint/crack sealing—Resealing of transverse and longitudinal joints and sealing of all slab cracks.
- Partial-depth joint repair—Shallow (less than half the slab depth) repairs of spalled joint segments.
- Full-depth slab replacement—Partial, full, or multiple slab removal and replacement with PCC.
- Diamond grinding—Longitudinal grinding of the concrete surface using a diamond-grinding machine.
- AC overlay—Resurfacing of existing pavement with asphalt structural course and a friction course.

Table 8. Design Feature Mean Cost Inputs Used in PaveSpec 3.0

Cost Item	**Cost (in 2003 Dollars)**
Transverse joint sealing	1.20/ft
Longitudinal joint sealing	1.00/ft
Transverse crack sealing	1.00/ft
Local: Partial-depth repairs of transverse joints	364.00/yd^2
Local: Full slab replacements	137.76/yd^2
Local: Partial slab replacements	135.00/yd^2
Global: Asphalt concrete overlay	11.00/yd^2
Global: Portland cement concrete overlay	15.00/yd^2
Global: Diamond grinding	3.01/yd^2
Percent user cost	5 (provides about the right amount of user impact on pay factor)
Estimated bid price	53.00/yd^2 (contractor's bid for 12.5-in. jointed plain concrete pavement)

1 ft = 0.305 m; 1 yd^2 = 0.836 m^2; 1 in. = 25.4 mm

SAMPLING AND TESTING METHODS

As discussed previously, existing department specifications require the following:

- Cores for thickness measurement taken from randomly selected locations, with each core representing no more than 2,500 yd^2 (2,090 m^2) of pavement area.
- Casting and subsequent strength testing of four cylinders representing 1 day's production of PCC.
- Operation of California-type profilograph along each wheelpath of each traffic lane longer than 250 ft (76.2 m), with average $PI_{0.2\text{-in}}$ computed for each 0.1-mi (0.16 km) section based on left and right wheelpath $PI_{0.2\text{-in}}$ values.

Under the PRS concept, pay adjustments are made on a lot-by-lot basis, with a lot being defined as a discrete quantity of constructed pavement having the same mix design, material sources, and design characteristics (e.g., joint spacing, drainage, dowel bar size) and subjected to the same climatic, traffic, and support conditions. The size of a lot is one lane in width and between 0.1 and 1.0 mi (0.160 and 1.61 km) long. Each lot is divided into sublots of approximately equal surface area, and all sampling and testing of concrete AQCs is performed at the sublot level.

For the SR 9A PRS, a *minimum* sublot length of 250 ft (76.2 m) was established, corresponding to the department's existing procedure for testing smoothness. In each sublot, it was determined that (a) two core borings be taken at random locations after 3 days for slab thickness measurement, (b) two cylinders be cast from one truck within the sublot and be tested for compressive strength after 28 days, and (c) profilograph traces be taken for each wheelpath. This defined sampling frequency is illustrated in figure 7, along with the layout of lots and sublots.

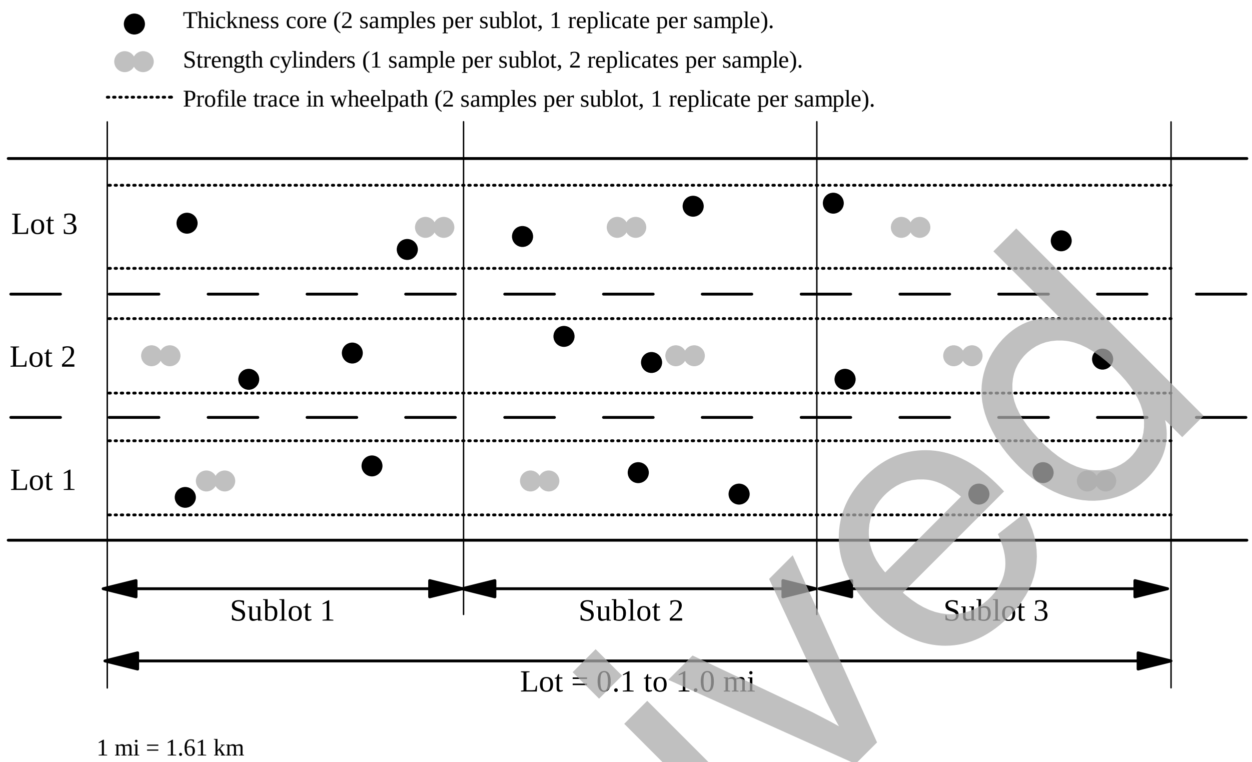


Figure 7. Illustration of lots, sublots, and sampling frequency.

It can be seen that the proposed PRS requires minimal changes to the department's existing sampling and testing procedures. The main requirement is that a complete set of AQCs be taken from each sublot to facilitate PRS performance projection.

Table 9 shows the testing methods associated within the PRS and FDOT's existing construction specifications for concrete strength, slab thickness, and initial smoothness. The testing methods for these AQCs are discussed further in the following sections.

Table 9. Testing Methods for the Performance-Related Specification Project

Acceptance Quality Characteristic	**No. of Samples[1]**	**No. of Replicates[1]**	**Sample Method**	**Evaluation Method**
Concrete strength	1	2	ASTM C-31	ASTM C-39
Slab thickness	2	1	ASTM C-42	ASTM C-42
Smoothness	2	1	FM 5-558	FM 5-558

[1] Samples and replicates per sublot.

Concrete strength—The cylindrical specimens shall be molded and cured in accordance with FM 1-T 023 (Making and Curing Test Cylinders) and tested in accordance with FM 1-T 022 (Testing Cylinders), standard Florida Test Methods. Improper sampling, molding, handling, and curing will be handled according to FDOT's existing specifications.

Slab thickness—Thickness cores shall be a minimum diameter of 2 in. (50.8 mm). The slab thickness at a cored location shall be recorded to the nearest 0.1 in. (25.4 mm) as the average of three caliper measurements of the core length. The three measurements shall be obtained and marked at locations spaced at approximately equal distances around the circumference of the core.

Initial smoothness—The pavement surface smoothness shall be tested using an electronic model of the California profilograph with 0.2-in. (5.1 mm) blanking band. The smoothness testing shall be conducted after the concrete cures and grinding have been completed. Pavement profiles shall be taken at the traffic wheelpaths (3 ft [0.9 m] from and parallel to each edge of pavement placed at 12-ft [3.66 m] width, or less). When pavement is placed at a greater width than 12 ft (3.7 m), the profile will be taken 3 ft (0.9 m) from and parallel to each edge and each side of the planned longitudinal joint. When the pavement being constructed is contiguous with an existing parallel pavement that was not constructed as a part of this contract, the profile parallel with the edge of pavement contiguous with the existing pavement shall not be taken. The profile shall be started and terminated 15 ft (4.8 m) from each bridge approach or existing pavement that is being joined.

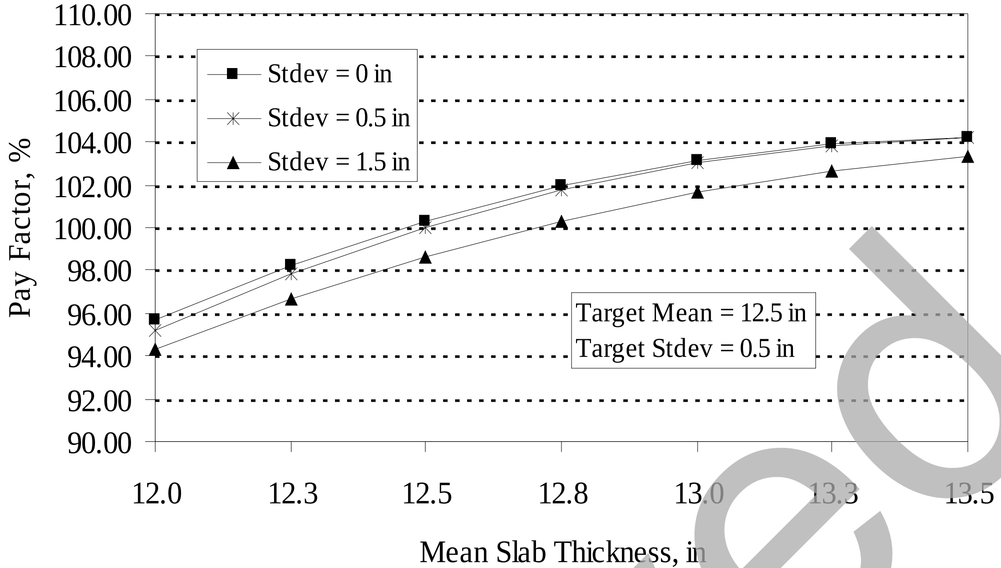
DEVELOPMENT OF PAY FACTORS FOR THE SR 9A PROJECT

Using the PaveSpec 3.0 software program and the various inputs discussed throughout this chapter, a set of concrete thickness, strength, and smoothness pay factors were developed for use in the SR 9A project. These resultant pay factors for slab thickness are shown in table 10. These factors are also illustrated in figure 8. The lowest noted pay factor is 93.67 percent for the RQL (12.0 in. [304.8 mm]) with a high lot standard deviation (2.0 in. [51.8 mm]). When the mean slab thickness reaches the MQL of 13.5 in. (342.9 mm), with an ideal standard deviation of 0.0 in., the pay factor is 104.26 percent. For the target standard deviation, the pay factor between the RQL and the MQL varies 9.09 percent. There is little increase in pay factor for variability less than the target value. Pay factors for standard deviations below the target value decrease at about twice the rate of pay factor increases for standard deviations above the target. The slab thickness pay factor curves are fairly flat due to the conservative design of 12.5 in. (317.5 mm) resulting from the AASHTO design procedures.

Table 10. Slab Thickness Pay Adjustment Table (% Pay Factor)

Lot Mean Slab Thickness, in.	**Lot Standard Deviation (computed from independent cores), in.**				
	0.0	**0.5[a]**	**1.0**	**1.5**	**2.0**
12.00	95.67	95.15	94.58	94.30	93.67
12.25	98.19	97.80	97.20	96.63	95.84
12.50[b]	100.27	100.00	99.39	98.63	97.74
12.75	101.92	101.74	101.15	100.30	99.38
13.00	103.13	103.03	102.49	101.64	100.75
13.25	103.91	103.87	103.41	102.65	101.86
13.50	104.26	104.24	103.89	103.33	102.70

[a] Target standard deviation. [b] Target mean.
1 in. = 25.4 mm



1 in. = 25.4 mm

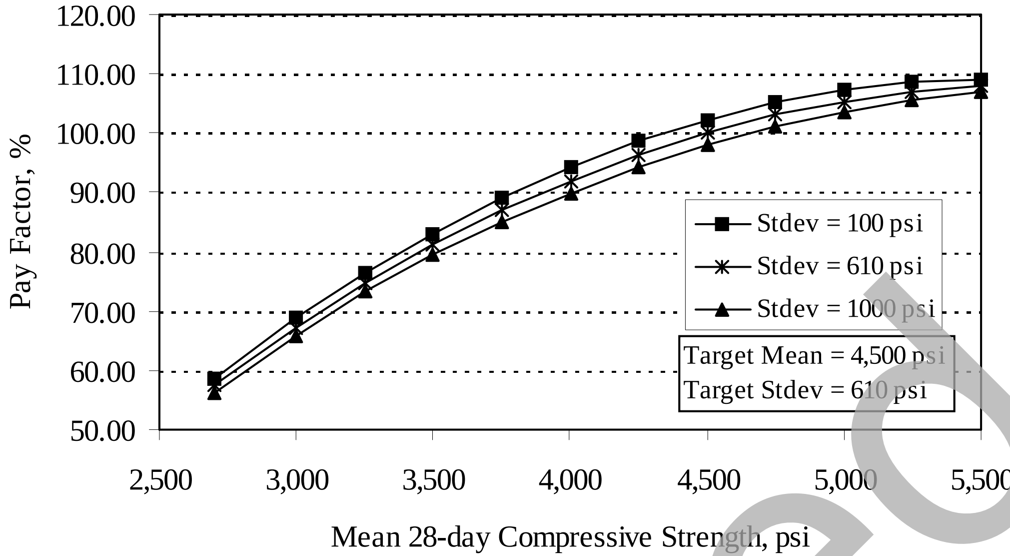
Figure 8. Slab thickness pay adjustment curves.

Pay factors for strength are shown in table 11 and figure 9. Obviously, PCC strength plays an important part in long-term pavement performance, particularly on the low side of the target. As a result, the pay factors at the RQL and MQL with target standard deviations range 50.7 percent, from 57.4 to 108.1 percent. For each incremental change in standard deviation from the target value, the pay factor changes about two times as fast for higher standard deviations compared with lower standard deviations.

Table 11. 28-Day Compressive Strength Pay Adjustment Table (% pay factor)

Lot Mean Strength, lbf/in²	**Lot Standard Deviation (computed using means of 2 cylinders), lbf/in²**					
	100	**325**	**550**	**610[a]**	**775**	**1,000**
2,700	58.63	58.13	57.55	57.40	57.05	56.27
3,000	68.72	68.13	67.44	67.27	66.86	65.94
3,250	76.26	75.61	74.84	74.65	74.20	73.18
3,500	83.03	82.32	81.49	81.27	80.78	79.67
3,750	89.01	88.19	87.20	86.95	86.32	85.09
4,000	94.22	93.33	92.24	91.97	91.23	89.93
4,250	98.65	97.73	96.60	96.32	95.53	94.21
4,500[b]	102.31	101.40	100.28	100.00	99.20	97.91
4,750	105.18	104.33	103.29	103.02	102.25	101.05
5,000	107.28	106.53	105.61	105.38	104.67	103.62
5,250	108.59	108.00	107.27	107.08	106.48	105.62
5,500	109.13	108.73	108.24	108.11	107.67	107.04

[a] Target standard deviation. [b] Target mean.
1 lbf/in² = 6.89 kPa



1 psi = 6.89 kPa

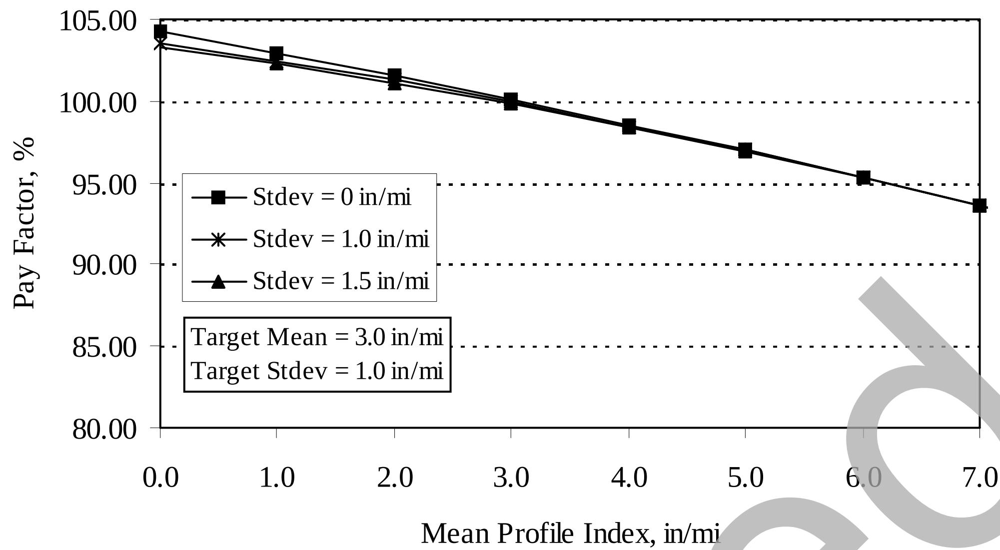
Figure 9. 28-day compressive strength pay adjustment curves.

Computed surface smoothness PI pay factors are shown in table 12 and figure 10. The range of pay factors between the RQL and the MQL for the target standard deviation is 9.89 percent (93.59 to 103.48). Variability within the range of 0 to 3 in./mi (0 to 47 mm/km) has greater effect on the pay factors. These curves were developed with 5 percent user costs. If a greater amount had been used, the curves would have been steeper.

Table 12. Surface Smoothness Pay Adjustment Table (% pay factor)

Lot Mean $PI_{0.2\text{-in}}$, in/mi	**Lot Standard Deviation (computed using means of 2 wheelpaths), in./mi**					
	0.0	**0.75**	**1.0[a]**	**1.5**	**2.25**	**3.0**
0.0	104.21	103.61	103.48	103.31	103.20	102.70
1.0	102.91	102.42	102.45	102.25	102.11	101.74
2.0	101.53	101.14	101.28	101.08	100.92	100.66
3.0[b]	100.08	100.08	100.00	99.79	99.63	99.47
4.0	98.56	98.35	98.35	98.35	98.25	98.16
5.0	97.04	97.04	97.04	96.90	96.78	96.74
6.0	95.38	95.38	95.38	95.29	95.21	95.20
7.0	93.59	93.59	93.59	93.57	93.54	93.54

[a] Target standard deviation. [b] Target mean.
1 in./mi = 16 mm/km



1 in./mi = 16 mm/km

Figure 10. Surface smoothness pay adjustment curves.

CHAPTER 4—IMPLEMENTATION OF THE PERFORMANCE-RELATED SPECIFICATION

PRE-BID CONSTRUCTION MEETING

A mandatory pre-bid conference was held in Jacksonville on July 19, 2001, for the SR 9A interchange to US 1 (project 209600-1-52-01) and the I-295 / SR 9A / I-95 interchange (project 213290-1-52-01). Attendees included representatives of 41 companies. Information about the letting date (August 29, 2001), the end date (February 2005), and incentives for early completion was provided. During the concrete pavement discussions, Tim Ruelke, district materials engineer, discussed the section 400-15.2.5.4 smoothness evaluation of bridges greater than 300 ft (91.4 m) and requirement for full grinding of the concrete pavement surfaces. Next, he presented the plans for implementing PRS on portions of the project. Mike Darter of ARA, Inc., presented the key aspects of PRS; testing methods; target values for strength, thickness, and smoothness; pay factor curves; probabilities for pay increases; and several case studies. The possibility of extra testing on the PRS site using the FHWA mobile concrete laboratory was also discussed.

PRE-CONSTRUCTION MEETING

The SR 9A project was let on September 26, 2001, and awarded in October 2001 to AMEC Civil, LLC, who held a subcontract with McCarthy Improvement to complete the concrete paving. On June 12, 2003, a pre-construction meeting was held in the project field office in Jacksonville with representatives from FDOT, FHWA, AMEC (prime contractor), McCarthy Improvement (paving subcontractor), JEAces (construction inspection), TARMAC (cement supplier), PTGcsc (field inspection), the University of North Florida, and ERES Consultants. Nasir Gharaibeh of ARA, Inc. presented a summary of the PRS methods planned for the SR 9A PRS pavement. This included the project layout, sampling and testing plans, target, rejectable, and maximum pay values for strength, smoothness, and thickness, and pay factor computation methods. FDOT also distributed the approved Technical Special Provisions for PRS for Rigid Pavements at the SR 9A site.

No significant problems or concerns were noted with the special provisions. The paving contractor was not concerned with meeting the post-grinding smoothness specifications. Because the lot and sublot definitions in the special provision precluded PI testing of areas less than 0.05 mi (264 linear ft [80.5 m]) in length, and the sublots west of the US 1 bridge did not meet the 0.05-mi (80.5 m) threshold, it was determined that the PI of these sublots would not be tested for the purpose of determining pay. The State materials office was asked to run PI tests for informational purposes only.

It was noted that specifications for grinding methods were not included in the special provision. Plans to begin paving in September 2003 were discussed, followed by a field tour of the PRS site.

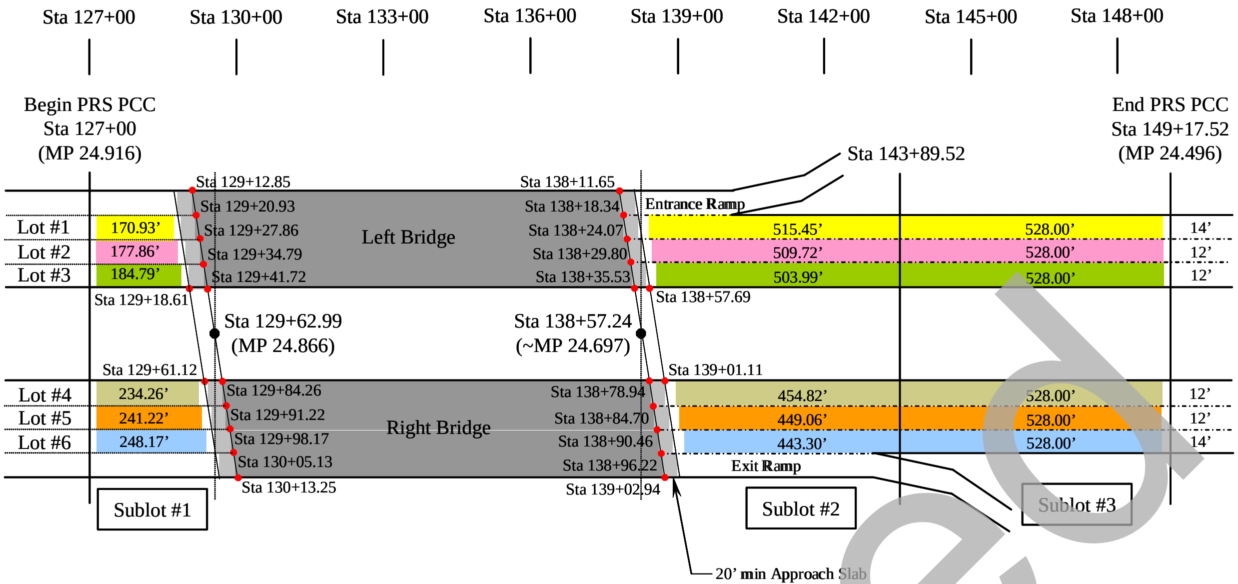
CONSTRUCTION

Construction of the base layer for the PRS project was completed in stages between December 2003 and June 2005. Paving of the PRS lots and sublots occurred between January 8, 2004, and April 29, 2004, for all but the sublot 1 sections of lots 1, 2, and 3. The inside lanes were paved together, and the widened outside lane was paved later. Grinding was also completed on the northbound sections in April 2004. The northbound lanes were opened to traffic on April 14, 2004, and southbound lanes were opened on July 17, 2005. Paving of sublot 1 of the southbound lanes was completed on June 6, 2005, with grinding conducted subsequently. Final lot and sublot layout, testing patterns, and paving operations are described below.

Layout of Lots and Sublots

An overview of the project site is shown in figure 11. Locations for the PRS lots and sublots remained as planned in the pre-construction meeting, according to the dimensions shown in figure 12. Each travel lane in the northbound and southbound directions was considered a lot, and the area on the east side of the bridge was divided into two approximately equal sublots. Paving lanes west of the bridge were also considered as single sublots. Note that on longer projects, all lanes included in the paving width are normally considered to be in the lot, reducing testing requirements.

Figure 11. Florida SR 9A performance-related specification project overview.



1 ft = 0.305 m

Figure 12. SR 9A lot and sublot layout for the performance-related specification project.

Paving Operations

Due to differing phasing demands, the northbound PRS sections were completed prior to the southbound lanes. Construction of the project in both directions included preparation of the embankment and base layers; placement of stringlines and dowel baskets; and concrete paving, finishing, curing, and surface grinding.

Embankment and Base Preparation

In the northbound lanes (sublot 1 of lots 4 and 5), the base surface grading was initially completed using a Topcon global positioning system (GPS) on the grader with two control stations. The accuracy of this system proved inadequate, and a third control station was used for final grading. No other problems were reported in the base surface preparation.

Stringline Placement

Nylon stringlines were installed using supports spaced at about 15 ft (4.8 m). The stringline supports were positioned and adjusted using a GPS receiver. Then the contractor used a stringline between the longitudinal stringlines to check the base for proper grade. Additional grading was required in sublot 1 of lot 5 prior to paving. The contractor placed stringline at the bridge to guide the paving train as it drove up onto the bridge surface.

Dowel Basket Placement

The contractor installed dowel baskets at the contraction joints and dowel baskets with expansion joint material on the sleeper slab near the bridge. These baskets were staked into the base material using steel stakes approximately 12 in. (300 mm) long. Wooden stakes were placed on both sides of the paving lane near the center of each dowel basket to assist in later sawing operations.

Paving

PCC paving was accomplished using a spreader with a side loader for the PCC mix and a slip-form paving machine, as shown in figure 13. The two inside lanes were paved in one pass, and the outside lanes were paved in an additional pass. The side-dump spreader had a wheel in the center to insert 0.5-in. (12.7 mm) tie bars in the longitudinal joint. Dowel basket areas were skipped during this insertion. On the side of the paving machine was a device that pushed bent tie bars into the edge of the pavement. A double layer of burlap was used behind the paver for initial texturing. No problems were reported with the nonagitating supply truck delays, possibly because of the short hauling distance.

Figure 13. Florida performance-related specification lots 4 and 5, sublot 1, paving.

Finishing and Curing

After about 30 minutes, the contractor used a separate device to apply a final burlap drag texture to the fresh concrete surface. That device also included a spray distribution system for evenly applying the curing compound.

Grinding

Grinding in the northbound lanes was completed by Diamond Surfaces using a Caterpillar 10-25 grinder. Southbound lanes were diamond ground by Central Atlantic Contracting using a Caterpillar 10-18 grinder. The specifications allowed for up to 30 percent unground dips, but the contractor left less than 3 percent of the surface unground.

SAMPLING AND TESTING

The general sampling and testing plan for the PRS lots is shown in figures 14 and 15. Two randomly selected 6-in. (150 mm) cylinders were filled from each sublot prior to placement for subsequent strength quality assurance testing. The engineer allowed sample collection to be done at the batch plant following mixing, because of the close proximity (approximately 4 minutes) of the plant to the construction site. Following grinding, profilograph measurements were collected in each wheelpath of each lane and approved with no subsequent grinding. Two core samples, 6 in. (150 mm) in diameter, of the P-501 surface were then collected from random locations in each sublot, 4 and 8 ft (1.2 and 2.4 m) from the adjacent joint. Results of this sampling and testing for strength, smoothness, and thickness are shown in tables 13, 14, and 15.

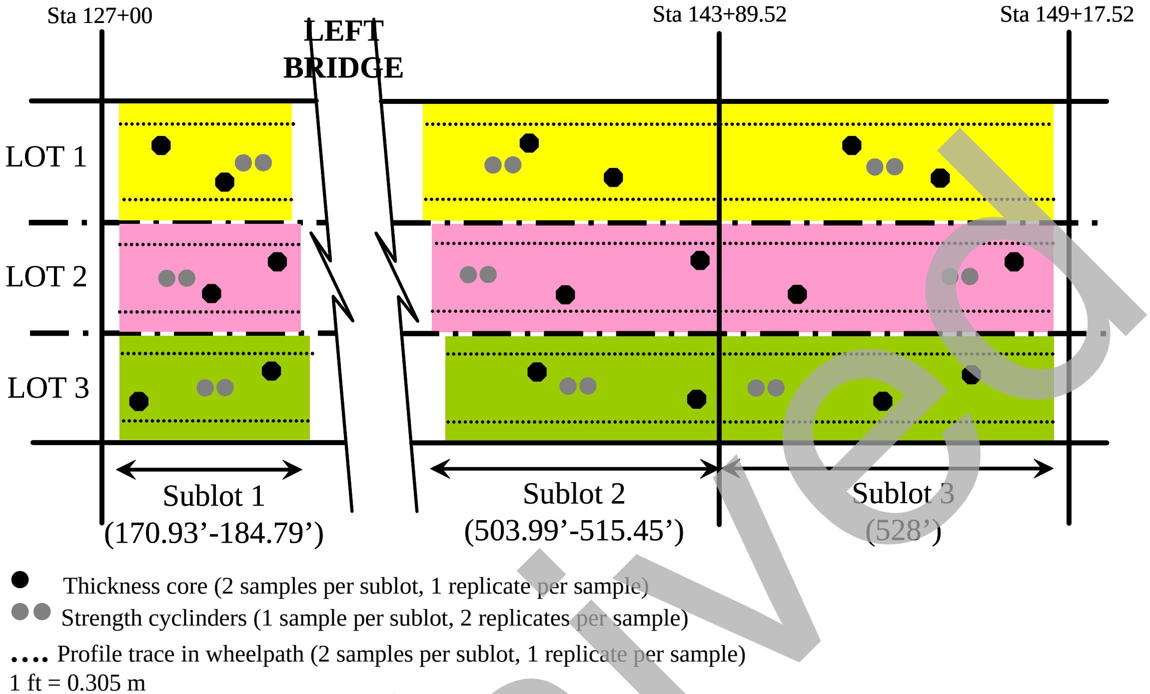


Figure 14. Southbound SR 9A sampling locations.

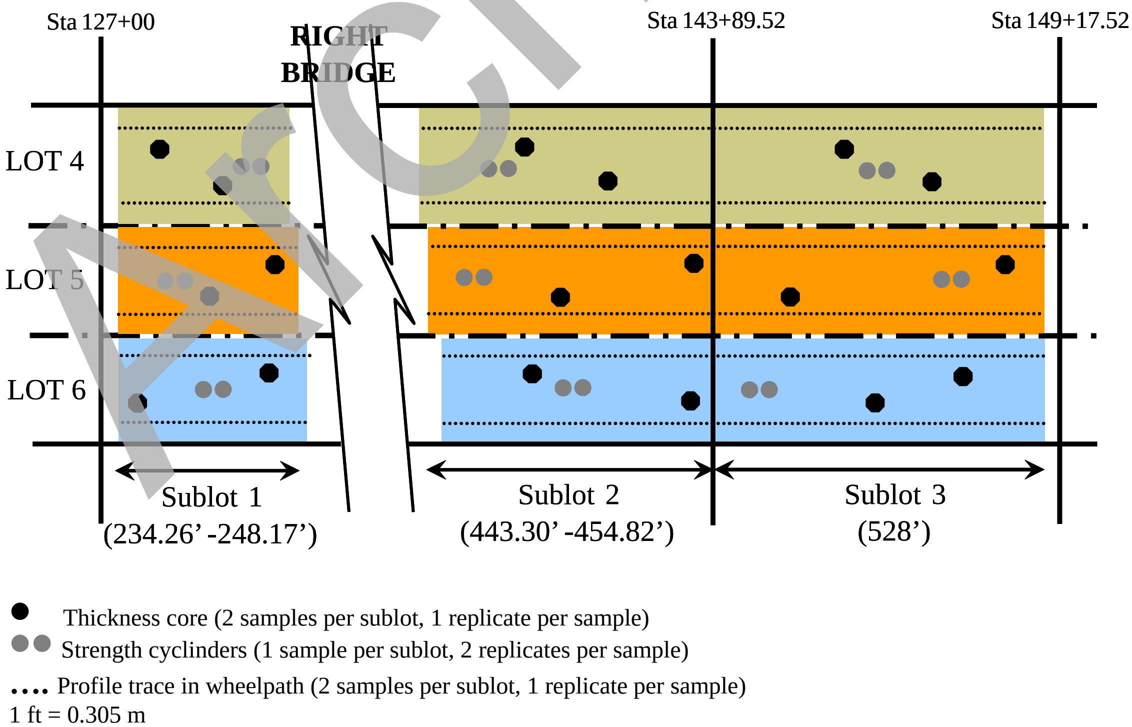


Figure 15. Northbound SR 9A sampling locations.

Average compressive strength results from all sublots except sublot 1 of lot 3 exceeded the target average 28-day compressive strength of 4,500 lbf/in^2 (31.0 MPa), as noted in table 13. Sublots 1 of lots 1 and 3 and sublot 2 of lot 5 were significantly lower than the averages of the other sublots. This is unusual because sublots 1 of lots 2 and 3 were reportedly paved simultaneously. No explanation was found for the lower values.

Average concrete pavement core thickness measurements, shown in table 14, were all at or above the 12.5-in. (320 mm) target average. Individual core thicknesses ranged from 12.0 to 14.6 in. (304.8 to 370.8 mm), with an average thickness of 13.3 in. (337.8 mm).

Smoothness measurement results, shown in table 15, indicate that the grinding contractor did an excellent job of achieving good surface smoothness. Sublot PI values ranged from 0 to 5.2 in./mi (0 to 81 mm/km). Sublots 1 of lots 1, 2, 3, and 4 were each less than 250 ft (76.2 m) long and were combined with respective sublots 2 for smoothness computations, as required by the PRS specification.

Table 13. SR 9A Performance-Related Specification Compressive Strength Testing Results

Lot	**Sublot**	**Sample No.**	**Placement Date**	**Compressive Strength, lbf/in^2**		
				Cylinder #1	**Cylinder #2**	**Average**
1	1	A1063	4/5/04	4,552	4,974	4,763
1	2	A1022	2/6/04	6,580	6,366	6,473
1	3	A1021	2/6/04	5,979	5,868	5,924
2	1	A1059	3/24/04	5,272	5,250	5,261
2	2	A1009	1/13/04	5,547	5,829	5,688
2	3	A1009	1/12/04	6,015	5,989	6,002
3	1	A1062	4/3/04	4,487	4,409	4,448
3	2	A1010	1/13/04	5,536	5,482	5,509
3	3	A1007	1/12/04	5,750	5,826	5,788
4	1	A1002	1/8/04	5,960	5,948	5,954
4	2	A1003	1/9/04	5,964	5,818	5,891
4	3	A1006	1/9/04	5,477	5,573	5,525
5	1	A1001	1/8/04	5,240	5,296	5,268
5	2	A1004	1/9/04	4,483	4,745	4,614
5	3	A1005	1/9/04	5,770	5,703	5,737
6	1	A1023	2/7/04	6,356	6,263	6,310
6	2	A1024	2/10/04	6,217	6,175	6,196
6	3	A1025	2/10/04	6,247	6,198	6,223

Note: Target average = 4,500 lbf/in^2 (31.0 MPa); target standard deviation = 610 lbf/in^2 (4,206 kPa); rejectable quality level = 2,700 lbf/in^2 (18.62 MPa); acceptance quality level = 5,500 lbf/in^2 (37.92 MPa).
1 lbf/in^2 = 6.89 kPa

Table 14. SR 9A Performance-Related Specification Thickness Testing Results

Lot	Sublot	Core Date	Station, ft		Thickness, in.		
			Core 1	Core 2	Core 1	Core 2	Average
1	1	3/30/04	127+40 L-3	128+61 L-3	13.8	13.0	13.4
1	2	3/30/04	142+00 L-3	142+56 L-3	12.9	12.3	12.6
1	3	3/30/04	145+11 L-3	148+22 L-3	12.6	12.6	12.6
2	1	3/30/04	128+01 L-2	128+05 L-2	13.5	14.5	14.0
2	2	3/30/04	139+41 L-2	143+80 L-2	13.3	13.5	13.4
2	3	3/30/04	144+12 L-2	149+00 L-2	13.1	14.3	13.7
3	1	3/30/04	127+25 L-1	129+00 L-1	13.7	12.7	13.2
3	2	3/30/04	139+25 L-1	143+80 L-1	13.1	13.2	13.2
3	3	3/30/04	145+00 L-1	148+85 L-1	13.3	14.6	14.0
4	1	3/30/04	128+00 R-1	128+99 R-1	12.9	12.0	12.5
4	2	3/30/04	141+21 R-1	142+00 R-1	13.2	13.1	13.2
4	3	3/30/04	145+11 R-1	147+00 R-1	12.5	13.4	13.0
5	1	3/30/04	128+89 R-2	129+49 R-2	13.2	13.2	13.2
5	2	3/30/04	141+75 R-2	143+80 R-2	13.5	13.7	13.6
5	3	3/30/04	144+13 R-2	148+91 R-2	13.4	13.5	13.5
6	1	3/30/04	127+13 R-3	129+54 R-3	12.8	13.8	13.3
6	2	3/30/04	141+60 R-3	143+82 R-3	13.7	13.0	13.4
6	3	3/30/04	145+22 R-3	147+36 R-3	13.3	13.0	13.2

Note: Target average = 12.5 in.; target standard deviation = 0.5 in.; rejectable quality level = 12 in.; acceptance quality level = 13.5 in.
1 ft = 0.305 m; 1 in. = 25.4 mm

Table 15. SR 9A Performance-Related Specification Smoothness Testing Results After Diamond Grinding

				Profile Index, in./mi		
Lot	**Sublot**	**Length, ft**	**Sample date**	**Right Wheelpath**	**Left Wheelpath**	**Average**
1	1, 2	695	5/9/05	0.99	0.00	0.50
1	3	528	5/9/05	5.20	2.30	3.75
2	1, 2	692	5/9/05	0.00	0.92	0.46
2	3	528	5/9/05	2.30	0.50	1.40
3	1, 2	690	5/9/05	1.38	1.15	1.25
3	3	528	5/9/05	0.60	0.00	0.30
4	1, 2	770	3/25/04	1.44	0.34	0.89
4	3	483	3/25/04	0.00	0.00	0.00
5	1	250	3/25/04	4.44	0.00	2.22
5	2	528	3/25/04	0.00	0.00	0.00
5	3	478	3/25/04	1.00	0.00	0.50
6	1	258	3/25/04	0.00	0.00	0.00
6	2	528	3/25/04	1.40	1.10	1.25
6	3	473	3/25/04	0.00	0.00	0.00

Note: Target average = 3.0 in./mi; target standard deviation = 1.0 in./mi;); rejectable quality level = 7.0 in./mi; acceptance quality level = 0 in./mi.
1 ft = 0.305 m; 1 in./mi = 16 mm/km

Average values for each field performance factor were computed for each as-constructed lot using the following method:

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad \text{Eq. 3}$$

where:

$\overline{X}$ = Mean of n random samples of the AQC under consideration for the lot.

X_i = Sample measurement (for smoothness and strength, X_i is a mean of multiple replicates, and for thickness the mean of all cores).

n = Sample size per lot, n for each AQC is as follows:
Strength: 1 sample per sublot (each is a mean of two cylinder measurements, or core measurements for partial lots).
Thickness: 2 samples (cores) per sublot.
Smoothness: number of required profile sections per lot (each is represented by the mean profile passes in the wheel paths)

Thickness, strength, and smoothness lot standard deviation was computed as follows:

$$s = \frac{\sqrt{\frac{\sum (X_i - \overline{X})^2}{(n-1)}}}{C_{SD}} \qquad \text{Eq. 4}$$

where:

C_{SD} = Correction factor (based on the total sample size, n) used to obtain unbiased estimate of the actual lot sample standard deviation. Appropriate C_{SD} values are determined using table 16.

Table 16. Correction Factors Used to Obtain Unbiased Estimates of the Lot Standard Deviation

No. of Samples, *n*	**Correction Factor, C_{SD}**
2	0.7979
3	0.8862
4	0.9213
5	0.9399
6	0.9515
7	0.9594
8	0.9650
9	0.9693
10	0.9726
30	0.9915

Results of the computations produced the summary of critical performance factors shown in table 17. These indicate that the lot compressive strength target AQL of 4,500 lbf/in^2 (31.03 MPa) was exceeded by all lots. The maximum lot standard deviation value was 372 lbf/in^2 (2,505 kPa), well below the target value of 610 lbf/in^2 (4,206 MPa). The range in standard deviations from 47 to 697 lbf/in^2 (0.32 to 4,806 MPa) indicates that the contractor is capable of significantly reducing the variability in strength properties.

All thickness lot averages exceeded the target value, with lot 2 exceeding the MQL of 13.5 in. (342.9 mm). The average lot thickness of 13.26 in. (336.8 mm) was well above the target level of 12.5 in. (317.5 mm). Variability (using standard deviation as a standard) within each lot ranged from 0.20 to 0.69 in. (5.1 to 17.5 mm), with the average lot standard deviation being exactly the target value of 0.5 in. (12.7 mm).

The average lot smoothness for the PRS sections was 0.96 in./mi (15 mm/km), well below the target of 3.00 in./mi (48 mm/km). Variability in smoothness levels was lower than the target 1.00 in./mi (16 mm/km), achieving an average lot standard deviation of 0.86 in./mi (14 mm/km).

Table 17. Performance-Related Specification Lot Quality Results

Lot No.	Strength, lbf/in^2		Thickness, in.		$PI_{0.2\text{-}in}$, in./mi	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	5,720	697	12.87	0.55	2.12	2.04
2	5,650	297	13.70	0.59	0.93	0.59
3	5,248	564	13.43	0.69	0.78	0.60
4	5,790	175	12.85	0.54	0.59	0.41
5	5,206	450	13.42	0.20	0.91	0.93
6	6,242	47	13.27	0.43	0.42	0.58
Average	5,642	372	13.26	0.50	0.96	0.86

1 lbf/in^2 = 6.89 kPa; 1 in. = 25.4 mm; 1 in./mi = 16 mm/km

COMPUTATION OF PAY FACTORS

Using the average lot performance information from table 17, pay factors for each lot were determined using the spreadsheet shown in figure 16 following the methods provided in the supplemental specification in appendix B. This method required that the lot composite (overall) pay factor be computed as follows:

$$PF_{composite} = (PF_{smoothness} * PF_{strength} * PF_{thickness}) / 10{,}000 \qquad \text{Eq. 5}$$

where:

$PF_{composite}$ = Composite (overall) pay factor, percent (with maximum set at 110 percent).
$PF_{strength}$ = Strength pay factor (obtain from table 10), percent.
$PF_{thickness}$ = Slab thickness pay factor (obtain from table 11), percent.
$PF_{smoothness}$ = Initial smoothness pay factor (obtain from table 12), percent.

The actual pay adjustment for the as-constructed lot was computed using the lot composite pay factor as follows:

$$PAYADJ_{Lot} = BID * AREA_{Lot} * (PF_{composite} - 100) / 100 \qquad \text{Eq. 6}$$

where:

$PAYADJ_{Lot}$ = Pay increase (+) or decrease (-), \$.
BID = Contractor bid price for pay item 350-1-19, $\$/yd^2$.
$AREA_{Lot}$ = Measured actual area of the as-constructed lot, yd^2.
$PF_{composite}$ = Composite pay factor (from equation 5), percent (e.g., 101 percent is expressed as 101.0).

$$PAY_{Lot} = BID * AREA_{Lot} + PAYADJ_{Lot} \qquad \text{Eq. 7}$$

where:

PAY_{Lot} = Adjusted payment for the as-constructed lot, \$.

Computed pay factors for strength, thickness, and smoothness are shown in table 18. Strength pay factors were exceptionally high, indicating the ease with which the contractor was able to achieve strengths greater than the AQL. This is not surprising because the average of the three projects evaluated in PRS preparation was 5,500 lbf/in^2 (37.92 MPa), much higher than the 4,500 lbf/in^2 (31.03 MPa) target. Thickness and smoothness pay factors were also higher than those associated with the target levels, providing incentives of about 3.5 and 2.5 percent, respectively. When the strength, thickness, and smoothness pay factors are multiplied together to determine the overall pay factor, the average incentive level is nearly 15 percent. However, the specification places an upper limit on incentives of 10 percent, so the overall project pay factor is held to 110 percent. These results indicate that all AQCs were achieved or exceeded in construction. Therefore, better than expected pavement performance should be anticipated.

Table 18. SR 9A Performance-Related Specification Computed and Maximum Pay Factors (PF)

Lot	**Strength PF**	**Thickness PF**	**Smoothness PF**	**Overall Project Unlimited PF**	**Overall Project Limited PF**
1	107.88	102.29	100.81	111.24	110.00
2	108.78	104.17	102.61	116.28	110.00
3	107.21	104	102.78	114.6	110.00
4	108.98	102.21	103.15	114.97	110.00
5	107.32	104.13	102.54	114.59	110.00
6	109.13	103.9	103.24	117.06	110.00
Avg.	108.22	103.45	102.52	114.79	110.00

LOT INFORMATION

Lot Number	5	Project No.	209600-1-52-01
Bid Price, $/sq yd	53	Begin Station	12700
Lot Length, feet	1218.28	End Station	14917.52
Lot Width, feet	12	Lane No.	R2
Resulting Lot Area, sq yds	**1624.37**	Paving Date(s)	1/8/04,1/9/04

THICKNESS

	Sublot 1	Sublot 2	Sublot 3
Thickness Core 1, in	13.2	13.5	13.4
Thickness Core 2, in	13.2	13.7	13.5
Sublot Thickness Mean, in	**13.2**	**13.6**	**13.45**

This is a full lot (3 sublots)

Resulting Samples per lot (n)	6
Lot Thickness Mean, in	13.42
Lot Thickness Mean Acceptable?	Yes
Notes on Lot Thickness Mean:	Lot mean thickness is between RQL and MQL.
Notes on Sublot Thickness Mean:	All sublots are at or above RQL
Std. Dev. Correction Factor	0.9515
Lot Thickness Std. Dev., in	0.20
Resulting Pay Factor:	**104.13%**

STRENGTH

	Sublot 1	Sublot 2	Sublot 3
Strength cylinder 1, psi	5,240	4,483	5,770
Strength cylinder 2, psi	5,296	4,745	5,703
Sublot Strength, psi	**5,268**	**4,614**	**5,737**

This is a full lot (3 sublots)

Resulting Samples per lot (n)	3
Lot Strength Mean, psi	5206.17
Lot Strength Mean Acceptable?	Yes
Notes on Lot Strength Mean:	Lot mean strength is between RQL and MQL.
Notes on Sublot Strength Mean:	All sublots are at or above RQL
Std. Dev. Correction Factor	0.8862
Lot Strength Std. Dev., psi	449.86
Resulting Pay Factor:	**107.32%**

SMOOTHNESS

	Sublot 1	Sublot 2	Sublot 3
PI for Pass 1, in/mi	4.44	0	1
PI for Pass 2, in/mi	0	0	0
Sublot Mean PI, in/mi	**2.22**	**0**	**0.5**

This is a full lot (3 sublots)

Resulting Samples per lot (n)	3
Lot Smoothness Mean, in/mi	0.91
Lot Smoothness Mean Acceptable?	Yes
Notes on Lot Smoothness Mean:	Lot mean smoothness is between RQL and MQL.
Notes on Sublot Smoothness Mean:	All sublots are at or below RQL.
Std. Dev. Correction Factor	0.8862
Lot Smoothness Std. Dev., in/mi	0.93
Resulting Pay Factor:	**102.54%**

Figure 16. Example pay factor computation worksheet.

CHAPTER 5—EVALUATION OF THE PERFORMANCE-RELATED SPECIFICATION

QUALITATIVE ASSESSMENT

The success and effectiveness of the PRS project was discussed with the contractor and the FDOT staff who participated in the PRS implementation. The discussion included questions assessing the functionality of the PRS, any related problems encountered in the process, and changes that were made in response to the PRS. Results of general questions indicate that the PRS documents were adequate, the PRS concept was desirable, and PRS implementation was not difficult.

Contractor Assessment

Interviews were completed with a representative of the paving contractor (McCarthy Improvement Company). The following comments and recommendations were received from the contractors.

Nick Wolf described the revised methods, advantages, and disadvantages of the PRS project in a recent article (Feingold, 2004): “We’re using a little more quality control and we were a lot more careful before starting. On this project we tried to exceed our normal high standards for workmanship. To do this took a little extra planning to make sure none of the little things were missed.” He indicated that the management staff met to specifically consider the PRS project and schedule prior to construction.

Wolf indicated some benefits and difficulties that the contractor experienced when following the PRS (Feingold, 2004). “It can be good for the contractor, because it allows the contractor to do whatever they want as long as they meet the specs provided. There’s no prescribed way on how to do things, so that can make getting started a little harder.” “They’re tough specs,” he said. “They strive for the best. To meet them, you have to do your best work. They don’t give you the leniency some other specs give you, but they provide you with a bonus for doing better work.”

Tony Dimaggio, Manager of Technical Services for Florida Businesses at concrete supplier Tarmac Titan America, described the concrete mix supplier’s perspective on the PRS project (Feingold, 2004):

> Instead of giving a spec saying “you’re going to put in this much cement and get this strength,” [FDOT] said, “What we really want is a smooth pavement and durability.” Our ready mix people put together a concrete mix that would meet the specs for minimum strength, but looked for something that was very workable for the smoothness they needed and the early strength they wanted on the job. We were really excited when we heard part of this job was a PRS, but the parameters they wanted resulted in a concrete mix that wasn’t that different from the rest of the job. A real performance-based specification would be when the owner says, “This is what I want and you figure out how to do it.” That gives the ready mix people and the contractors an opportunity to come up with a concrete that will work and save them some money.

Construction Management Assessment

Interviews were conducted and surveys were received from representatives of FDOT's consultant CEI team (PTGcsc/JEAces). Greg Graden of JEAces served as the roadway project engineer on the pavement construction. In an article in the June 2004 issue of *Florida Concrete*, Graden provided several comments regarding PRS (Feingold, 2004):

> The main objective of these PRS is to provide the agency with a methodology to assure that the design assumptions are being fulfilled, promote high quality construction, and to protect the agency from poor workmanship…. At the same time it allows the contractor the maximum freedom in deciding how to perform the construction. PRS provide rational methods for contract price adjustment based on the difference between the as-designed and as-constructed life-cycle costs of the pavement.

In the same article, Brett Pielstick, senior project engineer with PTGcsc, indicated, "It [PRS] does provide an opportunity for the contractor to be rewarded for doing good work or get penalties for poor workmanship or poor quality of material" (Feingold, 2004).

Graden and Ted Worthington (PTGcsc) agreed on the following conclusions and suggestions:

- The pay factor computation spreadsheet should be posted on the Web.
- Incentives may encourage the contractors to work harder at meeting critical quality levels.
- Contractors will likely focus on strength for the current specification because it is easy to achieve.
- They would like to see PRS implemented on a larger project with a different paving subcontractor to assess the sampling and testing plan and the contractor's responses. McCarthy Improvements is normally very conscientious and, therefore, little improvement was needed to meet the AQC levels.
- Presentations at the pre-bid and pre-construction meetings were helpful.
- The main problem encountered in administering PRS on this project was the period of elapsed time between paving and grinding of the various sublots—which postponed acquisition of the thickness and smoothness data—due to the need to coordinate these operations with operations on an adjacent, simultaneous project.

Florida Department of Transportation Assessment

FDOT engineers who had participated in the design and implementation of the PRS project responded as follows:

Bouzid Choubane, FDOT: "The results look promising. However, because of the project constraints, the performance data may be too limited to provide for enough quantitative information on conclusively assessing the subject PRS methodology. Further validation and refinement are needed on a larger scale."

Carrie A. Stanbridge, FDOT resident engineer / D2: "Glad to see the final product. It was also good to finally see the reason for the selection of the compressive strength target value."

Mike Bergin, FDOT:

> I suggest that a compressive strength window be required as opposed to a minimum required compressive strength. By this I mean that the contractor should be required to meet the compressive strength but not exceed it by too much. When the 28-day strength is substantially higher than the minimum required it normally means that the concrete was batched to produce a high early strength. The high early strength allows the contractor to get on the new concrete quickly but may result in shrinkage cracking which shortens the service life of the pavements. For instance, I suggest a target 28-day compressive strength of say 5,500 lbf/in^2 [37.92 MPa] (plus or minus 500 lbf/in^2 [3,447 kPa] at 28 days. If the contractor can control this, it will lower initial heat and provide a concrete with a slightly lower MOE [measure of effectiveness]. The combination of these will provide a more durable and longer lasting pavement.

QUANTITATIVE ASSESSMENT

Quantitative assessment of the effectiveness and usefulness of the PRS process can be accomplished by comparing the final PRS pay factors and payments against the factors that would have been implemented under the standard Florida DOT specification. In addition, the cost effectiveness of PRS specification can be summarized and compared against an independent analysis method.

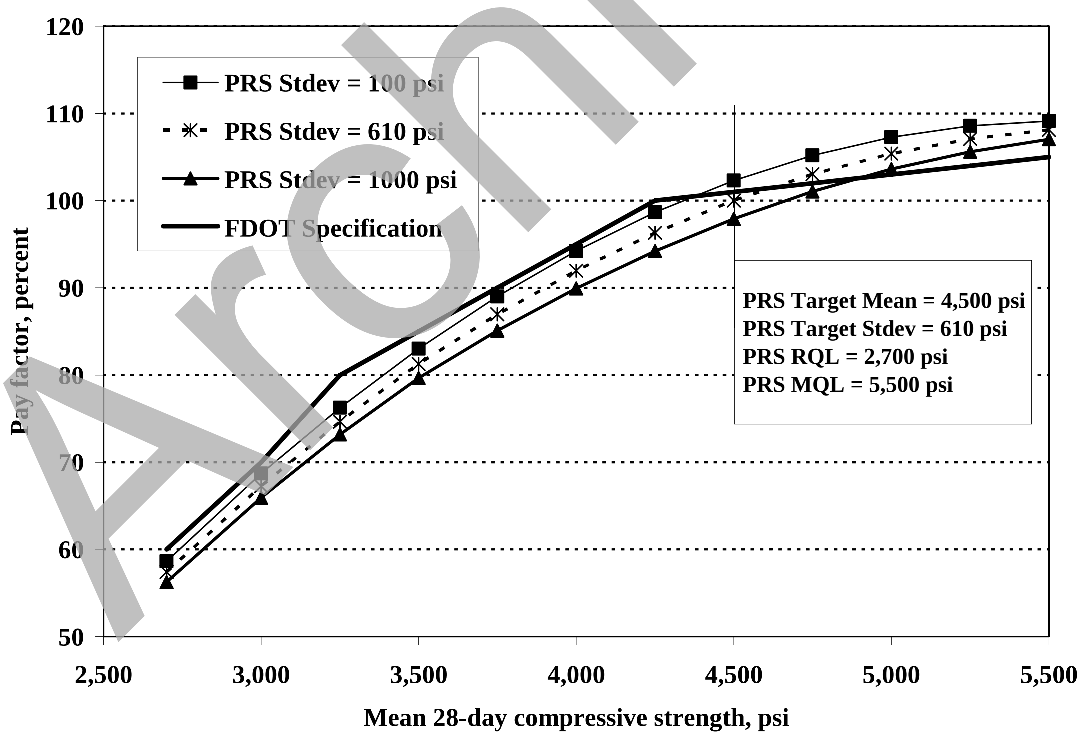
Comparison of Performance-Related Specification and Florida Department of Transportation Standard Specification Results

The quality levels used by the PRS and FDOT standard specifications are summarized in table 19. They include only slight differences in the specified quality requirements. Differences between the specifications are more evident in figures 17, 18, and 19, which summarize the pay factors associated with each specification. While the FDOT standard and PRS strength pay factors are similar, the FDOT thickness standard does not provide additional incentive for thicknesses above 12.8 in. (325.1 mm). FDOT smoothness pay factors are much more lenient with unground surfaces than the PRS pay factors that are based on fully ground surface measurements.

Table 19. Performance-Related Specification (PRS) and Florida Department of Transportation (FDOT) Standard Method Specification Quality Requirements

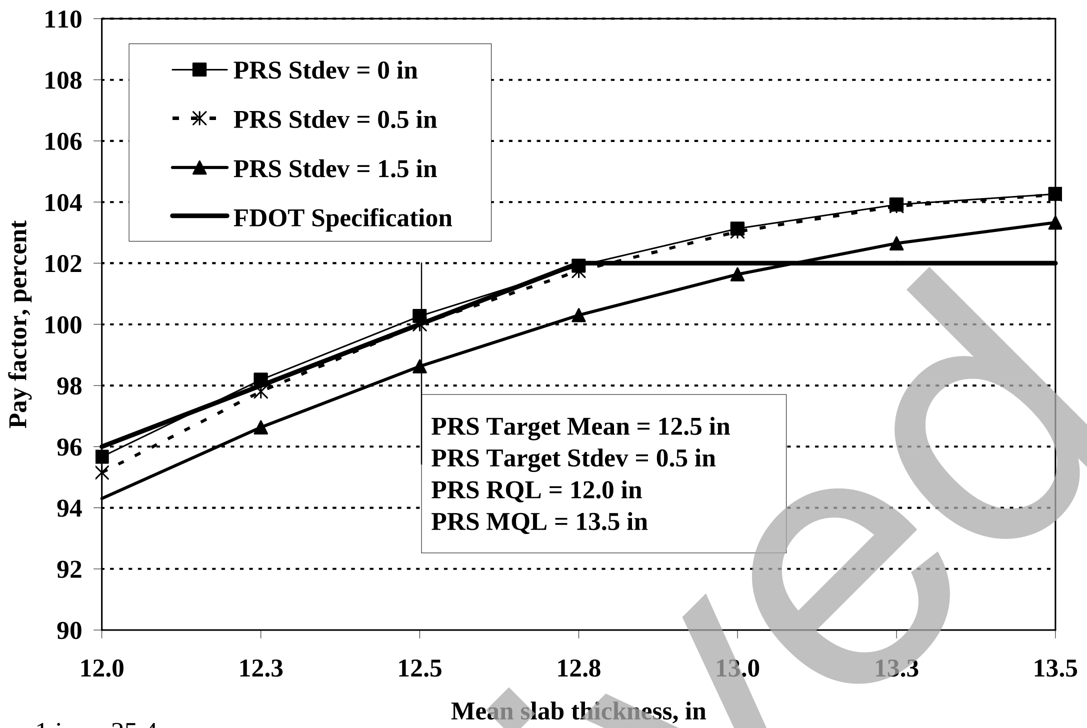
Factor	Detail	PRS	FDOT Standard
Strength	*Test methods*	*ASTM C-31, C-39*	*ASTM C-31, C-39*
	Lot AQC mean (std. dev.), lbf/in^2	4,500 (610)	4,510
	Lot RQL, lbf/in^2	2,700	2,700
	Lot MQL, lbf/in^2	5,500	N/A
Thickness	*Test methods*		
	Lot AQC mean (std. dev.), in.	12.5 (0.5)	12.5
	Lot RQL, in.	12.0	12.0
	Lot MQL, in.	13.5	12.75
Smoothness	*Test methods:*	*FM5-558E*	*FM5-558E*
	AQC mean (std. dev.), in./mi	3.0 (1.0)	3.5
	Lot RQL, in./mi	5.0	5.0
	Lot MQL, in./mi	0.0	2.0

AQC = acceptance quality characteristics; RQL = rejectable quality level; MQL = maximum quality level.
1 lbf/in^2 = 6.89 kPa; 1 in. = 25.4 mm; 1 in./mi = 16 mm/km



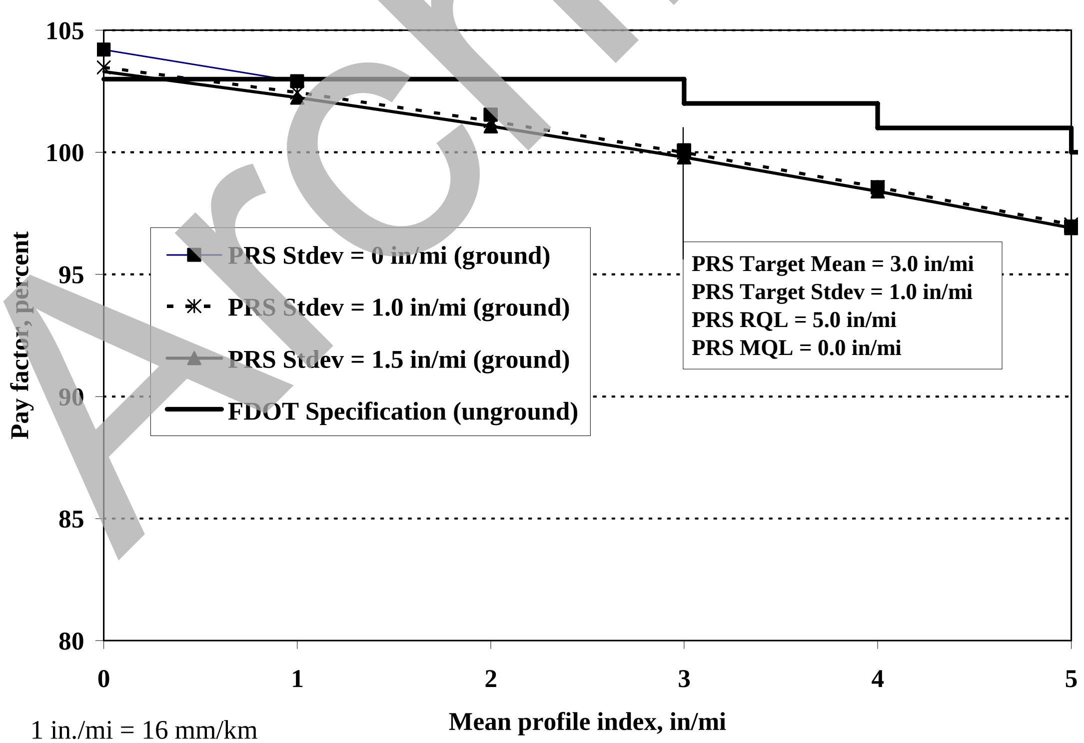
1 psi = 6.89 kPa

Figure 17. Comparison of strength pay factors for the performance-related specification (PRS) and the Florida Department of Transportation (FDOT) standard requirements.



1 in. = 25.4 mm

Figure 18. Comparison of thickness pay factors for performance-related specification (PRS) and the Florida Department of Transportation (FDOT) standard requirement.



1 in./mi = 16 mm/km

Figure 19. Comparison of smoothness pay factors for performance-related specification (PRS) and the Florida Department of Transportation (FDOT) standard requirement.

The FDOT contractor constructed the PRS sections with strength, thickness, and smoothness levels at a higher quality than the target values, as shown in table 20. Following the PRS specification, FDOT awarded an incentive for the PRS sections of 110 percent. This was based on the conclusion from the PRS models that the future LCC of the sections will be improved (reduced) by about 115 percent. Under the FDOT standard specifications, the incentive award for these sections would also have been 110 percent of the bid price.

Table 20. Target and As-Built, Project-Wide Acceptance Quality Characteristics Values

Acceptance Quality Characteristic	**Target**	**As-Built**
PCC compressive strength, lbf/in^2	4,500	5,642
PCC slab thickness, in.	12.5	13.3
Profile Index (California 0.2-in. blanking band), in./mi	3.0	1.0

PCC = portland cement concrete.
1 lbf/in^2 = 6.89 kPa; 1 in. = 25.4 mm; 1 in./mi = 16 mm/km

Closer inspection of the quality levels and pay factors provides additional information. For example, figure 20 shows the lot mean and standard deviation PCC strength range for each lot. The average strength of lot 1 is higher than that of lot 3, and their standard deviation levels are similar. Because of the higher strength, the pay factor for lot 1 is greater than that of lot 3. Variability also has an effect on pay factors, as can be seen by comparing the data from lots 1 and 4. The mean strength for these lots is very similar, but the standard deviation of lot 4 is about four times less than that of lot 1. This difference in variability resulted in the pay factor for lot 4 being about 1 percent greater than that for lot 1. Thus, both the mean and standard deviation of the AQC affect the incentive pay factors.

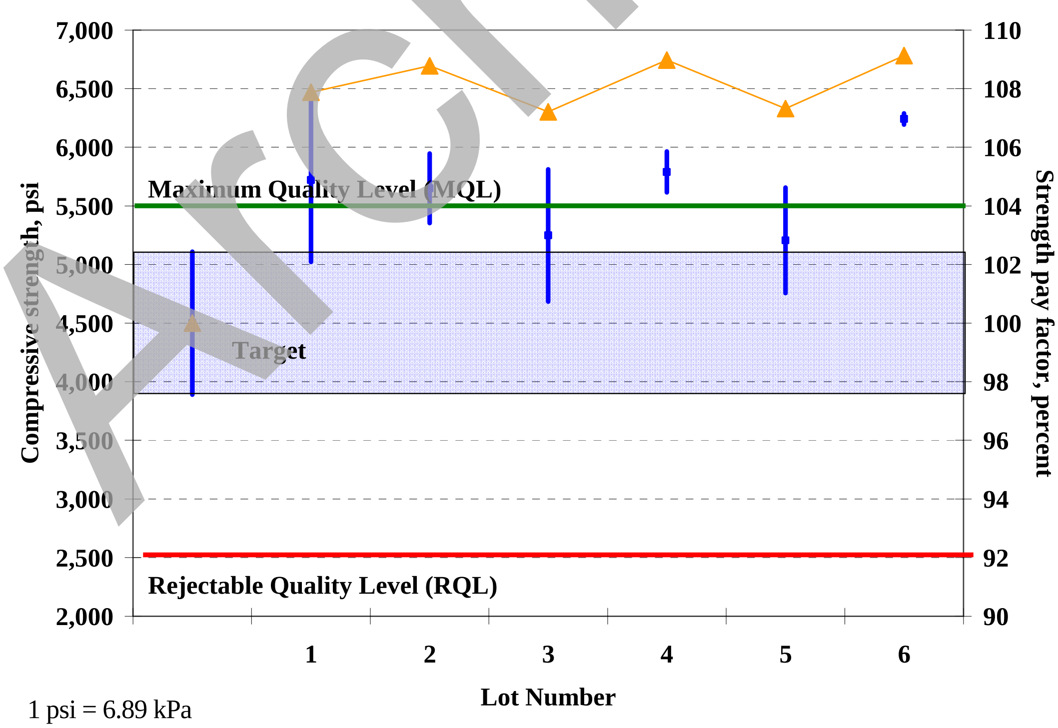
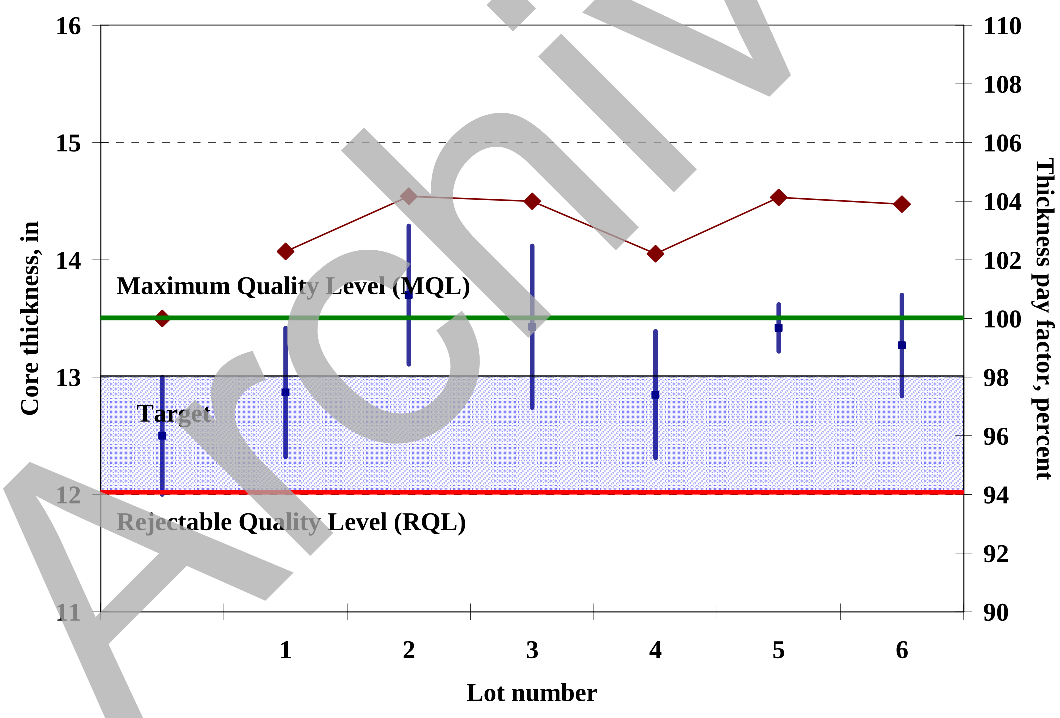


Figure 20. Comparison of performance-related specification strength results and pay factors by lot.

Similar observations from the PRS thickness data shown in figure 21 can be determined from the data for lots 1 and 2 (average value changes) and lots 3 and 5 (standard deviation changes). The effect of the reducing the standard deviation from 0.7 (lot 5) to 0.2 (lot 3) only increased the pay factor by 0.13. At these lower levels of variability, the effect of such changes is minimal. Figure 8 also helps to illustrate this effect.

Figure 22 shows the $PI_{0.2in}$ smoothness values and pay factors for each lot. The large effect of smoothness level on pay factor is evident, especially when comparing lot 1 with the other lots. Variability in lot smoothness data has only a small effect on pay factors, unless the standard deviation is closer to 0 in./mi.

High PCC strength levels played the largest role in increasing the overall pay factor levels, as shown in figure 23. With the exception of lot 1, which was low in all three AQCs, the unlimited overall pay factors were consistent. Because the average unlimited pay factor was 114.8 percent, this exceeded the specified 110 percent pay factor limit. Therefore, the improved pavement characteristics provided an estimated 14.8 percent improvement in LCC for which FDOT reimbursed the contractor with a 10 percent incentive bonus.



1 in. = 25.4 mm.

Figure 21. Comparison of performance-related specification thickness results and pay factors by lot.

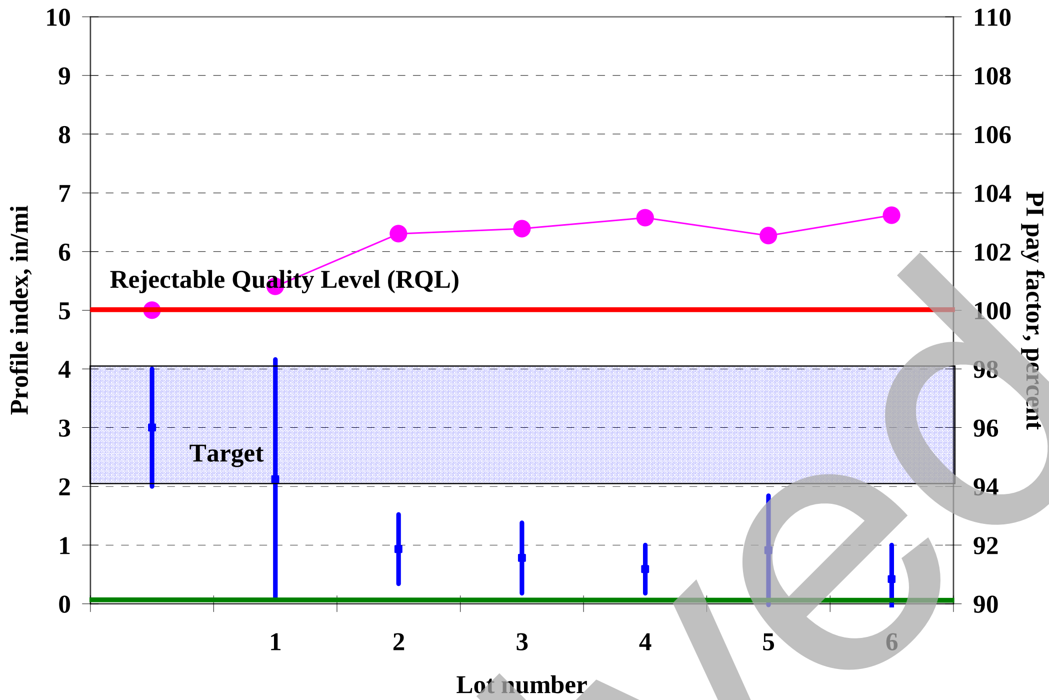


Figure 22. Comparison of performance-related specification smoothness results and pay factors by lot.

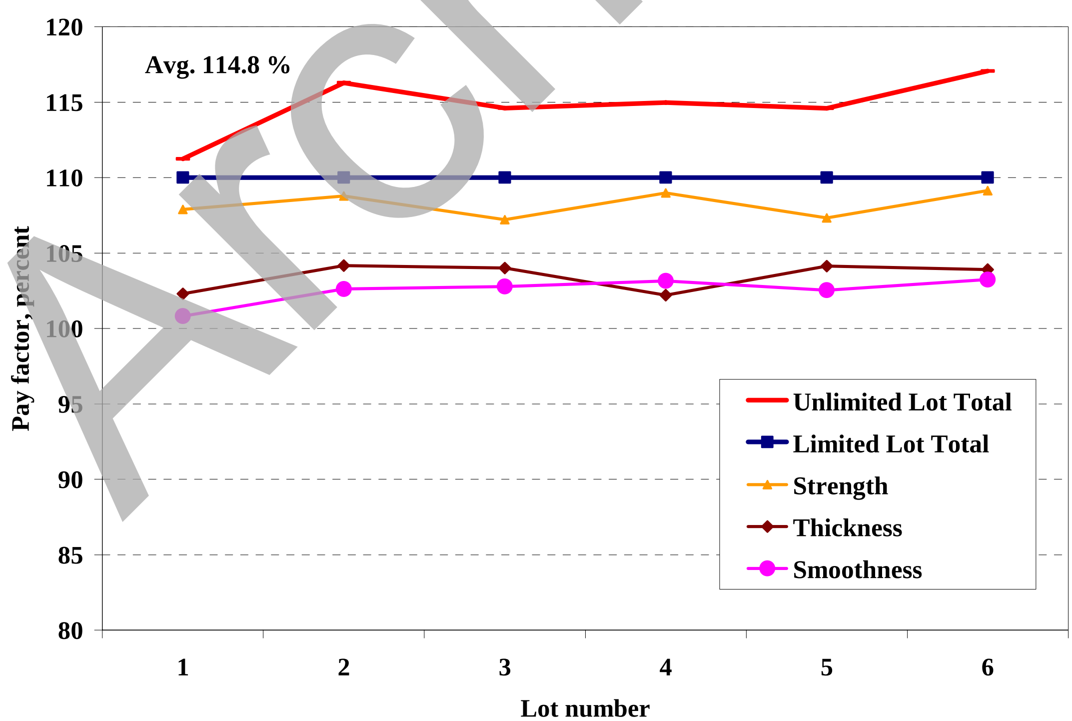


Figure 23. Summary of performance-related specification pay factor results by lot.

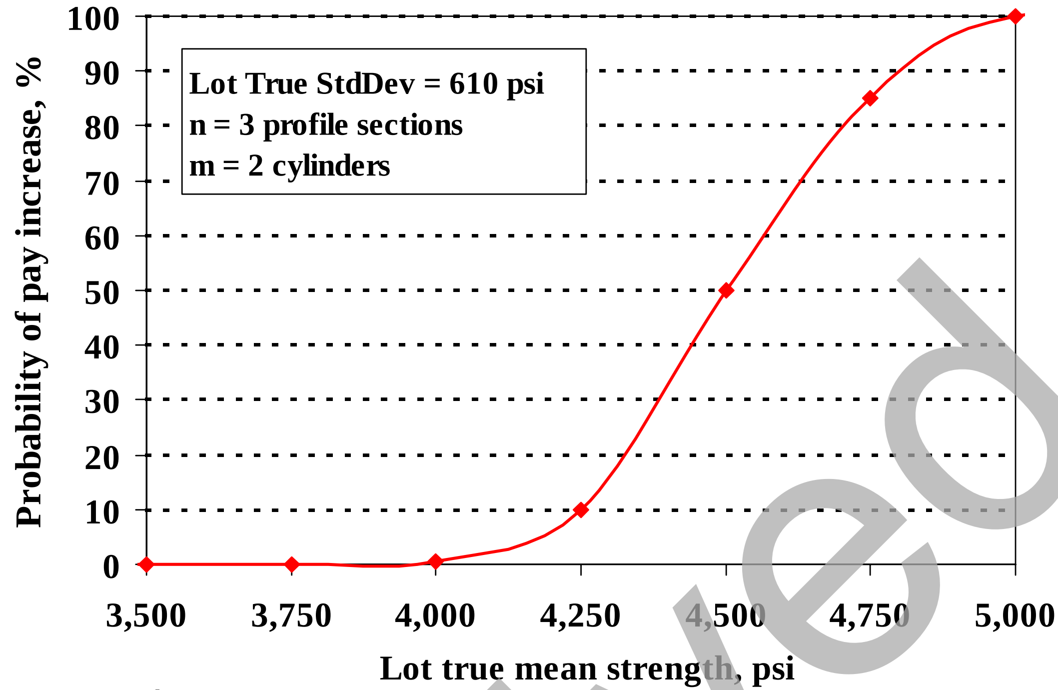
Independent Assessment of Effect on Pavement Life

An independent method was also used to compare the pavement life for both the target lot and the as-built lot AQCs. The NCHRP 1-37A mechanistic–empirical design and analysis software was used to predict the performance of the target (or as-designed) and the as-built JPCP (ARA, 2004). The distress and smoothness models in this software have been nationally calibrated under NCHRP 1-37A, which included several concrete pavement sections from Florida and should be reasonably applicable to the Jacksonville area. All inputs were held constant, while the three AQCs (thickness, smoothness, strength) were changed to the average achieved during construction, and the performance predictions of slab cracking, joint faulting, and IRI were estimated for the target and as-built pavement. Results indicated that the JPCP with target AQCs had a life of over 60 years due to the conservatism built into the project. The as-constructed pavement had an increased life of 16 percent. This independent method confirms that an increase in initial cost of 110 percent can be expected to achieve an approximate increase in pavement life of at least 16 percent.

RISK ANALYSIS

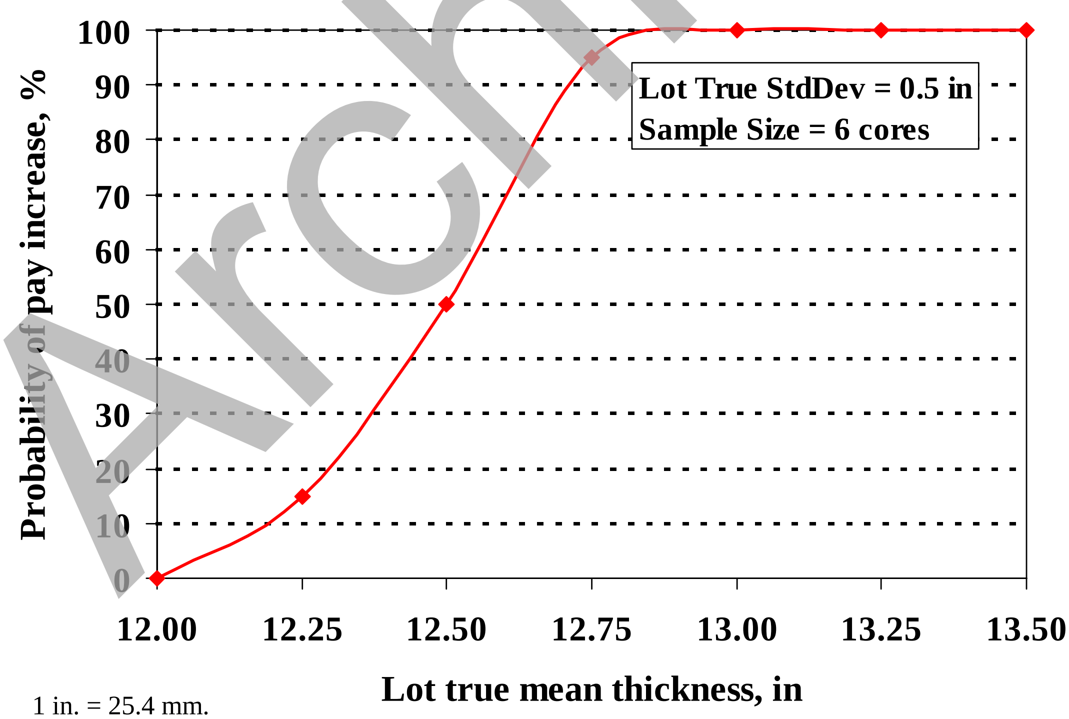
Information was developed that shows the risks of using the sampling and testing plan to both the agency and the contractor. The PaveSpec software provides expected pay charts that are graphical representations of an acceptance plan that show the relation between the actual quality of a given lot and the pay the contractor can expect to receive (on average) for submitted lots of that quality. Figures 24, 25, and 26 are provided in this section to show the expected pay for strength, thickness, and smoothness or PI, using the target standard deviations.

For example, the strength data in figure 24 provide useful information. If the contractor produces a lot with exactly the target mean strength of 4,500 lbf/in^2 (31.03 MPa) and standard deviation of 610 lbf/in^2 (4,206 kPa), the probability of acceptance with, say, 100 percent pay or better is 50 percent. If the contractor desires a higher probability to achieve an incentive, the mean strength of the lot could be increased to, say, 4,850 lbf/in^2 (33.44 MPa). The probability of acceptance with at least 100 percent is then 95 percent. Similarly, figure 25 indicates that the contractor must increase the mean concrete thickness to 12.75 in. (323.9 mm) to achieve a 95 percent probability of receiving a pay increase. Likewise, the contractor must achieve an average PI of about 2.5 in./mi (39.4 mm/km) to expect a pay increase with a 95 percent probability, as shown in figure 26.



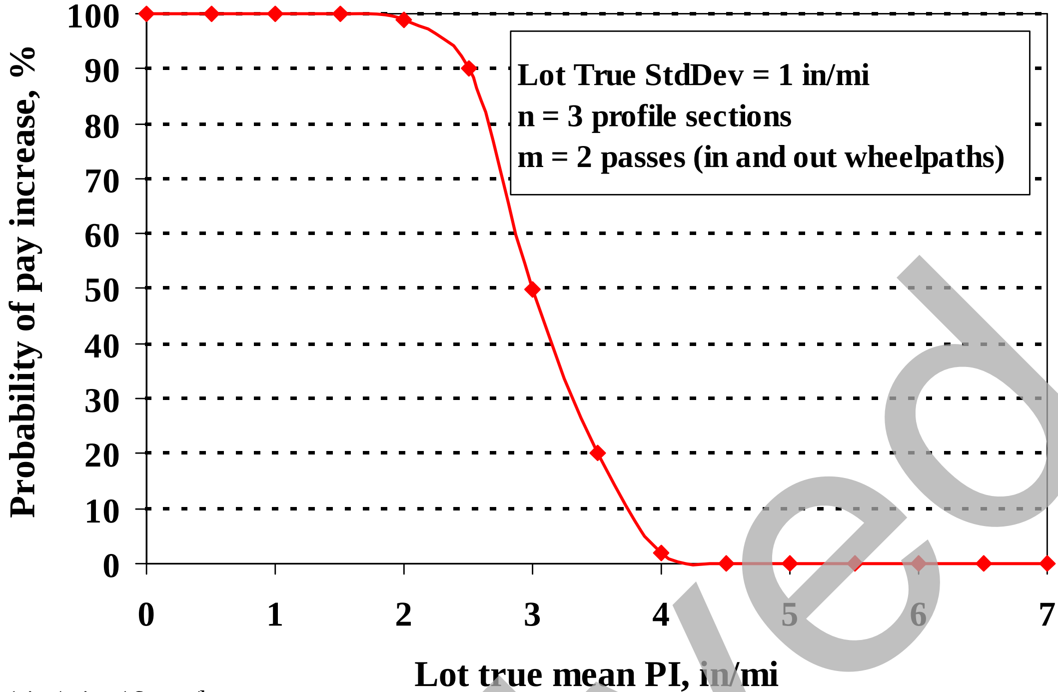
1 psi = 6.89 kPa.

Figure 24. Expected pay chart for compressive strength (standard deviation = 610 lbf/in^2).



1 in. = 25.4 mm.

Figure 25. Expected pay chart for slab thickness (standard deviation = 0.5 in.).



1 in./mi = 16 mm/km.

Figure 26. Expected pay chart for profile index (PI) (standard deviation = 1.0 in./mi).

The contractor also can affect the probability of receiving a pay increase by reducing or increasing the variability (standard deviation) of the quality levels in the project. For example, in figure 24, the contractor had a 50 percent probability of receiving incentive payments if the average slab thickness was 12.5 in. (317.5 mm) and the standard deviation was 0.5 in. (12.7 mm). If the contractor constructs a lot with the same average slab thickness and a standard deviation of 1.0 in. (25.4 mm), the probability of incentive award is reduced to 45 percent. Obviously many other statements could be created to analyze the risks using the acceptance plan. Also, changing the number of samples per sublot would change the slope of these curves, reducing the risk involved in sampling and testing.

On this project, the contractor chose to minimize the risk by constructing the pavement lots with properties near the maximum quality level and standard deviations below the target levels. This risk minimization also resulted in increased incentive pay for all lots and quality factors. It is not known how this strategy affected contractor profitability.

CHAPTER 6—SUMMARY AND RECOMMENDATIONS

SUMMARY

Implementation of a concrete pavement PRS on SR 9A (I-295 leg) in Jacksonville, Florida, was sponsored by the FHWA with full cooperation and significant assistance from the Florida DOT. This implementation provided FDOT and the pavement contracting industry with a better understanding of the methods, benefits, requirements, and results of PRS implementation.

Significant effort made by the FDOT staff, FDOT project managers, FHWA, and the researchers helped to define a reasonable specification that all parties understood and agreed upon. Three AQCs (PCC strength, PCC thickness, and surface smoothness) were selected for use in the PRS. Based on current FDOT specifications, evaluation of recent FDOT project data, and comments from the PRS implementation team, acceptance levels were selected, as shown in table 5. The team also collected and agreed upon the inputs for the PaveSpec 3.0 software that are shown in appendix A. This software was used to develop pay factor curves based on the life cycle costs of pavements with various strength, thickness, and smoothness properties. Following preparation of a practical field sampling plan, this information was compiled into the PRS shown in appendix A and provided to the contractors during bid letting.

Paving of the SR 9A PRS project was completed between January and April 2004. However, portions of the associated coring and smoothness measurements were not available until June 2005 due to delays in the surface grinding operations. Results of this field sampling and testing were compiled into pay factor computation spreadsheets for determining the final lot average and standard deviation values. Results of this testing and the associated pay factors are provided in chapter 4.

The average unlimited overall pay factor for the entire PRS project (all lots) was 114.8 percent. The contractor achieved incentive level properties in thickness, smoothness, and strength. Primarily, however, the very high strength levels controlled the overall pay factor for all lots. These levels in most lots exceeded the maximum quality limit of 5,500 lbf/in^2 (37.92 MPa), where the pay factor was capped. If the maximum quality level were not included, the overall pay factor would be nearly 115 percent. This means that, according to calibrated PRS performance models and expected costs, FDOT paid 10 percent in additional initial cost to receive an estimated 15 percent improvement (reduction) in future pavement life cycle cost.

This conclusion was verified independently using the new Mechanistic–Empirical Design Guide program that was developed under NCHRP 1-37A (ARA, 2004). This procedure predicts IRI, joint faulting, and slab cracking for jointed plain concrete pavements. The same inputs associated with the PRS target pavement were used in the software to predict the life of the pavement. Next, the as-built AQCs (strength, thickness, smoothness) of the pavement were input to determine their effect on predicted pavement life. The increased as-built pavement properties resulted in an expected increase of 16 percent in pavement life.

Surveys were distributed to the primary FDOT, contractor, and FHWA participants in the PRS implementation. Many useful comments and suggestions were received. Comments from all participants were very supportive of the PRS approach, as described in chapter 5.

RECOMMENDATIONS

Implementation of a PRS on SR 9A in Jacksonville, Florida went well, with many supportive comments from FDOT and the contractors. A few recommendations for future PRS activities can be gleaned from this implementation, as follows:

- Select the AQC target mean and standard deviations carefully. These levels must be representative of those expected by the agency for achieving 100 percent pay.
- Select the MQL carefully. The standard mix on the project regularly developed strengths greater than the MQL. As a result, it was not difficult for the contractor to meet or exceed the MQL on the PRS project.
- Consider the effect of pay factor limits on the contractor and the agency.
- Provide contractors with timely results and pay factors so that they can adjust their methods accordingly.
- Consider alternative methods for increasing sampling rate and reducing destructive testing. Particularly, thickness measurements could be increased and improved using a nondestructive method such as that used by the Wisconsin DOT.

BENEFITS OF PERFORMANCE-RELATED SPECIFICATION

The clear and rational approach of PRS, with well-defined target quality levels that are understandable to the contractor, are expected to lead to significantly improved highway construction quality, improved pavement performance, and a reduction in LCC. The full possibility of PRS may also offer the opportunity to optimize the design and construction process to provide acceptable performance for lower LCCs. Key benefits of PRS are listed below, some of which were demonstrated on this SR 9A project:

- Better linkage between design and construction.
- Higher quality pavements (through incentives). The overall unlimited pay factor was nearly 115 percent, which indicates a significantly higher quality level of construction. The true effect of lower variability (all AQCs had standard deviations at or below the target) may also have benefits that are not known at this time.
- Testing that focuses on key quality characteristics that relate to the pavement long-term performance. Any factor that is measured and paid by incentive will receive a lot of attention and focus on the project. Other AQCs such as dowel alignment, tie bar alignment, and consolidation around dowels would add to the comprehensiveness of a PRS project and avoid a disastrous situation where something (such as tie bar location) is not measured until well into the project only to discover it is out of specifications.
- Incentives and disincentives that are justified through reduction or increase in future LCC. They are not merely an opinion of the benefit of varying quality levels. The PaveSpec program calculated reasonable pay factors for SR 9A. An independent estimate of increased life of approximately 16 percent represents a very significant benefit to highway users.
- Specifications that give the contractors more responsibility and flexibility yet increased accountability may benefit both the contractor and owner. Additional full PRS projects are needed to prove this possibility.
- Allow contractors to be more innovative and more competitive.

- Both the contractor and State staff thought that PRS may lead to the elimination of contractors who are less oriented toward quality.
- PRS may provide a lower “fear factor” for contractors and less administrative complexity and work over the long term for the agency compared to warranty specifications.

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APPENDIX A—PAVESPEC INPUTS

Table A-1. Key Inputs to the PaveSpec 3.0 PRS Software

Input	Value	Source
Design		
Design Life	20 years	FL Design Manual
Pavement Type	JPC	Plans
Dowel Bar Diameter	1.25 in.	FL Design
Transverse Joint Spacing	16 ft	FL Design
PCC Modulus of Elasticity	4×10^6 lbf/in^2	FL Design Manual
Transverse Joint Sealant Type	Silicone	FDOT
Modulus of Subgrade Reaction (k-value)	200 lbf/in^2/in	FDOT
Water-Cement Ratio	0.42	FDOT's current specs: max w/c = 0.5
Percent Subgrade Material Passing #200	14% (Range: 1% to 56%)	FDOT
Base Permeability	Somewhat Permeable	FDOT
Base Thickness	48 in.	FDOT
Base Modulus of Elasticity	30,000 lbf/in^2	Project Team
PCC-Base Interface	Unbonded	Project Team
Base Erodibility Factor (1=ctb, 5=granular)	4	Project Team
Traffic		
Specify Traffic for Year:	1	Plans
ADT (both directions) in Traffic Year:	28,500	Plans
ESAL Growth Rate	2.4%	Plans
ESAL Growth Type	Compound	Project Team
Traffic Directional Factor	58%	Plans
Percent Trucks	14%	Plans
Percent Trucks in Outer Lane	65%	FL Des Manual
Average Truck Load Equivalency Factor	1.67 ESALs/truck	FL Des Manual
Climate		
Average Annual Freezing Index	0°F-days	DataPave
Average Annual Precipitation	51.2 in.	DataPave
Average Annual Air Freeze-Thaw Cycles	18	LTPP/RPPR data
Average Annual No. of Days > 90°F	57	DataPave
Climate Zone	Wet–Nonfreeze	DataPave
Unit Costs		
Transverse Joint Sealing	$1.20 per ft	Project Team
Longitudinal Joint Sealing	$1.00 per ft	Project Team

Input	Value	Source
Transverse Crack Sealing	$1.00 per ft	Project Team
Local, Full-depth Repairs of Transverse Joints	NA	NA
Local, Partial-depth Repairs of Transverse Joints	$50.00/yd^2	Project Team
Local, Full Slab Replacements	$137.76/yd^2	Florida Cost Data
Local, Partial Slab Replacements	N/A	N/A
Global, AC overlay	$11.00/yd^2	Project Team
Global, PCC overlay	N/A	N/A
Global, Diamond grinding	$3.01/yd^2	Florida Cost Data
User Cost, %	5%	Project Team
Basic Specification Information		
Project Name	9A (I-295)	Plans
Specification Level	Level 1 PRS only	Project Team
State	Florida	Plans
County	Duval	Plans
Project ID	209600-1-52-01	Plans
Traffic Direction	EB and WB	Plans
Dimensions and Lane Configuration		
Lane Configuration	Six, Divided	Plans
Lane 1 (outer) Width	14 ft	Plans
Lane 2 Width	12 ft	Plans
Lane 3 Width	12 ft	Plans
Shoulder Type	Tied PCC	Plans
Stress Load Transfer Efficiency	5%	Project Team
Inner Lane Cracking is X% of Outer Lane Cracking	10%	Project Team
Road Location	Urban	Plans
Starting Station	127+00	Plans
Ending Station	207+00 (Used 198+05.75)	Plans
Definition of Pavement Performance		
Predict Transverse Joint Faulting?	Yes	Project Team
Predict Transverse Joint Spalling?	Yes	Project Team
Predict Transverse Slab Cracking?	Yes	Project Team
Predict Decreasing Smoothness?	Yes	Project Team
Sample Concrete Strength for AQC?	Yes	Florida
Sample Slab Thickness for AQC?	Yes	Florida
Sample Air Content for AQC?	No	Florida
Sample Initial Smoothness for AQC?	Yes	Florida

Input	**Value**	**Source**
Sample Percent Consolidation Around Dowels for AQC?	No	Florida
AQC Sampling and Testing		
Strength, Sampling Method	Cylinders	Florida Existing Specifications
Strength, Timing of Cores	(N/A for Cylinders)	Florida Existing Specifications
Strength, Number of Samples Per Sublot	1	Florida Existing Specifications
Strength, Number of Replicates per Sample	2	Florida Existing Specifications
Strength, Target Timing of Testing	28 days	Florida Existing Specifications
Thickness, Sampling Method	Independent Cores	Florida Existing Specifications
Thickness, Timing of Samples	3 days	Project Team
Thickness, Number of Samples Per Sublot	2	Florida PRS
Thickness, Number of Replicates per Sample	1	Florida PRS
Initial Smoothness, Indicator	Profile Index (0.2-in. blanking band)	Florida Existing Specifications
Initial Smoothness, No. of Pass Locations Per Sublot	3	Florida PRS
Initial Smoothness, No. of Replicates Per Pass Location	2	Florida PRS
Initial Smoothness, Profilograph Reduction Method	Manual	Project Team
Consolidation, Timing of Samples	NA	NA
Consolidation, No. of Samples Per Sublot	NA	NA
Consolidation, No. of Replicates Per Sample	NA	NA
AQC As-Designed Target Value Definition		
Determine target LCC by	Estimate LCC through Simulation	Project Team
Concrete Strength, Sampling Method	Distribution	Project Team
Concrete Strength, Mean	4,500 lbf/in^2	Historic Data
Concrete Strength, Standard Deviation	610 lbf/in^2	Historic Data
Slab Thickness, Sampling Method	Distribution	Project Team
Slab Thickness, Mean	12.5 in.	Plans
Slab Thickness, Standard Deviation	0.5 in.	Historic Data
Initial Smoothness, Sampling Method	Distribution	Project Team
Initial Smoothness, Mean	3.0 in./mi	Florida Existing Specifications
Initial Smoothness, Standard Deviation	1.0 in./mi	Historic Data
% Consolidation Around Dowels, Sampling Method	NA	Not Applicable
% Consolidation Around Dowels, Mean	NA	Not Applicable

Input	Value	Source
% Consolidation Around Dowels, Standard Deviation	NA	Not Applicable
Simulation Control		
Number of Lots to Simulate at Each Factorial Point	1,500	Project Team
Minimum No. of Sublots per Lot to Simulate	3	Florida PRS
Maximum No. of Sublots per Lot to Simulate	3	Florida PRS
Average Bid Price	$30.00/yd^2	Estimated
Analysis Period	40 years	Project Team

Table A-2. Maintenance and Rehabilitation Strategy

Maintenance Plan Summary	
Transverse Joint Sealing	Seal 50% of transverse joints every 20 years.
Longitudinal Joint Sealing	Seal 50% of longitudinal joints every 20 years.
Transverse Crack Sealing	Seal 100% of transverse cracks every 20 years.
Localized Rehabilitation Plan Summary	
1. If lot average percent cracked slabs exceeds 10.00%, then apply full slab replacements to 100% of cracked slabs.	
2. If lot average percent spalled joints exceeds 10.00%, then apply partial-depth repairs to 100% of spalled joints.	
3. If cumulative percent cracked slabs exceeds 15.00%, then consider the sublot failed.	
4. If cumulative percent spalled joints exceeds 30.00%, then consider the sublot failed.	
5. If average transverse joint faulting exceeds 0.1000 in., then consider the sublot failed.	
6. If IRI exceeds 150 in/mi, then consider the sublot failed.	
7. If percent failed sublots exceeds 25%, then begin global rehab scenario 1 and STOP for this year.	
Global Rehabilitation Summary	
Prior to First Phase	Repair 100% of outstanding spalled joints with partial-depth repairs. Repair 100% of outstanding cracked slabs with full slab replacements.
Phase1	Diamond Grinding; Assumed Life; 10 years; Starting IRI: 60in/mi; Ending IRI: 150 in/mi.
Phase 2	AC Overlay; Assumed Life: 10 years; Starting IRI: 60in/mi; Ending IRI: 150 in/mi.
Phase 3	AC Overlay; Assumed Life: 10 years; Starting IRI: 60 in/mi: Ending IRI: 150 in/mi.
Phase 4	AC Overlay; Assumed Life: 10 years; Starting IRI: 60 in/mi; Ending IRI: 150 in/mi.

APPENDIX B—TECHNICAL SPECIAL PROVISIONS FOR PERFORMANCE-RELATED SPECIFICATIONS FOR RIGID PAVEMENT

(FINANCIAL PROJECT ID 209600-1-52-01—SR 9A, DUVAL CO.)

This Technical Special Provision applies to 12.5-in mainline pavement on FPID 209600-1-52-01, from Station 127+00 to Station 149+17.52, as shown on the plans.

1. INTRODUCTION

The Department will pilot a Performance-Related Specification for Portland cement concrete (PCC) pavement on this project. The Composite Pay Adjustment Factor is based on the difference between the estimated Life-Cycle Cost (LCC) of the as-designed pavement and the estimated LCC of the as-constructed pavement, as determined by the PaveSpec 3.0 software as defined in FHWA-RD-98-155, *Guide to Developing Performance-Related Specifications*. The Composite Pay Adjustment Factor will apply to pay item 350-1-19 (12.5-in mainline pavement only). The Composite Pay Adjustment Factor is based on the individual pay factors for the concrete strength, slab thickness, and initial smoothness. The minimum value of the Composite Pay Adjustment Factor shall be limited to 90 percent and the maximum value shall be limited to 110 percent.

2. BACKGROUND

The main objective of these performance-related specifications (PRS) is to provide the agency with a methodology to assure that the design assumptions are being fulfilled, promote high quality construction, and to protect the agency from poor workmanship. At the same time, it allows the contractor the maximum freedom in deciding how to perform the construction. PRS provide rational methods for contract price adjustment based on the difference between the as-designed and as-constructed life cycle costs of the pavements.

The proposed PRS were developed using Level 1 of the FHWA methodology, as defined in FHWA-RD-98-155, *Guide to Developing Performance-Related Specifications for PCC Pavements*, and implemented in the PaveSpec 3.0 software. PRS employ distress prediction models to relate the acceptance quality characteristics (AQCs) to future pavement performance and associated LCC. Figure 1 illustrates how the PRS methodology works. The FHWA website (www.tfhrc.gov/pavement/pccp/pavespec/pavespec.htm) provides additional information about PRS and the PaveSpec 3.0 software.

The pay adjustment factor (PF) is defined as the percentage of the bid price that the contractor is paid for the construction of a concrete pavement lot and is computed based on the difference between the as-constructed and as-designed LCC (in present-worth dollars) as follows:

$$PF^* = 100^*(BID + [LCC_{des} - LCC_{con}]) / BID \quad (1)$$

where:

BID = Contractor's bid price, $.
LCC_{des} = As-designed life cycle cost, $.
LCC_{con} = As-constructed life cycle cost, $.
* The pay adjustment factor (PF) will be applied to pay item 350-1-19 only.

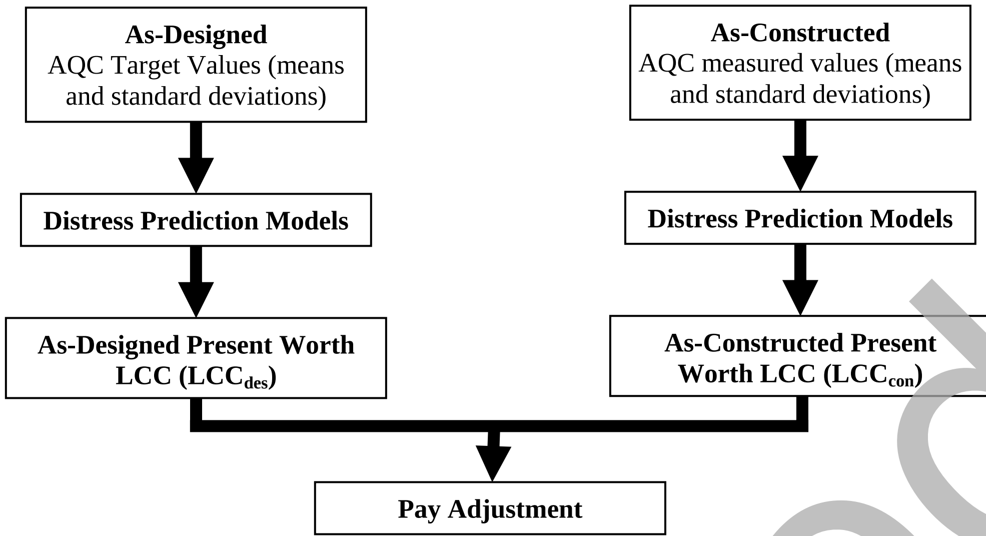

Figure 1. Basic concepts of LCC-based PRS.

The LCC is computed using prediction models for slab cracking, joint spalling, joint faulting, and pavement smoothness. A key aspect of using LCC to define the PFs is that the LCC of the as-constructed lot is the overall measure of quality, providing a rational way to develop an overall pay adjustment factor for the lot.

3. ACCEPTANCE QUALITY CHARACTERISTICS

Pay adjustment in these specifications is based on the following key quality characteristics only:

- Concrete strength.
- Slab thickness.
- Initial smoothness.

Several other quality characteristics (e.g., air content, slump, dowel placement, tie bar placement) are very important, but are not directly considered in these PRS. These quality characteristics and construction requirements are considered as described in FDOT's existing construction specifications. Also, contractors shall provide a concrete mix design according to FDOT's existing specifications.

3.1 Target Quality Levels

If the FDOT mean and standard deviation targets for each of the AQCs used for pay adjustment are met, the agency will pay 100 percent of the bid price. Table 1 shows target quality levels (mean and standard deviations) at which FDOT will pay 100 percent of the bid price.

Table 1. Lot AQC target mean and standard deviation.

AQC	Lot Target Values	
	Mean	**Standard Deviation**
Slab Thickness, in	12.5	0.5(1)
Concrete 28-day Compressive Strength, psi	4,500	610(2)
Initial Profile Index, in/mi	3.0	1.0(3)

(1) Thickness: mean and standard deviation computed from independent cores (2 cores per sublot)
(2) Strength: mean and standard deviation computed from averages of 2 cylinders per sublot
(3) Smoothness: mean and standard deviation computed from averages of inside and outside wheelpaths of the lane per lot

3.2 Rejectable Quality Levels

Rejectable quality level (RQL) is the level of quality below which (for thickness and strength) or above which (for smoothness) the pavement is deficient enough that a corrective action or "remove and replace" is warranted. Table 2 shows the RQLs (lot mean values) for each of the AQCs used for pay adjustment in these PRS.

If the quality of the as-constructed lot (as measured by the acceptance test results) of any of the AQCs is below the RQL, the Engineer will determine the appropriate corrective actions.

If the individual sublot value does not meet Table 2, the Engineer will determine the appropriate correction action or remove and replace. If the material is left in place, the pay factor will be based on the actual value and not the RQL.

Table 2. Lot AQC rejectable quality levels.

AQC	RQL (Lot Mean)
Slab Thickness, in	12.0
Concrete 28-day Compressive Strength, psi	2,700
Initial Profile Index, in/mi	Centerline radius ≥ 2000 ft: 5.0 Centerline radius < 2000 ft: 7.0

3.3 Maximum Quality Levels

Maximum quality level (MQL) is the level of quality at which the pavement is unnecessarily more conservative than the design so that no further pay increase will be applied. Table 3 shows the MQLs (lot mean values) for each of the AQCs used for pay adjustment in these PRS.

If the quality of the as-constructed lot (as measured by the acceptance test results) of *any* of the AQCs is higher (for thickness and strength) or lower (for smoothness) than the MQL, the pay factor at the MQL will be used for computing the composite PF and adjusting the payment. The actual values will be used to compute the standard deviation.

Table 3. Lot AQC maximum quality levels.

AQC	MQL (Lot Mean)
Slab Thickness, in	13.5
Concrete 28-day Compressive Strength, psi	5,500
Initial Profile Index, in/mi	0.0

3.4 Testing Methods

Table 4 shows the testing methods for slab thickness, concrete strength, and initial smoothness. The testing methods for these AQCs are discussed further in the following sections.

Table 4. Testing methods.

AQC	Test Method(1)
Slab Thickness, in	Cores (See below under "Slab Thickness")
Concrete 28-day Compressive Strength, psi	Cylinders (ASTM C-31 and C-39) Cores (ASTM C-42), for partial lots
Initial Profile Index, in/mi	Electronic Model of California Profilograph with 0.2-in blanking band (ASTM E-1274)

(1) All AQCs must be measured within the same sublot limits.

3.4.1 Concrete Strength

The required strength cylinders shall be cast from a randomly selected truck within the sublot. The cylindrical specimens shall be molded and cured in accordance with ASTM C-31 and tested in accordance with ASTM C-39 standard test methods.

3.4.2 Slab Thickness

The thickness of cores will be used for determining slab thickness. The thickness core borings shall be taken from randomly selected locations within the sublot. If corrective work that may affect thickness (such as grinding to meet the ride requirements) is performed, the thickness core borings shall be taken after the completion of these actions.

The core shall be a minimum of 4 in in diameter. The slab thickness at a cored location shall be recorded to the nearest 0.1 in, as the average of three caliper measurements of the core length. The three measurements shall be obtained and marked at locations spaced at approximately equal distances around the circumference of the core.

3.4.3 Initial Smoothness

The pavement surface smoothness shall be tested using an electronic model of the California Profilograph with 0.2-in blanking band. The smoothness testing shall be conducted after the concrete cures and all curing materials (except for the impervious coating) are removed.

Pavement profiles shall be taken at the traffic wheelpaths (3 ft from and parallel to each edge of pavement placed at 12 ft width, or less) after all grinding operations have been completed. When pavement is placed at a greater width than 12 ft, the profile will be taken 3 ft from and parallel to each edge and each side of the planned longitudinal joint. When the pavement being constructed is contiguous with an existing parallel pavement that was not constructed as a part of this contract, the profile parallel with the edge of pavement contiguous with the existing pavement shall not be taken. In this case, the sublot shall be represented by one profile. The profile shall be started and terminated 15 ft from each bridge approach or existing pavement that is being joined.

4. SPECIFICATION CHANGES

The provisions of Sections 346, 350, and 352 as it relates to the construction and acceptance of the 12.5-in concrete pavement are modified as follows:

Sub-article 350-3.13 (page 354) is deleted.

Sub-article 350-12.1 (page 358) is deleted and replaced with the following:

> 350-12.1 Finishing: As the water sheen disappears from the surface of the pavement and just before the concrete achieves its initial set, drag a seamless length of damp burlap that extends the full width of the strip of constructed pavement, longitudinally along the surface to produce a uniform gritty texture.
>
> Use a burlap drag that consists of two layers of medium weight burlap with the trailing edge of the lower layer extending approximately 2 in [50 mm] behind the upper layer. Support the burlap so that a length of at least 3 ft [1 m] of burlap is in contact with the pavement.
>
> Except in areas where using hand methods to construct the pavement, support the lead end of the burlap drag by a traveling bridge. Maintain the drag clean and free of incrusted mortar. Replace the burlap with new material as necessary.

Sub-article 352-4 (pages 370-372) is modified by the following:

The Department will perform all California Profilograph (FM 5-558) testing used for acceptance and pay.

5. SAMPLING PLAN FOR PAY ADJUSTMENT

A vital assumption upon which the statistical acceptance procedures are based is randomness of sampling. Random sampling is defined as a manner of sampling that allows every member of the population (lot) to have an equal opportunity of appearing in the sample. The PRS AQCs are measured for each sublot, and pay adjustment is made on a lot-by-lot basis. Thus, the sublot boundaries must be marked and maintained until finalizing the payment computation. The lot shall be divided into three sublots for sampling and testing purposes. Markers shall be placed every 0.05 mile along the mainline traffic lanes to help determine the lot and sublot limits.

The definitions of lot, sublot, and sampling frequency for compressive strength, thickness, and initial smoothness are presented below.

5.1 Pavement Lot

A pavement lot is defined as the amount of material or construction produced by the same process, so that each AQC is likely to be from the same distribution. Each lot is one lane in width and ranges between 0.1 and 1.0 mi in length. The maximum lot size is defined as a 1-day production of one lane, or 1.0 lane–mi, whichever is less. If the 1-day production is longer than 1.0 mile, the Engineer shall divide the 1-day production into multiple lots. If concrete placement includes two or more lanes in one pass, this production is still divided into lots consisting of one lane each. The Engineer may terminate the lot if there is any reason to believe that a special cause affected the process and resulted in a significant shift in the mean or standard deviation of any of the AQCs. Changes in the concrete mix design do not necessarily terminate the lot. This determination is made by the Engineer.

To meet the sampling frequency requirements (as discussed in the “Pavement Sublot” and “Sampling Frequency” sections of these specifications), the minimum lot length is 0.10 mi (528 ft). If the lot length is less than 0.10 mi, it shall be grouped with the next lot. If the last lot in the paving project is less than 0.10 mi long, it shall be grouped with the previous lot. In summary, the lot is 1-lane wide and ranges between 0.10 and 1.0 mi in length.

A partial lot is defined as a lot for which concrete strength testing was conducted on none or only one of the planned sublots due to premature stoppage of paving. Premature stoppage of paving is defined as the stoppage of pavement construction operations due to unexpected conditions such as weather or equipment problems. A partial lot shall be re-divided into sublots similar to a new lot.

If the concrete strength of a sublot of a partial lot has not been tested using cylinders, two drilled cores shall be taken from the sublot to measure the 28-day compressive strength of the in-place concrete. These cores shall be tested according to ASTM C-42. The Engineer may allow the thickness cores to be tested for strength. The core and cylinder test results shall be combined to determine the mean and standard deviation of the 28-day compressive strength for the partial lot.

5.2 Pavement Sublot

The application of this PRS requires that the lot be divided into discrete sublots and that sampling be conducted in each sublot for all AQCs. This means that strength, thickness, and smoothness shall be measured within each sublot boundary. The minimum sublot length is established so that at least one Profile Index (PI) measurement can be taken for each sublot. If the minimum pavement length for measuring PI is 0.05 mi, the minimum sublot length shall be 0.05 mi. If the lot is less than 0.15 mi long, it shall be divided into two sublots of approximately equal length. If the lot is 0.15 mi or longer, it shall be divided into three sublots of approximately equal length.

5.3 Sampling Frequency

The sampling frequencies for concrete strength, slab thickness, and smoothness are described below.

5.3.1 Concrete Strength

A strength test for each sublot is determined as the average of the 28-day compressive strength of two cylinders cast from a sample of concrete from the sublot. In the case of partial lots, the strength cylinders will be supplemented by cores. Thus, the strength sample size is one per sublot and the number of replicates per sample is two.

5.3.2 Slab Thickness

A thickness measurement for each sublot is determined by taking two core borings at two random locations in the sublot. Thus, the thickness sample size is two per sublot and the number of replicates per sample is one.

5.3.3 Initial Smoothness

A longitudinal profile trace shall be taken at each wheelpath (inside and outside) within each sublot. The Engineer will compute the PI for discrete sections within each sublot. The Engineer will set these sections to be of approximately equal length and be practical to measure. The PI values that constitute the smoothness sample are computed as the average of both wheelpath traces. Thus, the number of PI sections along the lot represents the sample size, and the number of wheelpaths (i.e., 2) represents the replicates per sample.

5.3.4 Slump, Air, and Temperature

Plastic properties will be determined at a frequency of one per sublot coinciding with the compressive strength sample.

6. PAY ADJUSTMENT

PRS recognize that marginal products still have some value and advocate payment adjustment schedules instead of requiring complete removal unless the pavement is so deficient that replacement or correction action is warranted (i.e., at the RQL). It shall be noted that the Department will provide the software that implements the pay adjustment computation procedure.

6.1 Individual Pay Adjustment Curves

Individual pay adjustment factors for concrete strength, slab thickness, and initial smoothness shall be determined using the pay factor curves shown in figures 2, 3, and 4 or tables 5, 6, and 7.

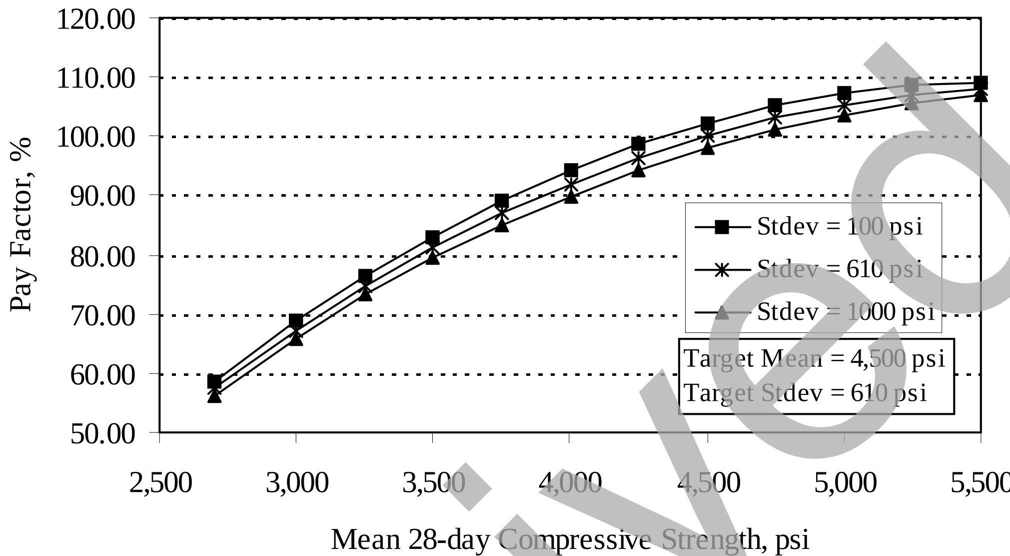

Figure 2. Concrete strength pay adjustment curve.

Table 5. Concrete strength pay adjustment table (PF, %).

Lot Mean Strength, psi	Lot Standard Deviation (computed using means of 2 cylinders), psi					
	100	**325**	**550**	**610***	**775**	**1,000**
2,700	58.63	58.13	57.55	57.40	57.05	56.27
3,000	68.72	68.13	67.44	67.27	66.86	65.94
3,250	76.26	75.61	74.84	74.65	74.20	73.18
3,500	83.03	82.32	81.49	81.27	80.78	79.67
3,750	89.01	88.19	87.20	86.95	86.32	85.09
4,000	94.22	93.33	92.24	91.97	91.23	89.93
4,250	98.65	97.73	96.60	96.32	95.53	94.21
4,500*	102.31	101.40	100.28	100.00	99.20	97.91
4,750	105.18	104.33	103.29	103.02	102.25	101.05
5,000	107.28	106.53	105.61	105.38	104.67	103.62
5,250	108.59	108.00	107.27	107.08	106.48	105.62
5,500	109.13	108.73	108.24	108.11	107.67	107.04

*Targets

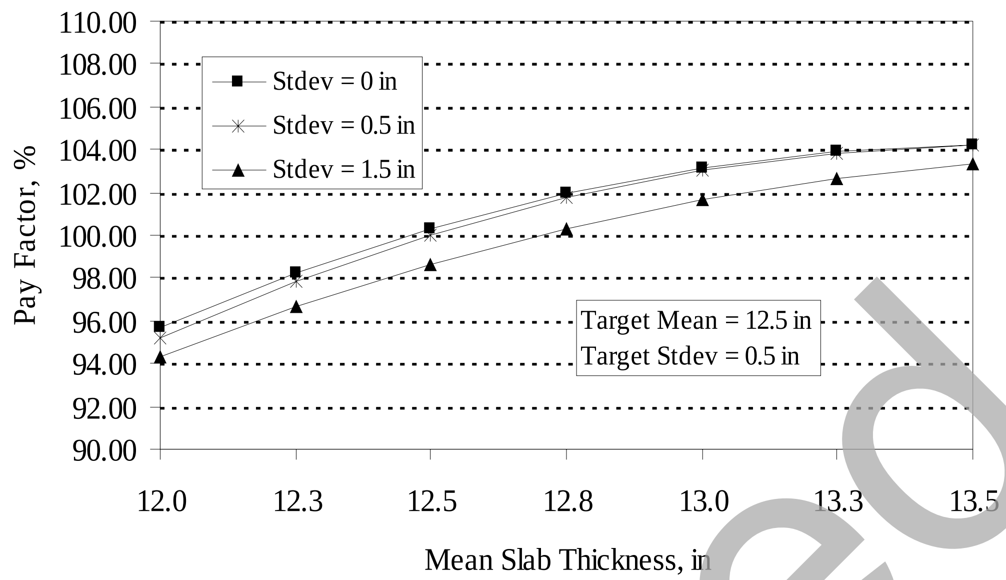

Figure 3. Slab thickness pay adjustment curve.

Table 6. Slab thickness pay adjustment table (PF, %).

Lot Mean Slab Thick-ness, in	Lot Standard Deviation (computed from independent cores), in.				
	0.0	**0.5***	**1.0**	**1.5**	**2.0**
12.00	95.67	95.15	94.58	94.30	93.67
12.25	98.19	97.80	97.20	96.63	95.84
12.50*	100.27	100.00	99.39	98.63	97.74
12.75	101.92	101.74	101.15	100.30	99.38
13.00	103.13	103.03	102.49	101.64	100.75
13.25	103.91	103.87	103.41	102.65	101.86
13.50	104.26	104.24	103.89	103.33	102.70

*Targets

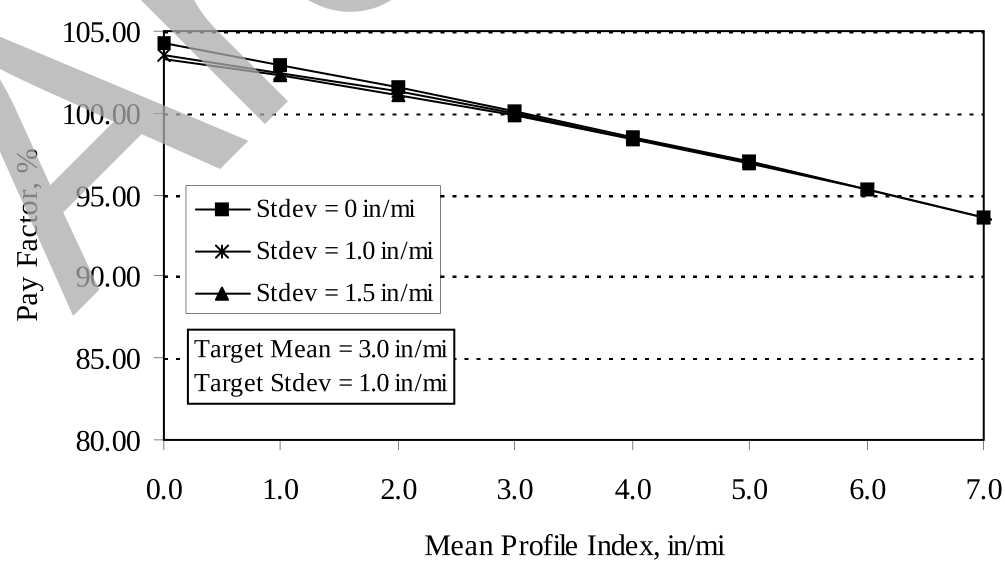

Figure 4. Initial smoothness pay adjustment curve.

Table 7. Initial smoothness pay adjustment table (PF, %).

Lot Mean PI, in/mi	Lot Standard Deviation (computed using means of 2 wheelpath profiles), in/mi					
	0.0	**0.75**	**1.0***	**1.5**	**2.25**	**3.0**
0.0	104.21	103.61	103.48	103.31	103.20	102.70
1.0	102.91	102.42	102.45	102.25	102.11	101.74
2.0	101.53	101.14	101.28	101.08	100.92	100.66
3.0*	100.08	100.08	100.00	99.79	99.63	99.47
4.0	98.56	98.35	98.35	98.35	98.25	98.16
5.0	97.04	97.04	97.04	96.90	96.78	96.74
6.0	95.38	95.38	95.38	95.29	95.21	95.20
7.0	93.59	93.59	93.59	93.57	93.54	93.54

*Targets

These curves and tables were developed using the PaveSpec 3.0 PRS software and account for the mean and standard deviation of the AQCs. Linear interpolation or extrapolation shall be used between the values shown in these tables, if needed.

The determination of individual pay factors from figures 2, 3, and 4 or tables 5, 6, and 7 requires computing the mean and standard deviation of the concrete strength, slab thickness, and initial smoothness for the as-constructed lot based on the field testing results. These statistics shall be calculated as follows:

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \qquad (2)$$

where:

$\overline{X}$ = Mean of *n* random samples of the AQC under consideration for the lot.

X_i = Sample measurement (for smoothness and strength, X_i is a mean of multiple replicates, and for thickness the mean of all cores).

n = Sample size per lot, *n* for each AQC is as follows:
Strength: 1 sample per sublot (each is a mean of two cylinder measurements, or core measurements for partial lots).
Thickness: 2 samples (cores) per sublot.
Smoothness: number of required profile sections per lot (each is represented by the mean profile passes in the wheelpaths)

The thickness lot standard deviation (where number of replicates = 1) is computed as follows:

$$s = \frac{\sqrt{\dfrac{\sum (X_i - \overline{X})^2}{(n-1)}}}{C_{SD}} \qquad (3)$$

The strength and smoothness unbiased lot standard deviation (where more than one replicate per sample are used) is computed as follows:

$$s = \frac{\sqrt{\frac{\sum (X_i - \overline{X})^2}{(n-1)m}}}{C_{SD}} \quad (4)$$

where:

m = Number of replicates per sample, m for strength and smoothness are as follows:

Strength: 2 replicates (i.e., 2 cylinders per sample, or cores for partial lots).
Smoothness: 2 replicates (i.e., wheelpaths per lane).

C_{SD} = Correction factor (based on the total sample size, n) used to obtain unbiased estimates of the actual lot sample standard deviation. Appropriate C_{SD} values are determined using table 8.

Table 8. Correction factors used to obtain unbiased estimates of the actual standard deviation.

Number of Samples, *n*	**Correction Factor, C_{SD}**
2	0.7979
3	0.8862
4	0.9213
5	0.9399
6	0.9515
7	0.9594
8	0.9650
9	0.9693
10	0.9726
30	0.9915

6.2 Computation of Pay Adjustment

The lot composite (overall) pay factor is computed as follows:

$$PF_{composite} = (PF_{smoothness} * PF_{strength} * PF_{thickness}) / 10000 \quad (5)$$

where:

$PF_{composite}$ = Composite (overall) pay factor, percent.
$PF_{strength}$ = Strength pay factor (obtain from table 5), percent.
$PF_{thickness}$ = Slab thickness pay factor (obtain from table 6), percent.
$PF_{smoothness}$ = Initial smoothness pay factor (obtain from table 7), percent.

The actual pay adjustment for the as-constructed lot is computed using the lot composite pay factor as follows:

$$PAYADJ_{Lot} = BID * AREA_{Lot} * (PF_{composite} - 100) / 100 \quad (6)$$

where:

$PAYADJ_{Lot}$ = Pay increase (+) or decrease (-), \$.
BID = Contractor bid price for pay item 350-1-19, \$/yd^2.
$AREA_{Lot}$ = Measured actual area of the as-constructed lot, yd^2.
$PF_{composite}$ = Composite pay factor (from equation 5), percent (e.g., 101 percent is expressed as 101.0).

$$PAY_{Lot} = BID * AREA_{Lot} + PAYADJ_{Lot} \quad (7)$$

where:
PAY_{Lot} = Adjusted payment for the as-constructed lot, \$.

U.S. Department of Transportation
Federal Highway Administration

Office of Infrastructure
Office of Pavement Technology
Federal Highway Administration
U.S. Department of Transportation
1200 New Jersey Avenue, SE
Washington, DC 20590

Telephone: 202-366-0120
Fax: 202-493-2070
www.fhwa.dot.gov/infrastructure/pavement/concrete

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