Performance-Related Specifications for Pcc Pavements. Volume II: Appendix B-Field Demonstrations

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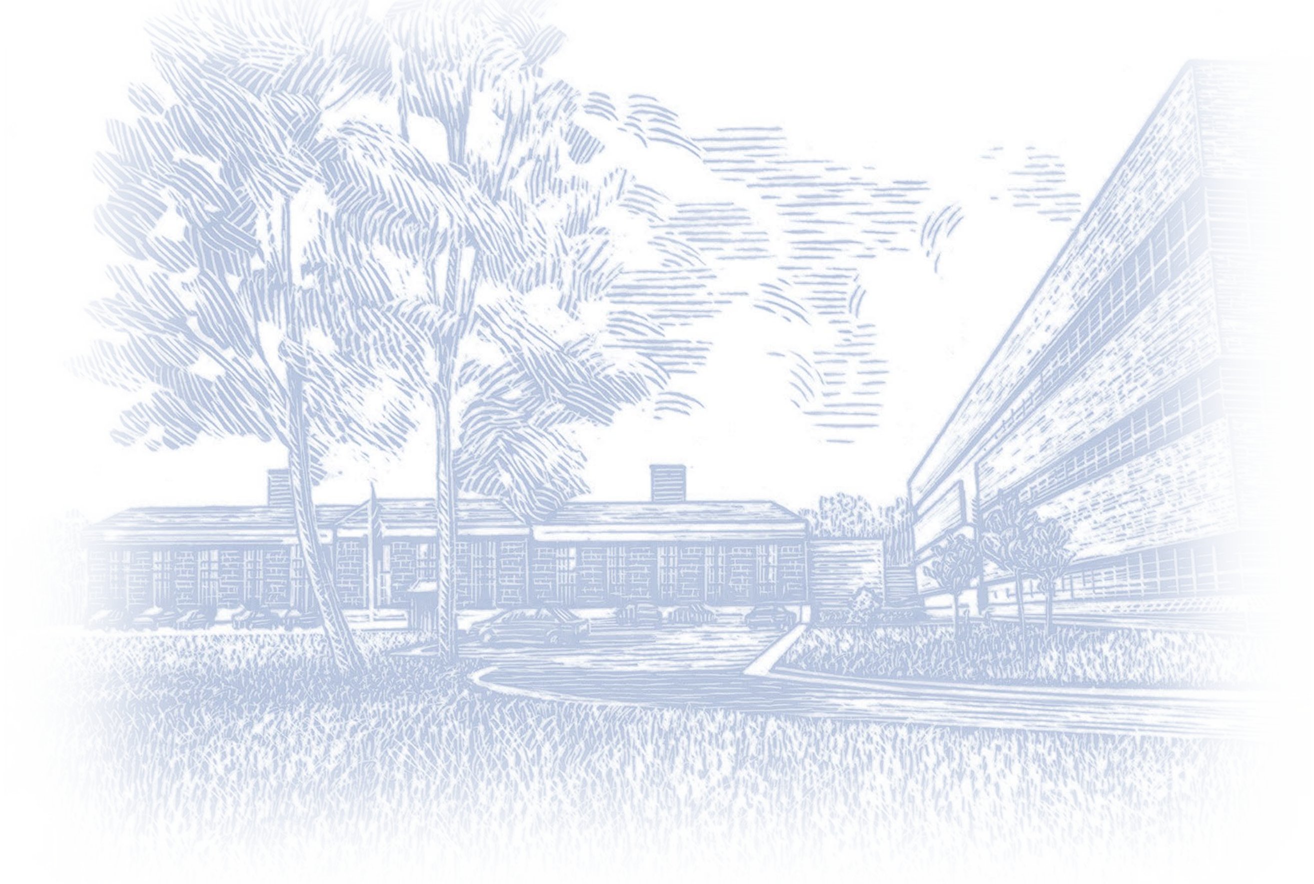

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Foreword

This report is the second volume of a four-volume set of reports presenting the results of a study to further the development of performance-related specifications for portland cement concrete pavement construction. The report describes an investigation into the practicality and implementability of the recommended performance-related specifications. The investigation, which includes field simulation of the specifications, provides valuable insight for highway agencies planning to develop and use performance-related specifications. This report will be of interest to engineers concerned with quality assurance, specifications, and construction of concrete pavements.

Sufficient copies of this report are being distributed to provide a minimum of 3 copies to each FHWA resource center and division office, and 10 copies to each State highway agency. Direct distribution is being made to the division offices. Additional copies for the public are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161.

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Introduction

A prototype performance-related specification (PRS) for jointed plain concrete pavement (JPCP) was developed in a previous Federal Highway Administration (FHWA) study.(1-4) This prototype has been revised under the current project to make it more practical and implementable. As a means of assessing its practicality, three different methods were used to demonstrate and test both developed specification levels (Level 1 and Level 2).

The first method of demonstrating the prototype PRS involved the conduct of field trials at four actual new construction projects (one conducted by the research team, and the other three in conjunction with FHWA Office of Technology Applications [OTA] personnel). The PRS simulation software (PaveSpec) was used to develop the Level 1 and Level 2 preconstruction output for each project (reflecting the project-specific design, climatic, and traffic conditions). A PRS-based sampling and testing plan was then applied, and the required samples were collected to demonstrate both Level 1 and Level 2 procedures. Finally, the PaveSpec simulation software was used to determine *shadow* pay factors and adjustments for each project (i.e., the contractor's pay was not affected by the PRS-based pay factors and adjustments computed as part of the demonstration).

The second demonstration method involved developing Level 1 specifications for three typical designs used by a State Highway Agency (SHA). It was decided to develop these specifications for typical designs in Iowa since it was the site of the first shadow field trial. Preconstruction output (pay factor charts and corresponding equations) were developed for each of the chosen designs. Finally, the trends within and between each project's preconstruction output was analyzed.

The third demonstration method consisted of comparing historical pay adjustments (actually paid by the SHA) to PRS-based price adjustments predicted for the same pavement lots. This study was conducted using historical (archived) acceptance quality characteristic (AQC) and pay adjustment data. Archived data were retrieved for a total of 41 lots from 7 projects in 3 States. Next, Level 1 preconstruction output (pay factor charts and corresponding equations) were developed for each project being investigated. The retrieved AQC data were then used in conjunction with the Level 1 preconstruction output to determine PRS-based Level 1 lot pay factors. Historical pay adjustment data representing the same defined lots were then obtained and compared to the computed PRS-based pay adjustments.

This volume shows details of the three methods used to demonstrate the revised prototype PRS. Its specific purpose is to illustrate the investigation into the specification's practicality and implementability. Chapter 2 contains a summary of the original PRS shadow field trial conducted by the research team in Ottumwa, Iowa. Chapter 3 discusses the details of the three additional shadow field trials conducted in conjunction with OTA personnel. Chapter 4 discusses the development of the Level 1 specifications for three typical pavement designs for a chosen SHA (Iowa). Chapter 5 includes details of the study using historical SHA data to compare actual historical pay adjustments to predicted PRS-based pay adjustments for the same pavement lots. Finally, chapter 6 summarizes the results of these different demonstrations used to assess the revised prototype PRS's practicality and implementability.

Original Shadow Field Trial: Ottumwa, Iowa

Introduction

As a first step in investigating the practicality and implementability of the revised prototype PRS, the research team conducted the first shadow field trial in Ottumwa, Iowa in October 1996. The field trial was labeled a shadow operation because it did not interfere with the contractor's construction procedures or SHA's acceptance procedures. Therefore, contractor pay was not affected in any way by the pay factors computed using the prototype approach.

This chapter discusses all aspects of the original field trial, including the chosen lot and sublot definitions, sampling and testing plan, PRS pay adjustment calculations, problems encountered, and a summary of the lessons learned.

Objectives Of The Field Trial

The overall objective of the original field trial was to verify the draft specification's effectiveness, identify potential problem areas, and determine its reasonableness. Specific objectives of the field trial included:

- Evaluating the definitions and procedures for determining PRS lots and sublots.
- Applying and evaluating the PRS acceptance sampling and testing plans in terms of their practicality, timeliness, and reliability. An evaluation of the field management of the sampling and testing and reporting procedures was conducted, and problem areas were identified.
- Applying and evaluating the calculation procedure used to determine contractor pay for each lot. The trial was limited in the sense that the contractor pay was not affected by the results.
- Obtaining feedback from the contractor and the SHA on the reasonableness and potential improvements of the PRS.

Explanation Of Level 1 And Level 2 PRS Procedures

Two different implementation levels of the draft specification were investigated at the original field trial. As a means of addressing many implementation obstacles, the research team has proposed the development of these different levels of the draft specification—titled simply *Level 1* and *Level 2*. The two PRS levels mainly differ in the AQC sampling and testing methods and the payment adjustment procedures. Both the Level 1 and Level 2 draft specifications were applied and investigated as part of the field trial. A more detailed explanation of both levels is included in the following paragraphs.

Introduction to a Level 1 PRS

The Level 1 PRS is based on the prototype specification previously developed for the FHWA.(1,2) It includes five AQC's: concrete strength, slab thickness, entrained air content, initial smoothness, and percent consolidation around dowels. The agency may choose to include any or all of these AQC's in the specification. The proposed Level 1 PRS may be implemented using the SHA's current field sampling and laboratory testing procedures. Therefore, the Level 1 PRS should be readily implementable in any SHA with minimal change to the agency's current acceptance procedures.

In the Level 1 PRS, pavement performance may be defined by any or all of the following distress indicators: transverse slab cracking (fatigue), transverse joint faulting, transverse joint spalling, and pavement smoothness over time. Performance models for each of the distress indicators are based on the quality level of one or more of the included AQC's. Calculated life-cycle costs (LCC's) (for both the as-designed and as-constructed pavements) are based on a chosen rehabilitation policy and defined unit costs. All of this simulation is conducted using the revised PaveSpec (Microsoft® Windows™-based) software.

The pay factor computation method used in the Level 1 PRS is based on calculating independent pay factors for each AQC. Each of these pay factors is determined from a series of developed pay factor vs. AQC mean curves and corresponding pay factor equations. These curves, each specific to a different as-constructed AQC standard deviation, are created by correlating simulated lot pay factors over a range of AQC means. Each calculated pay factor is, therefore, a function of the measured as-constructed mean and standard deviation, target mean and standard deviation, and the chosen sample size.

Final payment for the lot is based on an agency-selected composite pay factor (CPF) equation, expressed as a simple mathematical manipulation of the individual AQC pay factors. It is suggested that the SHA apply a cap (maximum value) to this overall CPF for budgetary purposes.

Introduction to a Level 2 PRS

The proposed Level 2 PRS is an expansion and refinement of the proposed Level 1 PRS. Theoretically, the Level 2 PRS represents the dynamic transition from the proposed Level 1 specification to an ideal PRS that would include all AQC's that affect pavement performance. The current Level 2 PRS is, therefore, defined by the research being conducted under this project. It is understood that the definition of this Level 2 PRS will change when future research work provides improved or additional distress indicator prediction models and AQC sampling or testing methods.

A Level 2 specification may also be based on the measurement of the same five AQC's used in the Level 1 approach. A major difference between the proposed Level 1 and Level 2 PRS is that all AQC's included in the proposed Level 2 PRS are ideally measured on the in-place pavement. Pavement performance is determined using the same distress indicator prediction models defined for the Level 1 approach. All performance simulation and cost calculations are performed using the PaveSpec software.

The pay factor computation method used in the Level 2 PRS calculates lot-based pay factors by comparing simulated as-designed (target) and as-constructed LCC's directly. Interactions of AQC's are included in the simulations (e.g., an increase in flexural strength may counteract a decrease in slab thickness). The pay factor calculation is based on the premise of liquidated damages. Measured AQC sample means and standard deviations are incorporated into the pavement performance simulation, and the LCC is then used as the one overall representative quality characteristic. Final payment for the lot is based on the one overall pay factor simulated using PaveSpec.

Project Information

The field trial project location was carefully selected for the original shadow PRS. The research team searched for not only an appropriate project, but an appropriate SHA/contractor team as well. The researchers defined a desirable SHA/contractor team as one that possessed the following:

- Considerable interest in PRS.
- Experience with quality control/quality assurance (QC/QA) specifications.
- Willingness to facilitate the field trial.

After careful consideration, the research team chose the following project for the field trial:

State: Iowa

County: Wapello

Highway: Iowa State Route 23

Location: 1.61 km southeast of Eddyville and extending southeast on Iowa State Route 23 to near Chillicothe

Project Length: 9.31 km of mainline paving

Description: New construction of two lanes (in one direction)—expansion from a two-lane (one lane in each direction) to a four-lane (two lanes in each direction) divided highway

Contractor: Fred Carlson Co.

Specification Development

One important aspect of the PRS approach is that the developed specifications are *project-specific*. Therefore, the representative Level 1 and Level 2 specifications were developed prior to going to the field by tailoring the PRS methodology to the field trial project conditions (design, climatic, and traffic). The development of the respective specifications involved a number of steps, each of which is described below. (Note: Due to the timing of this project, this PRS demonstration was completed using the original prototype specification and PaveSpec 1.0 software.(1-3))

Definition of Pavement Performance

For the original field trial, pavement performance was defined in terms of all four available distress indicators (transverse slab cracking, transverse joint faulting, transverse joint spalling, and pavement smoothness over time [expressed in terms of present serviceability rating (PSR)]).

Selection of AQC's to be Included in the Specification

For this specific project, the following four AQC's (and sampling/testing methods, where appropriate) were selected for inclusion in both specification levels:

- Concrete Strength.
- Slab Thickness.
- Entrained Air Content.
- Initial Smoothness.

Under the current research project, the PRS was expanded to include percent consolidation around dowels as a fifth AQC; however, the methods for incorporating percent consolidation around dowels into the PRS procedure were not available at the time of the construction of this project.

Identifying Constant Inputs

Constant variables are defined as those variables required by the distress indictor models that do not differ between the as-designed and as-constructed pavements. These variables define many of the pavement's design characteristics and can be grouped into categories such as traffic, climatic, design (materials, slab support, and load transfer), and cost information. Values for the constant variables (representing this project) were either obtained from the Iowa Department of Transportation (Iowa DOT) or assumed using engineering judgment. The specific constants used for this field trial are presented in table 1. (Note: The constant inputs presented in table 1 are those required by the old distress prediction models used in the prototype PaveSpec software.(1-3) These variables differ slightly from those constant values required by the new distress indicator models included in the revised PaveSpec 2.0 software [as shown in figure 1 of volume I].)

Table 1. Constant inputs defining the original field trial project (Ottumwa, Iowa).

Project Information		
	Pavement Type	Plain, doweled
	Road Location	Rural, 4 or more lanes, divided
	Design Life	30 years
	Project Length	9.31 km
	Number of Lanes in One Direction	2
	Lane Width	3.7 m
	Joint Spacing	6.1 m
Traffic Information		
	Total Design ESAL's	12.7 million
	1996 AADT	4,600 vehicles per day
	2016 AADT	5,725 vehicles per day
	Percent Trucks	28 percent
Materials and Climatic Information		
	Annual Temperature Range	49 ºC
	Freezing Index	300 degree-days
	Average Annual Precipitation	89 cm
	Projected Annual Freeze-Thaw Cycles (at 7.6 cm below the pavement surface)	15
	Joint Sealant Type	Liquid
Slab Support Information		
	Base Type	Granular
	Modulus of Subgrade Reaction	33.9 MPa/m (subgrade only)
	Subgrade Soil Type	Fine-grained (A-4 to A-7)
	Presence of Longitudinal Subdrains	Yes
Load Transfer Information		
	Dowel Bar Diameter	3.8 cm
	Presence of Tied PCC Shoulder/Widened Slab	No
Cost Information		
	Construction Bid	\$ 24.10 /m^2
	Cost of Overlay (current)	\$ 10.77 /m^2
	Cost of Joint Patching (current)	\$ 95.69 /m^2

	Cost of Slab Replacement (current)	$ 83.73 /m^2
	Annual Interest Rate	6 percent
	Annual Inflation Rate	3 percent

Notes: ESAL = equivalent single-axle load; AADT = annual average daily traffic; PCC = portland cement concrete.

Definition of the Required As-Designed AQC Target Values

One very important responsibility that falls on the agency is identifying the as-designed target means and standard deviations of the chosen AQC's. It is important because the contractor pay will be based on how well the contractor matches these chosen values. The as-designed means and standard deviations define the quality levels for which the agency is willing to pay 100 percent of the bid price (on average). Since expected pay (EP) curves were not available to identify the agency-desired AQC quality levels (interpreting EP curves is the method recommended in volume I), engineering judgment was used to determine the as-designed AQC target means and standard deviations based on the current Iowa DOT specifications. Explanations of the interpretive methods used are included in the following sections.

Concrete Strength

Section 2301.31 of the Iowa construction specification discussed concrete strength. Iowa addresses strength by requiring that the placed concrete achieve a designated minimum flexural strength by a designated minimum age. No price adjustments are applied based on strength. Therefore, the achievement of the required minimum strength is only used to determine when the contractor can have access to the pavement with his/her vehicles. The table in section 2301.31 of the Iowa DOT design manual contains the required minimum flexural strengths and corresponding minimum ages for different combinations of concrete class and cement type. The data from that table are presented in table 2.

Table 2. Iowa DOT concrete strength specification guidelines (from the Iowa DOT rigid design manual—Section 2301.31).

Class of Concrete	Type of Cement	Minimum Age	Minimum Flexural Strength, MPa [1]
A	Type I	14 days[2]	3.45
A	Type III	7 days	3.45
B	Type I	14 days	See note 3
B	Type III	7 days	See note 3
C	Type I	7 days[4]	3.45
C	Type III	48 hours	3.45
M	Type I	48 hours	3.45
F	Type III	N/A	2.76
FF	Type III	N/A	2.41

Notes: 1. The original Iowa table was expressed in English units. The strength values shown in this table have been converted to metric.
2. 10 days for concrete 203 mm or more in thickness.
3. 2.76 MPa strength required if placed after September 15.
4. 5 days for concrete 229 mm or more in thickness.

The Ottumwa project used a Class C concrete with a Type I cement. Based on these characteristics, and the fact that the design thickness was 279 mm (see note 4 of table 2), a minimum third-point loading flexural strength (modulus of rupture) of 3.45 MPa was required in 5 days. Since there was not a clear expected 28-day modulus of rupture or compressive strength associated with this mix, the expected modulus of rupture was assumed to be equal to a commonly used design value of 4.48 MPa. (Note: This is the mean strength used to design the pavement using the American Association of State and Highway Transportation Officials [AASHTO] guide.) A coefficient of variation of 0.1 was assumed, giving an expected standard deviation of 0.45 MPa. This includes point-to-point materials and testing variation. It represents the standard deviation between individual specimens; in other words, no averaging of test results is completed prior to the calculation of the standard deviation. These values were used to define the as-designed target strength for the Level 1 PRS.

Under the Level 2 PRS, concrete strength was chosen to be investigated using a 3-day core compressive strength. This compressive strength was then converted to a 28-day compressive strength using maturity concepts. Therefore, it was important to determine the 28-day compressive strength equivalent to a 28-day modulus of rupture of 4.48 MPa. Equation 1 was used for this conversion.

$$M_{R(28\ days)} = 0.83035 * [f'_{C(28\ days)}]^{0.5} \qquad (1)$$

where

$M_{R(28\ days)}$ = 28-day third-point portland cement concrete (PCC) modulus of rupture, MPa. This equation is converted from the equation $M_{R(28\ days)} = 10 * [f'_{C(28\ days)}]^{0.5}$ expressed in English units (psi).

$f'_{C(28\ days)}$ = 28-day compressive strength, MPa.

Equation 1 may be rewritten so that compressive strength is a function of modulus of rupture. This equation results in the following:

$$f'_{C(28\ days)} = [M_{R(28\ days)} / 0.83035]^2 \qquad (2)$$

Therefore, the expected 28-day compressive strength mean may be calculated as the following (using equation 2):

$$f'_{C(28\ days)} = [(4.48\ MPa) / 0.83035]^2$$

$$= 29.13\ MPa$$

A coefficient of variation of 0.10 was also assumed for compressive strength, thus making the expected 28-day compressive strength standard deviation approximately 2.91 MPa. These values were used to define the as-designed target strength for the Level 2 PRS.

Slab Thickness

Section 2301.35 of the Iowa specification discusses the pay adjustments made based on slab thickness. Pay adjustments are made based on a calculated *quality index* (QI) of the cores. This QI is calculated using equation 3.

$QI = (X - T)/S$ (3)

where

QI = Quality index for the lot pavement thickness.

X = Mean core thickness for the lot, mm.

T = Current agency design thickness determined from the pavement design procedure, mm. (Provided by the agency as 279 mm.)

S = Core thickness standard deviation for the lot, mm.

Therefore, the QI will be negative if the current agency design thickness is larger than the mean core thickness of the lot.

For any assumed target standard deviation, an appropriate corresponding PRS target mean may be computed by rewriting equation 3 so that the measured core thickness (X) is a function of QI, S, and T. The computed measured core thickness is then assumed to be the representative PRS target mean thickness (X_{TARGET}). This relationship is shown in equation 4.

$X_{TARGET} = (QI * S) + T$ (4)

where

X_{TARGET} = PRS target mean thickness, mm.

QI = Quality index for the lot pavement thickness.

S = Assumed core thickness standard deviation for the lot, mm.

T = Current agency design thickness determined from the pavement design procedure, mm. (Provided by the agency as 279 mm.)

The specific payment schedule is included in Section 2301.35 of the Iowa design specification and summarized in table 3. Note that the percent payment identifies the pay adjustment as a percentage of the contract unit bid price.

Table 3. Iowa DOT payment schedule for slab thickness (from the Iowa DOT rigid design manual—Section 2301.35).

Percent Payment	QI Range
103	1.25 or more
101	0.86 to 1.24
100	0.41 to 0.85
98	0.20 to 0.40
95	0.00 to 0.19
90	-0.25 to -0.01
80	-0.40 to -0.26
70	-0.41 or less

Note: If a QI of -0.41 or less is obtained, additional cores shall be taken to determine the extent and severity of the deficiencies. Depending on the results of this study, the engineer will require one of the following procedures:

(a) The deficient lot shall be removed and replaced with pavement at the contractor's expense, meeting the contract requirements. Payment for the replaced pavement will be as provided above.

(b) The pavement represented by cores deficient from design thickness by more than 2.54 cm shall be replaced. These areas will be defined by limits one-half the distance to the next core that is not deficient from design thickness by more than 2.54 cm. The remainder of the deficient lot may be left in place and paid for at 70 percent of the contract price.

If all lots for each contract item have a quality index of 1.25 or more, the percentage of payment will be 105 percent for the project.

Given this specification, we can see that 100-percent pay will be paid for QI's computed in the range of 0.41 to 0.85. The midpoint of 0.63 is, therefore, used to estimate the target thickness mean. Based on engineering judgment, a PRS target thickness standard deviation (representing good thickness quality control) was assumed to be 6 mm for this project. This standard deviation represents point-to-point variation as measured from cores, and includes both construction process and measurement variation. A corresponding target thickness is then computed based on a QI of 0.63, a standard deviation of 6 mm, and a current agency design thickness of 279 mm. This target thickness mean is calculated as the following, using equation 4:

$X_{TARGET} = (QI * S) + T$

$= (0.63 * 6 \text{ mm}) + 279 \text{ mm}$

$= 283 \text{ mm}$

Therefore, a target thickness mean and standard deviation of 283 and 6 mm, respectively, were chosen for the field trial. (Note: Although the methods outlined in volume I recommend setting the PRS target thickness mean equal to the current agency design thickness [279 mm for this project], here it was believed that the agency was actually asking for better quality. Therefore, the PRS target thickness mean was adjusted appropriately.)

Entrained Air Content

Section 2301.04 of the Iowa specification discusses entrained air content. Under the Iowa specification, entrained air content is measured with a pressure air meter on "fresh or unvibrated" concrete. The specification provides the following guidelines for the desired entrained air content range (measured as a percentage):

- Minimum = 6.0 percent.
- Maximum = 8.0 percent.
- Target = 7.0 percent.

Based on this acceptable range of 6.0 to 8.0 percent, the Iowa specification was translated into a representative target mean and standard deviation. The target mean was chosen to be 7.0 percent (the midpoint of this acceptable range), and the target standard deviation was assumed to be equal to 0.5 percent, based on engineering judgment.

Initial Smoothness

The Iowa DOT's *Supplemental Specifications for Pavement Smoothness, SS-5130* (dated July 12, 1994), contains guidelines for initial smoothness. The Ottumwa project is a primary road, mainline, not curbed, with a posted speed of greater than 45 mi/h (72.4 km/h). Therefore, the smoothness requirements in mm/km are contained in Schedule A as determined by the table titled *Schedule for Identification of Pavements and Bridge Approach Sections* in Iowa's supplemental specification. Table 4 presents the pertinent pay adjustments (contained in Schedule A) of the smoothness specification.

Table 4. Pertinent Iowa DOT payment schedule for initial smoothness.

SINGLE LIFT PAVEMENTS [1]	
mm/km per Segment [2]	**Interstate & Multi-Lane Divided Primary Roads [3], Pay Adjustment ($/ 0.16-km segment)**
0 – 16	+ 650
17 – 32	+ 550
33 – 47	+ 450
48 – 110	Unit Price
111 – 158 [4]	Grind or (–300)
159 & greater [5]	Grind Only

Notes: 1. For single lift pavements, if all segments in a project qualify for 100-percent payment with no grinding, the qualifying incentive payment as indicated in note 3 will be increased by $50 per segment.

2. For each segment of pavement that has an initial index within the limits listed, with no grinding, the contractor will receive a pay adjustment as shown in the tabulation for the appropriate category. The original table was expressed in English units; the smoothness values shown in this table have been converted to metric.

3. If all segments in a section of pavement in this category qualify for 100-percent payment with no grinding, the qualifying incentive payment will be increased by $100 per segment.

4. For segments with an initial index of 111 to 158 mm/km, the contractor may grind the surface to a final index of 110 mm/km or better or accept a price reduction for each segment of pavement in non-compliance equal to the amount shown for the appropriate category.

5. For segments with an initial index of 159 mm/km and greater, the contractor shall grind the surface to a final index of 110 mm/km or better. In lieu of grinding the surface to a final index of 110 mm/km or better, the contractor may elect to replace part or all of the segment.

Based on the payment schedule presented in table 4, the range for 100-percent pay is a measured initial smoothness of 48 to 110 mm/km. Therefore, a value of 79 mm/km (the midpoint of this range) was chosen as the target initial smoothness mean, while the target initial smoothness standard deviation was assumed to be 16 mm/km (based on engineering judgment). The standard deviation of initial smoothness includes both variations between profiles and testing variability.

Summary of Chosen Target Values

The estimated target means and standard deviations for the four chosen AQC's are summarized for the Level 1 and Level 2 PRS in tables 5 and 6, respectively.

Table 5. Estimated Level 1 AQC target means and standard deviations for the Iowa field trial project.

Acceptance Quality Characteristic	**Target Mean**	**Target Standard Deviation[1]**
28-day modulus of rupture (third-point loading), MPa	4.48	0.45
Slab thickness, mm	283	6
Entrained air content, %	7.0	0.5
Initial smoothness, mm/km	79	16

[1] Computed from individual tests (no averaging is performed); thus, it includes both materials/process and testing measurement variation.

Table 6. Estimated Level 2 AQC target means and standard deviations for the Iowa field trial project.

Acceptance Quality Characteristic	Target Mean	Target Standard Deviation[1]
28-day compressive strength, MPa	29.13	2.91
Slab thickness, mm	283	6
Entrained air content, %	7.0	0.5
Initial smoothness, mm/km	79	16

[1] Computed from individual tests (no averaging is performed); thus, it includes both materials/process and testing measurement variation.

Definition of Lots and Sublots

One of the final steps in preparing for the development of preconstruction output is the identification of the number of lots and sublots per lot to be analyzed. The following definitions were used as a guide for the selection of lot and sublot lengths at the original field trial:

> Lot—A discrete quantity of constructed pavement to which an acceptance procedure (and corresponding pay adjustment) is applied. All pavement placed within a lot shall consist of the same mix design and material sources; shall be subjected to the same support conditions (base type, base thickness, subbase type, subbase thickness, subgrade treatment); and shall consist of the same design characteristics (joint spacing, drainage, shoulder type, dowel bar diameter, traffic, and AQC design values). The target lot length shall be equal to one day's production or less. The minimum lot length shall not be less than 0.16 km. Any section of lesser length shall be added to the preceding lot.
>
> Sublot—A portion of a lot. Each lot is divided into sublots of approximately equal surface area. Sublot lengths are selected so that one or more samples may be taken from each sublot for each considered AQC. The minimum sublot length shall not be less than 0.16 km (to accommodate the measurement of initial smoothness). Any section of lesser length shall be added to the preceding sublot. Each as-constructed sublot should initially be assumed to be equal to the chosen target sublot length.

Three consecutive days of mainline paving (one lot per day for October 1 through October 3, 1996) were selected to be investigated for this project. Prior to arriving at the site, it was estimated that the contractor would be paving approximately 0.76 km per day. Based on the available research team personnel and sampling and testing equipment, it was decided to obtain three or four sublots per lot with a target sublot length of 0.20 km.

During the acceptance procedures, the following guidelines were used to determine the actual sublot lengths in the field:

- Minimum sublot length was 0.16 km—requirements for sampling initial smoothness.

- Maximum sublot length was 0.48 km.

- The final sublot length in a lot was determined using the following guidelines:

    1. If the final sublot length was less than 0.16 km, then that material was added to the previous sublot. If additional samples were taken from locations within this final sublot length (locations determined prior to construction), they were included with the samples representing the previous sublot.

    2. If the final sublot length was greater than 0.16 km, but less than the chosen target sublot length of 0.20 km, then the actual final sublot length was used.

Development of PRS Preconstruction Output

The final step in the specification development process involves the development of preconstruction output. For the Level 1 specification, this involves constructing individual pay factor charts (and corresponding pay factor equations) for the four AQC's. Individual AQC pay factors (representing the as-constructed quality) may be computed using these equations by knowing the as-constructed AQC lot means and standard deviations. (Note: Each pay factor chart is specific to the chosen constant values, target means, and target standard deviations.)

For the Level 2 specification, this involves estimating the target as-designed life-cycle cost (LCC_{DES}). A Level 2 overall lot pay factor may then be calculated as a function of LCC_{DES}, the determined as-constructed life-cycle cost (LCC_{CON}), and the chosen contract bid price. More information on developing preconstruction output is provided in chapter 7 of volume I, in the section titled *Step-By-Step Guide to Generating PRS Preconstruction Output*. The specific procedure used to develop the preconstruction output representing the original field trial project is explained in detail in the following sections.

Level 1—Development of Individual AQC Pay Factor Curves

The following step-by-step procedure was used to develop Level 1 pay factor charts and corresponding pay factor equations for the original field trial. (Note: Each of these steps is accomplished using the PaveSpec PRS demonstration software.)

1. *Define lots and sublots*. As previously discussed, the lot size was defined as one day of mainline paving and estimated to be 762 linear meters. It was decided to divide each lot into three or four sublots based on the amount of paving the contractor completed. Since pay factors are dependent on the number of sublots, it was decided to develop AQC pay factor charts and equations for both cases.

2. *Define the number of samples per sublot*. A sampling frequency of two samples per sublot was used for each AQC at the field trial. In a Level 1 PRS, we assume that all of the material in a lot are represented by the same statistical population. Because of this assumption, the total sample size *N* may be represented by the number of sublots *n* times the number of samples per sublot. Therefore, the total sample size N was 6 and 8 for the cases of three and four sublots, respectively.

3. *Define the Level 1 AQC target means and standard deviations*. The Level 1 target as-designed AQC means and standard deviations for this project were defined in table 5.

4. *Choose a range of as-constructed means for each AQC*. Reasonable ranges of AQC means were selected that defined the values to be used in the PaveSpec simulations. These chosen ranges of simulation means for each AQC (based on the chosen AQC target values) are presented in table 7.

Table 7. As-constructed AQC mean ranges for simulation.

Acceptance Quality Characteristic	Chosen AQC Simulation Mean Ranges
28-day modulus of rupture (third-point loading), MPa	3.78 – 5.18
Slab thickness, mm	273 – 293
Entrained air content, %	2.0 – 7.0
Initial smoothness, mm/km	0 – 180

5. *Choose specific as-constructed AQC standard deviation levels for the simulation of pay factor curves*. The pay factor curves not only depend on the as-constructed AQC mean, but the as-constructed AQC standard deviation as well. Therefore, three different standard deviation levels were chosen (for each AQC) representing *very good, good, and poor* AQC quality control. Table 8 contains the different levels of AQC standard deviation used in the simulation of individual AQC pay factor curves.

Table 8. As-constructed AQC standard deviation levels for simulation.

Acceptance Quality Characteristic	AQC Standard Deviation Levels for Simulations		
28-day modulus of rupture (third-point loading), MPa	0.00	0.45	0.90
Slab thickness, mm	0	6	13
Entrained air content, %	0.0	0.5	1.5
Initial smoothness, mm/km	0	16	47

6. *Simulate the target as-designed LCC's.* In order to calculate pay factors for different hypothetical levels of as-constructed AQC quality, the target as-designed LCC's had to be simulated. The *PaveSpec* specification simulation software was used to estimate target as-designed LCC means from 500 simulation lots for 3 and 4 sublots (both with 2 AQC samples per sublot). Each of the 500 lots was simulated by randomly selecting AQC samples from the target value distributions summarized in table 5. The simulations were conducted using a 60-year analysis life (twice the design life) and included 5 percent of the calculated user costs. The

resulting simulated Level 1 mean as-designed present worth (PW) LCC values (for the cases of three and four sublots per lot) were the following:

LCC_{DES} (3 sublots) = $ 488,412/ km

LCC_{DES} (4 sublots) = $ 492,034/ km

To better demonstrate the PRS methodology, the distresses over time associated with a typical sublot at this project (reflecting the chosen constant inputs and AQC target means only) are presented in table 9. (Note: Only the first 50 years of the 60-year analysis life are displayed in table 9.) These data show that the first asphalt overlay is predicted to be applied at the end of year 35, thereby resulting in the setting of the PSR value to an assumed value of 4.50, and the zeroing of the other distresses. Associated LCC's are computed based on a maintenance and rehabilitation (M & R) plan defined by the following detailed procedures:

- The first year of overlay application is triggered when PSR ≤ 3.0. (Note: Other distresses are still displayed for the year in which an overlay is applied, because they are addressed as part of the pre-overlay repair.)
- Any cracked slab or spalled joint is replaced in the year in which it is determined to be failed (e.g., if it is determined that five slabs are cracked in year one, all five slabs are assumed to be replaced in year one).
- After the application of the first global rehabilitation (asphalt overlay), the following apply:

1. Transverse cracking, transverse joint spalling, and transverse joint faulting are no longer predicted (i.e., they are set equal to zero for the remaining years).
2. PSR is set equal to an assumed value of 4.50.
3. Additional asphalt overlays are applied using an assumed overlay life of 20 years.
4. The PSR is assumed to decrease linearly from 4.50 to 3.00 over the assumed 20-year life.

Table 9. Typical distresses over time representative of the as-designed pavement at the Iowa field trial project.

Year	Cumulative ESAL's (millions)	Avg Faulting (mm/joint)	Total Transverse Cracking (m/km)	Transverse Joint Spalling (No. spalled joints/km)	PSR
Initial	0.00	0.00	0	0	4.64
1	0.42	0.10	37	0	4.63
2	0.85	0.14	52	0	4.44
3	1.27	0.17	64	0	4.36
4	1.69	0.20	74	0	4.32
5	2.11	0.23	83	1	4.27

6	2.54	0.25	90	1	4.23
7	2.96	0.27	98	1	4.20
8	3.38	0.29	104	1	4.15
9	3.80	0.31	111	1	4.12
10	4.23	0.33	117	2	4.08
11	4.65	0.35	123	2	4.05
12	5.07	0.36	128	2	4.02
13	5.50	0.38	134	3	3.97
14	5.92	0.39	139	4	3.88
15	6.34	0.41	144	4	3.85
16	6.76	0.42	148	5	3.81
17	7.19	0.43	153	6	3.78
18	7.61	0.45	158	7	3.74
19	8.03	0.46	162	7	3.70
20	8.45	0.47	166	8	3.67
21	8.88	0.49	171	9	3.62
22	9.30	0.50	175	10	3.58
23	9.72	0.51	179	11	3.53
24	10.14	0.52	183	12	3.50
25	10.57	0.53	187	14	3.46
26	10.99	0.54	191	14	3.41
27	11.41	0.55	195	16	3.35
28	11.83	0.57	199	17	3.31
29	12.26	0.58	202	19	3.26
30	12.68	0.59	206	20	3.22
31	13.10	0.60	210	21	3.16
32	13.53	0.61	213	23	3.11
33	13.95	0.62	217	24	3.06
34	14.37	0.63	221	26	3.00
35	14.79	0.64	224	28	4.50
36	15.22	0.00	0	0	4.43
37	15.64	0.00	0	0	4.35
38	16.06	0.00	0	0	4.28

39	16.48	0.00	0	0	4.20
40	16.91	0.00	0	0	4.13
41	17.33	0.00	0	0	4.05
42	17.75	0.00	0	0	3.98
43	18.17	0.00	0	0	3.90
44	18.60	0.00	0	0	3.83
45	19.02	0.00	0	0	3.75
46	19.44	0.00	0	0	3.68
47	19.87	0.00	0	0	3.60
48	20.29	0.00	0	0	3.53
49	20.71	0.00	0	0	3.45
50	21.13	0.00	0	0	3.38

These M & R procedures are used to determine sublot LCC's that are then summarized into overall lot LCC's used to compute pay factors.

7. *Simulate as-constructed LCC's and calculate an independent AQC pay factor for each hypothetical as-constructed mean/standard deviation pair*. The hypothetical as-constructed mean/as-constructed standard deviation pair values (coming from combinations of means and standard deviations defined in steps 5 and 6) were used to define individual sessions in the PaveSpec software. Each AQC was investigated independently for each session (for example, if strength was being investigated, all of the other AQC as-constructed means and standard deviations were set equal to the target values). Each pair was used in PaveSpec to simulate a corresponding LCC_{CON}. A pay factor was calculated for each pair using equation 5.

$$PF_{LOT} = 100 * (BID + [LCC_{DES} - LCC_{CON}]) / BID \qquad (5)$$

where

PF_{LOT} = Overall pay factor for the as-constructed lot, percent.

BID = Representative contractor's unit bid price for the lot, \$/km.

= \$176,295/km for this project.

LCC_{DES} = Target as-designed life-cycle unit cost for the lot (simulated in step 6 using target AQC's), PW\$/km.

LCC_{CON} = As-constructed life-cycle unit cost for the lot (computed using AQC test results from the as-constructed lot), PW\$/km.

The simulated pay factors (from PaveSpec) representing lot sample sizes of N=6 (three sublots) and N=8 (four sublots) are summarized by AQC in tables 10 through 13.

Table 10. 28-day modulus of rupture—simulated Level 1 pay factors for three and four sublots and two samples per sublot (lot sample size N=6 and N=8, respectively).

As-Constructed Strength Mean, MPa	Simulated Pay Factors at Different Strength Standard Deviations, %					
	As-Constructed Std Dev = 0.00 MPa		As-Constructed Std Dev = 0.45 MPa		As-Constructed Std Dev = 0.90 MPa	
	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)
3.78	60.4	61.8	53.5	53.8	46.9	47.4
4.48	109.1	110.8	100.0	100.2	85.6	87.8
5.18	130.8	132.8	128.8	130.7	122.0	121.6

Table 11. Slab thickness—simulated Level 1 pay factors for three and four sublots and two samples per sublot (lot sample size N=6 and N=8, respectively).

As-Constructed Thickness Mean, mm	Simulated Pay Factors at Different Thickness Standard Deviations, %					
	As-Constructed Std Dev = 0 mm		As-Constructed Std Dev = 6 mm		As-Constructed Std Dev = 13 mm	
	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)
276	87.8	87.5	86.9	85.7	84.7	82.5
278	92.3	91.6	91.4	90.3	88.2	87.3
281	96.8	97.1	95.4	94.8	91.9	92.1
283	101.6	102.0	99.2	98.5	98.1	96.3
286	105.2	104.6	104.8	104.5	100.5	100.7
288	109.8	109.5	108.2	107.7	106.3	104.3
291	112.7	113.3	111.1	112.3	109.8	109.6

Table 12. Entrained air content—simulated Level 1 pay factors for three and four sublots and two samples per sublot (lot sample size N=6 and N=8, respectively).

As-Constructed Entrained Air Content Mean, %	Simulated Pay Factors at Different Entrained Air Content Standard Deviations, %					
	As-Constructed Std Dev = 0.0%		As-Constructed Std Dev = 0.5%		As-Constructed Std Dev = 1.0%	
	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)
3.00	93.1	93.5	92.7	93.4	92.5	93.3
5.00	96.1	96.4	95.9	96.4	95.7	96.3
7.00	100.6	100.1	100.0	100.0	99.2	99.2

Table 13. Initial smoothness—simulated Level 1 pay factors for three and four sublots and two samples per sublot (lot sample size N=6 and N=8, respectively).

As-Constructed Initial Smoothness Mean, mm/km	Simulated Pay Factors at Different Initial Smoothness Standard Deviations, %					
	As-Constructed Std Dev = 0.0 cm/km		As-Constructed Std Dev = 16 mm/km		As-Constructed Std Dev = 47 mm/km	
	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)	3 sublots (N=6)	4 sublots (N=8)
0	103.0	102.6	—	—	—	—
16	102.6	103.1	—	—	—	—
47	101.7	101.9	101.1	102.3	—	—
79	101.3	101.1	100.4	100.8	—	—
110	97.9	97.2	97.5	97.5	96.4	95.8
142	94.5	93.8	95.4	94.4	92.8	92.3
174	89.9	89.6	89.3	89.7	88.3	87.3

— not applicable

8. *Plot charts of pay factor versus AQC mean*. The simulated pay factors determined in step 7 can be graphed easily as a function of the AQC mean. Each AQC pay factor chart contains three different curves corresponding to the three different standard deviation levels chosen in step 5. Best-fit regression equations were fit through each pay factor curve representing one chosen as-constructed AQC standard deviation. Figure 1 contains AQC pay factor charts for the case when three sublots are used (or N=6). Figure 2 contains AQC pay factor charts for the case when four sublots are used (or N=8). Table 14 summarizes the best-fit pay factor regression

equations at different as-constructed AQC standard deviations for the cases of three and four sublots.

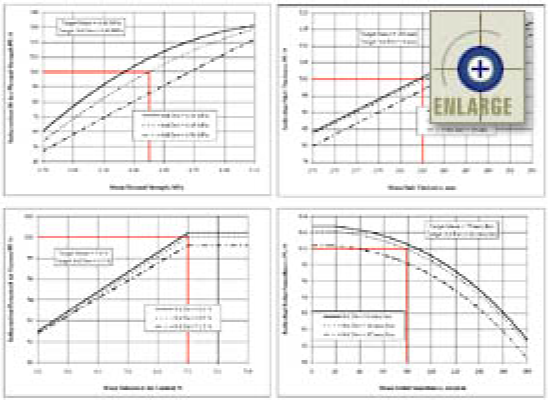


Figure 1. Level 1 individual AQC pay factor charts for the case of three sublots (lot sample size N=6).

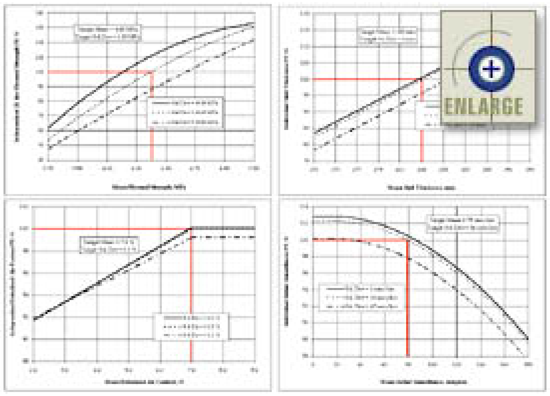


Figure 2. Level 1 individual AQC pay factor charts for the case of four sublots (lot sample size N=8).

Table 14. Level 1 AQC best-fit regression equations for three and four sublots (lot sample size N=6 and N=8, respectively).

Acceptance Quality Characteristic	As-Const. Std. Dev.	No. of Sublots	Pay Factor Regression Equation, x = mean value in MPa
28-day flexural strength (third-point loading)	0.00 MPa	3	$PF_{S-(x,\ 0.00)} = -27.3878x^2 + 295.6802x - 665.9437$
		4	$PF_{S-(x,\ 0.00)} = -27.3864x^2 + 296.0963x - 666.1364$
	0.45 MPa	3	$PF_{S-(x,\ 0.45)} = -17.8866x^2 + 214.0493x - 500.0361$
		4	$PF_{S-(x,\ 0.45)} = -16.0461x^2 + 198.7017x - 468.2167$
	0.90 MPa	3	$PF_{S-(x,\ 0.90)} = -2.1727x^2 + 73.1099x - 198.4116$
		4	$PF_{S-(x,\ 0.90)} = -6.5625x^2 + 111.8002x - 281.4419$
Slab thickness	0 mm	3	$PF_{T-(x,\ 0)} = 1.6606 - 369.4054$
		4	$PF_{T-(x,\ 0)} = 1.6971 - 379.84$
	6 mm	3	$PF_{T-(x,\ 6)} = 1.6254 - 360.3357$
		4	$PF_{T-(x,\ 6)} = 1.7478 - 394.98$
	13 mm	3	$PF_{T-(x,\ 13)} = 1.6887 - 381.1839$
		4	$PF_{T-(x,\ 13)} = 1.7421 - 397.27$
Plastic entrained air content (PF's are limited to the values computed at the mean value of 7.0%)	0.0%	3	$PF_{A-(x,\ 0.0)} = 1.875x + 87.225$
		4	$PF_{A-(x,\ 0.0)} = 1.65x + 88.417$
	0.5%	3	$PF_{A-(x,\ 0.5)} = 1.825x + 87.225$
		4	$PF_{A-(x,\ 0.5)} = 1.65x + 88.35$
	1.5%	3	$PF_{A-(x,\ 1.5)} = 1.675x + 87.425$
		4	$PF_{A-(x,\ 1.5)} = 1.475x + 88.892$
Initial smoothness	0 mm/km	3	$PF_{SM-(x,\ 0)} = -7.6401E\text{-}07x^3 - 2.941E\text{-}04x^2 - 3.7398E\text{-}04x + 102.84$
		4	$PF_{SM-(x,\ 0)} = 2.8014E\text{-}07x^3 - 6.0387E\text{-}04x^2 + 1.7964E\text{-}02x + 102.72$

	16 mm/km	3	$PF_{SM\text{-}(x,\ 16)} = -7.6401E\text{-}07x^3 - 2.941E\text{-}04x^2 - 3.7398E\text{-}04x + 102.23$
		4	$PF_{SM\text{-}(x,\ 16)} = 2.8014E\text{-}07x^3 - 6.0387E\text{-}04x^2 + 1.7964E\text{-}02x + 102.20$
	47 mm/km	3	$PF_{SM\text{-}(x,\ 47)} = -7.6401E\text{-}07x^3 - 2.941E\text{-}04x^2 - 3.7398E\text{-}04x + 100.48$
		4	$PF_{SM\text{-}(x,\ 47)} = 2.8014E\text{-}07x^3 - 6.0387E\text{-}04x^2 + 1.7964E\text{-}02x + 102.05$

Level 2—Development of the LCC_{DES}

The LCC_{DES} was simulated using the same procedure discussed in step 6 of the Level 1 explanation. The PaveSpec specification simulation software was used to estimate target as-designed life-cycle cost means from 500 simulation lots for the cases of 3 and 4 sublots (both with 2 AQC samples per sublot). The simulations were conducted using a 60-year analysis life (twice the design life) and included 5 percent of the calculated user costs. These resulting simulated Level 2 LCC_{DES} values were the following:

LCC_{DES} (3 sublots) = \$ 488,412 /km

LCC_{DES} (4 sublots) = \$ 492,034 /km

Sampling And Testing Plan

Field sampling and testing was conducted for the acceptance of concrete strength, slab thickness, air content, and initial smoothness. Details of the sampling and testing methods used for each AQC are discussed in the following sections. A summary of all of the Level 1 and Level 2 acceptance sampling and testing (including sampling method; number, location, and timing of sampling; and a testing summary) is contained in tables 15 and 16, respectively.

Table 15. Summary of the Level 1 sampling and testing conducted at the PRS field trial.

AQC	Sampling Method	Sampling Summary			Testing Summary
		Number of Samples Per Sublot	Location of Samples	Timing of Sampling	
Concrete Strength	Beams	(2)—152-mm x 152-mm x 762-mm beams	One beam each was taken at two randomly selected longitudinal locations	Material taken from in front of paver during construction	2 beams (1 each from 2 longitudinal locations) were tested for flexural strength (using third-point loading) at 28 days.
Slab Thickness	Cores	(2)—102-mm diameter cores	One core each was cut at two randomly selected locations	Cores were cut at 4 days (96 hours equivalent maturity)	Thickness for each of the 2 cores was determined by averaging 3 independent core length measurements (per core) taken with a ruler.
Entrained Air Content	Pressure Meter	(2)—pressure meter tests	One test was taken at two randomly selected longitudinal locations	Material taken from in front of paver during construction	Entrained air content was determined directly using a pressure meter.

Initial Smoothness	California Profilograph	(2)—passes with the profilograph	One pass down the center of each of two lanes	Next day after construction (as soon as contractor and State allow)	Each of the 2 profiles traces was reduced using a 5.1-mm blanking band. The smoothness results were then converted to units of mm/km.

Table 16. Summary of the Level 2 sampling and testing conducted at the PRS field trial.

		Sampling Summary			
AQC	**Sampling Method**	**Number of Samples Per Sublot**	**Location of Samples**	**Timing of Sampling**	**Testing Summary**
Concrete Strength	Cores	(2)—102-mm diameter cores	One core was cut at each of two randomly selected locations	Cores were cut at 4 days (96 hours equivalent maturity)	The cores were tested for compressive strength at 4 days. The 4-day compressive strengths were translated to 28-day flexural (third-point loading) strengths using maturity concepts.
	Thermocouple Tree	(1)—thermocouple tree	One randomly selected location	Placed in the pavement base in front of the paver (prior to paving)	Temperature at mid-depth in the pavement was monitored over time for maturity.
Slab Thickness	Cores	(2)—102-mm diameter	Thickness was	Cores were cut at 4	The thickness for each core

		cores (same samples used for Level 1)	measured on the two cores taken for concrete strength	days (96 hours equivalent maturity)	was determined by averaging 3 independent core length measurements (per core) taken with a ruler.
Entrained Air Content	Pressure Meter	(2)—pressure meter tests (same samples used for Level 1)	One test was taken at two randomly selected longitudinal locations	Material taken from in front of paver during construction	Entrained air content was determined directly using a pressure meter.
Initial Smoothness	California Profilograph	(2)—passes with the profilograph (same samples used for Level 1)	One pass down the center of each of two lanes	Next day after construction (as soon as contractor and State allow)	Each of the 2 profile traces was reduced using a 5.1-mm blanking band. The smoothness results were then converted to units of mm/km.

Concrete Strength

Data were collected during the field trial so that both the Level 1 and Level 2 PRS prototypes could be evaluated. The Level 1 strength pay factor was calculated using the 28-day strength data from beams cast in the field and cured under standard laboratory conditions for a 28-day period. The Level 2 PRS was investigated to evaluate the possibility of providing the contractor with a quicker indication of the strength results so that he may make adjustments sooner. Therefore, the Level 2 pay factor was based on a 28-day flexural strength predicted from early age (4-day) cores. (Note: 3-day cores were desired; however, due to the relatively cold field curing conditions, the 3-day sampling was postponed.)

In order to predict the 28-day flexural strength at a significantly earlier age at the Iowa field trial, strength development and interstrength relationship curves for the specific concrete mixture ingredients needed were developed in the laboratory prior to the beginning of construction. After obtaining adequate amounts of the coarse and fine aggregates, cement, flyash, and admixtures to be used for the field trial concrete, concrete beam and cylinder specimens were cast in the laboratory. The maturity of the laboratory samples was measured over the curing period, and the samples were tested for compressive strength, splitting tensile strength, and flexural strength (third-point loading) at ages of 1, 3, 5, 7, 14, 21, and 28 days. The maturity of the concrete at these test intervals was recorded based on the calculated Arrhenius method of maturity in accordance with ASTM C 1074, *Standard Practice for Estimating*

Concrete Strength by the Maturity Method.(5) The datum temperature was calculated using the procedure outlined in the annex of the test method, with mortar samples cured in three different temperature water baths and tested at incremental ages based on the final setting time of the mortars.

A curve representing the strength development for these tests was plotted over the maturity period and is presented in figure 3. An interstrength relationship curve was then developed by plotting flexural versus compressive strength over equivalent maturity intervals. A best-fit equation was then determined from the plotted data points. This developed interstrength relationship is shown in figure 4.

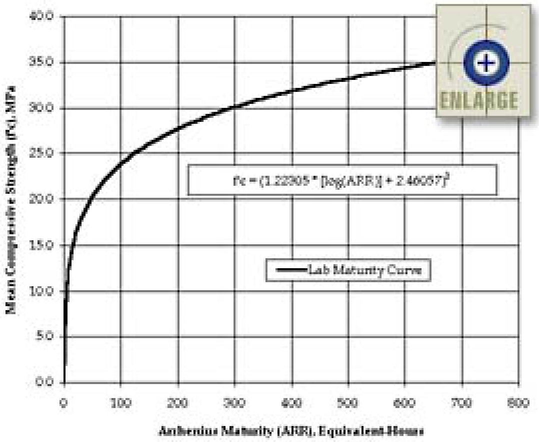


Figure 3. Laboratory-developed compressive strength versus maturity curve for the Iowa field trial concrete mix.

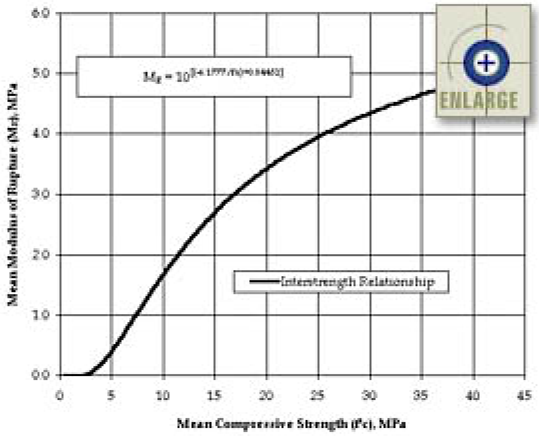


Figure 4. Laboratory-developed flexural versus compressive interstrength relationship for the Iowa field trial mix.

Once the strength and maturity standards were developed in the laboratory, they were used in the field to predict the 28-day flexural strength required for input into the PaveSpec computer program. Each sublot in the field was instrumented with maturity measuring devices allowing the equivalent laboratory maturity to be established for the samples tested at 4 days of age. Each measured compressive strength was plotted against its equivalent maturity (at the time of testing).

Invariably, the data points did not fall directly on the developed maturity curve. Representative values were then estimated using the *vertical shift* method. This method essentially involves shifting the developed curve vertically until it passes through the plotted data point. The specific procedure used to determine equivalent 28-day compressive strengths consists of the following:

1. Compute the difference between sample compressive strength and the compressive strength determined from the lab maturity curve (both values are computed at a maturity equal to the sample testing maturity).

2. Determine the estimated 28-day laboratory compressive strength (using the lab maturity curve) at an equivalent 28-day maturity.

3. Estimate the sample's 28-day compressive strength (28-day equivalent maturity) by adding the computed difference (computed in step 1) to the estimated 28-day laboratory compressive strength (computed in step 2).

More information on using this procedure to estimate 28-day strengths using maturity concepts is contained in chapter 5 of volume I in the section titled *Available AQC Sampling and Testing Procedures*.

Slab Thickness

Slab thickness was measured on all cores taken for the Level 2 investigation of concrete strength (i.e., no additional cores were cut from the pavement for the determination of slab thickness). These samples were used for acceptance in both specification levels. Level 1 acceptance was based on the computed mean and standard deviation of all of the cores' thickness measured within the entire lot. Level 2 acceptance was based on the average core thickness measured within each sublot. Details of the specific Level 1 and Level 2 sampling and testing procedures are shown in tables 15 and 16, respectively.

Entrained Air Content

Entrained air content was measured in the field using pressure meter tests on fresh concrete. Two samples were taken from each sublot (one each for two different random locations) and used for acceptance under both specification levels. Details of the Level 1 and Level 2 sampling and testing procedures are shown in tables 15 and 16, respectively.

Initial Smoothness

Initial smoothness was measured at the Iowa field trial using a California profilograph. Two passes were made with the profilograph (by the SHA) for each sublot. The passes consisted of one pass down the center of each of the two lanes. The collected profilograms were then reduced (5.1-mm blanking band) by the SHA using a computerized method to obtain initial profile indices. These computed profile indices were used for the acceptance of initial smoothness in both specification levels. Additional details of the specific Level 1 and Level 2 sampling and testing procedures are shown in tables 15 and 16, respectively.

The sampling and thermocouple tree locations were randomly selected for each sublot using the guidelines set forth in volume I, in the section titled *Selection of Random Sampling Locations* (chapter 5). A summary of the project layout and selected sampling and thermocouple tree locations is contained in table 17. Detailed project layout diagrams of lots 1, 2, and 3 are presented in figures 5, 6, and 7, respectively.

Table 17. Summary of lot and sublot layout and sampling locations.

Construction Date	Lot	Sublot	Starting Station	Ending Station	Sublot Length, m	Lot Length, m	Longitudinal Sample Locations		Thermocouple Tree Station
							Longitudinal Sample ID	**Longitudinal Sample Station**	
10/1/96	1	1.1	106+80	116+20	287	707	1.1.A	108+02	113+40
							1.1.B	113+30	
		1.2	116+20	121+50	162		1.2.A	117+20	121+45
							1.2.B	120+65	
		1.3	121+50	129+98	258		1.3.A	122+85	125+60
							1.3.B	124+80	
10/2/96	2	2.1	129+98	135+50	168	975	2.1.A	132+04	131+81
							2.1.B	133+40	
		2.2	135+50	141+95	197		2.2.A	135+75	140+35
							2.2.B	140+30	
		2.3	141+95	148+40	197		2.3.A	142+90	146+85
							2.3.B	147+25	
		2.4	148+40	161+95	413		2.4.A	149+85	154+40
							2.4.B	154+40	
							2.4.C *(air only)*	155+45	
							2.4.D *(air only)*	159+15	
10/3/96	3	3.1	161+95	168+50	200	926	3.1.A	163+50	167+93
							3.1.B	167+90	
		3.2	168+50	175+00	198		3.2.A	170+30	174+80
							3.2.B	174+75	

		3.3	175+00	181+50	198		3.3.A	178+35	180+70
							3.3.B	180+70	
		3.4	181+50	192+34	330		3.4.A	182+50	184+10
							3.4.B	184+10	

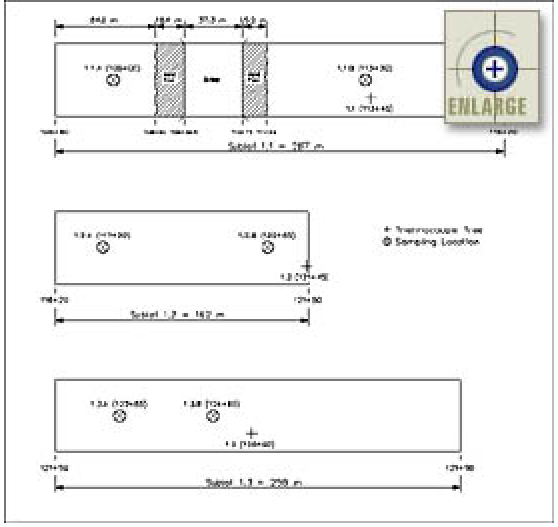


Figure 5. Lot 1 project layout at the Iowa field trial.

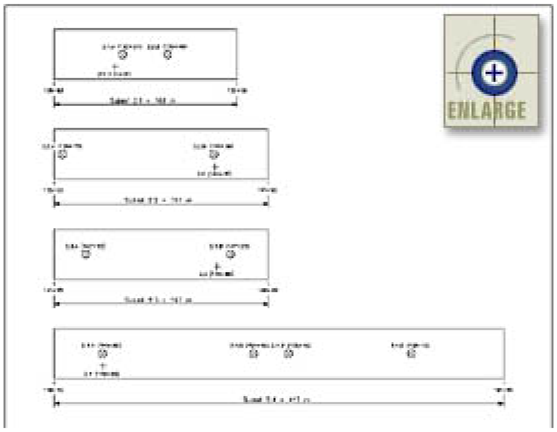


Figure 6. Lot 2 project layout at the Iowa field trial.

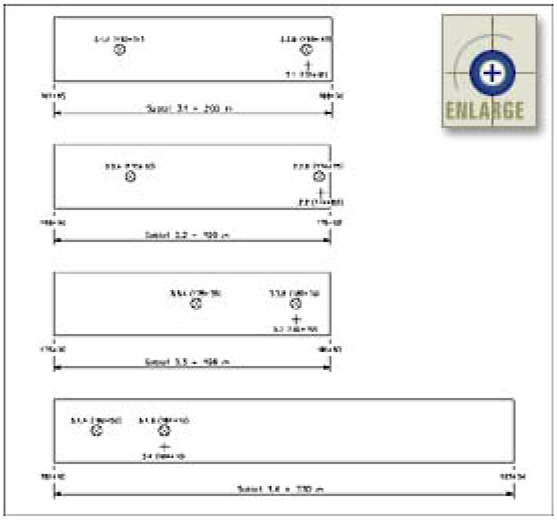


Figure 7. Lot 3 project layout at the Iowa field trial.

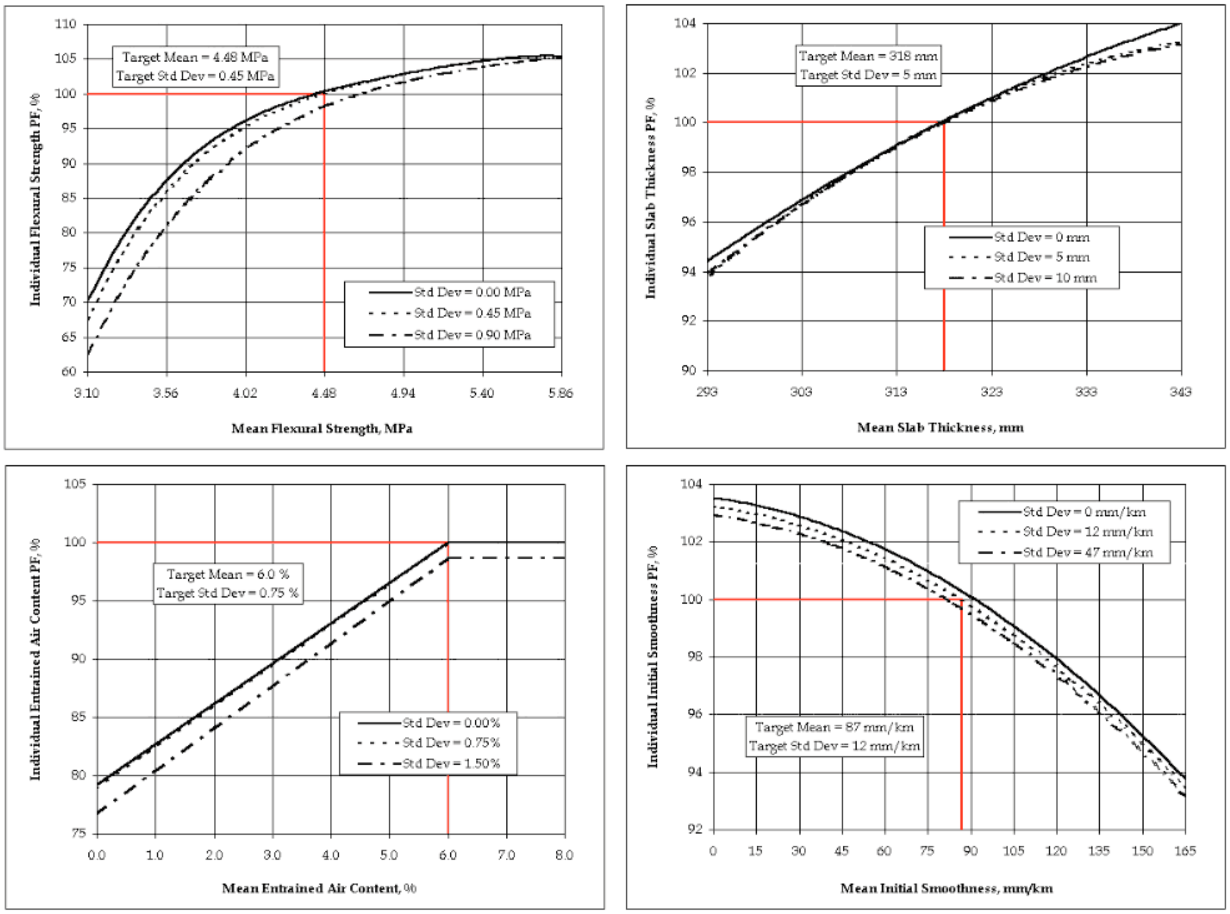


Figure 8.

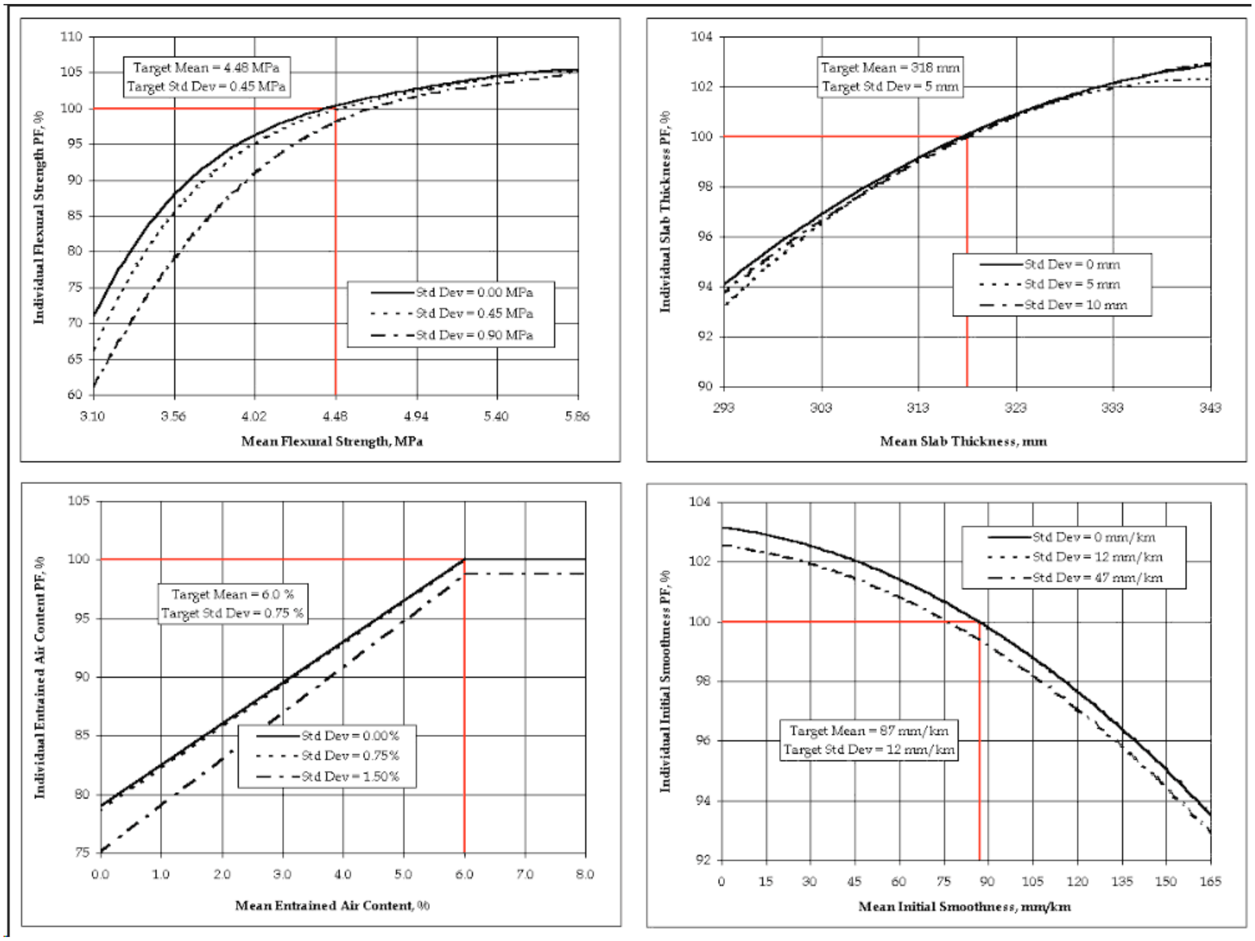

Individual Flexural Strength PF, %
110
105
100
95
90
85
80
75
70
65
60
3.10
3.56
4.02
4.48
4.94
5.40
5.86
Mean Flexural Strength, MPa
Target Mean = 4.48 MPa
Target Std Dev = 0.45 MPa
Std Dev = 0.00 MPa
Std Dev = 0.45 MPa
Std Dev = 0.90 MPa
Individual Slab Thickness PF, %
104
102
100
98
96
94
92
90
293
303
313
323
333
343
Mean Slab Thickness, mm
Target Mean = 318 mm
Target Std Dev = 5 mm
Std Dev = 0 mm
Std Dev = 5 mm
Std Dev = 10 mm
Individual Entrained Air Content PF, %
105
100
95
90
85
80
75
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Mean Entrained Air Content, %
Target Mean = 6.0 %
Target Std Dev = 0.75 %
Std Dev = 0.00%
Std Dev = 0.75%
Std Dev = 1.50%
Individual Initial Smoothness PF, %
104
102
100
98
96
94
92
0
15
30
45
60
75
90
105
120
135
150
165
Mean Initial Smoothness, mm/km
Target Mean = 87 mm/km
Target Std Dev = 12 mm/km
Std Dev = 0 mm/km
Std Dev = 12 mm/km
Std Dev = 47 mm/km

Figure 9.

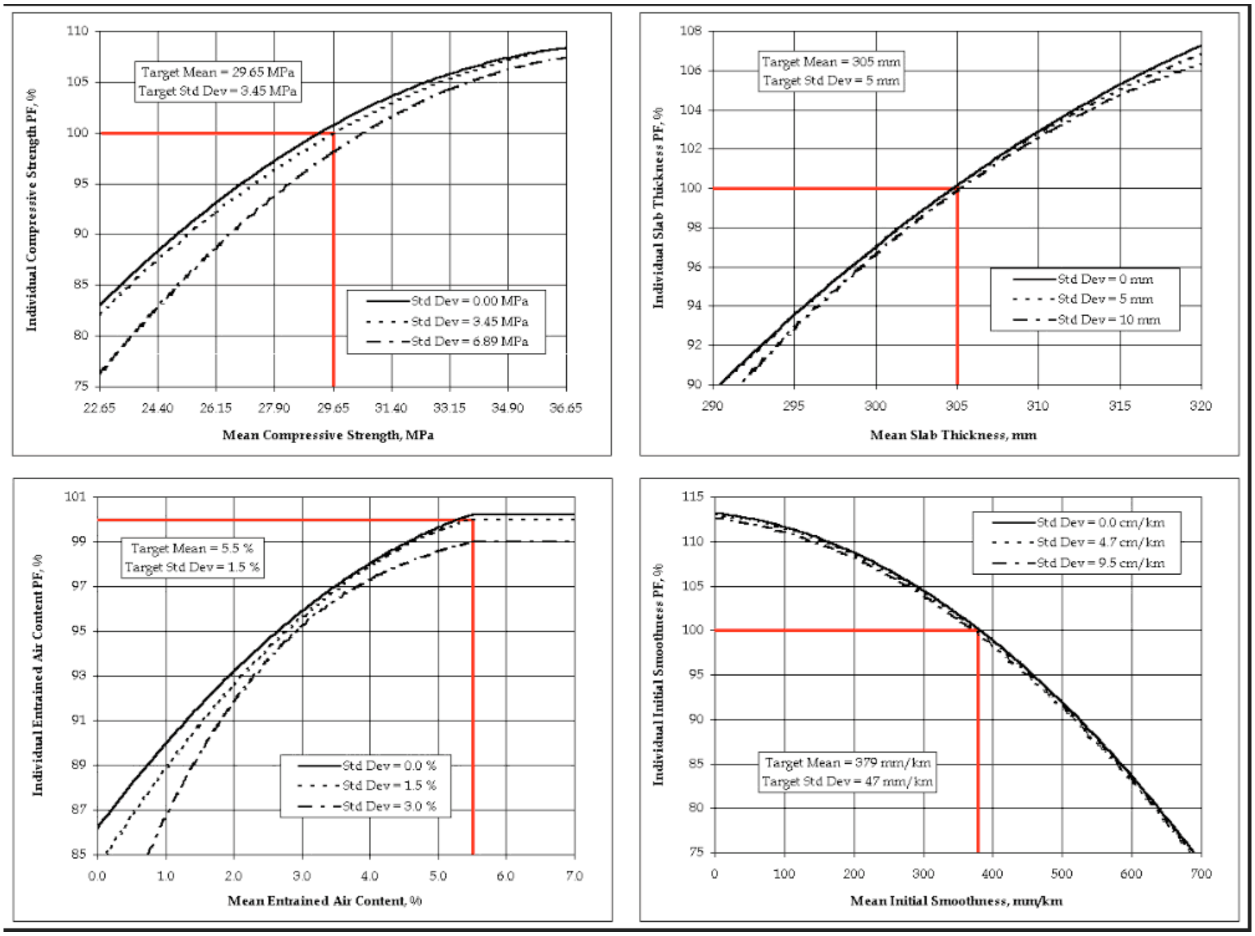

Target Mean = 29.65 MPa
Target Std Dev = 3.45 MPa
Std Dev = 0.00 MPa
Std Dev = 3.45 MPa
Std Dev = 6.89 MPa
Individual Compressive Strength PF, %
Mean Compressive Strength, MPa
110
105
100
95
90
85
80
75
22.65
24.40
26.15
27.90
29.65
31.40
33.15
34.90
36.65
Target Mean = 305 mm
Target Std Dev = 5 mm
Std Dev = 0 mm
Std Dev = 5 mm
Std Dev = 10 mm
Individual Slab Thickness PF, %
Mean Slab Thickness, mm
108
106
104
102
100
98
96
94
92
90
290
295
300
305
310
315
320
Target Mean = 5.5 %
Target Std Dev = 1.5 %
Std Dev = 0.0 %
Std Dev = 1.5 %
Std Dev = 3.0 %
Individual Entrained Air Content PF, %
Mean Entrained Air Content, %
101
99
97
95
93
91
89
87
85
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Target Mean = 379 mm/km
Target Std Dev = 47 mm/km
Std Dev = 0.0 cm/km
Std Dev = 4.7 cm/km
Std Dev = 9.5 cm/km
Individual Initial Smoothness PF, %
Mean Initial Smoothness, mm/km
115
110
105
100
95
90
85
80
75
0
100
200
300
400
500
600
700

Figure 10.

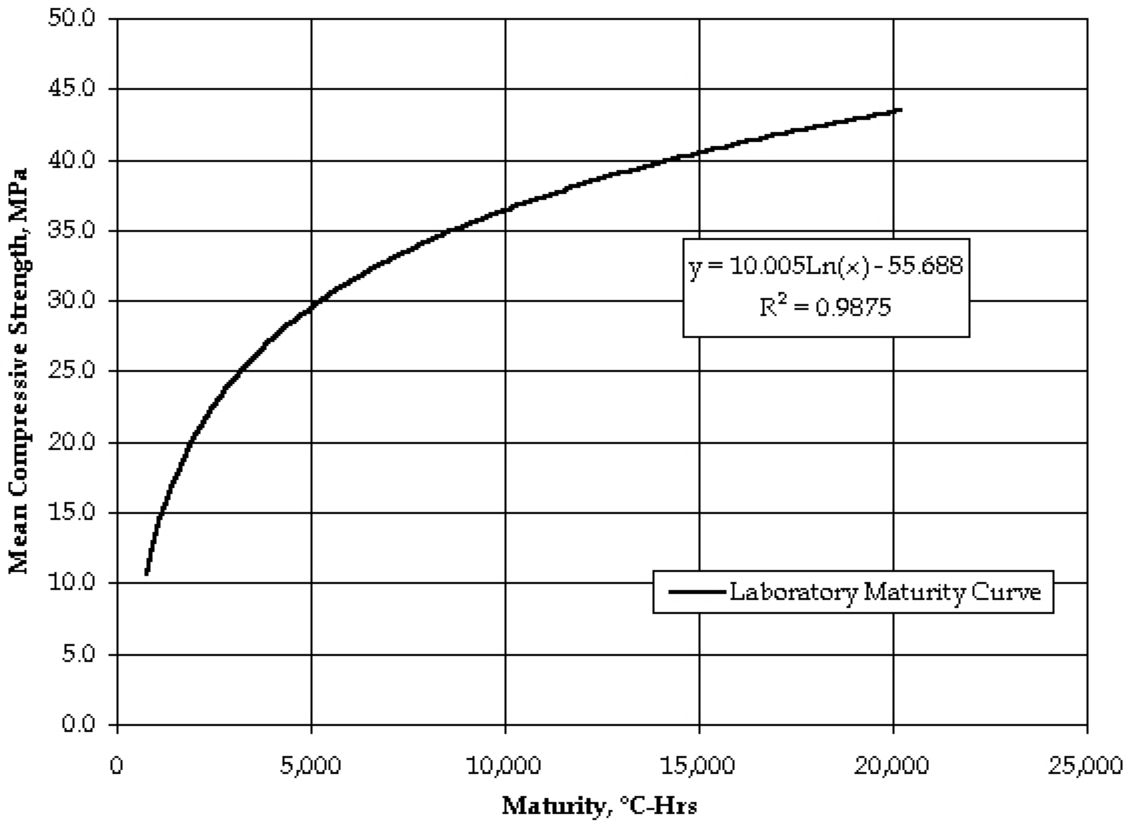

50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Mean Compressive Strength, MPa
0
5,000
10,000
15,000
20,000
25,000
Maturity, °C-Hrs
y = 10.005Ln(x) - 55.688
R2 = 0.9875
Laboratory Maturity Curve

Figure 11.

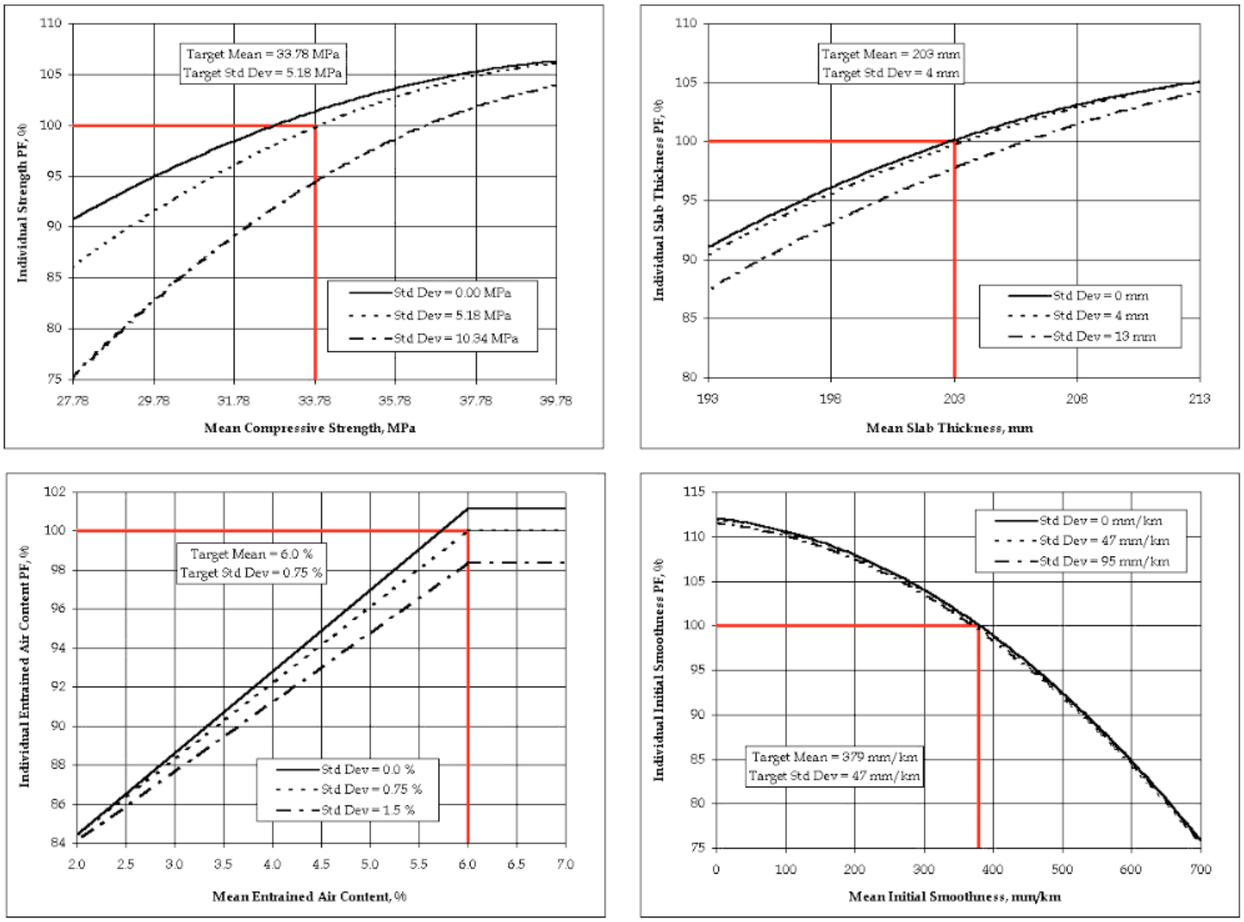

110
105
100
95
90
85
80
75
Individual Strength PF, %
Target Mean = 33.78 MPa
Target Std Dev = 5.18 MPa
Std Dev = 0.00 MPa
Std Dev = 5.18 MPa
Std Dev = 10.34 MPa
27.78
29.78
31.78
33.78
35.78
37.78
39.78
Mean Compressive Strength, MPa
110
105
100
95
90
85
80
Individual Slab Thickness PF, %
Target Mean = 203 mm
Target Std Dev = 4 mm
Std Dev = 0 mm
Std Dev = 4 mm
Std Dev = 13 mm
193
198
203
208
213
Mean Slab Thickness, mm
102
100
98
96
94
92
90
88
86
84
Individual Entrained Air Content PF, %
Target Mean = 6.0 %
Target Std Dev = 0.75 %
Std Dev = 0.0 %
Std Dev = 0.75 %
Std Dev = 1.5 %
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Mean Entrained Air Content, %
115
110
105
100
95
90
85
80
75
Individual Initial Smoothness PF, %
Std Dev = 0 mm/km
Std Dev = 47 mm/km
Std Dev = 95 mm/km
Target Mean = 379 mm/km
Target Std Dev = 47 mm/km
0
100
200
300
400
500
600
700
Mean Initial Smoothness, mm/km

Figure 12.

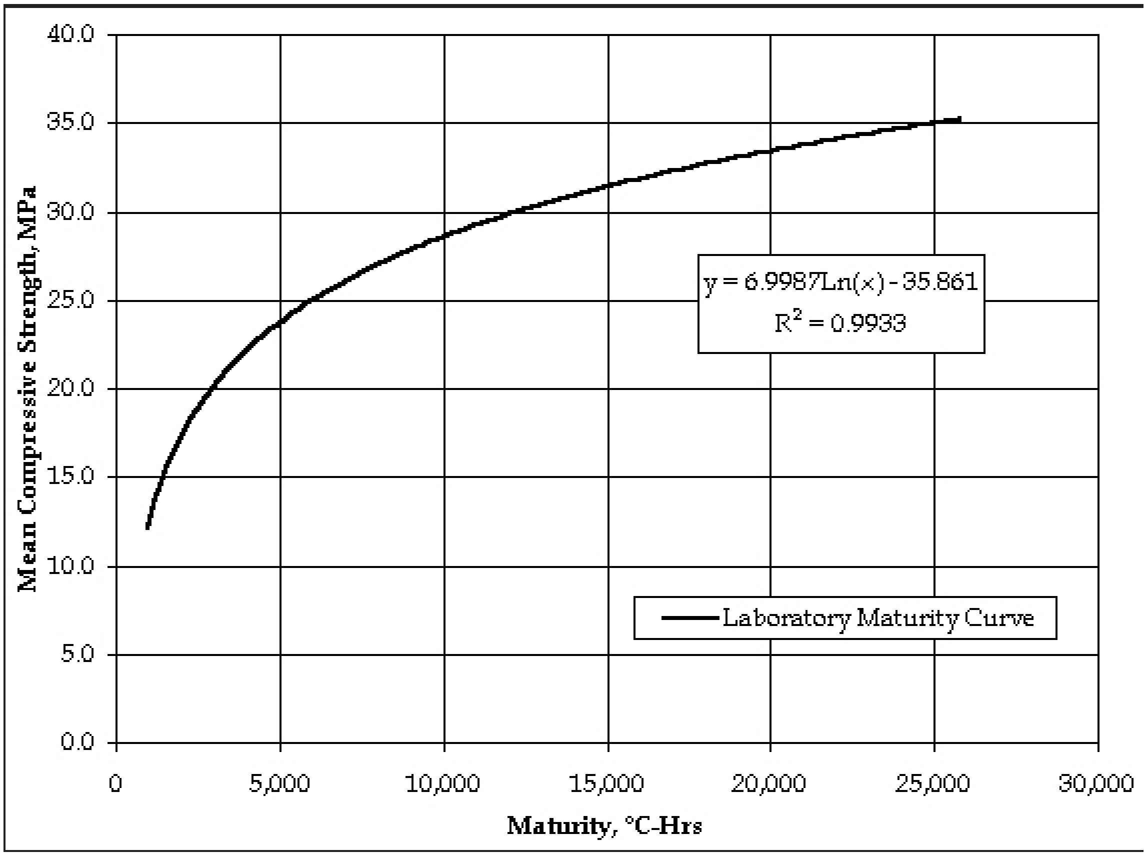


Figure 13.

Summaries of the Level 1 and Level 2 samples collected for each lot (using the sampling and testing procedures outlined in tables 15 and 16) are presented in tables 18 and 19, respectively.

Table 18. Summary of Level 1 field sampling and testing results for each lot.

LOT 1						
Construction Date	**Sublot**	**Sample Number**	**Measured 28-day Flexural Strength (from beams), MPa**	**Slab Thickness, mm**	**Plastic Entrained Air Content, %**	**Initial Smoothness, mm/km**
10/1/96	1.1	1	4.83	303	7.2	68
		2	4.65	298	7.3	44
	1.2	1	4.79	305	6.3	71
		2	4.55	316	6.6	8

	1.3	1	5.10	313	8.4	14
		2	4.79	307	7.3	14
Average	—	—	4.78	307	7.2	36
Std Dev	—	—	0.20	7	0.8	30
LOT 2						
Construction Date	**Sublot**	**Sample Number**	**Measured 28-day Flexural Strength (from beams), MPa**	**Slab Thickness, mm**	**Plastic Entrained Air Content, %**	**Initial Smoothness, mm/km**
10/2/96	2.1	1	4.79	307	7.6	47
		2	5.03	304	6.7	8
	2.2	1	4.65	318	7.3	71
		2	5.00	318	7.0	13
	2.3	1	4.79	309	8.2	84
		2	4.83	306	6.7	96
	2.4	1	4.90	302	7.2	122
		2	4.59	302	7.2	47
Average	—	—	4.82	308	7.2	62
Std Dev	—	—	0.16	7	0.5	41
LOT 3						
Construction Date	**Sublot**	**Sample Number**	**Measured 28-day Flexural Strength (from beams), MPa**	**Slab Thickness, mm**	**Plastic Entrained Air Content, %**	**Initial Smoothness, mm/km**
10/3/96	3.1	1	4.34	310	7.8	169
		2	5.07	316	8.2	79
	3.2	1	4.90	307	7.2	140
		2	4.38	312	8.3	57
	3.3	1	4.48	315	7.2	153
		2	4.52	310	8.1	13
	3.4	1	4.93	315	7.8	155
		2	4.69	296	7.6	55

Average	—	—	4.66	310	7.8	103
Std Dev	—	—	0.29	7	0.4	61

Table 19. Summary of Level 2 field sampling and testing results for each lot.

LOT 1						
Construction Date	**Sublot**	**Sample Number**	**Estimated 28-day Flex. Str. (from 4-day cores), MPa**	**Slab Thickness, mm**	**Plastic Entrained Air Content, %**	**Initial Smoothness, mm/km**
10/1/96	1.1	1	4.88	303	7.2	68
		2	4.60	298	7.3	44
	1.2	1	4.67	305	6.3	71
		2	4.69	316	6.6	8
	1.3	1	4.64	313	8.4	14
		2	4.70	307	7.3	14
Average	—	—	4.70	307	7.2	36
Std Dev	—	—	0.10	7	0.8	30
LOT 2						
Construction Date	**Sublot**	**Sample Number**	**Estimated 28-day Flex. Str. (from 4-day cores), MPa**	**Slab Thickness, mm**	**Plastic Entrained Air Content, %**	**Initial Smoothness, mm/km**
10/2/96	2.1	1	4.83	307	7.6	47
		2	5.06	304	6.7	8
	2.2	1	4.89	318	7.3	71
		2	4.96	318	7.0	13
	2.3	1	4.92	309	8.2	84
		2	4.84	306	6.7	96
	2.4	1	5.02	302	7.2	122
		2	4.95	302	7.2	47
Average	—	—	4.93	308	7.2	62

Std Dev	—	—	0.08	7	0.5	41
LOT 3						
Construction Date	**Sublot**	**Sample Number**	**Estimated 28-day Flex. Str. (from 4-day cores), MPa**	**Slab Thickness, mm**	**Plastic Entrained Air Content, %**	**Initial Smoothness, mm/km**
10/3/96	3.1	1	4.86	310	7.8	169
		2	4.89	316	8.2	79
	3.2	1	4.95	307	7.2	140
		2	4.82	312	8.3	57
	3.3	1	4.90	315	7.2	153
		2	4.92	310	8.1	13
	3.4	1	4.76	315	7.8	155
		2	4.89	296	7.6	55
Average	—	—	4.88	310	7.8	103
Std Dev	—	—	0.06	7	0.4	61

Calculation Of Shadow Pay Factors

Level 1 Pay Factors

The Level 1 shadow pay factors were calculated using the measured AQC lot means and standard deviations presented in table 18. The measured standard deviations are then used to select the appropriate equations from table 14. (Note: The appropriate equations are those developed for standard deviation values nearest to the measured value.) Level 1 AQC pay factors are then determined by interpolating between pay factors computed using the selected appropriate equations. A detailed explanation of the calculation of the lot 1 pay factors is contained below. The same procedures were used to calculate pay factors for lots 2 and 3.

Pay Factor Calculations for Lot 1

The measured as-constructed AQC means and standard deviations representing lot 1 are the following:

- 28-day Flexural Strength: Mean = 4.78 MPa, Std Dev = 0.20 MPa.
- Slab Thickness: Mean = 307 mm, Std Dev = 7 mm.
- Entrained Air Content: Mean = 7.2%, Std Dev = 0.8%.
- Initial Smoothness: Mean = 36 mm/km, Std Dev = 30 mm/km.

Lot 1 contains only three sublots; therefore, the equations (presented in table 14) representing the case of three sublots are used to calculate individual AQC pay factors.

Lot 1 As-Constructed 28-day Beam Flexural Strength (Mean = 4.78 MPa, Std Dev = 0.20 MPa):

At a mean of 4.78 MPa, and a standard deviation of 0.00 MPa:

$PF_{S\text{-}(4.78,\ 0.00)} = -27.3878(4.78)^2 + 295.6802(4.78) - 665.9437 = 121.64\%$ (6)

At a mean of 4.78 MPa, and a standard deviation of 0.45 MPa:

$PF_{S\text{-}(4.78,\ 0.45)} = -17.8866(4.78)^2 + 214.0493(4.78) - 500.0361 = 114.44\%$ (7)

The pay factor for the case with strength mean and standard deviation equal to 4.78 and 0.20 MPa is interpolated (using an assumed linear relationship) by the following equation:

$PF_{S\text{-}(4.78,\ 0.20)} = PF_{S\text{-}(4.78,\ 0.45)} + (PF_{S\text{-}(4.78,\ 0.00)} - PF_{S\text{-}(4.78,\ 0.45)}) * [(0.45\text{ MPa} - 0.20\text{ MPa}) / (0.45\text{ MPa} - 0.00\text{ MPa})]$ (8)

$= 114.44\% + (121.64\% - 114.44\%) * [(0.25\text{ MPa})/(0.45\text{ MPa})]$

$= 118.44\%$

Lot 1 As-Constructed Thickness (Mean = 307 mm, Std Dev = 7 mm):

At a mean of 307 mm, and a standard deviation of 6 mm:

$PF_{T\text{-}(307,\ 6)} = 1.6254(307) - 360.3357 = 138.66\%$ (9)

At a mean of 307 mm, and a standard deviation of 13 mm:

$PF_{T\text{-}(307,\ 13)} = 1.6887(307) - 381.1839 = 137.25\%$ (10)

The pay factor for the case with thickness mean and standard deviation equal to 307 and 7 mm is interpolated (using an assumed linear relationship) by the following equation:

$PF_{T\text{-}(307,\ 7)} = PF_{T\text{-}(307,\ 13)} + (PF_{T\text{-}(307,\ 7)} - PF_{T\text{-}(307,\ 13)}) * [(13\text{ mm} - 7\text{ mm}) / (13\text{ mm} - 6\text{ mm})]$ (11)

$= 137.27\% + (138.66\% - 137.27\%) * [(6\text{ mm})/(7\text{ mm})]$

$= 138.46\%$

Lot 1 As-Constructed Entrained Air Content (Mean = 7.2%, Std Dev = 0.8%):

The computed as-constructed entrained air content mean was found to be greater than the target mean strength value of 7.0 percent. When this case occurs, the pay factors are assumed to be held constant at the pay factor values computed using the target mean. Therefore, individual entrained air content pay factors were computed with an assumed mean equal to 7.0 percent.

At a mean of 7.0 percent and a standard deviation of 0.5 percent:

$PF_{A\text{-}(7.0,\ 0.5)} = 1.825(7.0) + 87.225 = 100.00\%$ (12)

At a mean of 7.0 percent and a standard deviation of 1.5 percent:

$PF_{A\text{-}(7.0,\ 1.5)} = 1.675(7.0) + 87.425 = 99.15\%$ (13)

The pay factor for the case with entrained air content mean and standard deviation equal to 7.0 and 0.8 percent, respectively, was interpolated (using an assumed linear relationship) by the following equation:

$PF_{A\text{-}(7.0,\ 0.8)} = PF_{A\text{-}(7.0,\ 1.5)} + (PF_{A\text{-}(7.0,\ 0.5)} - PF_{S\text{-}(7.0,\ 1.5)}) * [(1.5\% - 0.8\%) / (1.5\% - 0.5\%)]$ (14)

$= 99.15\% + (100.00\% - 99.15\%) * [(0.7\%)/(1.0\%)]$

$= 99.75\%$

This computed value is, therefore, used to represent the case where entrained air content mean and standard deviation are equal to 7.2 and 0.8 percent, respectively.

Lot 1 As-Constructed Initial Smoothness (Mean = 36 mm/km, Std Dev = 30 mm/km):

At a mean of 36 mm/km, and a standard deviation of 16 mm/km:

$PF_{SM\text{-}(36,\ 16)} = -7.6401E\text{-}07(36)^3 - 2.941E\text{-}04(36)^2 - 3.7398E\text{-}04(36) + 102.23$ (15)

$= 101.80\%$

At a mean of 36 mm/km, and a standard deviation of 47 mm/km:

$PF_{SM\text{-}(36,\ 47)} = -7.6401E\text{-}07(36)^3 - 2.941E\text{-}04(36)^2 - 3.7398E\text{-}04(36) + 100.48$ (16)

$= 100.05\%$

The pay factor for the case with initial smoothness mean and standard deviation equal to 36 and 30 mm/km is interpolated (using an assumed linear relationship) by the following equation:

$PF_{SM\text{-}(36,\ 30)} = PF_{SM\text{-}(36,\ 47)} + (PF_{SM\text{-}(36,\ 16)} - PF_{SM\text{-}(36,\ 47)}) * [(47\text{ mm/km} - 30\text{ mm/km}) / (47\text{ mm/km} - 16\text{ mm/km})]$ (17)

$= 100.05\% + (101.80\% - 100.05\%) * [(17\text{ mm/km}) / (31\text{ mm/km})]$

$= 101.01\%$

Calculation of the Lot 1 Composite Pay Factor Equation

Finally, the overall lot CPF is computed as a function of the individually determined AQC pay factors. The product method was chosen to define the CPF equation at the Iowa field trial. The product CPF method involves multiplying the individual AQC pay factors (expressed as decimals, e.g., 103 percent = 1.03). The resulting lot CPF equation is expressed as the following:

$CPF_{LOT} = PF_S * PF_T * PF_A * PF_{SM}$ (18)

where

PF_S = Independently determined pay factor (expressed as a decimal) for concrete strength.

PF_T = Independently determined pay factor (expressed as a decimal) for slab thickness.

PF_A = Independently determined pay factor (expressed as a decimal) for entrained air content.

PF_{SM} = Independently determined pay factor (expressed as a decimal) for initial smoothness.

More information on selecting CPF equations is contained in chapter 6 of volume I, in the section titled *Defining a Level 1 Composite Pay Factor Equation*.

For the Iowa shadow field trial, the lot 1 CPF was computed as follows, using equation 18:

$$CPF_{LOT} = PF_S * PF_T * PF_A * PF_{SM}$$

$$= (1.1844) * (1.3846) * (0.9975) * (1.0001) = 1.6360$$

which translates to 163.6%.

A practical overall lot pay factor cap of 110 percent was then applied for demonstration purposes. This chosen maximum value would be subjectively determined (for budgetary purposes) by each SHA. More information on choosing limits for computed CPF's is contained in chapter 6 of volume I, in the section titled *Selecting Pay Factor Limits*.

To better illustrate the basis of the PRS method, table 20 shows a comparison of typical as-constructed distresses for lot 1 (based on the computed lot 1 AQC Level 1 means discussed in this section) to the typical distresses estimated for the as-designed pavement (presented previously in table 9). (Note: Only the first 50 years of the 60-year analysis life are displayed in table 20.) The distress data show that the as-designed pavement would typically require an asphalt overlay at year 35, while the quality measured for the as-constructed lot 1 would postpone the first year of overlay until year 45.

Table 20. Comparison of typical as-designed distresses over time to typical distresses representing the as-constructed lot 1 (level 1 samples) at the Iowa field trial project.

		Avg Faulting (mm/joint)		Total Transverse Cracking (m/km)		Transverse Joint Spalling (No. spalled joints/km)		PSR	
Year	Cumulative ESAL's (millions)	AD	AC Lot 1	AD	AC Lot 1	AD	AC Lot 1	AD	AC Lot 1
Initial	0.00	0.00	0.00	0	0	0	0	4.64	4.84
1	0.42	0.10	0.08	37	20	0	0	4.63	4.83
2	0.85	0.14	0.12	52	29	0	0	4.44	4.76
3	1.27	0.17	0.15	64	35	0	0	4.36	4.66
4	1.69	0.20	0.17	74	41	0	0	4.32	4.63
5	2.11	0.23	0.20	83	45	1	1	4.27	4.62

6	2.54	0.25	0.22	90	50	1	1	4.23	4.59
7	2.96	0.27	0.23	98	54	1	1	4.20	4.57
8	3.38	0.29	0.25	104	57	1	1	4.15	4.54
9	3.80	0.31	0.27	111	61	1	1	4.12	4.53
10	4.23	0.33	0.28	117	64	2	2	4.08	4.50
11	4.65	0.35	0.30	123	67	2	2	4.05	4.48
12	5.07	0.36	0.31	128	70	2	2	4.02	4.45
13	5.50	0.38	0.32	134	73	3	3	3.97	4.42
14	5.92	0.39	0.34	139	76	4	4	3.88	4.39
15	6.34	0.41	0.35	144	79	4	4	3.85	4.36
16	6.76	0.42	0.36	148	81	5	5	3.81	4.33
17	7.19	0.43	0.37	153	84	6	6	3.78	4.32
18	7.61	0.45	0.39	158	86	7	7	3.74	4.24
19	8.03	0.46	0.40	162	89	7	7	3.70	4.21
20	8.45	0.47	0.41	166	91	8	8	3.67	4.18
21	8.88	0.49	0.42	171	93	9	9	3.62	4.15
22	9.30	0.50	0.43	175	96	10	10	3.58	4.12
23	9.72	0.51	0.44	179	98	11	11	3.53	4.07
24	10.14	0.52	0.45	183	100	12	12	3.50	4.05
25	10.57	0.53	0.46	187	102	14	14	3.46	4.01
26	10.99	0.54	0.47	191	104	14	14	3.41	3.98
27	11.41	0.55	0.48	195	106	16	16	3.35	3.94
28	11.83	0.57	0.49	199	108	17	17	3.31	3.89
29	12.26	0.58	0.50	202	110	19	19	3.26	3.86
30	12.68	0.59	0.50	206	112	20	20	3.22	3.81
31	13.10	0.60	0.51	210	114	21	21	3.16	3.77
32	13.53	0.61	0.52	213	116	23	23	3.11	3.72
33	13.95	0.62	0.53	217	118	24	24	3.06	3.69
34	14.37	0.63	0.54	221	120	26	26	3.00	3.63
35	14.79	0.64	0.55	224	121	28	28	4.50	3.58
36	15.22	0.00	0.56	0	123	0	30	4.43	3.54
37	15.64	0.00	0.56	0	125	0	32	4.35	3.48
38	16.06	0.00	0.57	0	127	0	34	4.28	3.44

39	16.48	0.00	0.58	0	128	0	35	4.20	3.38
40	16.91	0.00	0.59	0	130	0	37	4.13	3.33
41	17.33	0.00	0.60	0	132	0	39	4.05	3.26
42	17.75	0.00	0.60	0	134	0	42	3.98	3.21
43	18.17	0.00	0.61	0	135	0	43	3.90	3.15
44	18.60	0.00	0.62	0	137	0	46	3.83	3.09
45	19.02	0.00	0.63	0	139	0	48	3.75	4.50
46	19.44	0.00	0.00	0	0	0	0	3.68	4.43
47	19.87	0.00	0.00	0	0	0	0	3.60	4.35
48	20.29	0.00	0.00	0	0	0	0	3.53	4.28
49	20.71	0.00	0.00	0	0	0	0	3.45	4.20
50	21.13	0.00	0.00	0	0	0	0	3.38	4.13

All of the calculated Level 1 pay factors for lots 1, 2, and 3 are summarized in table 21.

Table 21. Summary of Level 1 AQC values and calculated pay factors.

LOT 1				
Acceptance Quality Characteristic	**Statistic**	**As-Des. Targets**	**As-Con. Values**	**Computed Level 1 Pay Factors, %**
28-day Flex Strength, MPa	Mean	4.48	4.78	118.4
	Std Dev	0.45	0.20	
Slab Thickness, mm	Mean	283	307	138.5
	Std Dev	6	7	
Plastic Entrained Air Content, %	Mean	7.0	7.2	99.8
	Std Dev	0.5	0.8	
Initial Smoothness, mm/km	Mean	79	36	101.0
	Std Dev	16	30	
Lot 1—Level 1 CPF				163.6 (110.0 cap)
LOT 2				
Acceptance Quality Characteristic	**Statistic**	**As-Des. Targets**	**As-Con. Values**	**Computed Level 1 Pay Factors, %**

28-day Flex Strength, MPa	Mean	4.48	4.82	120.5
	Std Dev	0.45	0.16	
Slab Thickness, mm	Mean	283	308	140.1
	Std Dev	6	7	
Plastic Entrained Air Content, %	Mean	7.0	7.2	100.0
	Std Dev	0.5	0.5	
Initial Smoothness, mm/km	Mean	79	62	99.5
	Std Dev	16	41	
Lot 2—Level 1 CPF				168.0 (110.0 cap)
LOT 3				
Acceptance Quality Characteristic	**Statistic**	**As-Des. Targets**	**As-Con. Values**	**Computed Level 1 Pay Factors, %**
28-day Flex Strength, MPa	Mean	4.48	4.66	111.9
	Std Dev	0.45	0.29	
Slab Thickness, mm	Mean	283	310	143.4
	Std Dev	6	7	
Plastic Entrained Air Content, %	Mean	7.0	7.8	100.1
	Std Dev	0.5	0.4	
Initial Smoothness, mm/km	Mean	79	103	96.5
	Std Dev	16	61	
Lot 3—Level 1 CPF				155.0 (110.0 cap)

Level 2 Pay Factors

The Level 2 pay factors were determined directly through simulation using the measured as-constructed means and standard deviations (presented in table 19). Pay factors were simulated (from 500 simulated lots and including 5-percent user costs) using both sets of flexural strength data (i.e., directly from 28-day beam breaks and estimated from 4-day core compressive strengths using maturity concepts). All of the calculated Level 2 pay factors for lots 1, 2, and 3 are summarized in table 22.

Table 22. Summary of Level 2 AQC values and calculated pay factors.

LOT 1				
Acceptance Quality Characteristic	Statistic	As-Des. Targets	As-Constructed Results (including different strength results)	
			Est. from 28-day beams	Est. from 4-day cores
28-day Flex Strength, MPa	Mean	4.48	4.78	4.70
	Std Dev	0.45	0.20	0.10
Slab Thickness, mm	Mean	283	307	
	Std Dev	6	7	
Plastic Entrained Air Content, %	Mean	7.0	7.2	
	Std Dev	0.5	0.8	
Initial Smoothness, mm/km	Mean	79	36	
	Std Dev	16	30	
Lot 1—Level 2 Simulated Pay Factors			142.3 (110.0% cap)	136.3 (110.0% cap)
LOT 2				
Acceptance Quality Characteristic	Statistic	As-Des. Targets	As-Constructed Results (including different strength results)	
			Est. from 28-day beams	Est. from 4-day cores
28-day Flex Strength, MPa	Mean	4.48	4.82	4.93
	Std Dev	0.45	0.16	0.08
Slab Thickness, mm	Mean	283	308	
	Std Dev	6	7	
Plastic Entrained Air Content, %	Mean	7.0	7.2	
	Std Dev	0.5	0.5	
Initial Smoothness, mm/km	Mean	79	62	
	Std Dev	16	41	

Lot 2—Level 2 Simulated Pay Factors			143.0 (110.0% cap)	136.3 (110.0% cap)
LOT 3				
Acceptance Quality Characteristic	**Statistic**	**As-Des. Targets**	**As-Constructed Results (including different strength results)**	
			Est. from 28-day beams	**Est. from 4-day cores**
28-day Flex Strength, MPa	Mean	4.48	4.66	4.88
	Std Dev	0.45	0.29	0.06
Slab Thickness, mm	Mean	283	310	
	Std Dev	6	7	
Plastic Entrained Air Content, %	Mean	7.0	7.8	
	Std Dev	0.5	0.4	
Initial Smoothness, mm/km	Mean	79	103	
	Std Dev	16	61	
Lot 3—Level 2 Simulated Pay Factors			134.2 (110.0% cap)	130.8 (110.0% cap)

Summary Of Lessons Learned

A number of valuable lessons were learned from the original field trial experience. A few of these are summarized briefly below.

- *Fix the sublot length to one constant value*—It quickly became apparent that varying sublot lengths in the field causes much confusion. As a result of the original field trial experience, it is recommended that one target sublot length be chosen and used to lay out all sublots prior to the paving of each lot. This can be done on a day-by-day (lot-by-lot) basis.

- *Choose a practical target sublot length*—It also became obvious that the sublot length chosen for the first day of paving (0.16 km) was impractical for the type and amount of sampling and testing being conducted. There simply was not enough time to complete all of the testing and get to the next randomly selected location. Therefore, it is important to consider the type and amount of sampling and testing required, the personnel available, and the location of the testing facilities relative to the job site when choosing an appropriate target sublot length.

- *Choose a minimum length between longitudinal sampling locations*—As previously stated, it was often very difficult to conduct sampling at the randomly selected locations due to the selection of sampling locations that were too close to each other. In response to this problem, it is recommended that the SHA decide on a practical minimum length between sampling locations when samples are required to be taken from the fresh concrete during the construction process.

- *Limit pay factors to chosen practical maximum values*—The original field trial demonstrated the need for SHA's to select practical maximum pay factors. At the field trial, the contractor generally provided an extra 25 mm of pavement thickness on each of the three investigated lots. This extra thickness resulted in relatively large pay factors. Since it would be impossible for almost any SHA to make pay adjustments of this magnitude, it is realized that the pay factors will need to be capped at some agency-chosen practical value. The pay factor maximums could be applied to the individual AQC pay factors, the overall lot pay factor, or both. For demonstration purposes at the original field trial, the final overall pay factor was capped at 110 percent for both specification levels.

Summary

This chapter summarizes the results of the first shadow field trial conducted to demonstrate the prototype PRS.(1-3) The Level 1 method proved to be a valid, practical PRS method that should be easily implementable by most SHA's. All aspects of the field trial were discussed, including definitions of lots and sublots, the developed sampling and testing plan, and shadow PRS pay adjustment calculations. Valuable experience was obtained from the Iowa field trial, and all of the lessons learned were used to revise the prototype PRS developed under the previous FHWA research.(1-3)

Additional OTA Shadow Field Trials

Introduction

Three additional PRS prototype shadow field trials were conducted in conjunction with FHWA OTA personnel during the 1997 construction season. The objectives of these additional field trials were twofold: (1) to continue the verification of the overall PRS prototype approach (including the sampling and testing methods), and (2) to familiarize OTA personnel with the general PRS concepts while allowing them to gain experience in the application of the prototype PRS approach on actual construction projects.

Three different field trials were selected for investigation by OTA personnel. These included projects in Albuquerque, New Mexico; Poplar Bluff, Missouri; and Manhattan, Kansas. Both the Level 1 and Level 2 PRS prototypes were demonstrated at each of the projects. Pay factors were computed for each project based on the acceptance of four different AQC's: concrete strength, slab thickness, air content, and initial smoothness. AQC sampling and testing methods were based on SHA standard procedures. Appropriate PRS-related AQC sampling and testing was conducted at each project by OTA personnel (using the OTA concrete trailer).

This chapter discusses all of the pertinent details related to each project demonstration, including details of the specification development, the conducted sampling and testing, and the computation of shadow pay factors.

State-Specific Level 1 Pay Factor Charts for Different Typical Designs

Introduction

A second method used to demonstrate the Level 1 PRS prototype specification involved developing general pay factor charts for typical designs within a chosen SHA. As a follow-up to the original shadow field trial, the research team developed Level 1 pay factor charts representative of three typical pavement designs used in Iowa. The objectives of this exercise were twofold:

1. To demonstrate how the Level 1 prototype approach can be used by a SHA to develop pay factor charts for commonly used designs—each chart being specific to a particular road classification and climatic region.

2. To illustrate an example of the trends that may occur between different pay factor charts developed for different pavement classes.

This chapter explains the details of selecting the different pavement designs, the development of the respective pay factor charts, an analysis of the observed trends within and between the developed charts, and the conclusions and recommendations resulting from this exercise.

Defining Three Different Pavement Designs

The first step was the selection of three typical PCC pavement designs used in Iowa. Each pavement design was selected to be specific to an assumed traffic level representing medium, heavy, or very heavy traffic. All three pavement designs were assumed to have a 40-year design life. The chosen cumulative ESAL values (over the 40-year design lives) for each of the chosen traffic classifications consisted of the following:

- Medium Traffic: 2.5 million ESAL’s
- Heavy Traffic: 7.5 million ESAL’s
- Very Heavy Traffic: 30.0 million ESAL’s

Definition Of Pavement Performance

For the development of these pay factor charts, pavement performance was defined in terms of all of the four available distress indicators (i.e., transverse slab cracking, transverse joint faulting, transverse joint spalling, and pavement smoothness over time).

Selection Of Acceptance Quality Characteristics

For the three chosen typical designs, Level 1 pay factor charts were developed for each of the following four AQC’s:

- Concrete Strength.
- Slab Thickness.
- Entrained Air Content.
- Initial Smoothness.

Selection Of Representative Constant Values

The representative constant values required to simulate the corresponding pay factor charts (for the three chosen designs) were determined based on information provided by Iowa SHA personnel. Values for the climatic-related variables and unit costs were assumed to be the same as those used at the original PRS field trial conducted in Wapello County, Iowa, in 1996 (see chapter 2 of this volume). More information on the selection of constant variables is presented in chapter 5 of volume I, in the section titled *Identification of Constant Variable Values*. The specific values chosen to represent each of the three typical designs are presented in table 71. (Note: The constant inputs presented in table 71 are those required by the old distress prediction models used in the prototype PaveSpec software.(1-3) These variables differ slightly from those constant values required by the new distress indicator models included in the revised PaveSpec 2.0 software [as shown in figure 1 of volume I].)

Table 71. Chosen constant variable values for the required PRS inputs for three typical pavement designs in Iowa.

Variable	Design 1 (Medium Traffic)	Design 2 (Heavy Traffic)	Design 3 (Very Heavy Traffic)
Project Information			
Pavement Type	Doweled, JPCP		
Road Location	Rural Setting		
Highway Type	Undivided	Divided	Divided
Design Life	40 years		
No. of Lanes in One Direction	1	2	2
Lane Width	3.7 m		
Joint Spacing	6.1 m		
Traffic Information			
Total Design Traffic	2.5 MESAL’s	7.5 MESAL’s	30.0 MESAL’s
Initial Year Traffic	62,500 ESAL’s	187,500 ESAL’s	750,000 ESAL’s
Traffic Growth Type	Simple Linear Trend		
Materials and Climatic Information			
Annual Temperature Range	22 ºC		
Freezing Index	750 degree-days		
Average Annual Precipitation	81.3 cm		
Projected Annual Freeze-Thaw Cycles	12		

	(at 7.6 cm below the pavement surface)			
	Salt Present	Yes		
	Joint Sealant Type	Liquid Asphalt		
Slab Support Information				
	Base Type	Granular		
	Modulus of Subgrade Reaction	40.7 MPa/m		
	Subgrade Soil Type	Fine-grained (AASHTO A4-A7)		
	Presence of Longitudinal Subdrains	Yes		
Load Transfer Information				
	Dowel Bar Diameter	3.2 cm	3.8 cm	3.8 cm
	Presence of Tied PCC Shoulder	Yes		
Cost Information				
	Construction Bid, Traffic Lanes (based on $\$86.32/\mathrm{m}^3$)	$\$17.89/\mathrm{m}^2$	$\$20.08/\mathrm{m}^2$	$\$23.32/\mathrm{m}^2$
	Cost of Asphalt Overlay	$\$10.76/\mathrm{m}^2$		
	Cost of Patching a Joint	$\$95.68/\mathrm{m}^2$		
	Cost of Replacing a Slab	$\$83.72/\mathrm{m}^2$		
	Assumed Asphalt Overlay Life	20 years		

Selection Of AQC Target Values

Four different AQC’s were chosen to demonstrate the Level 1 PRS approach for each of the three typical designs. These included 28-day flexural strength (third-point loading), slab thickness, plastic entrained air content (using a pressure meter), and initial smoothness (measured using a 5.1-mm blanking band). The AQC target means and standard deviations for each of the three designs were estimated by interpreting the current Iowa construction specifications. These values were determined using the same procedures utilized in determining the target values at the original Iowa field trial in 1996 (see the section titled *Definition of the Required As-Designed AQC Target Values* in chapter 2 of this volume). The chosen AQC as-designed target means and standard deviations are presented in table 72 (the actual specification design thickness means are shown as a comparative reference).

Table 72. Chosen AQC as-designed target values for three typical pavement designs in Iowa.

AQC	Design 1 (Medium Traffic)	Design 2 (Heavy Traffic)	Design 3 (Very Heavy Traffic)
28-day Flexural Strength (third-point loading)			
PRS Target Mean	4.48 MPa		
PRS Target Std Dev	0.45 MPa		
Slab Thickness			
Specification Design Mean	203 mm	229 mm	267 mm
PRS Target Mean	207 mm	233 mm	271 mm
PRS Target Std Dev	6 mm		
Entrained Air Content			
PRS Target Mean	7.0%		
PRS Target Std Dev	0.5%		
Initial Smoothness (5.1-mm blanking band)			
PRS Target Mean	79 m/km		
PRS Target Std Dev	16 mm/km		

Selection Of Simulation Parameters

A number of simulation-related parameters are required to simulate LCC's representing the as-designed and as-constructed pavement lots. The individual Level 1 AQC pay factor charts were simulated using the following simulation parameters:

- 80-year analysis life (twice the 40-year design life).
- 4 sublots per lot.
- 4 samples per sublot (for each AQC).
- 100 simulated lots for each simulated LCC.
- 5 percent of the computed user costs are included.

These simulation parameters are used in conjunction with the defined constant variable values and selected AQC target values to generate the preconstruction output.

Simulation Of AQC Pay Factor Charts And Corresponding Pay Factor Equations

The final step in the specification development process involves the development of the preconstruction output. For the Level 1 specification, this involves constructing individual pay factor charts (and corresponding pay factor equations) for the four AQC's. Individual AQC pay factors may be computed using these equations by knowing the as-constructed AQC lot means and standard deviations. (Note: Each pay factor chart is specific to the chosen constant values, target means, and standard deviations.)

Step-by-Step Procedure Used to Develop Individual Level 1 AQC Pay Factor Curves

The following step-by-step procedure was used to develop Level 1 pay factor charts and corresponding pay factor equations for the three typical Iowa designs. (Note: Each of these steps is accomplished using the PaveSpec PRS demonstration software.)

1. *Define the number of sublots per lot*. As mentioned previously, four sublots

2. *Define the number of samples per sublot*. A sampling frequency of four samples per sublot was used for each of the four AQC's. In a Level 1 PRS, we assume that all of the material in a lot is represented by the same statistical population. Based on this assumption, the total sample size *N* may be represented by the number of sublots, *n,* times the number of samples per sublot. Therefore, the total sample size N was 16 for the case of 4 sublots.

3. *Define the Level 1 AQC target means and standard deviations*. The Level 1 target as-designed AQC means and standard deviations for the three typical designs were defined in table 72.

4. *Choose a range of as-constructed means for each AQC*. Reasonable ranges of AQC means are selected that will define the values used in the PaveSpec simulations. These chosen ranges of AQC simulation means (based on the chosen AQC target values for each of the three designs) are presented in table 73.

Table 73. As-constructed AQC simulation mean ranges for the three typical

AQC	Design 1 (Medium Traffic)	Design 2 (Heavy Traffic)	Design 3 (Very Heavy Traffic)
28-day Flexural Strength (third-point loading), MPa	3.78 – 5.18		
Slab Thickness, mm	187 – 227	213 – 253	251 – 291
Entrained Air Content, %	0.0 – 7.0		
Initial Smoothness (5.1-mm blanking band), mm/km	0 – 240		

5. *Choose specific as-constructed AQC standard deviation levels for the simulation of pay factor curves*. The pay factor curves not only depend on the as-constructed AQC mean, but the as-constructed AQC standard deviation as well. Table 74 contains the three different standard deviation levels chosen (for each AQC) representing *very good, good, and poor* AQC quality control. These different levels of AQC standard deviation are used in the simulation of individual AQC pay

6.

Table 74. As-constructed AQC standard deviation levels for simulation

AQC	Design 1 (Medium Traffic)	Design 2 (Heavy Traffic)	Design 3 (Very Heavy Traffic)
28-day flexural strength (third-point loading), MPa	0.00, 0.45, 0.90		
Slab thickness, mm	0, 6, 13		
Entrained air content, %	0.0, 0.5, 1.5		
Initial smoothness (5.1-mm blanking band), mm/km	0, 16, 79		

6. *Simulate the target as-designed LCC's.* In order to calculate pay factors for different hypothetical levels of as-constructed AQC quality, the target as-designed LCC's had to first be simulated. The *PaveSpec* specification simulation software was used to estimate target as-designed LCC means (for each of the 3 chosen designs) from 100 simulation lots, for the case of 4 sublots per lot and 4 AQC samples per sublot. Each individual lot was simulated by randomly selecting AQC samples from the target value distributions summarized in table 72. The simulations were conducted using an 80-year analysis life (twice the 40-year design life) and include 5 percent of the calculated user costs. The resulting simulated Level 1 mean as-designed LCC values (for the case of four sublots) for the three respective typical designs, were

- Design 1 (Medium Traffic): $LCC_{DES(1)}$ = $668,709/km.
- Design 2 (Heavy Traffic): $LCC_{DES(2)}$ = $706,135/km.
- Design 3 (Very Heavy Traffic): $LCC_{DES(3)}$ = $722,795/km.

To better demonstrate the PRS method, the estimated typical distresses over time associated with each of the three Iowa designs (reflecting the chosen constant inputs and the AQC target means only) are presented in figure 14. These distresses reflect the predicted first overlay application at year 33 for Designs 1 and 2, and year 30 for design 3. The M & R plan defined for the original Iowa field trial was also used here.

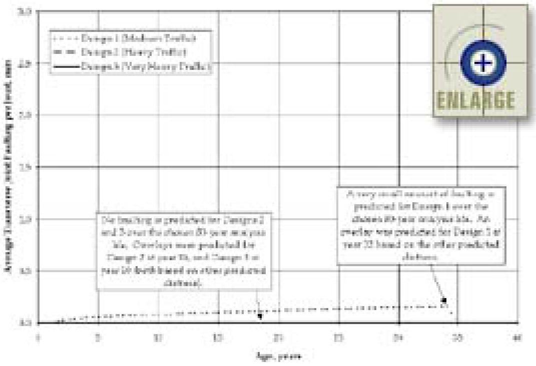
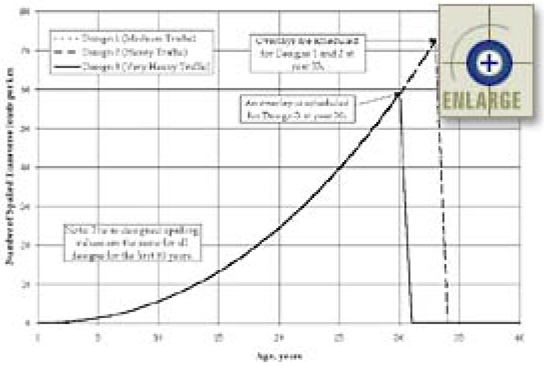
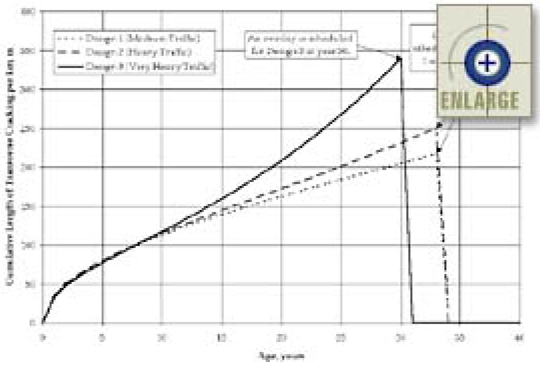
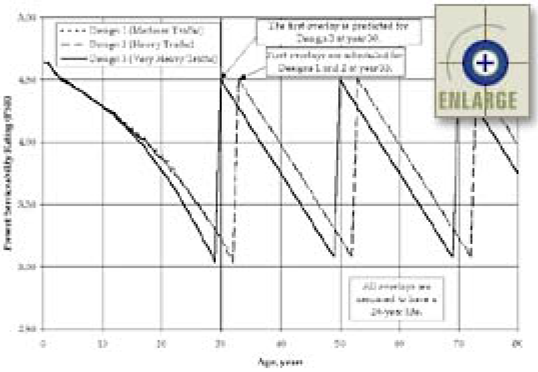


Figure 14. Estimated typical as-designed distresses over time associated with each of the three typical designs (reflecting the chosen constant inputs and the AQC target means only).







7. *Simulate as-constructed LCC's and calculate an independent AQC pay factor for each hypothetical as-constructed mean/standard deviation pair*. The hypothetical as-constructed mean/as-constructed standard deviation pair values (coming from combinations of means and standard deviations defined in steps 5 and 6, respectively) were used to define individual simulation sessions in the PaveSpec software. Each AQC was investigated independently for each session (for example, if strength was being investigated, all of the other AQC as-constructed means and standard deviations were set equal to the target values). Each pair was used in PaveSpec to simulate a corresponding LCC_{CON}. A pay factor was calculated for each pair using equation 5. The simulated pay factors (from PaveSpec) are summarized by AQC in tables 75 through 77.

8.

Table 75. Design 1 (medium traffic)—simulated Level 1 pay factors for four sublots and four samples per sublot (lot sample size N=16).

As-Constructed Means	Simulated pay factors at different as-constructed standard deviations, %		
28-day Flexural Strength (third-point loading), MPa	**SD = 0.00 MPa**	**SD = 0.45 MPa**	**SD = 0.90 MPa**
3.78	48.6	47.3	43.4
4.48	101.3	100.0	93.4
5.18	128.8	127.9	123.8
Slab Thickness, mm	**SD = 0 mm**	**SD = 6 mm**	**SD = 13 mm**
187	49.8	48.8	46.6
207	99.2	100.0	98.1
227	126.9	127.2	126.6
Entrained Air Content, %	**SD = 0.0%**	**SD = 0.5%**	**SD = 1.5%**
2.0	67.4	66.8	66.0
7.0	101.8	100.0	97.5
Initial Smoothness (0.0-mm blanking band), mm/km	**SD = 0 mm/km**	**SD = 16 mm/km**	**SD = 79 mm/km**
0	112.5	112.5	110.8
79	100.6	100.0	99.2
240	58.6	58.2	57.3

Table 76. Design 2 (heavy traffic)—simulated Level 1 pay factors for four sublots and four samples per sublot (lot sample size N=16).

As-Constructed Means	Simulated pay factors at different as-constructed standard deviations, %		
28-day Flexural Strength (third-point loading), MPa	**SD = 0.00 MPa**	**SD = 0.45 MPa**	**SD = 0.90 MPa**
3.78	70.9	67.7	61.6
4.48	100.5	100.0	94.9
5.18	115.9	116.1	113.5
Slab Thickness, mm	**SD = 0 mm**	**SD = 6 mm**	**SD = 13 mm**
213	74.7	73.4	71.5
233	100.7	100.0	99.5
253	114.4	114.3	114.0
Entrained Air Content, %	**SD = 0.0%**	**SD = 0.5%**	**SD = 1.5%**
2.0	77.1	76.9	76.7
7.0	101.0	100.0	98.5
Initial Smoothness (0.0-mm blanking band), mm/km	**SD = 0 mm/km**	**SD = 16 mm/km**	**SD = 79 mm/km**
0	107.1	107.1	106.0
79	100.5	100.0	99.9
240	79.1	78.8	78.4

Table 77. Design 3 (Very Heavy Traffic)—simulated Level 1 pay factors for four sublots and four samples per sublot (lot sample size N=16).

As-Constructed Means	Simulated pay factors at different as-constructed standard deviations, %		
28-day Flexural Strength (third-point loading), MPa	**SD = 0.00 MPa**	**SD = 0.45 MPa**	**SD = 0.90 MPa**
3.78	74.1	72.3	67.7
4.48	101.7	100.0	93.6
5.18	119.0	118.1	114.0
Slab Thickness, mm	**SD = 0 mm**	**SD = 6 mm**	**SD = 13 mm**
251	79.1	78.7	76.7
271	100.7	100.0	99.2
291	116.4	116.0	115.8
Entrained Air Content, %	**SD = 0.0%**	**SD = 0.5%**	**SD = 1.5%**
2.0	85.4	84.6	83.8
7.0	100.6	100.0	99.1
Initial Smoothness (0.0-mm blanking band), mm/km	**SD = 0 mm/km**	**SD = 16 mm/km**	**SD = 79 mm/km**
0	106.6	105.2	103.4
79	100.4	100.0	99.3
240	84.9	84.6	84.2

8. *Plot charts of pay factor vs. AQC mean*. The simulated pay factors determined in step 7 can easily be graphed as a function of the AQC mean. Each AQC pay factor chart contains three different curves corresponding to the three different standard deviation levels chosen in step 5. Best-fit regression equations were fit through each individual pay factor curve representing one chosen as-constructed AQC standard deviation. Figures 15 through 17 contain AQC pay factor charts representing the three typical Iowa pavement designs. The best-fit pay factor regression equations (at different as-constructed AQC standard deviations) for the three chosen typical designs are summarized in tables 78 through 80. (Note: All of these charts and pay factor equations are specific to the assumed simulation parameters of four sublots per lot and four AQC samples per sublot.)

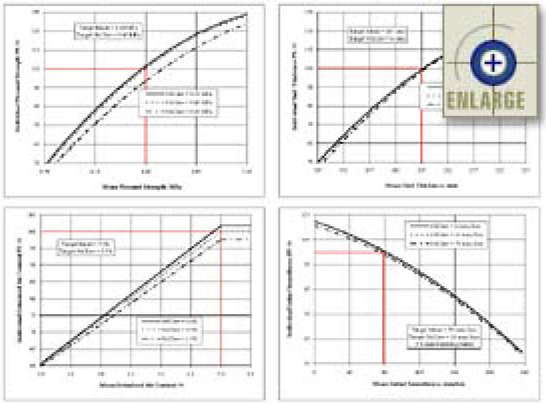


Figure 15. Design 1 (medium traffic)—simulated Level 1 individual AQC pay factor charts for the case of four sublots per lot and four samples per sublot (lot sample size N=16).

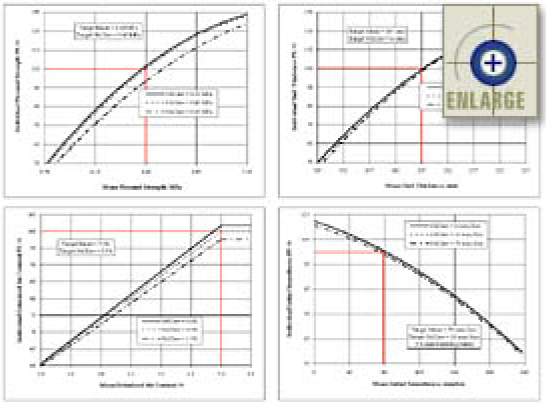


Figure 16. Design 2 (heavy traffic)—simulated Level 1 individual AQC pay factor charts for the case of four sublots per lot and four samples per sublot (lot sample size N=16).

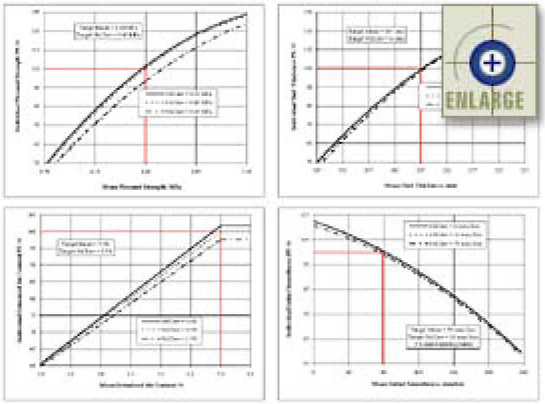


Figure 17. Design 3 (very heavy traffic)—simulated Level 1 individual AQC pay factor charts for the case of four sublots per lot and four samples per sublot (lot sample size N=16).

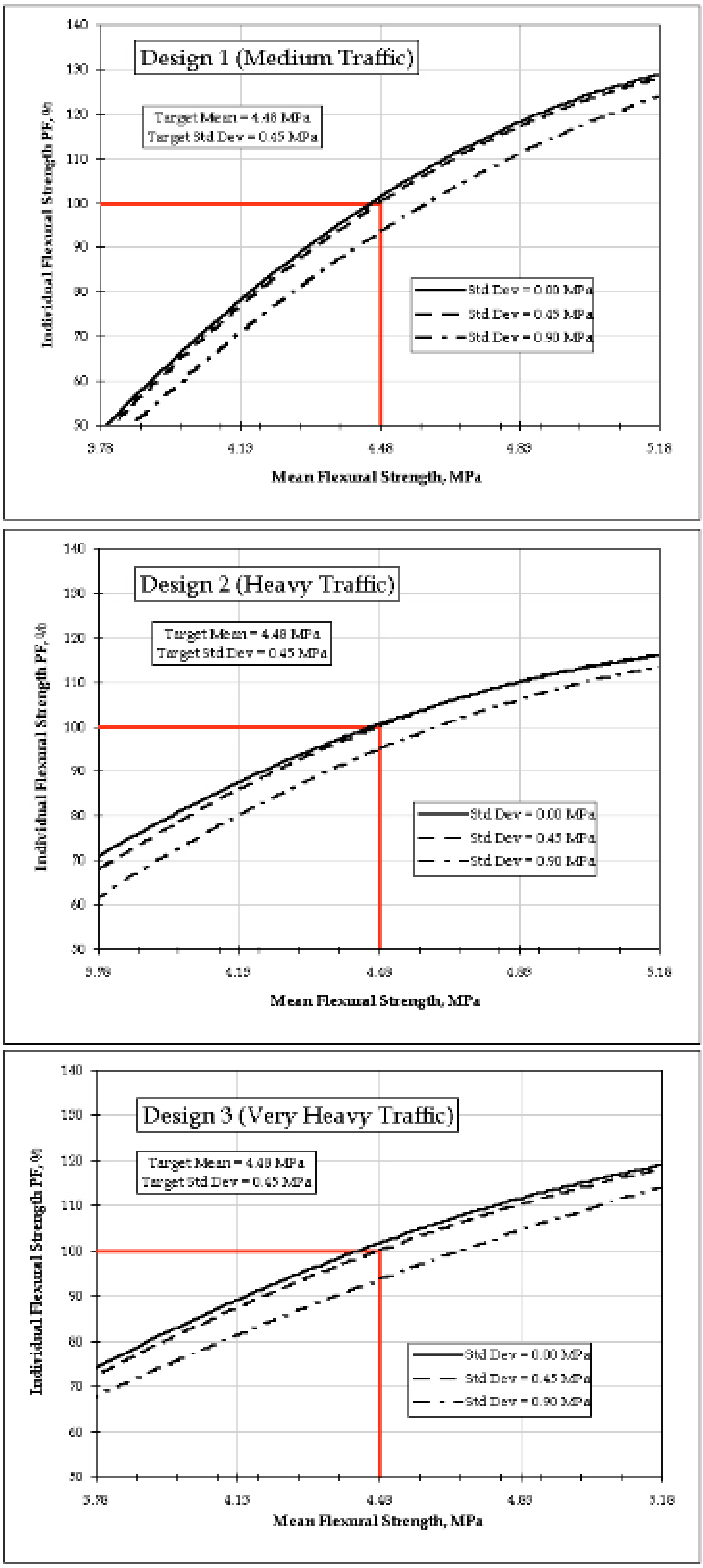

Design 1 (Medium Traffic)
Target Mean = 4.48 MPa
Target Std Dev = 0.45 MPa
Std Dev = 0.00 MPa
Std Dev = 0.45 MPa
Std Dev = 0.90 MPa
Individual Flexural Strength PF, %
Mean Flexural Strength, MPa
140
130
120
110
100
90
80
70
60
50
3.78
4.13
4.48
4.83
5.18
Design 2 (Heavy Traffic)
Target Mean = 4.48 MPa
Target Std Dev = 0.45 MPa
Std Dev = 0.00 MPa
Std Dev = 0.45 MPa
Std Dev = 0.90 MPa
Individual Flexural Strength PF, %
Mean Flexural Strength, MPa
140
130
120
110
100
90
80
70
60
50
3.78
4.13
4.48
4.83
5.18
Design 3 (Very Heavy Traffic)
Target Mean = 4.48 MPa
Target Std Dev = 0.45 MPa
Std Dev = 0.00 MPa
Std Dev = 0.45 MPa
Std Dev = 0.90 MPa
Individual Flexural Strength PF, %
Mean Flexural Strength, MPa
140
130
120
110
100
90
80
70
60
50
3.78
4.13
4.48
4.83
5.18

Figure 18.

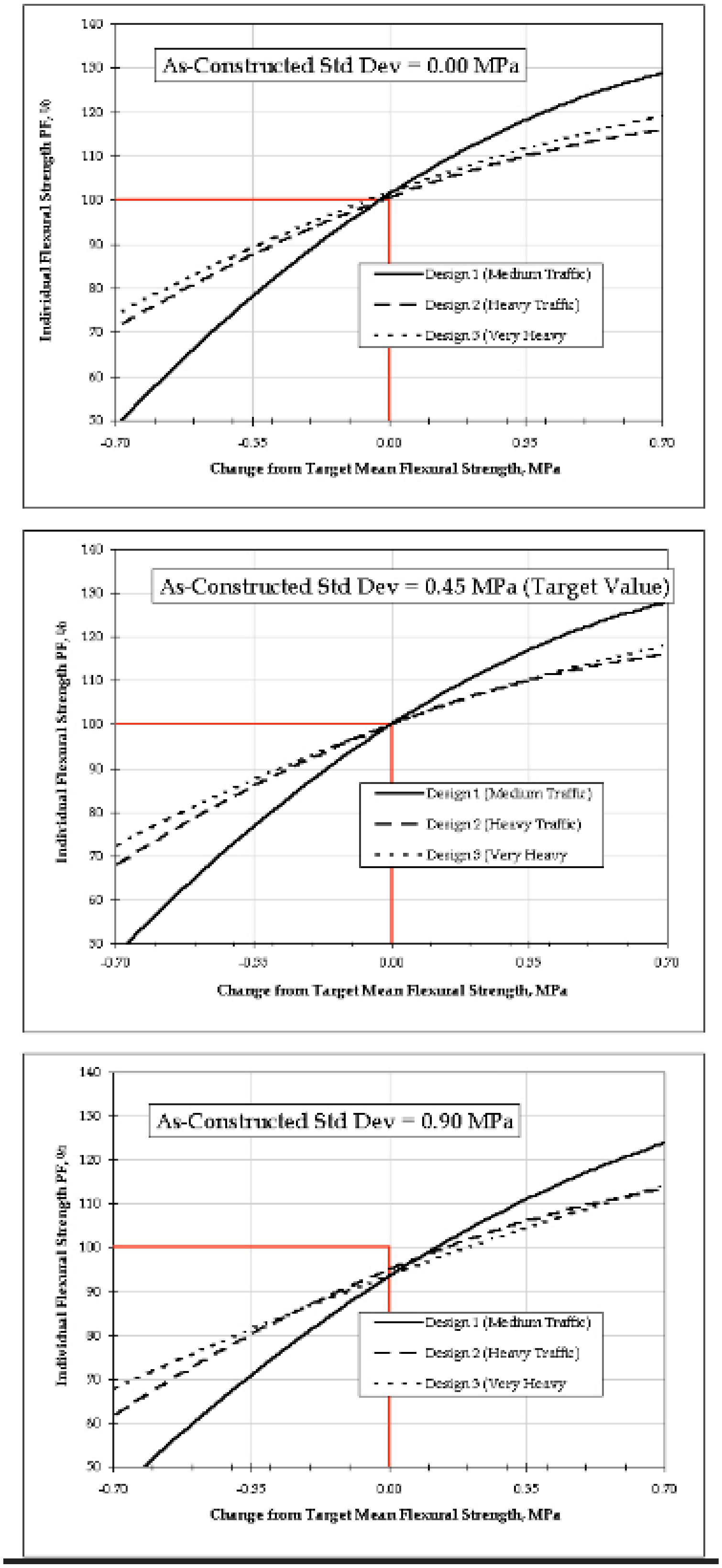
As-Constructed Std Dev = 0.00 MPa
As-Constructed Std Dev = 0.45 MPa (Target Value)
As-Constructed Std Dev = 0.90 MPa
Individual Flexural Strength PF, %
Change from Target Mean Flexural Strength, MPa
Design 1 (Medium Traffic)
Design 2 (Heavy Traffic)
Design 3 (Very Heavy
140
130
120
110
100
90
80
70
60
50
-0.70
-0.35
0.00
0.35
0.70

Figure 19.

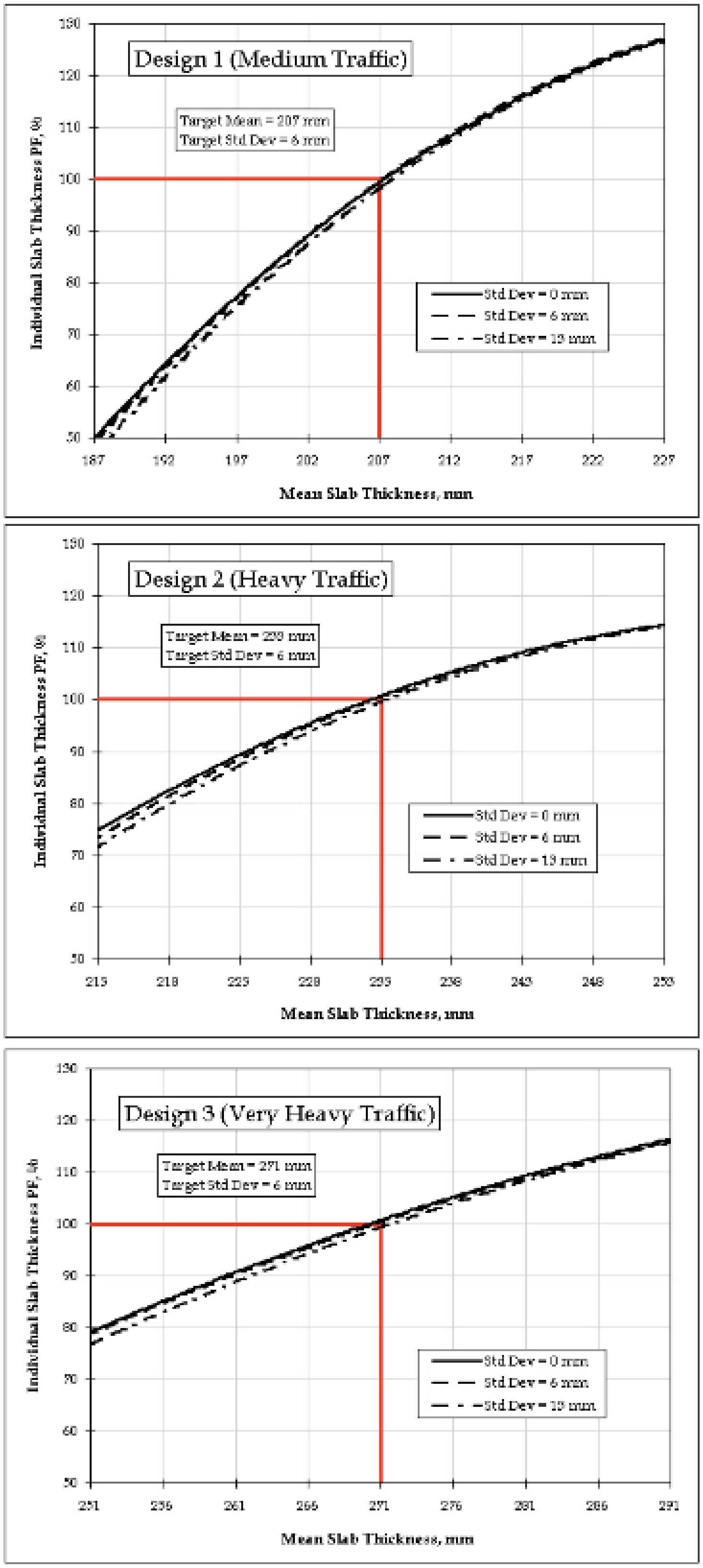

Design 1 (Medium Traffic)
Target Mean = 207 mm
Target Std Dev = 6 mm
Std Dev = 0 mm
Std Dev = 6 mm
Std Dev = 13 mm
Individual Slab Thickness PF, %
130
120
110
100
90
80
70
60
50
187
192
197
202
207
212
217
222
227
Mean Slab Thickness, mm
Design 2 (Heavy Traffic)
Target Mean = 233 mm
Target Std Dev = 6 mm
Std Dev = 0 mm
Std Dev = 6 mm
Std Dev = 13 mm
Individual Slab Thickness PF, %
130
120
110
100
90
80
70
60
50
213
218
223
228
233
238
243
248
253
Mean Slab Thickness, mm
Design 3 (Very Heavy Traffic)
Target Mean = 271 mm
Target Std Dev = 6 mm
Std Dev = 0 mm
Std Dev = 6 mm
Std Dev = 13 mm
Individual Slab Thickness PF, %
130
120
110
100
90
80
70
60
50
251
256
261
266
271
276
281
286
291
Mean Slab Thickness, mm

Figure 20.

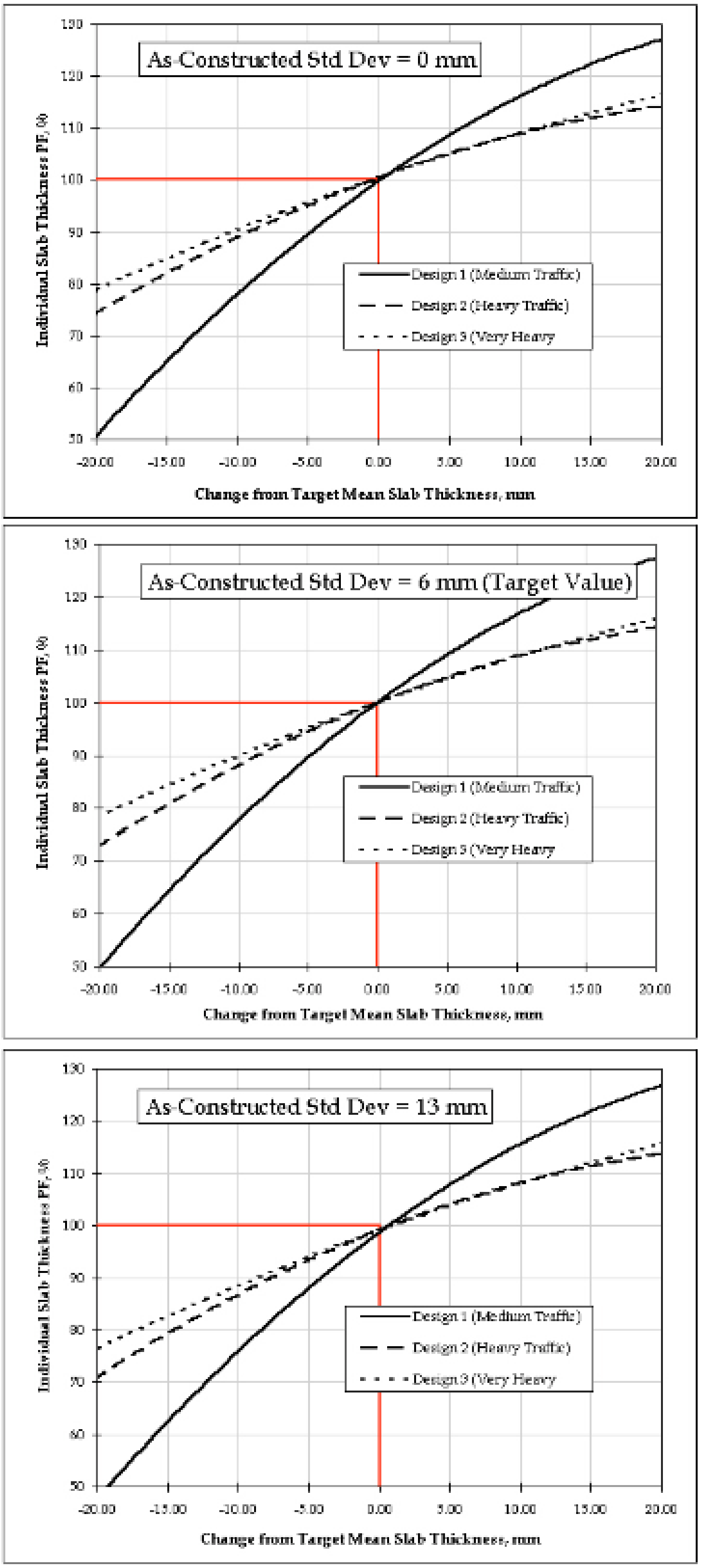

As-Constructed Std Dev = 0 mm
As-Constructed Std Dev = 6 mm (Target Value)
As-Constructed Std Dev = 13 mm
Individual Slab Thickness PF, %
Change from Target Mean Slab Thickness, mm
130
120
110
100
90
80
70
60
50
-20.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
20.00
Design 1 (Medium Traffic)
Design 2 (Heavy Traffic)
Design 3 (Very Heavy

Figure 21.

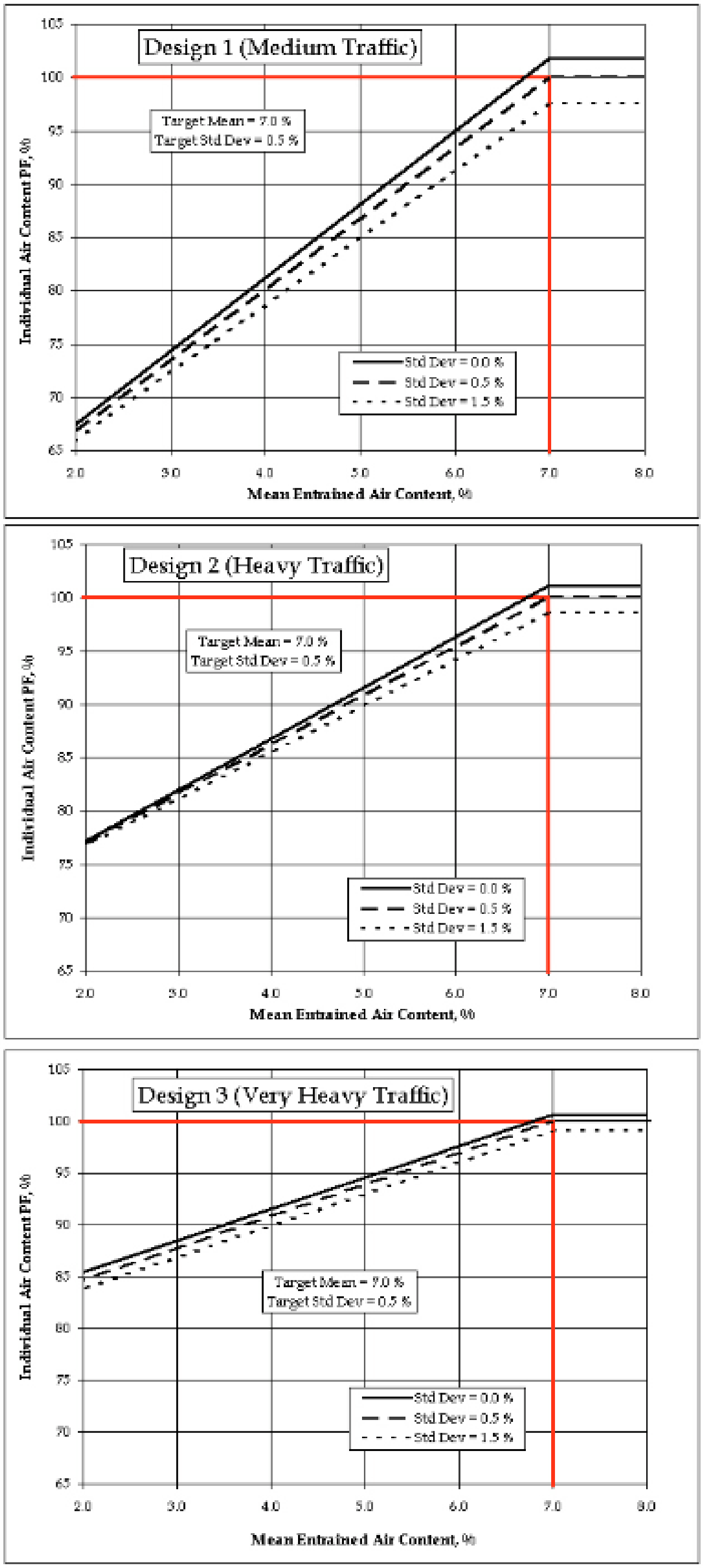

Design 1 (Medium Traffic)
Target Mean = 7.0 %
Target Std Dev = 0.5 %
Std Dev = 0.0 %
Std Dev = 0.5 %
Std Dev = 1.5 %
Individual Air Content PF, %
Mean Entrained Air Content, %
105
100
95
90
85
80
75
70
65
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Design 2 (Heavy Traffic)
Target Mean = 7.0 %
Target Std Dev = 0.5 %
Std Dev = 0.0 %
Std Dev = 0.5 %
Std Dev = 1.5 %
Individual Air Content PF, %
Mean Entrained Air Content, %
Design 3 (Very Heavy Traffic)
Target Mean = 7.0 %
Target Std Dev = 0.5 %
Std Dev = 0.0 %
Std Dev = 0.5 %
Std Dev = 1.5 %
Individual Air Content PF, %
Mean Entrained Air Content, %

Figure 22.

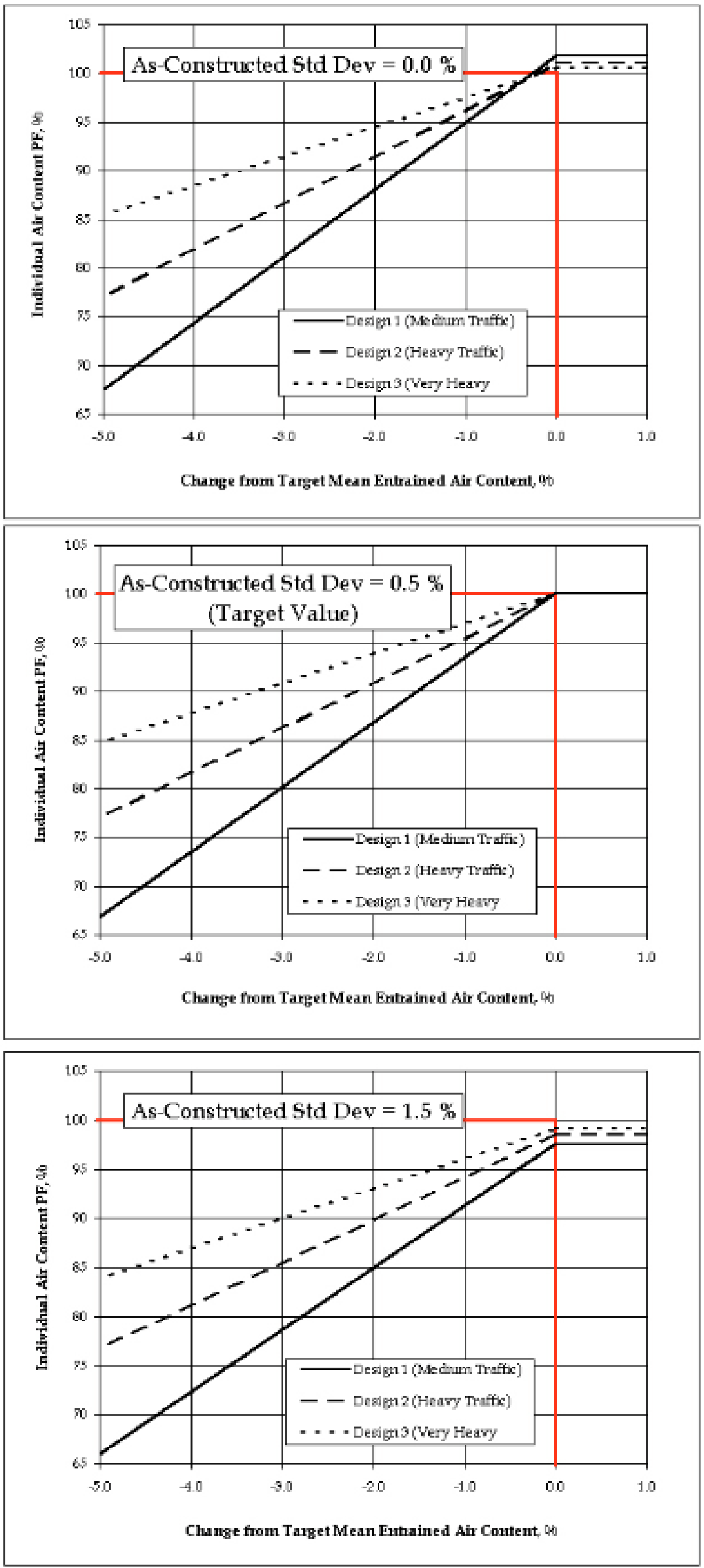

As-Constructed Std Dev = 0.0 %
As-Constructed Std Dev = 0.5 %
(Target Value)
As-Constructed Std Dev = 1.5 %
Individual Air Content PF, %
Change from Target Mean Entrained Air Content, %
Design 1 (Medium Traffic)
Design 2 (Heavy Traffic)
Design 3 (Very Heavy
105
100
95
90
85
80
75
70
65
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0

Figure 23.

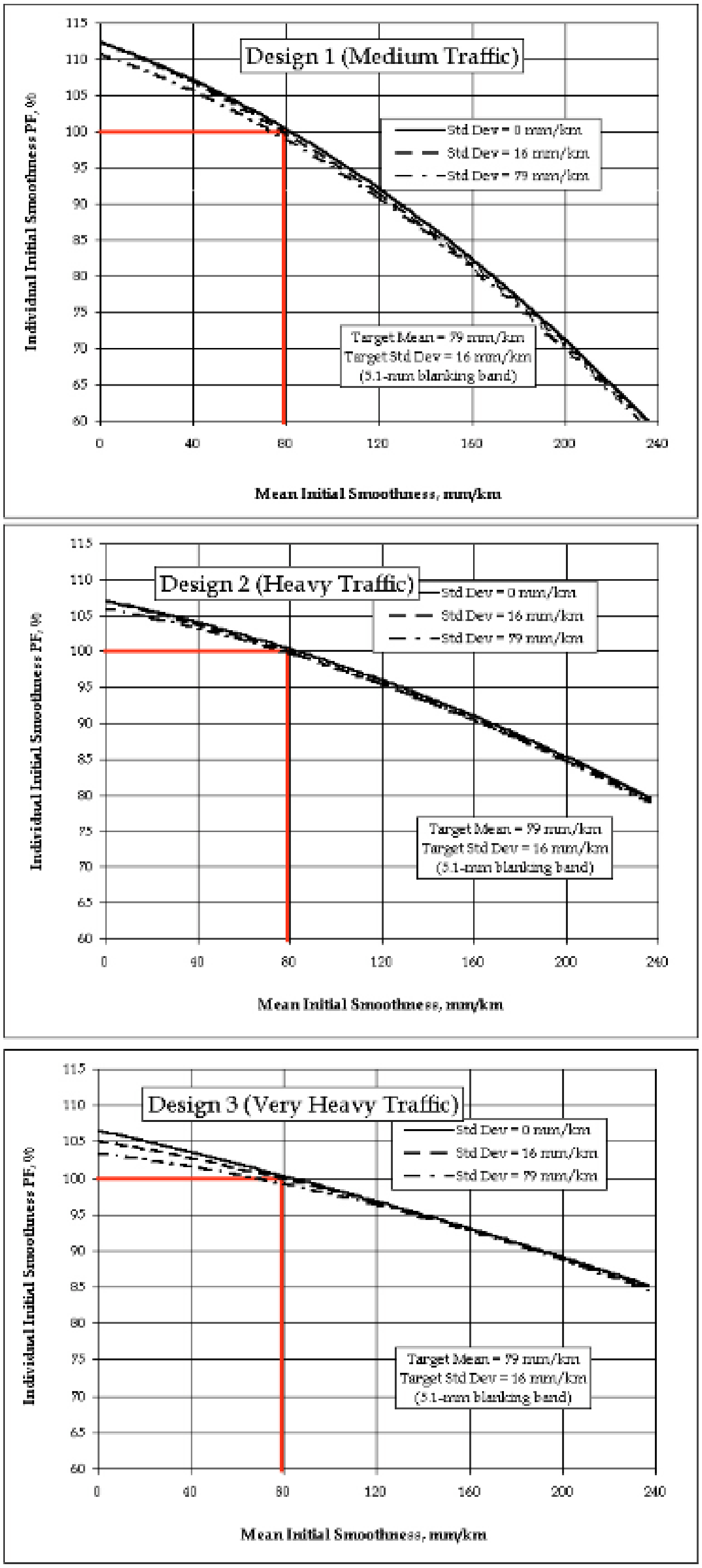

Design 1 (Medium Traffic)
Std Dev = 0 mm/km
Std Dev = 16 mm/km
Std Dev = 79 mm/km
Target Mean = 79 mm/km
Target Std Dev = 16 mm/km
(5.1-mm blanking band)
Individual Initial Smoothness PF, %
Mean Initial Smoothness, mm/km
115
110
105
100
95
90
85
80
75
70
65
60
0
40
80
120
160
200
240
Design 2 (Heavy Traffic)
Std Dev = 0 mm/km
Std Dev = 16 mm/km
Std Dev = 79 mm/km
Target Mean = 79 mm/km
Target Std Dev = 16 mm/km
(5.1-mm blanking band)
Individual Initial Smoothness PF, %
Mean Initial Smoothness, mm/km
Design 3 (Very Heavy Traffic)
Std Dev = 0 mm/km
Std Dev = 16 mm/km
Std Dev = 79 mm/km
Target Mean = 79 mm/km
Target Std Dev = 16 mm/km
(5.1-mm blanking band)
Individual Initial Smoothness PF, %
Mean Initial Smoothness, mm/km

Figure 24.

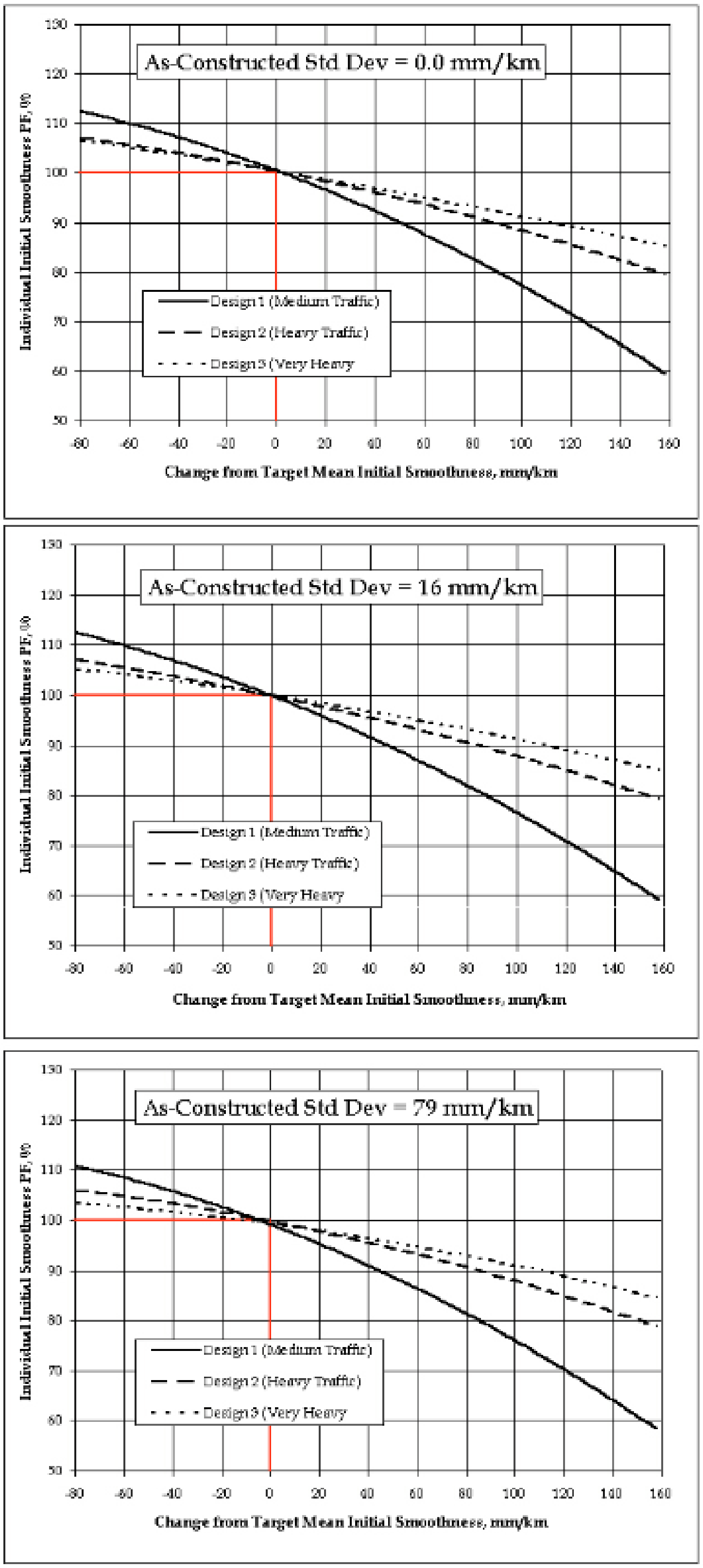

As-Constructed Std Dev = 0.0 mm/km
Individual Initial Smoothness PF, %
130
120
110
100
90
80
70
60
50
-80
-60
-40
-20
0
20
40
60
80
100
120
140
160
Change from Target Mean Initial Smoothness, mm/km
Design 1 (Medium Traffic)
Design 2 (Heavy Traffic)
Design 3 (Very Heavy
As-Constructed Std Dev = 16 mm/km
Individual Initial Smoothness PF, %
Change from Target Mean Initial Smoothness, mm/km
Design 1 (Medium Traffic)
Design 2 (Heavy Traffic)
Design 3 (Very Heavy
As-Constructed Std Dev = 79 mm/km
Individual Initial Smoothness PF, %
Change from Target Mean Initial Smoothness, mm/km
Design 1 (Medium Traffic)
Design 2 (Heavy Traffic)
Design 3 (Very Heavy

Figure 25.

Table 78. Design 1 (medium traffic)—Level 1 AQC best-fit regression equations for the case of four sublots per lot and four samples per sublot (lot sample size N=16).

AQC	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value
28-day Flexural Strength (third-point loading)	0.00 MPa	$PF_{S\text{-}(x,\ 0.00)} = -25.7189x^2 + 287.7179x - 671.4876$
	0.45 MPa	$PF_{S\text{-}(x,\ 0.45)} = -25.3191x^2 + 284.4695x - 666.2597$
	0.90 MPa	$PF_{S\text{-}(x,\ 0.90)} = -19.9880x^2 + 236.5143x - 565.0175$
Slab Thickness	0 mm	$PF_{T\text{-}(x,\ 0)} = -2.7195\text{E-}02x^2 + 13.1846x - 1464.7132$
	6 mm	$PF_{T\text{-}(x,\ 6)} = -2.8791\text{E-}02x^2 + 13.8807x - 1540.1355$
	13 mm	$PF_{T\text{-}(x,\ 13)} = -2.8768\text{E-}02x^2 + 13.9090x - 1548.3911$
Plastic Entrained Air-Content (for 0 to 7% only)	0.0%	$PF_{A\text{-}(x,\ 0.0)} = 6.8683x + 53.6719$
	0.5%	$PF_{A\text{-}(x,\ 0.5)} = 6.64x + 53.52$
	1.5%	$PF_{A\text{-}(x,\ 1.5)} = 6.315x + 53.335$
Initial Smoothness	0 mm/km	$PF_{SM\text{-}(x,\ 0)} = -4.6066\text{E-}04x^2 - 0.1139x + 112.45$
	16 mm/km	$PF_{SM\text{-}(x,\ 16)} = -4.2248\text{E-}04x^2 - 0.1246x + 112.48$
	79 mm/km	$PF_{SM\text{-}(x,\ 79)} = -4.7001\text{E-}04x^2 - 0.1100x + 110.8$

Table 79. Design 2 (heavy traffic)—Level 1 AQC best-fit regression equations for the case of four sublots per lot and four samples per sublot (lot sample size N=16).

AQC	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value
28-day Flexural Strength (third-point loading)	0.00 MPa	$PF_{S\text{-}(x,\ 0.00)} = -14.5726x^2 + 162.7450x - 336.0902$
	0.45 MPa	$PF_{S\text{-}(x,\ 0.45)} = -16.5210x^2 + 182.6422x - 386.6551$
	0.90 MPa	$PF_{S\text{-}(x,\ 0.90)} = -15.0809x^2 + 172.2030x - 373.8903$
Slab Thickness	0 mm	$PF_{T\text{-}(x,\ 0)} = -1.5438E\text{-}02x^2 + 8.1861x - 968.5134$
	6 mm	$PF_{T\text{-}(x,\ 6)} = -1.6236E\text{-}02x^2 + 8.5896x - 1019.5902$
	13 mm	$PF_{T\text{-}(x,\ 13)} = -1.6794E\text{-}02x^2 + 8.8875x - 1059.5914$
Plastic Entrained Air-Content (for 0 to 7% only)	0.0%	$PF_{A\text{-}(x,\ 0.0)} = 4.7850x + 67.5050$
	0.5%	$PF_{A\text{-}(x,\ 0.5)} = 4.6183x + 67.6719$
	1.5%	$PF_{A\text{-}(x,\ 1.5)} = 4.3700x + 67.9200$
Initial Smoothness	0 mm/km	$PF_{SM\text{-}(x,\ 0)} = -2.0616E\text{-}04x^2 - 0.0673x + 107.10$
	16 mm/km	$PF_{SM\text{-}(x,\ 16)} = -1.7625E\text{-}04x^2 - 0.0753x + 107.05$
	79 mm/km	$PF_{SM\text{-}(x,\ 79)} = -2.3768E\text{-}04x^2 - 0.0579x + 105.95$

Table 80. Design 3 (very heavy traffic)—Level 1 AQC best-fit regression equations for the case of four sublots per lot and four samples per sublot (lot sample size N=16).

AQC	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value
28-day Flexural Strength (third-point loading)	0.00 MPa	$PF_{S\text{-}(x,\ 0.00)} = -10.5255x^2 + 126.3893x - 253.3085$
	0.45 MPa	$PF_{S\text{-}(x,\ 0.45)} = -9.8374x^2 + 120.8210x - 243.8380$
	0.90 MPa	$PF_{S\text{-}(x,\ 0.90)} = -5.4613x^2 + 82.0068x - 164.2257$
Slab Thickness	0 mm	$PF_{T\text{-}(x,\ 0)} = -7.4090E\text{-}03x^2 + 4.9484x - 696.1730$
	6 mm	$PF_{T\text{-}(x,\ 6)} = -7.2153E\text{-}03x^2 + 4.8425x - 682.2020$
	13 mm	$PF_{T\text{-}(x,\ 13)} = -7.5020E\text{-}03x^2 + 5.0440x - 716.7401$
Plastic Entrained Air-Content (for 0 to 7% only)	0.0%	$PF_{A\text{-}(x,\ 0.0)} = 3.0383x + 79.3319$
	0.5%	$PF_{A\text{-}(x,\ 0.5)} = 3.0733x + 78.4869$
	1.5%	$PF_{A\text{-}(x,\ 1.5)} = 3.0583x + 77.7019$
Initial Smoothness	0 mm/km	$PF_{SM\text{-}(x,\ 0)} = -7.3172E\text{-}05x^2 - 0.0727x + 106.60$
	16 mm/km	$PF_{SM\text{-}(x,\ 16)} = -1.2338E\text{-}04x^2 - 0.0561x + 105.20$
	79 mm/km	$PF_{SM\text{-}(x,\ 79)} = -1.7278E\text{-}04x^2 - 0.0384x + 103.40$

Comparison of Estimated Level 1 PRS Pay Adjustments to Actual Pay Adjustments

Introduction

A final demonstration of the PRS consisted of a comparative analysis of the actual price adjustments awarded to the contractor (using the governing SHA specifications) versus those that would have been assessed if the current PRS approach had governed the projects. Such an analysis provides insight into how much of a change would be typical for SHA's using the PRS technology. This analysis was based on historical data retrieved from three SHA's, representing 33 lots from 7 JPCP projects. Table 85 contains more specific information on these projects.

Table 85. Projects investigated for pay adjustment comparisons.

State	Project ID	County	Number of Lots
Kansas	KS-1	Wyandotte	3
	KS-2	Greenwood	7
	KS-3	Reno	5
	KS-4[a]	Pottawatomie	2
Wisconsin	WI-1	Clark	5
	WI-2	Clark	8
Iowa	IA-1[b]	Wapello	3
		Total Number of Lots	33

Notes: [a] This project was one of the OTA field trials (details are presented in chapter 3).
[b] This project was the original field trial (details are presented in chapter 2).

The required data collected for each pavement lot included:

- **Constant values—project-specific design, traffic, and climatic variable values.**
- **AQC target values—representative as-designed target means and standard deviations for concrete strength, slab thickness, entrained air content, and initial smoothness. (These were interpreted from the governing SHA construction specifications using the guidelines provided in chapter 5 of volume I, *Selection of AQC Target Values*.)**
- **Actual AQC sampling and testing data.**
- **Actual lot price adjustments received by the contractor.**

Some data adjustment was required to resolve inconsistencies between theoretical versus actual sublot and lot identification.

The actual AQC sampling and testing data were used to compute PRS-based lot CPF's using the following procedure:

1. **Representative Level 1 AQC pay factor charts and equations were simulated (for each of the seven projects) based on the constant and target values retrieved from the SHA's. This Level 1 preconstruction output was generated in accordance with the procedure outlined in chapter 7 of volume I, *Step-by-Step Guide to Generating PRS Preconsruction Output*.**
2. **Each project was divided into lots and sublots in accordance with the guidelines used to define lots and sublots at the original Iowa field trial (see chapter 2 of this volume, *Definition of Lots and Sublots*). Each day of paving represented a separate lot.**
3. **The actual AQC sampling and testing data were summarized into means and standard deviations representing each lot.**
4. **The calculated representative lot AQC means and standard deviations were used in the developed pay factor equations to compute individual AQC pay factors representing each lot.**
5. **The individual AQC pay factors were then used in an assumed CPF equation to compute overall representative PRS-based lot pay factors.**

Finally, the PRS-based CPF's were directly compared with the actual pay adjustments made to the contractor on the respective lots. This chapter discusses all aspects of this comparative analysis. Due to the similarities of projects within each SHA, the discussion is divided by State. An overall summary of the combined results from all States is also included.

Kansas Projects

Constant Variable Inputs

Most of the design- and traffic-related variable inputs required to simulate the Level 1 pay factor curves representing each project were obtained directly from KDOT personnel. Many of the cost-related variables were assumed to be equal to those values used at the Kansas OTA field trial (KS-4). Climatic variable values were obtained from available climatic databases. All assumed items are marked as such. The constant variables defining Kansas projects KS-1, KS-2, and KS-3 are presented in tables 86 through 88, respectively. The constant values defining project KS-4 (the Kansas OTA field trial) are presented in table 54 as part of the *OTA Field Trial #3* documentation.

Table 86. Constant inputs defining the KS-1 archived project.

Project Information		
	State	Kansas
	County	Wyandotte
	District	Shawnee Office
	Route	I-635 NB
	Design method	AASHTO 93
Project Type		
	Pavement type	Plain, doweled
	Road location	Urban, divided
	Design life	20 years
	Analysis life	40 years (assumed)
	Overlay life	10 years (assumed)
	Project length	4.096 km
	Number of lanes in one direction	3
	Lane width	3.7 m
	Joint spacing	4.8 m
Traffic Information		
	Total design ESAL's	25,359,615
	Traffic growth factor	0% (assumed)
	Traffic growth method	Simple (assumed)
Materials and Climatic Information		
	Annual temperature range	21.1 ºC (assumed)
	Freezing index	200 degree-days (assumed)
	Average annual precipitation	69.4 cm (assumed)
	Annual freeze-thaw cycles in pavement (at a depth of 7.6 cm)	10 (assumed)
	Salt present	Yes (assumed)
	Transverse joint sealant type	Preformed compression seal
Slab Support Information		
	Base type	Bound drainable base, PCC

	Modulus of subgrade reaction	156 MPa/m
	Subgrade soil type	Fine-grained (A-4 to A-7) (assumed)
	Presence of longitudinal subdrains	Yes
Load Transfer Information		
	Dowel bar diameter	3.5 cm
	Presence of tied PCC shoulder	Yes (assumed)
Cost Information		
	Construction bid	\$32.29/m^2
	Cost of overlay (current)	\$10.76/m^2 (assumed)
	Cost of joint patching (current)	\$77.74/m^2 (assumed)
	Cost of slab replacement (current)	\$59.80/m^2 (assumed)
	Annual interest rate	6% (assumed)
	Annual inflation rate	3% (assumed)

Table 87. Constant inputs defining the KS-2 archived project.

Project Information		
	State	Kansas
	County	Greenwood
	District	Iola Office
	Route	K-96 & U.S. 400 EB
	Design method	AASHTO 86
Project Type		
	Pavement type	Plain, doweled
	Road location	Rural, undivided
	Design life	20 years
	Analysis life	40 years (assumed)
	Overlay life	10 years (assumed)
	Project length	16.88 km
	Number of lanes in one direction	1
	Lane width	3.7 m

	Joint spacing	4.8 m
Traffic Information		
	Total design ESAL's	7,459,260
	Traffic growth factor	0% (assumed)
	Traffic growth method	Simple (assumed)
Materials and Climatic Information		
	Annual temperature range	21.1 ºC (assumed)
	Freezing index	0 degree-days (assumed)
	Average annual precipitation	69.4 cm (assumed)
	Annual freeze-thaw cycles in pavement (at a depth of 7.6 cm)	6 (assumed)
	Salt present	Yes (assumed)
	Transverse joint sealant type	Preformed compression seal
Slab Support Information		
	Base type	Bound drainable base, PCC
	Modulus of subgrade reaction	45 MPa/m
	Subgrade soil type	Fine-grained (A-4 to A-7) (assumed)
	Presence of longitudinal subdrains	Yes
Load Transfer Information		
	Dowel bar diameter	2.5 cm
	Presence of tied PCC shoulder	Yes (assumed)
Cost Information		
	Construction bid	\$22.90/m^2
	Cost of overlay (current)	\$10.76/m^2 (assumed)
	Cost of joint patching (current)	\$77.74/m^2 (assumed)
	Cost of slab replacement (current)	\$59.80/m^2 (assumed)
	Annual interest rate	6% (assumed)
	Annual inflation rate	3% (assumed)

Table 88. Constant inputs defining the KS-3 archived project.

Project Information		
	State	Kansas
	County	Reno
Project Type		
	Pavement type	Plain, doweled
	Road location	Rural, divided
	Design life	20 years
	Analysis life	40 years (assumed)
	Overlay life	10 years (assumed)
	Project length	6.7 km
	Number of lanes in one direction	2
	Lane width	3.7 m
	Joint spacing	4.8 m
Traffic Information		
	Total design ESAL's	6,721,450
	Traffic growth factor	0% (assumed)
	Traffic growth method	Simple (assumed)
Materials and Climatic Information		
	Annual temperature range	21.1 ºC (assumed)
	Freezing index	0 degree-days (assumed)
	Average annual precipitation	71.1 cm (assumed)
	Annual freeze-thaw cycles in pavement (at a depth of 7.6 cm)	6 (assumed)
	Salt present	Yes (assumed)
	Transverse joint sealant type	Preformed compression seal
Slab Support Information		
	Base type	PCC-treated
	Modulus of subgrade reaction	54 MPa/m
	Subgrade soil type	Fine-grained (A-4 to A-7) (assumed)
	Presence of longitudinal subdrains	No

Load Transfer Information		
	Dowel bar diameter	3.2 cm
	Presence of tied PCC shoulder	Yes (assumed)
Cost Information		
	Construction bid	$\$33.37/\text{m}^2$
	Cost of overlay (current)	$\$10.76/\text{m}^2$ (assumed)
	Cost of joint patching (current)	$\$77.74/\text{m}^2$ (assumed)
	Cost of slab replacement (current)	$\$59.80/\text{m}^2$ (assumed)
	Annual interest rate	6% (assumed)
	Annual inflation rate	3% (assumed)

AQC Target Values

Appropriate AQC target values were determined for each project by interpreting the Kansas construction specification. The specification was interpreted in accordance with the guidelines set forth in chapter 5 of volume I (*Selection of AQC Target Values*). The chosen AQC target means and standard deviations used to define the agency-desired quality for projects KS-1, KS-2, and KS-3 are summarized in tables 89 through 91. The AQC target means and standard deviations chosen for project KS-4 (the Kansas OTA field trial) are presented in table 56 as part of the *OTA Field Trial #3* documentation.

Table 89. Level 1 AQC target means and standard deviations for the KS-1 archived project (Wyandotte Co.).

Acceptance Quality Characteristic	Target Mean	Target Standard Deviation
28-day compressive strength, MPa	24.8	3.6
Slab thickness, mm	279	4
Entrained air content, percent	6.0	0.75
Initial smoothness, mm/km (0.0-mm blanking band)	379	47

Note: Computed from individual tests (no averaging is performed); thus, it includes both materials/process and testing measurement variation.

Table 90. Level 1 AQC target means and standard deviations for the KS-2 archived project (Greenwood Co.).

Acceptance Quality Characteristic	Target Mean	Target Standard Deviation
28-day compressive strength, MPa	24.8	3.4
Slab thickness, mm	229	4
Entrained air content, percent	6.0	0.75
Initial smoothness, mm/km (0.0-mm blanking band)	379	47

Note: Computed from individual tests (no averaging is performed); thus, it includes both materials/process and testing measurement variation.

Table 91. Level 1 AQC target means and standard deviations for the KS-3 archived project (Reno Co.).

Acceptance Quality Characteristic	Target Mean	Target Standard Deviation
28-day compressive strength, MPa	31.5	3.4
Slab thickness, mm	254	4
Entrained air content, percent	6.0	0.75
Initial smoothness, mm/km (0.0-mm blanking band)	379	47

Note: Computed from individual tests (no averaging is performed); thus, it includes both materials/process and testing measurement variation.

Retrieval of Actual AQC Sampling and Testing Data

Actual AQC sampling and testing data were retrieved from KDOT historical files for different days of paving at each archived Kansas project. Each day was assumed to be equal to one lot of paving. Archived data were retrieved for concrete strength, slab thickness, and initial smoothness (entrained air content data were not collected since no entrained air content pay adjustments were computed under the actual Kansas construction specifications). All of the test values within each lot were summarized into representative lot means and standard deviations. The lot means and standard deviations were then used to determine representative

Level 1 AQC lot pay factors for each respective lot. The as-constructed AQC lot means and standard deviations computed for each Kansas project are summarized in tables 92 through 95.

Table 92. Computed as-constructed AQC lot means and standard deviations for the Kansas KS-1 project (Wyandotte Co.).

	28-day Compressive Strength, MPa		Slab Thickness, mm		Initial Smoothness, mm/km	
Lot	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	25.4	0.3	296	6	355	45
2	25.9	0.5	293	4	209	38
3	24.6	3.6 [1]	287	2	313	52

Note: [1] Only one strength sample was taken within lot 3; therefore, the as-constructed 28-day compressive strength standard deviation was assumed to be equal to the chosen target standard deviation of 3.6 MPa.

Table 93. Computed as-constructed AQC lot means and standard deviations for the Kansas KS-2 project (Greenwood Co.).

	28-day Compressive Strength, MPa		Slab Thickness, mm		Initial Smoothness, mm/km	
Lot	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	36.1	1.4	242	6	195	41
2	33.0	7.4	234	7	158	69
3	35.2	0.1	238	7	183	34
4	35.4	0.3	236	9	179	28
5	36.5	1.4	239	5	195	67
6	35.1	2.2	231	4	217	33
7	35.3	0.0	233	4	218	47

Table 94. Computed as-constructed AQC lot means and standard deviations for the Kansas KS-3 archived project (Reno Co.).

	28-day Compressive Strength, MPa		Slab Thickness, mm		Initial Smoothness, mm/km	
Lot	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	37.3	3.4	260	5	63	12
2	41.3	2.9	261	4	52	18
3	43.8	4.8	259	3	74	19
4	43.8	5.9	256	5	37	17
5	49.0	3.6	257	4	44	17

Table 95. Computed as-constructed AQC lot means and standard deviations for the Kansas KS-4 project (Pottawatomie Co.).

	28-day Compressive Strength, MPa		Slab Thickness, mm		Initial Smoothness, mm/km	
Lot	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	37.4	1.6	208	14	211	27
2	39.1	3.1	213	16	186	55

Simulation of Level 1 AQC Pay Factor Charts and Equations

Independent AQC Level 1 pay factor charts were simulated for each project based on the respective identified constant variable values and AQC target values. Based on the typical daily amount of AQC sampling and testing observed in the historical records, it was decided that PRS-based pay adjustments for projects KS-1, KS-2, and KS-3 would be most realistic if the pay factor equations were developed for the case of five sublots per lot and three samples per sublot. PRS-based pay equations for project KS-4 were developed for the case of three sublots per lot, and two samples per sublot (this was the sampling frequency used at the field trial).

Each simulated LCC (used to construct the AQC pay factor curves) was determined as the mean of 500 simulated lot LCC's—using a 40-year analysis life (two times the 20-year design life) and including 5 percent of the calculated user costs. The simulated representative as-designed LCC means for each of the four Kansas projects were simulated as the following :

- **KS-1, Wyandotte Co.: $706,966/km.**
- **KS-2, Greenwood Co.: $711,625/km.**
- **KS-3, Reno Co.: $647,702/km.**
- **KS-4, Pottawatomie Co.: $625,799/km.**

Pay factor curves for each Kansas project were calculated for different chosen AQC standard deviations, over reasonable ranges of AQC means. The simulated AQC pay factor curves representing Kansas projects KS-1, KS-2, and KS-3 are presented in figures 26 through 28, respectively. The corresponding pay factor regression equations for these three projects are presented in tables 96 through 98, respectively. The pay factor curves and regression equations for the KS-4 project are presented as part of the *OTA Field Trial #3* documentation in figure 12 and table 62, respectively.

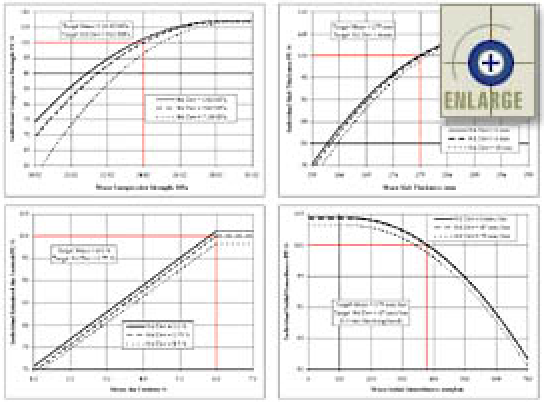


Figure 26. Level 1 individual AQC pay factor charts for archived project KS-1 (five sublots, three samples per sublot).

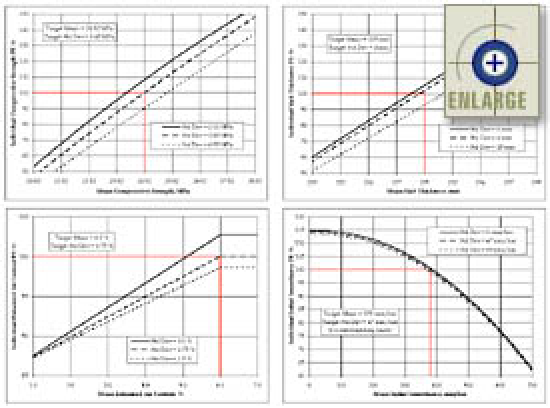


Figure 27. Level 1 individual AQC pay factor charts for archived project KS-2 (five sublots, three samples per sublot).

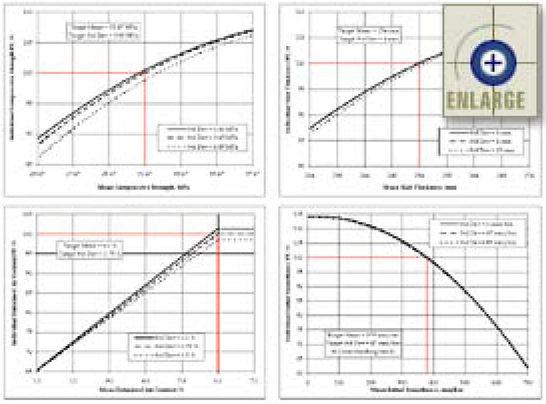


Figure 28. Level 1 individual AQC pay factor charts for archived project KS-3 (five sublots, three samples per sublot).

Table 96. Level 1 AQC best-fit regression equations for archived project KS-1 (five sublots, three samples per sublot [lot sample size N=15]).

Acceptance Quality Characteristic	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value	Maximum Pay Factor, %	x-Value at Maximum Pay Factor
28-day Cylinder Compressive Strength	0.0 MPa	$PF_{S\text{-}(x,\ 0.0)} = -0.3049x^2 + 17.8047x - 152.8772$	107.04	29.2 MPa
	3.6 MPa	$PF_{S\text{-}(x,\ 3.6)} = -0.3438x^2 + 20.1499x - 188.3132$	106.90	29.3 MPa
	7.3 MPa	$PF_{S\text{-}(x,\ 7.3)} = -0.4194x^2 + 24.9301x - 264.0556$	106.46	29.7 MPa
Slab Thickness	0 mm	$PF_{T\text{-}(x,\ 0)} = -2.6949\text{E-}02x^2 + 15.7459x - 2195.2267$	104.77	292 mm
	4 mm	$PF_{T\text{-}(x,\ 4)} = -2.7817\text{E-}02x^2 + 16.2580x - 2270.9400$	104.58	292 mm
	13 mm	$PF_{T\text{-}(x,\ 13)} = -2.8796\text{E-}02x^2 + 16.8605x - 2363.7344$	104.33	293 mm
Plastic Entrained Air Content	0.00%	$PF_{A\text{-}(x,\ 0.00)} = 6.09x + 64.56$	101.10	6.0%
	0.75%	$PF_{A\text{-}(x,\ 0.75)} = 6.11x + 63.34$	100.00	6.0%
	1.50%	$PF_{A\text{-}(x,\ 1.50)} = 5.9167x + 62.7298$	98.23	6.0%
Initial Smoothness (0.0-mm blanking band)	0 mm/km	$PF_{SM\text{-}(x,\ 0)} = -7.0189\text{E-}05x^2 + 1.8403\text{E-}02x + 103.20$	104.41	131 mm/km
	47 mm/km	$PF_{SM\text{-}(x,\ 47)} = -7.0189\text{E-}05x^2 + 1.8403\text{E-}02x + 103.10$	104.31	131 mm/km
	79 mm/km	$PF_{SM\text{-}(x,\ 79)} = -7.0189\text{E-}05x^2 + 1.8403\text{E-}02x + 101.94$	103.15	131 mm/km

Note: The pay factors are held equal to the equation's maximum pay factor value when the measured value surpasses the corresponding "x-Value at Maximum Pay Factor" (i.e., greater than the corresponding value for strength, thickness, and entrained air content; less than the corresponding value for initial smoothness).

Table 97. Level 1 AQC best-fit regression equations for archived project KS-2 (five sublots, three samples per sublot [lot sample size N=15]).

Acceptance Quality Characteristic	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value	Maximum Pay Factor, %	x-Value at Maximum Pay Factor
28-day Cylinder Compressive Strength	0.0 MPa	$PF_{S\text{-}(x,\ 0.0)} = -0.2752x^2 + 26.2980x - 374.9736$	n/a	n/a
	3.4 MPa	$PF_{S\text{-}(x,\ 3.4)} = -0.1583x^2 + 20.4789x - 310.7396$	n/a	n/a
	6.9 MPa	$PF_{S\text{-}(x,\ 6.9)} = -0.0730x^2 + 15.7397x - 255.6552$	n/a	n/a
Slab Thickness	0 mm	$PF_{T\text{-}(x,\ 0)} = -1.0182\text{E-}02x^2 + 9.0643x - 1436.8200$	n/a	n/a
	4 mm	$PF_{T\text{-}(x,\ 4)} = -5.1116\text{E-}03x^2 + 6.7336x - 1172.1800$	n/a	n/a
	13 mm	$PF_{T\text{-}(x,\ 13)} = 4.3262\text{E-}03x^2 + 2.1927x - 636.3400$	n/a	n/a
Plastic Entrained Air Content	0.00%	$PF_{A\text{-}(x,\ 0.00)} = 3.0333x + 84.5002$	102.70	6.0%
	0.75%	$PF_{A\text{-}(x,\ 0.75)} = 2.5333x + 84.002$	100.00	6.0%
	1.50%	$PF_{A\text{-}(x,\ 1.50)} = 2.2667x + 84.9998$	98.60	6.0%

Initial Smoothness (0.0-mm blanking band)	0 mm/km	$PF_{SM\text{-}(x,\,0)} = -1.17E\text{-}04x^2 + 7.7294E\text{-}03x + 114.60$	114.73	33 mm/km
	47 mm/km	$PF_{SM\text{-}(x,\,47)} = -1.17E\text{-}04x^2 + 7.7294E\text{-}03x + 113.86$	113.99	33 mm/km
	95 mm/km	$PF_{SM\text{-}(x,\,95)} = -1.17E\text{-}04x^2 + 7.7294E\text{-}03x + 113.12$	113.25	33 mm/km

Note: The entrained air content pay factors are held equal to the equation's maximum pay factor value when the measured mean is greater than the "x-Value at Maximum Pay Factor" value for entrained air content. The initial smoothness pay factors are held equal to the equation's maximum pay factor value when the measured mean is less than the corresponding "x-Value at Maximum Pay Factor" value for initial smoothness.

Table 98. Level 1 AQC best-fit regression equations for archived project KS-3 (five sublots, three samples per sublot [lot sample size N=15]).

Acceptance Quality Characteristic	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value	Maximum Pay Factor, %	x-Value at Maximum Pay Factor
28-day Cylinder Compressive Strength	0.0 MPa	$PF_{S\text{-}(x,\,0.0)} = -6.5198E\text{-}02x^2 + 5.5980x - 11.1427$	109.02	42.9 MPa
	3.4 MPa	$PF_{S\text{-}(x,\,3.4)} = -6.8682E\text{-}02x^2 + 5.8739x - 16.8399$	108.75	42.8 MPa
	6.9 MPa	$PF_{S\text{-}(x,\,6.9)} = -7.5821E\text{-}02x^2 + 6.4527x - 29.1986$	108.09	42.6 MPa
Slab Thickness	0 mm	$PF_{T\text{-}(x,\,0)} = -6.9819E\text{-}03x^2 + 4.0442x - 476.7190$	108.92	290 mm
	4 mm	$PF_{T\text{-}(x,\,4)} = -6.9819E\text{-}03x^2 + 4.0430x - 476.5964$	108.85	290 mm
	13 mm	$PF_{T\text{-}(x,\,13)} = -7.3057E\text{-}03x^2 + 4.2301x - 503.6188$	108.69	290 mm
Plastic Entrained Air Content	0.00%	$PF_{A\text{-}(x,\,0.00)} = 7.2067x + 58.1098$	101.35	6.0%
	0.75%	$PF_{A\text{-}(x,\,0.75)} = 6.9850x + 58.0900$	100.00	6.0%
	1.50%	$PF_{A\text{-}(x,\,1.50)} = 6.6471x + 58.5336$	98.42	6.0%
Initial Smoothness (0.0-mm blanking band)	0 mm/km	$PF_{SM\text{-}(x,\,0)} = -1.1818E\text{-}04x^2 + 8.0542E\text{-}03x + 114.0875$	114.22	34 mm/km
	47 mm/km	$PF_{SM\text{-}(x,\,47)} = -1.1818E\text{-}04x^2 + 8.0542E\text{-}03x + 113.9050$	114.04	34 mm/km
	95 mm/km	$PF_{SM\text{-}(x,\,95)} = -1.1818E\text{-}04x^2 + 8.0542E\text{-}03x + 113.5488$	113.69	34 mm/km

Note: The pay factors are held equal to the equation's maximum pay factor value when the measured value surpasses the corresponding "x-Value at Maximum Pay Factor" (i.e., greater than the corresponding value for strength, thickness, and entrained air content; less than the corresponding value for initial smoothness).

Calculation of Pay Adjustments

Lot pay factors were calculated for all of the Kansas projects based on the computed representative AQC lot means and standard deviations. These values were used to compute pay factors using two different calculation methods—using the actual Kansas governing construction specification and using the developed Level 1 PRS pay factor equations. The details of both pay factor calculation methods are described separately below.

Calculation of Pay Adjustments Using the Governing Kansas Construction Specification

For three of the projects (KS-1, KS-2, and KS-3), the governing Kansas construction specification applied pay adjustments to concrete strength, slab thickness, and initial smoothness (no pay adjustments were based on air content). For the KS-4 project, pay adjustments were only applied to slab thickness and initial smoothness. Individual concrete strength and slab thickness pay factors were determined based on the computed lot AQC means and standard deviations of the retrieved AQC testing data. Although initial smoothness pay factors could have been determined from the retrieved field data, the actual initial smoothness-related pay adjustment values (in dollars) were provided by KDOT personnel. All of the details of the pay adjustment procedures included in the governing Kansas construction specification are discussed below.

Individual Concrete Strength (28-day Compressive) Pay Adjustments

Pay adjustments for concrete strength are addressed in section 11.0, *Basis of Payment,* of the Kansas QC/QA specification. This concrete strength acceptance procedure is discussed in detail in the *OTA Field Trial #3* documentation (see the section titled *Concrete Strength* in chapter 3). The concrete strength pay adjustment procedure is based on determining a compressive strength quality index (Q_{STR}) using equation 34. The computed Q_{STR} is used to select the appropriate compressive strength pay adjustment factor (P_{STR}) from table 55.

As an example, let us look at lot 1 from the KS-1 project. For this lot, the representative lot mean and standard deviation (obtained from lot sample test values) were computed to be 25.4 and 0.3 MPa, respectively. Since the LSL for the KS-1 project was given as 20.0 MPa, the corresponding Q_{STR} can be calculated as the following using equation 34:

$$Q_{STR} = (X_{STR} - LSL_{STR}) / S_{STR}$$

$$= (25.4 - 20.0) / 0.3$$

$$= 18.00$$

This computed Q_{STR} of 18.00 is translated into a P_{STR} of 103 percent using the pay schedule presented in table 55.

Individual Slab Thickness Pay Adjustments

Payment for slab thickness is also addressed in section 11.0, *Basis of Payment,* of the Kansas QC/QA specification. This slab thickness acceptance procedure is discussed in detail in the *OTA Field Trial #3* documentation (see the section titled *Slab Thickness* in chapter 3). The concrete strength pay adjustment procedure is based on determining a slab thickness quality index (Q_{THK}) using equation 35. The computed Q_{THK} is used to select the appropriate compressive strength pay adjustment factor (P_{THK}) from table 55.

Again, Lot 1 from the KS-1 archived project will be used as an example. For this particular lot, the representative slab thickness lot mean and standard deviation (obtained from lot sample values) were computed to be 296 and 6 mm, respectively. The design slab thickness for this lot was chosen to be 279 mm; therefore, the LSL_{THK} was calculated to be 5 mm less than the design thickness, or 274 mm. The corresponding Q_{THK} value was then calculated to be the following using equation 35.

$$Q_{THK} = (X_{THK} - LSL_{THK}) / S_{THK}$$

$= (296 – 274) / 6$

$= 3.67$

This computed Q_{THK} of 3.67 is translated into a P_{THK} of 103 percent using the pay schedule presented in table 55.

Calculation of the Strength/Thickness Composite Pay Adjustments

Using the Kansas QC/QA specification, a combined strength/thickness composite pay factor is calculated for each lot as a function of the independently determined P_{STR} and P_{THK}. This composite pay factor ($CPF_{STR/THK}$) is computed using equation 46 and rounded to the nearest hundredth (0.01).

$$CPF_{STR/THK} = (P_{STR} * P_{THK}) / 100 \qquad (46)$$

where

$CPF_{STR/THK}$ = Strength/thickness composite pay factor.

P_{STR} = Compressive strength pay adjustment factor.

P_{THK} = Slab thickness pay adjustment factor.

For our example, the independent concrete strength and slab thickness pay factors were both calculated to be 103 percent ($P_{STR} = P_{THK} = 103$). Therefore, the composite strength/thickness pay factor was calculated (using equation 46) as the following:

$$CPF_{STR/THK} = (P_{STR} * P_{THK}) / 100$$

$$= (103 * 103) / 100$$

$$= 106.09 \text{ percent}$$

Initial Smoothness Pay Adjustments

Pay adjustments for initial smoothness were addressed in section 502 of a 1990 Kansas DOT special provision to the standard construction specifications. This initial smoothness acceptance procedure is discussed in detail in the *OTA Field Trial #3* documentation (see the section titled *Initial Smoothness* in chapter 3). Under this special provision, pavement smoothness was measured on each 0.16-km section using a California profilograph. The data were then reduced using a 0.0-mm blanking band. Pay adjustments were independently determined for each 0.16-km section.

The actual pay adjustment data (in actual dollars) was provided for each 0.16-km section included at each of the four Kansas projects. A total pay adjustment for each included lot was determined by summing all of the pay adjustments computed for the 0.16-km sections included in each of the defined lots. For our example lot, the initial smoothness lot pay adjustment was computed to be $0.00 (i.e., for this pavement lot, the contractor achieved an average pay factor of 100 percent).

Summary of Pay Adjustments Using the Governing Kansas Construction Specification

A summary of the lot pay factors and pay adjustments calculated using the actual governing KDOT construction specification is presented in tables 99 through 101. Table 99 contains a summary of the concrete strength pay factor calculations. Table 100 contains a summary of the slab thickness pay factor calculations. Table 101 contains a summary of all of the AQC pay factors and adjustments (determined for all of the Kansas projects) using the governing Kansas construction specifications.

Table 99. Summary of actual concrete strength lot pay factors computed in accordance with the governing Kansas DOT specification.

Project	Lot [1]	Total Number of Samples in the Lot	Computed Lot 28-day Compressive Strength Mean, MPa	Computed Lot 28-day Compressive Strength Standard Deviation, MPa	Lower Specification Limit (LSL), MPa	Computed Strength Quality Index (Q_{STR})	Computed Strength Pay Factor (P_{STR}), %
KS-1	1	2	25.4	0.3	20.0	18.00	103.00
	2	2	25.9	0.5	20.0	11.80	103.00
	3	1	24.6	3.6	20.0	1.28	100.00
KS-2	1	2	36.1	1.4	20.0	11.50	103.00
	2	2	33.0	7.4	20.0	1.76	103.00
	3	2	35.2	0.1	20.0	152.00	103.00
	4	2	35.4	0.3	20.0	51.33	103.00
	5	2	36.5	1.4	20.0	11.79	103.00
	6	4	35.1	2.2	20.0	6.86	103.00
	7	2	35.3	0.0	20.0	— [2]	103.00
KS-3	1	5	37.3	3.4	26.9	3.06	103.00
	2	5	41.3	2.9	26.9	4.97	103.00
	3	5	43.8	4.8	26.9	3.52	103.00
	4	5	43.8	5.9	26.9	2.86	103.00
	5	5	49.0	3.6	26.9	6.14	103.00

Note: [1] Compressive strength pay adjustments were not applied on project KS-4.
[2] A strength quality index could not be calculated for this lot due to a measured standard deviation = 0 MPa.

Table 100. Summary of actual slab thickness lot pay factors computed in accordance with the governing Kansas DOT specification.

Project	Lot	Total Number of Samples in the Lot	Computed Lot Slab Thickness Mean, mm	Computed Lot Slab Thickness Standard Deviation, mm	Lower Specification Limit (LSL), mm	Computed Thickness Quality Index (Q_{THK})	Computed Thickness Pay Factor (P_{THK}), %
KS-1	1	5	296	6	274	3.67	103.00
	2	8	293	4	274	4.75	103.00
	3	5	287	2	274	6.50	103.00
KS-2	1	7	242	6	224	3.00	103.00
	2	12	234	7	224	1.29	100.00
	3	9	238	7	224	2.00	103.00
	4	9	236	9	224	1.33	100.00
	5	11	239	5	224	3.00	103.00
	6	11	231	4	224	1.75	103.00
	7	10	233	4	224	2.25	103.00
KS-3	1	5	260	5	249	2.20	103.00
	2	5	261	4	249	3.00	103.00
	3	5	259	3	249	3.33	103.00
	4	5	256	5	249	1.40	100.00
	5	5	257	4	249	2.00	103.00
KS-4	1	4	214	8	198	1.95	103.00
	2	5	217	14	198	1.29	100.00

Table 101. Summary of all of the pay factors and adjustments (determined for the Kansas projects) using the governing Kansas construction specifications.

Project	Lot	Total Lot Area, m^2	Bid Price, \$/m^2	Strength Pay Factor (P_{STR}), %	Thickness Pay Factor, (P_{THK}), %	Strength/ Thickness Pay Factor ($CPF_{STR\text{-}THK}$), %	Computed Strength/ Thickness Pay Adjustment, \$	KDOT Reported Initial Smoothness Pay Adjustment, \$	Total Lot Pay Adjustment, \$	Total Project Pay Adjustment, \$
KS-1	1	4,457	32.29	103.00	103.00	106.09	8,765	0	8,765	44,008
	2	6,850		103.00	103.00	106.09	13,469	14,872	28,341	
	3	4,770		100.00	103.00	103.00	4,621	2,281	6,902	
KS-2	1	6,428	22.90	103.00	103.00	106.09	8,965	13,403	22,368	182,316
	2	10,395		103.00	100.00	103.00	7,141	18,406	25,547	
	3	8,586		103.00	103.00	106.09	11,974	15,870	27,844	
	4	5,748		103.00	100.00	103.00	3,949	12,374	16,323	
	5	9,315		103.00	103.00	106.09	12,991	17,083	30,074	
	6	10,765		103.00	103.00	106.09	15,013	15,909	30,923	
	7	10,947		103.00	103.00	106.09	15,267	13,971	29,238	
KS-3	1	7,090	33.37	103.00	103.00	106.09	14,409	10,606	25,016	175,340
	2	6,767		103.00	103.00	106.09	13,752	13,431	27,183	
	3	10,602		103.00	103.00	106.09	21,546	14,001	35,546	
	4	11,962		103.00	100.00	103.00	11,976	28,543	40,519	
	5	10,794		103.00	103.00	106.09	21,935	25,141	47,076	
KS-4	1	3,897	33.49	—	103.00	103.00	3,915	4,558	8,373	11,991
	2	4,629		—	100.00	100.00	0	3,618	3,618	

Note: Pay factors were not applied to strength in the KS-4 project.

Calculation of Pay Adjustments Using the Level 1 PRS Approach

PRS-based pay adjustments were calculated for all of the lots included in the four Kansas projects based on the computed AQC lot means and standard deviations. Each PRS-based lot pay adjustment was computed by using the measured AQC lot mean in the appropriate developed pay factor equations and then interpolating between the results based on the measured AQC lot standard deviation. A detailed explanation of the calculation of PRS Level 1 pay factors for an example lot is contained below.

The measured as-constructed AQC means and standard deviations representing lot 1 of KS-1 were the following:

- 28-day Compressive Strength: Mean = 25.4 MPa, Std Dev = 0.3 MPa.
- Slab Thickness: Mean = 296 mm, Std Dev = 6 mm.
- Initial Smoothness: Mean = 355 mm/km, Std Dev = 45 mm/km.

The pay factor equations presented in table 96 are used to calculate individual AQC pay factors.

Measured As-Constructed Compressive Strength (Mean = 25.4 MPa, Std Dev = 0.3 MPa):

At a mean of 25.4 MPa and a standard deviation of 0.0 MPa:

$$PF_{S\text{-}(25.4,\ 0.0)} = -0.3049(25.4)^2 + 17.8047(25.4) - 152.8772 = 102.65\% \qquad (47)$$

At a mean of 25.4 MPa and a standard deviation of 3.6 MPa:

$$PF_{S\text{-}(25.4,\ 3.6)} = -0.3438(25.4)^2 + 20.1499(25.4) - 188.3132 = 101.69\% \qquad (48)$$

The pay factor for the case with strength mean and standard deviation equal to 25.4 and 0.3 MPa, respectively, is interpolated (using an assumed linear relationship) by the following equation:

$$PF_{S\text{-}(25.4,\ 0.3)} = PF_{S\text{-}(25.4,\ 3.6)} + (PF_{S\text{-}(25.4,\ 0.0)} - PF_{S\text{-}(25.4,\ 3.6)}) * [(3.6\ \text{MPa} - 0.3\ \text{MPa}) / (3.6\ \text{MPa} - 0.0\ \text{MPa})] \qquad (49)$$

$$= 101.69\% + (102.65\% - 101.69\%) * [(3.3\ \text{MPa}) / (3.6\ \text{MPa})]$$

$$= 102.57\%$$

Measured As-Constructed Thickness (Mean = 296 mm, Std Dev = 6 mm):

At a mean of 296 mm and a standard deviation of 4 mm:

$$PF_{T\text{-}(296,\ 4)} = -2.7817\text{E-}02(296)^2 + 16.2580(296) - 2270.94 = 104.21\% \qquad (50)$$

At a mean of 296 mm and a standard deviation of 13 mm:

$$PF_{T\text{-}(296,\ 13)} = -2.8796\text{E-}02(296)^2 + 16.8605(296) - 2363.7344 = 103.98\% \qquad (51)$$

The pay factor for the case with thickness mean and standard deviation equal to 296 and 6 mm, respectively, is interpolated (using an assumed linear relationship) by the following equation:

$$PF_{T\text{-}(296,\ 6)} = PF_{T\text{-}(296,\ 13)} + (PF_{T\text{-}(296,\ 4)} - PF_{T\text{-}(296,\ 13)}) * [(13\ \text{mm} - 6\ \text{mm}) / (13\ \text{mm} - 4\ \text{mm})] \qquad (52)$$

$$= 103.98\% + (104.21\% - 103.98\%) * [(7\ \text{mm})/(9\ \text{mm})]$$

$$= 104.16\%$$

Measured As-Constructed Initial Smoothness (Mean = 355 mm/km, Std Dev = 45 mm/km):

At a mean of 355 mm/km and a standard deviation of 0 mm/km:

$$PF_{SM\text{-}(355,\ 0)} = -7.0189\text{E}{-}05(355)^2 - 0.1840(355) + 103.2 = 100.89\% \qquad (53)$$

At a mean of 355 mm/km and a standard deviation of 47 mm:

$$PF_{SM\text{-}(355,\ 47)} = -7.0189\text{E}{-}05(355)^2 - 0.1840(355) + 103.1 = 100.79\% \qquad (54)$$

The pay factor for the case with initial smoothness mean and standard deviation equal to 355 and 45 mm/km, respectively, is interpolated (using an assumed linear relationship) by the following equation:

$$PF_{SM-(355,\,45)} = PF_{SM-(355,\,47)} + (PF_{SM-(355,\,0)} - PF_{SM-(355,\,47)}) * [(47\text{ mm/km} - 45\text{ mm/km})/(47\text{ mm/km} - 0\text{ mm/km})] \quad (55)$$

$$= 100.79\% + (100.89\% - 100.79\%) * [(2\text{ mm/km}) / (47\text{ mm/km})]$$

$$= 100.79\%$$

Calculation of the PRS Composite Pay Factor and Pay Adjustment

The overall composite pay factor for the example lot is calculated using the *product method* (i.e., the individual AQC pay factors are multiplied together). This composite pay factor equation is shown in equation 56. Note that the individual AQC pay factors are expressed as decimals in the CPF equation (e.g., a pay factor of 102 percent is expressed as 1.02).

$$CPF_{LOT} = PF_{STRENGTH} * PF_{THICKNESS} * PF_{SMOOTHNESS} \quad (56)$$

For the Level 1 analysis, it was also decided to apply AQC pay factor limits in a manner similar to those limits applied using the actual Kansas construction specifications. The Kansas QC/QA specification allowed maximum pay factors of 103 percent for concrete strength and slab thickness. Therefore, the maximum composite pay factor for strength/thickness was computed as 1.03 * 1.03 = 1.0609, or a 6.09-percent maximum pay adjustment. In addition to the strength/thickness pay factor, the KDOT specification also allows up to an 8.00-percent pay adjustment for initial smoothness. Therefore, using the Kansas QC/QA specification, the maximum incentive pay adjustment (computed as the sum of the strength/thickness and initial smoothness pay adjustments) is approximately 114 percent. These same pay factor limits were, therefore, used for this analysis.

For the example lot, the composite pay factor is calculated as the following using equation 56. (Note: The thickness pay factor computed to be 1.0416 has been limited to the chosen maximum of 1.03.):

$$CPF_{LOT} = PF_{S-(25.4,\,0.3)} * PF_{T-(296,\,6)} * PF_{SM-(355,\,45)}$$

$$= (1.0257) * (1.0300) * (1.0079) = 1.0648$$

which translates to an overall pay factor of 106.48 percent.

Overall lot pay adjustments are calculated using equation 57.

$$PAY_{LOT} = (CPF_{LOT} - 1) * BID * AREA_{LOT} \quad (57)$$

where

PAY_{LOT} **= Overall Level 1 PRS lot price adjustment, $.**

CPF_{LOT} **= Overall lot composite pay factor (expressed as a decimal).**

BID = Contractor unit bid price, $/m^2.

$AREA_{LOT}$ = Total area of the lot, m^2.

For the example lot, the unit bid price was \$32.29/m^2, and the total lot area was 4,457 m^2. Therefore, using the computed limited CPF_{LOT} of 1.0648, the overall Level 1 lot price adjustment was computed as the following using equation 57:

$$PAY_{LOT} = (CPF_{LOT} - 1) * BID * AREA_{LOT}$$

$$= (1.0648 - 1) * 32.29 * 4,457$$

$$= 9,973 \text{ dollars}$$

A summary of all the Level 1 PRS pay factors and pay adjustments (calculated for all the lots in the four Kansas projects) is presented in table 102.

Table 102. Summary of all the Level 1 PRS pay factors and adjustments determined for the Kansas projects.

Project	Lot	Total Lot Area, m^2	Bid Price, \$/m^2	Independent Strength Pay Factor (P_{STR}), % (103% cap)[1]	Independent Thickness Pay Factor (P_{THK}), % (103% cap)[2]	Independent Smoothness Pay Factor (P_{SM}), % (108% cap)[3]	Lot Composite Pay Factor (CPF_{LOT}), % (limited to 114.0%)[4]	Total Lot PRS Pay Adjustment (based on limited PF's), \$	Total Project PRS Pay Adjustment (based on limited PF's), \$
KS-1	1	4,457	32.29	102.57	103.00	100.79	106.48	9,973	43,953
	2	6,850		103.00	103.00	104.34	110.69	23,645	
	3	4,770		99.33	103.00	104.30	106.71	10,335	
KS-2	1	6,428	22.90	103.00	103.00	108.00	114.00	20,608	199,362
	2	10,395		103.00	103.00	108.00	114.00	33,326	
	3	8,586		103.00	103.00	108.00	114.00	27,527	
	4	5,748		103.00	103.00	108.00	114.00	18,428	
	5	9,315		103.00	103.00	108.00	114.00	29,864	
	6	10,765		103.00	103.00	108.00	114.00	34,513	
	7	10,947		103.00	103.00	108.00	114.00	35,096	
KS-3	1	7,090	33.37	103.00	102.74	108.00	114.00	33,123	207,156
	2	6,767		103.00	102.98	108.00	114.00	31,614	
	3	10,602		103.00	102.25	108.00	113.74	48,611	
	4	11,962		103.00	100.81	108.00	112.14	48,459	
	5	10,794		103.00	101.21	108.00	112.59	45,349	
KS-4	1	3,897	33.49	103.00	101.39	107.51	112.27	16,014	37,717
	2	4,629		103.00	103.00	108.24	114.00	21,704	

Notes: [1] Independent strength pay factors are capped at a maximum of 103%.
[2] Independent slab thickness pay factors are capped at a maximum of 103%.
[3] Independent initial smoothness pay factors are capped at a maximum of 108%.

[4] Lot CPF’s are computed using the *product* method (see volume I, chapter 6, for more information on the product CPF method). Lot CPF’s are capped at a maximum of 114%.

Comparison of Kansas PRS-Based Pay Adjustments to Actual Pay Adjustments

Direct comparisons of the actual pay adjustments computed using the governing KDOT construction specification to those computed using the Level 1 PRS are presented in table 103. Ratios of the Level 1 PRS pay adjustments to the actual pay adjustments are also contained in table 103. For the Kansas projects, the Level 1 lot PRS pay adjustments (capped at a maximum of 114 percent) were generally found to be greater than those determined using the KDOT specification. This trend held true for 12 of the 17 lots investigated. However, there appeared to be fairly large variations in the computed lot ratios, within each project. The average of these lot ratios (within each project) were computed to be the following:

- KS-1: 1.16
- KS-2: 1.09
- KS-3: 1.20
- KS-4: 3.96

Table 103. Direct comparison of Level 1 PRS pay adjustments to those computed using the governing Kansas construction specifications.

Project	Lot	Pay Adjustments Computed Using the Governing KDOT Construction Specification		Pay Adjustments Computed Using the Level 1 PRS Method		Ratio of Computed Level 1 PRS Pay Adjustments to Those Determined Using the Governing KDOT Specification	
		Total Lot Pay Adjustment, $	Total Project Pay Adjustment, $	Total Lot Pay Adjustment, $	Total Project Pay Adjustment, $	Ratio of Lot Pay Adjustments	Ratio of Project Pay Adjustments
KS-1	1	8,765	44,008	9,973	43,953	1.14	1.00
	2	28,341		23,645		0.83	
	3	6,902		10,335		1.50	
KS-2	1	22,368	182,316	20,608	199,362	0.92	1.09
	2	25,547		33,326		1.30	
	3	27,844		27,527		0.99	
	4	16,323		18,428		1.13	
	5	30,074		29,864		0.99	
	6	30,923		34,513		1.12	
	7	29,238		35,096		1.20	
KS-3	1	25,016	175,340	33,123	207,156	1.32	1.18
	2	27,183		31,614		1.16	
	3	35,546		48,611		1.37	
	4	40,519		48,459		1.20	
	5	47,076		45,349		0.96	

KS-4	1	8,373	11,991	16,014	37,717	1.91	3.15
	2	3,618		21,704		6.00	

Note: The Level 1 PRS-based lot pay adjustments were computed using a maximum CPF of 114.0 percent.

Wisconsin Projects

Two Wisconsin projects were investigated as part of the pay adjustment study. The two projects were conducted on the same State highway with the same design; however, the design thickness for each was expressed differently. The WI-1 project was specified by the SHA in the traditional English units as 11.00 in (converted to 279 mm), while the design thickness for WI-2 was expressed directly in metric units as 275 mm. Because there was a slight difference in design thickness between the two methods, WI-1 and WI-2 were investigated independently. The details of the investigations of each project are discussed in the following sections.

Constant Variable Inputs

Most of the design- and traffic-related variable inputs required to simulate the WI-1 and WI-2 Level 1 pay factor curves were obtained directly from Wisconsin Department of Transportation (WisDOT) personnel. Most of the climatic variable values were obtained from available climatic databases. All variables that were assumed are marked as such. The constant variables defining both WI-1 and WI-2 are presented in table 104.

Table 104. Constant inputs defining the WI-1 and WI-2 archived projects.

Project Information		
	State	Wisconsin
	County	Clark
	Route	STH-29
	Design method	AASHTO 72
Project Type		
	Pavement type	Plain, doweled
	Road location	Rural, divided
	Design life	27 years
	Analysis life	54 years (assumed)
	Overlay life	10 years (assumed)
	Project length	WI-1 = 6.459 km; WI-2 = 10.240 km

	Number of lanes in one direction	2
	Lane width	4.27 m
	Joint spacing	5.64 m
Traffic Information		
	Total design ESAL's	11,400,000
	Traffic growth factor	0% (assumed)
	Traffic growth method	Simple (assumed)
Materials and Climatic Information		
	Annual temperature range	25 ºC (assumed)
	Freezing index	1,500 degree-days (assumed)
	Average annual precipitation	81.3 cm (assumed)
	Annual freeze-thaw cycles in pavement (at a depth of 7.6 cm)	8 (assumed)
	Salt present	Yes (assumed)
	Transverse joint sealant type	None
Slab Support Information		
	Base type	Open-graded
	Modulus of subgrade reaction	33.93 MPa/m
	Subgrade soil type	Fine-grained (A-4 to A-7) (assumed)
	Presence of longitudinal subdrains	Yes
Load Transfer Information		
	Dowel bar diameter	3.8 cm
	Presence of tied PCC shoulder	No
Cost Information		
	Construction bid	$21.70/m^2
	Cost of overlay (current)	$10.76/m^2 (assumed)
	Cost of joint patching (current)	$95.68/m^2 (assumed)
	Cost of slab replacement (current)	$83.72/m^2 (assumed)
	Annual interest rate	6% (assumed)

	Annual inflation rate	3% (assumed)

AQC Target Values

Appropriate AQC target values were determined for each project by interpreting the Wisconsin construction specification. The specification was interpreted in accordance with the guidelines set forth in chapter 5 of volume I (*Selection of AQC Target Values*). The chosen AQC target means and standard deviations used to define the agency-desired quality for projects WI-1 and WI-2 are summarized in tables 105 and 106.

Table 105. Level 1 AQC target means and standard deviations for the Wisconsin WI-1 archived project.

Acceptance Quality Characteristic	Target Mean	Target Standard Deviation
28-day compressive strength, MPa	29.3	3.8
Slab thickness, mm	279	5
Entrained air content, percent	7.0	0.75
Initial smoothness, mm/km (5.1-mm blanking band)	134	12

Note: Computed from individual tests (no averaging is performed); thus, it includes both materials/process and testing measurement variation.

Table 106. Level 1 AQC target means and standard deviations for the Wisconsin WI-2 archived project.

Acceptance Quality Characteristic	Target Mean	Target Standard Deviation
28-day compressive strength, MPa	29.3	3.8
Slab thickness, mm	275	5
Entrained air content, percent	7.0	0.75
Initial smoothness, mm/km (5.1-mm blanking band)	134	12

Note: Computed from individual tests (no averaging is performed); thus, it includes both materials/process and testing measurement variation.

Retrieval of Actual AQC Sampling and Testing Data

Actual AQC sampling and testing data were retrieved from WisDOT historical files for different days of paving at each archived project. Each day was assumed to be equal to one lot of paving. Archived data were retrieved for concrete strength, slab thickness, and initial smoothness (entrained air content data were not collected since no entrained air content pay adjustments were computed under the actual Wisconsin construction specification). All of the test values within each lot were summarized into representative lot means and standard deviations. The lot means and standard deviations were then used to determine representative Level 1 AQC lot pay factors for each respective lot. The as-constructed AQC lot means and standard deviations computed for each Wisconsin project are summarized in tables 107 and 108.

Table 107. Computed as-constructed AQC lot means and standard deviations for the Wisconsin WI-1 project.

	28-day Compressive Strength, MPa		Slab Thickness, mm		Initial Smoothness, mm/km	
Lot	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	26.5	2.63	288	6	83	20
2	27.7	3.52	282	3	136	15
3	28.7	2.45	284	4	56	2
4	26.8	2.64	283	4	57	12
5	25.3	1.51	283	4	40	6

Table 108. Computed as-constructed AQC lot means and standard deviations for the Wisconsin WI-2 project.

	28-day Compressive Strength, MPa		Slab Thickness, mm		Initial Smoothness, mm/km	
Lot	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	26.6	1.82	284	6	50	34

2	28.5	1.81	286	5	54	21
3	31.5	2.95	280	7	29	14
4	29.7	4.20	279	3	40	6
5	29.5	3.57	280	4	76	17
6	27.7	2.17	279	3	37	15
7	29.3	3.25	280	5	33	11
8	27.9	1.72	279	4	54	23

Simulation of Level 1 AQC Pay Factor Charts and Equations

Independent AQC Level 1 pay factor charts were simulated for each project based on the respective identified constant variable values and AQC target values. Based on the typical daily amount of AQC sampling and testing observed in the historical records, it was decided that PRS-based pay adjustments for projects WI-1 and WI-2 would be most realistic if the pay factor equations were developed for the case of four sublots per lot and four samples per sublot.

Each simulated LCC (used to construct the AQC pay factor curves) was determined as the mean of 500 simulated lot LCC's—using a 54-year analysis life (two times the 27-year design life) and including 5 percent of the calculated user costs. The simulated representative as-designed LCC means for each of the two Wisconsin projects were simulated as the following:

- **WI-1: $731,672/km.**
- **WI-2: $733,880/km.**

Pay factor curves for each Wisconsin project were calculated for different chosen AQC standard deviations, over reasonable ranges of AQC means. The simulated AQC pay factor curves representing projects WI-1 and WI-2 are presented in figures 29 and 30, respectively. The corresponding pay factor regression equations for these two projects are presented in tables 109 and 110, respectively.

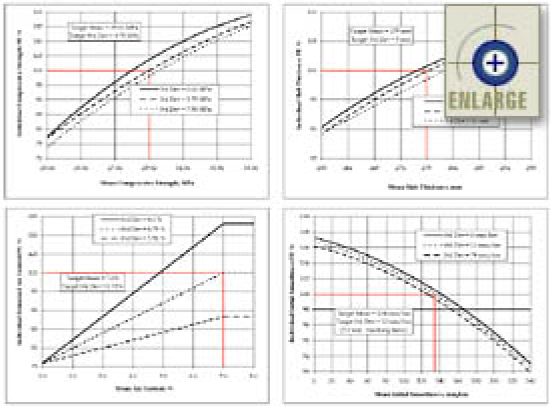


Figure 29. Level 1 individual AQC pay factor charts for archived project WI-1 (four sublots, four samples per sublot).

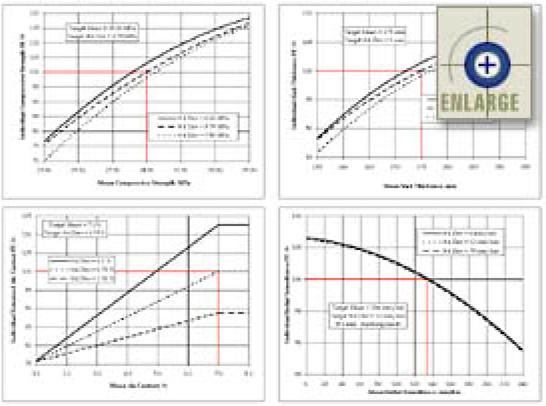


Figure 30. Level 1 individual AQC pay factor charts for archived project WI-2 (four sublots, four samples per sublot).

Table 109. Level 1 AQC best-fit regression equations for archived project WI-1 (four sublots, four samples per sublot [lot sample size N=16]).

Acceptance Quality Characteristic	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value	Maximum Pay Factor, % [1]	x-Value at Maximum Pay Factor [2]
28-day Cylinder Compressive Strength	0.0 MPa	$PF_{S\text{-}(x,\,0.0)} = -0.1510x^2 + 12.3152x - 127.4788$	119.04	35.3 MPa
	3.8 MPa	$PF_{S\text{-}(x,\,3.8)} = -8.8667E\text{-}02x^2 + 8.5054x - 73.0972$	116.66	35.3 MPa
	7.6 MPa	$PF_{S\text{-}(x,\,7.6)} = -9.7922E\text{-}02x^2 + 9.1798x - 86.7822$	115.24	35.3 MPa
Slab Thickness	0 mm	$PF_{T\text{-}(x,\,0)} = -5.8005E\text{-}03x^2 + 3.6405x - 463.4489$	106.50	299 mm
	5 mm	$PF_{T\text{-}(x,\,5)} = -5.1116E\text{-}03x^2 + 3.2844x - 418.6378$	106.43	299 mm
	10 mm	$PF_{T\text{-}(x,\,10)} = -1.6533E\text{-}03x^2 + 1.3575x - 151.5733$	106.50	299 mm
Plastic Entrained Air Content	0.00%	$PF_{A\text{-}(x,\,0.00)} = 6.1983x + 69.7119$	113.10	7.0%
	0.75%	$PF_{A\text{-}(x,\,0.75)} = 4.0167x + 71.8831$	100.00	7.0%
	1.50%	$PF_{A\text{-}(x,\,1.50)} = 2.0767x + 73.7431$	88.28	7.0%
Initial Smoothness (5.1-mm blanking band)	0 mm/km	$PF_{SM\text{-}(x,\,0)} = -1.6099E\text{-}04x^2 - 2.9090E\text{-}02x + 107.30$	107.30	0 mm/km
	12 mm/km	$PF_{SM\text{-}(x,\,12)} = -1.6099E\text{-}04x^2 - 2.9090E\text{-}02x + 106.80$	106.80	0 mm/km
	79 mm/km	$PF_{SM\text{-}(x,\,79)} = -1.6099E\text{-}04x^2 - 2.9090E\text{-}02x + 106.24$	106.24	0 mm/km

Note: [1]The pay factors are held equal to the equation's maximum pay factor value when the measured value surpasses the corresponding "x-Value at Maximum Pay Factor" (i.e., greater than the corresponding value for strength, thickness, and entrained air content; less than the corresponding value for initial smoothness).

[2]The chosen "x-Value at maximum pay factor" values were set equal to the limits used for the pay factor charts.

Table 110. Level 1 AQC best-fit regression equations for archived project WI-2 (four sublots, four samples per sublot [lot sample size N=16]).

Acceptance Quality Characteristic	As-Constructed Standard Deviation	Pay Factor Regression Equation, x = mean value	Maximum Pay Factor, % [1]	x-Value at Maximum Pay Factor [2]
28-day Cylinder Compressive Strength	0.0 MPa	$PF_{S\text{-}(x,\,0.0)} = -0.1540x^2 + 12.5081x - 131.3025$	118.36	35.3 MPa
	3.8 MPa	$PF_{S\text{-}(x,\,3.8)} = -0.1096x^2 + 9.8473x - 94.4481$	116.59	35.3 MPa
	7.6 MPa	$PF_{S\text{-}(x,\,7.6)} = -0.1438x^2 + 12.2372x - 137.0659$	115.74	35.3 MPa
Slab Thickness	0 mm	$PF_{T\text{-}(x,\,0)} = -1.0763E\text{-}02x^2 + 6.3611x - 833.9018$	105.92	295 mm
	5 mm	$PF_{T\text{-}(x,\,5)} = -8.0470E\text{-}03x^2 + 4.8568x - 627.0755$	105.40	295 mm
	10 mm	$PF_{T\text{-}(x,\,10)} = -9.2159E\text{-}03x^2 + 5.5508x - 730.3761$	105.11	295 mm
Plastic Entrained Air Content	0.00%	$PF_{A\text{-}(x,\,0.00)} = 6.1200x + 69.7600$	112.60	7.0%
	0.75%	$PF_{A\text{-}(x,\,0.75)} = 4.0583x + 71.5919$	100.00	7.0%
	1.50%	$PF_{A\text{-}(x,\,1.50)} = 2.1950x + 73.5050$	88.87	7.0%
Initial Smoothness (5.1-mm blanking band)	0 mm/km	$PF_{SM\text{-}(x,\,0)} = -2.4770E\text{-}04x^2 - 1.4476E\text{-}02x + 106.60$	106.60	0 mm/km
	12 mm/km	$PF_{SM\text{-}(x,\,12)} = -2.4770E\text{-}04x^2 - 1.4476E\text{-}02x + 106.40$	106.40	0 mm/km
	79 mm/km	$PF_{SM\text{-}(x,\,79)} = -2.4770E\text{-}04x^2 - 1.4476E\text{-}02x + 106.34$	106.34	0 mm/km

Note: [1] The pay factors are held equal to the equation's maximum pay factor value when the measured value surpasses the corresponding "x-Value at Maximum Pay Factor" (i.e., greater than the corresponding value for strength, thickness, and entrained air content; less than the corresponding value for initial smoothness).
[2] The chosen "x-Value at Maximum Pay Factor" values were set equal to the limits used for the pay factor charts.

Calculation of Pay Adjustments

Lot pay adjustments were calculated for the two Wisconsin projects based on the computed representative AQC lot means and standard deviations. These values were used to compute pay factors using two different calculation methods—using the actual Wisconsin governing construction specification and using the developed Level 1 PRS pay factor equations. The details of both pay factor calculation methods are described separately below.

Calculation of Pay Adjustments Using the Governing Wisconsin Construction Specification

The governing Wisconsin construction specification applied pay adjustments to concrete strength, slab thickness, and initial smoothness (no pay adjustments were based on air content). All of the details of the pay adjustment procedures included in the governing Wisconsin construction specification are discussed below.

Individual Concrete Strength (28-day Compressive) Pay Adjustments

Unit concrete strength pay adjustments were provided for each lot by WisDOT personnel. Individual lot pay adjustments were computed by multiplying the total volume of concrete in

each lot by the provided unit pay adjustment. The total volume of concrete for the lot was computed using equation 58.

LotVolume = ((T/1000) * W * L) **(58)**

where

LotVolume = Total estimated volume of concrete within the lot, m^3.

T = Design thickness, mm.

W = Defined lot width, m.

L = Measured lot length, m.

As an example, let us look at lot 1 from the WI-1 project. For this lot, the concrete strength unit pay adjustment was given as –\$1.24/m^3. Using the design thickness of 279 mm, a defined lot width of 7.92 m, and the measured lot length of 1,153 m, the total estimated lot volume was calculated as 2,553 m^3 using equation 58. The total concrete strength pay adjustment for lot 1 of the WI-1 project was then computed as –\$1.24/m^3 * 2,553 m^3 = –\$3,166.

Individual Slab Thickness Pay Adjustment

Slab thickness pay adjustments were assumed to be applied using the pay factor schedule provided in the draft *Wisconsin Quality Management Program (QMP)* provisions. This table of thickness-based disincentives is presented in table 111.

Table 111. Wisconsin draft QMP slab thickness pay adjustment schedule.

Average Thickness Deficiency, mm	Pay adjustment per 76.2-m lane unit, $
0 – 10	0
11 – 15	–1,140
16 – 20	–2,100
21 – 25	–2,670

No slab thickness cores were found to be deficient in the WI-1 and WI-2 projects. Therefore, individual slab thickness pay factors for all lots are set equal to 100 percent.

Initial Smoothness Pay Adjustments

Pay factors for initial smoothness were computed using the pay schedule presented in table 112.

Table 112. Wisconsin concrete pavement smoothness pay factors.

Profile Index (5.1-mm blanking band), mm/km	Initial Smoothness Pay Factor (PF_{SM}), percent of contract unit bid price
0 – 76	105
77 – 178	102
179 – 254	100
255 – 305	98
306 – 381	96
≥ 382	92

Note: Measurements have been converted to metric from English units.

The lot initial smoothness pay adjustments are calculated using equation 59.

$$PAY_{SM} = (PF_{SM} / 100 - 1) * BID * AREA_{LOT} \quad (59)$$

where

PAY_{SM} = Lot initial smoothness-related pay adjustment, $.

PF_{SM} = Initial smoothness lot pay factor determined from table 112.

BID = Contractor unit bid price, $\$/m^2$.

$AREA_{LOT}$ = Total area of the lot, m^2.

As an example, lot 1 of project WI-1 had a reported mean profile index of 83 mm/km. The corresponding pay factor for this lot was determined as 102 percent from table 112. For the example lot, the unit bid price was $\$21.70/m^2$ and the total lot area was 2,553 m^2. Therefore, the overall lot initial smoothness pay adjustment was computed as the following using equation 59:

$$PAY_{SM} = (PF_{SM} - 1) * BID * AREA_{LOT}$$

$$= (1.02 - 1) * 21.70 * 9{,}138$$

$$= +3{,}966 \text{ dollars}$$

Summary of Pay Adjustments Using the Governing Wisconsin Construction Specification

A summary of the lot pay factors and pay adjustments calculated using the actual governing WisDOT construction specification is presented in table 113.

Table 113. Summary of all of the pay factors and adjustments (determined for the Wisconsin projects) using the governing Wisconsin construction specifications.

				Concrete Strength		Slab Thickness	Initial Smoothness			
Project	Lot	Total Lot Area, m^2	Bid Price, $/$m^2$	Unit Pay Adjustment[1], $/$m^3$	Lot Strength Pay Adjustment, $	Lot Slab Thickness Pay Adjustment, $[2]	Pay Factor, %	Lot Initial Smoothness Pay Adjustment, $	Total Lot Pay Adjustment, $	Total Project Pay Adjustment, $
WI-1	1	9,138	21.70	–1.24	–3,166	0	102.00	3,966	800	11,645
	2	10,688		–1.24	–3,711	0	100.00	0	–3,711	
	3	12,085		0.34	1,148	0	102.00	5,244	6,392	
	4	9,297		–1.24	–3,228	0	102.00	4,034	806	
	5	9,976		–1.24	–3,463	0	105.00	10,822	7,358	
WI-2	1	7,521	21.70	–0.76	–1,569	0	102.00	3,263	1,694	56,208
	2	8,781		0.78	1,895	0	102.00	3,810	5,705	
	3	9,573		1.27	3,340	0	105.00	10,385	13,725	
	4	7,774		0.00	0	0	105.00	8,433	8,433	
	5	11,499		0.44	1,406	0	102.00	4,989	6,396	
	6	7,782		0.00	0	0	105.00	8,442	8,442	
	7	7,227		0.44	884	0	105.00	7,840	8,724	
	8	5,555		0.44	679	0	102.00	2,410	3,090	

Notes: [1] The volume of concrete in a lot (in units of m^3) is calculated using the reported total lot area and the defined respective design thickness.
[2] No deficient thickness cores were found within either of the two projects; therefore, all slab thickness lot pay adjustments were equal to zero.

<u>Calculation of Pay Factors Using the Level 1 PRS Approach</u>

PRS-based pay adjustments were calculated for all of the lots included in the two Wisconsin projects based on the computed AQC lot means and standard deviations. Each PRS-based lot pay adjustment was computed by using the measured AQC lot mean in the appropriate developed pay factor equations and then interpolating between the results based on the measured AQC lot standard deviation. A detailed explanation of the calculation of PRS Level 1 pay factors for an example lot is contained below.

The measured as-constructed AQC means and standard deviations representing lot 1 of WI-1 were the following:

- 28-day Compressive Strength: Mean = 26.5 MPa, Std Dev = 2.6 MPa.
- Slab Thickness: Mean = 288 mm, Std Dev = 6 mm.
- Initial Smoothness: Mean = 83 mm/km, Std Dev = 20 mm/km.

The pay factor equations presented in table 109 are used to calculate individual AQC pay factors.

Measured As-Constructed Compressive Strength (Mean = 26.5 MPa, Std Dev =2.6 MPa):

At a mean of 26.5 MPa and a standard deviation of 0.0 MPa:

$$PF_{S\text{-}(26.5,\ 0.0)} = -0.15104(26.5)^2 + 12.3152(26.5) - 127.4788 = 92.80\% \tag{60}$$

At a mean of 26.5 MPa and a standard deviation of 3.8 MPa:

$$PF_{S\text{-}(26.5,\ 3.8)} = -0.08867(26.5)^2 + 8.5054(26.5) - 73.0972 = 90.03\% \tag{61}$$

The pay factor for the case with strength mean and standard deviation equal to 26.5 and 2.6 MPa, respectively, is interpolated (using an assumed linear relationship) by the following equation:

$$PF_{S\text{-}(26.5,\ 2.6)} = PF_{S\text{-}(26.5,\ 3.8)} + (PF_{S\text{-}(26.5,\ 0.0)} - PF_{S\text{-}(26.5,\ 3.8)}) * [(3.8\text{ MPa} - 2.6\text{ MPa}) / (3.8\text{ MPa} - 0.0\text{ MPa})] \tag{62}$$

$$= 90.03\% + (92.80\% - 90.03\%) * [(1.2\text{ MPa})/(3.8\text{ MPa})]$$

$$= 90.90\%$$

Measured As-Constructed Thickness (Mean = 288 mm, Std Dev = 6 mm):

At a mean of 288 mm and a standard deviation of 5 mm:

$$PF_{T\text{-}(288,\ 5)} = -5.1116E\text{-}03(288)^2 + 3.2844(288) - 418.6378 = 103.29\% \tag{63}$$

At a mean of 296 mm and a standard deviation of 10 mm:

$$PF_{T\text{-}(288,\ 10)} = -1.6533E\text{-}03(288)^2 + 1.3575(288) - 151.5733 = 102.26\% \tag{64}$$

The pay factor for the case with thickness mean and standard deviation equal to 288 and 6 mm, respectively, is interpolated (using an assumed linear relationship) by the following equation:

$$PF_{T\text{-}(288,\ 6)} = PF_{T\text{-}(288,\ 10)} + (PF_{T\text{-}(288,\ 5)} - PF_{T\text{-}(288,\ 10)}) * [(10\text{ mm} - 6\text{ mm}) / (10\text{ mm} - 5\text{ mm})] \tag{65}$$

$$= 102.26\% + (103.29\% - 102.26\%) * [(4\text{ mm})/(5\text{ mm})]$$

$$= 103.09\%$$

Measured As-Constructed Initial Smoothness (Mean = 83 mm/km, Std Dev = 20 mm/km):

At a mean of 83 mm/km and a standard deviation of 12 mm/km:

$$PF_{SM\text{-}(83,\ 12)} = -1.6099E{-}04(83)^2 - 2.9090E\text{-}02(83) + 106.80 = 103.28\% \tag{66}$$

At a mean of 83 mm/km and a standard deviation of 79 mm:

$$PF_{SM\text{-}(83,\,79)} = -1.6099\text{E}{-04}(83)^2 - 2.9090\text{E-}02(83) + 106.24 = 102.72\% \qquad (67)$$

The pay factor for the case with initial smoothness mean and standard deviation equal to 83 and 20 mm/km, respectively, is interpolated (using an assumed linear relationship) by the following equation:

$$PF_{SM\text{-}(83,\,20)} = PF_{SM\text{-}(83,\,79)} + (PF_{SM\text{-}(83,\,12)} - PF_{SM\text{-}(83,\,79)}) * [(79\text{ mm/km} - 20\text{ mm/km}) / (79\text{ mm/km} - 12\text{ mm/km})] \qquad (68)$$

$$= 102.72\% + (103.28\% - 102.72\%) * [(59\text{ mm/km})/(67\text{ mm/km})]$$

$$= 103.21\%$$

Calculation of the PRS Composite Pay Factor and Pay Adjustment

The overall composite pay factor for the example lot is calculated using the *product method* (i.e., the individual AQC pay factors are multiplied together). This composite pay factor equation is shown in equation 56. Note that the individual AQC pay factors are expressed as decimals in the CPF equation (e.g., a pay factor of 102 percent is expressed as 1.02).

For the Level 1 analysis, it was decided to apply practical AQC pay factor limits in a manner similar to those limits applied using the actual Wisconsin construction specifications. The concrete strength and slab thickness were limited typical maximum pay factors of 103 percent, while an upper limit of 105 percent was applied for initial smoothness. It is important to note that pay factor limits must be determined by an agency when applying a Level 1 PRS.

For the example lot, the composite pay factor is calculated as the following using equation 56. (Note: The thickness pay factor computed to be 1.0309 has been limited to the chosen maximum of 1.03):

$$CPF_{LOT} = PF_{S\text{-}(26.5,\,2.6)} * PF_{T\text{-}(288,\,6)} * PF_{SM\text{-}(83,\,20)}$$

$$= (0.9090) * (1.0300) * (1.0321) = 0.9663$$

which translates to an overall pay factor of 96.63 percent.

Overall lot pay adjustments are calculated using equation 57. For the example lot, the unit bid price was \$21.70/m^2, and the total lot area was 2,553 m^2. Therefore, using the computed limited CPF_{LOT} of 0.9663, the overall Level 1 lot price adjustment was computed as the following using equation 57:

$$PAY_{LOT} = (CPF_{LOT} - 1) * BID * AREA_{LOT}$$

$$= (0.9663 - 1) * 21.70 * 9{,}138$$

$$= -6{,}683 \text{ dollars}$$

A summary of all the Level 1 PRS pay factors and pay adjustments (calculated for both Wisconsin projects) is presented in table 114.

Table 114. Summary of all the Level 1 PRS pay factors and adjustments determined for the Wisconsin projects.

Project	Lot	Total Lot Area, m^2	Bid Price, $\$/m^2$	Independent Strength Pay Factor (P_{STR}), % (103% cap)[1]	Independent Thickness Pay Factor (P_{THK}), % (103% cap)[2]	Independent Smoothness Pay Factor (P_{SM}), % (105% cap)[3]	Lot Composite Pay Factor (CPF_{LOT}), %[4]	Total Lot PRS Pay Adjustment (based on limited PF's), $	Total Project PRS Pay Adjustment (based on limited PF's), $
WI-1	1	9,138	21.70	90.90	103.00	103.21	96.63	–6,683	–20,238
	2	10,688		94.85	101.29	99.84	95.92	–9,455	
	3	12,085		99.27	101.90	105.00	106.22	16,309	
	4	9,297		92.00	101.67	104.63	97.86	–4,308	
	5	9,976		86.69	101.69	105.00	92.56	–16,101	
WI-2	1	7,521	21.70	91.09	103.00	105.00	98.52	–2,417	82,780
	2	8,781		98.67	103.00	104.89	106.60	12,567	
	3	9,573		103.00	101.57	105.00	109.84	20,443	
	4	7,774		101.27	102.12	105.00	108.59	14,489	
	5	11,499		100.77	102.23	103.85	106.99	17,449	
	6	7,782		95.52	102.11	105.00	102.42	4,082	
	7	7,227		100.55	102.13	105.00	107.83	12,273	
	8	5,555		96.49	102.01	104.88	103.23	3,894	

Notes: [1] Independent strength pay factors are capped at a maximum of 103%.
[2] Independent slab thickness pay factors are capped at a maximum of 103%.
[3] Independent initial smoothness pay factors are capped at a maximum of 105%.
[4] Lot CPF's are computed using the *product* method (see volume I, chapter 6, for more information on the product CPF method).

Comparison of Wisconsin PRS-Based Pay Adjustments to Actual Pay Adjustments

Direct comparisons of the actual pay adjustments computed using the governing WisDOT construction specification to those computed using the Level 1 PRS are presented in table 115. Ratios of the Level 1 PRS pay adjustments to the actual pay adjustments are also contained in table 115. As with the Kansas projects, the computed pay ratios (Level 1 pay adjustments to actual pay adjustments) for the Wisconsin projects varied greatly within each project.

Table 115. Direct comparison of Level 1 PRS pay adjustments to those computed using the governing Wisconsin construction specifications.

Project	Lot	Pay Adjustments Computed Using the Governing WisDOT Construction Specification		Pay Adjustments Computed Using the Level 1 PRS Method		Ratio of Computed Level 1 PRS Pay Adjustments to Those Determined Using the Governing WisDOT Specification	
		Total Lot Pay Adjustment, $	Total Project Pay Adjustment, $	Total Lot Pay Adjustment, $	Total Project Pay Adjustment, $	Ratio of Lot Pay Adjustments	Ratio of Project Pay Adjustments
WI-1	1	800	11,645	–6,683	–20,238	–8.35	–1.74
	2	–3,711		–9,455		2.55	
	3	6,392		16,309		2.55	
	4	806		–4,308		–5.34	
	5	7,358		–16,101		–2.19	
WI-2	1	1,694	56,208	–2,417	82,780	–1.43	1.47
	2	5,705		12,567		2.20	
	3	13,725		20,443		1.49	
	4	8,433		14,489		1.72	
	5	6,396		17,449		2.73	
	6	8,442		4,082		0.48	
	7	8,724		12,273		1.41	
	8	3,090		3,894		1.26	

For project WI-1, four of the five PRS level 1 lot pay adjustments were computed to be negative, mainly due to deficient concrete strength. The actual SHA pay adjustments for these lots were generally low; however, the negative adjustments applied to concrete strength were not as harsh as those applied under the level 1 PRS approach. An analysis of the computed pay ratios showed an average lot ratio of –2.16. (Note: Practical minimum Level 1 PRS pay factors could be used by the SHA to make pay adjustments more closely match the pay adjustments currently used by the SHA.)

An analysis of the second Wisconsin project, WI-2, showed that the Level 1 lot PRS pay adjustments were generally found to be greater than those determined using the WisDOT specification. This trend held true for seven of the eight lots investigated. The average lot ratio for this project was computed to be 1.23.

Iowa Project

Actual pay adjustment information was obtained for the original Ottumwa, Iowa project described in detail in chapter 2 of this volume. The constant variable inputs defined for this project are presented in table 1. The chosen Level 1 AQC target values are presented in table 5. Pay adjustments were only applied to initial smoothness and slab thickness under the governing Iowa construction specification. All aspects of the pay adjustment analysis of the Ottumwa, Iowa project (IA-1) are contained in the following sections.

Retrieval of Actual AQC Sampling and Testing Data

Actual AQC sampling and testing data were retrieved from Iowa DOT historical files for different days of paving at the IA-1 project. Each day was assumed to be equal to one lot of paving. Archived data were retrieved for slab thickness and initial smoothness only. All of the test values within each lot were summarized into representative lot means and standard deviations. The lot means and standard deviations were then used to determine representative Level 1 AQC lot pay factors for each respective lot. The as-constructed AQC lot means and standard deviations computed for the IA-1 project are summarized in table 116.

Table 116. Computed as-constructed AQC lot means and standard deviations for the Iowa IA-1 project.

	Slab Thickness, mm		Initial Smoothness (5.1-mm blanking band), mm/km	
Lot	Mean	Std Dev	Mean	Std Dev
1	307	7	36	28
2	308	7	62	39
3	310	6	103	58

Simulation of Level 1 AQC Pay Factor Charts and Equations

Independent AQC Level 1 pay factor charts were simulated for the project based on the respective identified constant variable values and AQC target values. A complete summary of the procedures used to develop these curves for the IA-1 project is contained in the section titled *Level 1—Development of Individual AQC Pay Factor Curves and Equations*. The IA-1 Level 1 pay factor charts, for the cases of 3 and 4 sublots, are presented in figures 1 and 2, respectively. Corresponding best-fit regression equations for the simulated pay factor curves are contained in table 14.

Calculation of Pay Adjustments

Lot pay adjustments were calculated for the Iowa project based on the computed representative AQC lot means and standard deviations. These values were used to compute pay factors using the two different calculation methods—using the actual Iowa governing construction specification and using the developed Level 1 PRS pay factor equations. Details of both pay factor calculation methods are described separately below.

Calculation of Pay Adjustments Using the Governing Iowa Construction Specification

The governing Iowa construction specification applied pay adjustments to slab thickness and initial smoothness only. Slab thickness pay adjustments were computed (using the measured AQC lot data) in accordance with table 3. Initial smoothness pay adjustments were computed in accordance with table 4. A complete discussion of the Iowa acceptance procedures is contained in chapter 2 in the section titled *Definition of the Required As-Designed AQC Target Values*. A summary of the actual lot pay factors and pay adjustments computed using the governing Iowa DOT construction specification is presented in table 117.

Table 117. Summary of all of the pay factors and adjustments (determined for the original Iowa field trial [IA-1]) using the governing Iowa construction specifications.

Project	Lot	Total Lot Area, m²	Bid Price, $/m²	Slab Thickness Pay Factor, %	Computed Slab Thickness Lot Pay Adjustment, $	Initial Smoothness Lot Pay Adjustment, $	Total Lot Pay Adjustment, $	Total Project Pay Adjustment, $
IA-1	1	5,599	24.10	103.00	4,048	3,974	8,022	18,912
	2	7,722		103.00	5,583	0	5,583	
	3	7,341		103.00	5,307	0	5,307	

Calculation of Pay Factors Using the Level 1 PRS Approach

PRS-based pay adjustments were calculated for all of the lots included in the Iowa project based on the computed AQC lot means and standard deviations. Each PRS-based lot pay adjustment was computed by using the measured AQC lot mean in the appropriate developed pay factor equations and then interpolating between the results based on the measured AQC lot standard deviation. A detailed example of the calculation of PRS Level 1 pay factors at the Iowa project is contained in chapter 2 in the section titled *Calculation of Shadow Pay Factors*.

It was decided to apply practical AQC pay factor limits similar to those applied using the actual Iowa construction specifications. The slab thickness pay factor was limited to 103 percent, based on the maximum shown in table 3. The initial smoothness pay factor was limited to 105 percent, based on the payment schedule presented in table 4. A summary of all the Level 1 PRS pay factors and pay adjustments (calculated for the Iowa project) is presented in table 118.

Table 118. Summary of all the Level 1 PRS pay factors and adjustments determined for the original Iowa field trial (IA-1).

Project	Lot	Total Lot Area, m^2	Bid Price, \$/m^2	Independent Thickness Pay Factor (P_{THK}), % (103% cap)[1]	Independent Smoothness Pay Factor (P_{SM}), % (105% cap)[2]	Lot Composite Pay Factor (CPF_{LOT}), %[3]	Total Lot PRS Pay Adjustment (based on limited PF's), \$	Total Project PRS Pay Adjustment (based on limited PF's), \$
IA-1	1	5,599	24.10	103.00	101.10	104.13	5,577	6,580
	2	7,722		103.00	99.50	102.49	4,625	
	3	7,341		103.00	95.10	97.95	–3,621	

Notes: [1] Independent slab thickness pay factors are capped at a maximum of 103%.
[2] Independent initial smoothness pay factors are capped at a maximum of 105%.
[3] Lot CPF's are computed using the *product* method (see volume I, chapter 6, for more information on the product CPF method).

Comparison Of Iowa PRS-Based Pay Adjustments To Actual Pay Adjustments

Direct comparisons of the actual pay adjustments computed using the governing Iowa DOT construction specification to those computed using the Level 1 PRS are presented in table 119. Ratios of the Level 1 PRS pay adjustments to the actual pay adjustments are also contained in table 119. An analysis of the lot pay adjustments showed that the lot 1 and lot 2 pay adjustments were similar using the two methods. For those lots, the level 1 PRS pay adjustments were computed to be less than those computed using the governing Iowa specification. For the third lot, a disincentive was computed using the Level 1 PRS approach (due to initial smoothness being of poorer quality than the chosen as-designed target value), whereas the governing specification indicated that no pay adjustment was necessary.

Table 119. Direct comparison of Level 1 PRS pay adjustments to those computed using the governing Iowa construction specifications.

		Pay Adjustments Computed Using the Governing Iowa DOT Construction Specification		Pay Adjustments Computed Using the Level 1 PRS Method		Ratio of Computed Level 1 PRS Pay Adjustments to Those Determined Using the Governing Iowa DOT Specification	
Project	Lot	Total Lot Pay Adjustment, \$	Total Project Pay Adjustment, \$	Total Lot Pay Adjustment, \$	Total Project Pay Adjustment, \$	Ratio of Lot Pay Adjustments	Ratio of Project Pay Adjustments
IA-1	1	8,022	18,912	5,577	6,580	0.70	0.35
	2	5,583		4,625		0.83	
	3	5,307		–3,621		–0.68	

Summary Of Pay Adjustment Comparisons (All SHA Data)

Overall, the comparison of actual pay adjustments (computed using the SHA's governing specification) to Level 1 PRS pay adjustments showed that the trends can vary greatly from lot to lot. PRS-based pay factors were limited using the actual SHA pay factor limits (when available). A majority of the lots (20 of 33) showed that the Level 1 PRS pay adjustment was greater than that determined using the governing SHA specification. Ratios of PRS-based pay adjustments to actual pay adjustments were computed for each lot and project included in the study. An analysis of the absolute values of these ratios showed overall average lot and project ratios of 1.85 and 1.43, respectively (i.e., on average, lot and project pay adjustments [positive or negative] were 1.85 and 1.43 times larger under PRS). A complete summary of the actual versus PRS pay adjustments (for all 33 lots) is shown in table 120. Figure 31 contains a chart showing the PRS pay adjustments versus the actual pay adjustments (using SHA specifications) for all of the SHA's.

Table 120. Summary of actual pay adjustments to Level 1 PRS-based pay adjustments for all SHA's.

		Pay Adjustments Computed Using the Governing SHA Construction Specification		Pay Adjustments Computed Using the Level 1 PRS Method		Ratio of Computed Level 1 PRS Pay Adjustments to Those Determined Using the Governing SHA Construction Specification	
Project	Lot	Total Lot Pay Adjust., $	Total Project Pay Adjust., $	Total Lot Pay Adjust., $	Total Project Pay Adjust., $	Ratio of Lot Pay Adjustments	Ratio of Project Pay Adjustments
KS-1	1	8,765	44,008	9,973	43,953	1.14	1.00
	2	28,341		23,645		0.83	
	3	6,902		10,335		1.50	
KS-2	1	22,368	182,316	20,608	199,362	0.92	1.09
	2	25,547		33,326		1.30	
	3	27,844		27,527		0.99	
	4	16,323		18,428		1.13	
	5	30,074		29,864		0.99	
	6	30,923		34,513		1.12	
	7	29,238		35,096		1.20	
KS-3	1	25,016	175,340	33,123	207,156	1.32	1.18
	2	27,183		31,614		1.16	
	3	35,546		48,611		1.37	
	4	40,519		48,459		1.20	
	5	47,076		45,349		0.96	
KS-4	1	8,373	11,991	16,014	37,717	1.91	3.15

	2	3,618		21,704		6.00	
WI-1	1	800	11,645	–6,683	–20,238	–8.35	–1.74
	2	–3,711		–9,455		2.55	
	3	6,392		16,309		2.55	
	4	806		–4,308		–5.34	
	5	7,358		–16,101		–2.19	
WI-2	1	1,694	56,208	–2,417	82,780	–1.43	1.47
	2	5,705		12,567		2.20	
	3	13,725		20,443		1.49	
	4	8,433		14,489		1.72	
	5	6,396		17,449		2.73	
	6	8,442		4,082		0.48	
	7	8,724		12,273		1.41	
	8	3,090		3,894		1.26	
IA-1	1	8,022	18,912	5,577	6,580	0.70	0.35
	2	5,583		4,625		0.83	
	3	5,307		–3,621		–0.68	
Average of the computed ratios (taking the signs into consideration)						0.76	0.93
Average of the absolute values of the computed ratios						1.85	1.43

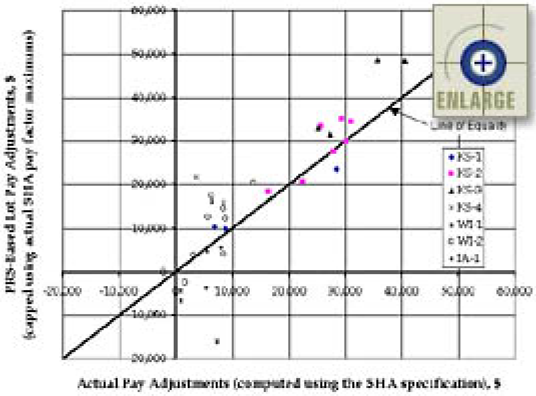


Figure 31. PRS pay adjustments versus actual pay adjustments (computed using SHA governing specifications) for all SHA data (33 lots, 7 projects, 3 SHA's).

Summary and Conclusions

Summary

The prototype PRS for jointed plain concrete pavement was demonstrated using three different methods in order to assess its practicality. The methods used to accomplish this task were the following:

1. *PRS shadow field trials*—Four shadow field trials (new construction projects) were conducted and documented as part of this research project. The PRS simulation software (PaveSpec) was used to develop preconstruction output for each project (reflecting the project-specific design, climatic, and traffic conditions). A PRS-based sampling and testing plan was then applied, and the required samples were collected to demonstrate the PRS procedures. Finally, the PaveSpec simulation software was used to determine *shadow* pay factors and adjustments for each project (i.e., the contractor's pay was not affected by the PRS-based pay factors and adjustments computed as part of the demonstration). Chapter 2 contains a discussion of the original shadow field trial (Ottumwa, Iowa). Chapter 3 contains a discussion of the three field trials conducted with OTA personnel.

2. *Development of Level 1 specifications for three typical pavement designs (within a given SHA)*—Level 1 PRS preconstruction output was developed for three typical pavement designs used in Iowa. Chapter 4 contains a complete discussion of these specification development procedures, as well as an analysis of trends observed within and between the typical designs.

- *Comparison of actual pay adjustments (computed using the governing SHA specifications) to PRS-based price adjustments*—Historical (archived) AQC and pay adjustment data were obtained for 33 pavement lots representing 7 projects from 3 SHA's. Level 1 preconstruction output (pay factor charts and corresponding equations) were developed for each investigated project. The retrieved AQC data were then used in conjunction with the Level 1 preconstruction output to determine PRS-based Level 1 lot pay factors. Historical pay adjustment data representing the same defined lots were then compared to the computed PRS-based pay adjustments, and the results were discussed. Chapter 5 contains a complete discussion of this analysis (divided into sections according to SHA).

This volume contains detailed documentation of all three methods used to demonstrate the prototype PRS. Conclusions of the three demonstration methods are summarized in the following section.

Conclusions

Demonstration Method #1—Shadow Field Trials

Much valuable experience was obtained from the conduct of the four shadow PRS field trials. Some practical recommendations resulting from the field trial experiences are as follows:

- *Fix the sublot length to one constant value*—As a result of the original field trial experience, it is recommended that one target sublot length be chosen and used to lay out all sublots prior to the paving of each lot. This should be done on a day-by-day (lot-by-lot) basis.

- *Choose a practical target sublot length*—The target sublot length should be chosen based on the anticipated amount of sampling and testing required, the personnel available, and the location of the testing facilities relative to the job site.

- *Choose a minimum length between longitudinal sampling locations*—It is recommended that the SHA decide on a practical minimum length between sampling locations when samples are required to be taken from the fresh concrete during the construction process.

- *Limit pay factors to chosen practical maximum values*—Pay factors must be capped at an agency-chosen maximum practical value. The original field trial demonstrated the need for practical maximum pay factors. At this project, the contractor provided approximately 25 mm of extra pavement thickness (in excess of the as-designed target value) on each of the three investigated lots. This extra thickness resulted in relatively large pay factors (approximately 160 percent) before the application of caps. Since it would be impossible for almost any SHA to make pay adjustments of this magnitude, pay factors must be capped at some agency-chosen practical value. The pay factor maximums could be applied to the individual AQC pay factors, the overall lot pay factor, or both.

Demonstration Method #2—Level 1 Preconstruction Output for Three Typical Designs

Level 1 pay factor charts and equations were developed for three typical JPCP designs in Iowa. The three typical designs were based on medium, heavy, and very heavy traffic levels. An analysis of the developed preconstruction output showed a number of trends within and between the constructed Level 1 pay factor charts. Many of these were found to be valid for the four different AQC's used in this demonstration. The observed general trends were the following:

- Pay factors increased as the quality of the measured AQC mean improved (i.e., increases in flexural strength, slab thickness, and air content mean; decreases in initial smoothness mean).

- At a given AQC mean, pay factors increased as the measured AQC standard deviation decreased.

- Pay factor curves generally became flatter as traffic level increased. This trend may be due to increased reliability factors built into the designs with heavier traffic (increases in slab thickness).

Demonstration Method #3—Comparison of PRS-Based Pay Adjustments to Actual SHA Pay Adjustments

The pay adjustment comparison showed that PRS and actual pay adjustments can differ greatly between projects. The study was conducted by limiting the PRS-based pay factors to those maximum pay factors allowed by each SHA. Overall, a majority of the lots (20 of 33) showed that the Level 1 PRS pay adjustments were greater than those determined using the governing SHA specification. Ratios of PRS-based pay adjustments to actual pay adjustments were computed for each lot and project included in the study. An analysis of the absolute values of these ratios showed overall average lot and project ratios of 1.85 and 1.43, respectively (i.e., on average, lot and project pay adjustments [positive or negative] were 1.85 and 1.43 times larger under PRS).

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