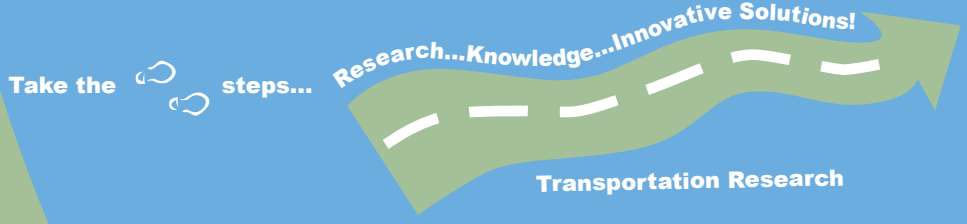
RESEARCH

2007-09

Implementation of an International Roughness Index for Mn/DOT Pavement Construction and Rehabilitation



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16. Abstract (Limit: 200 words)

This report documents the development and preparation for implementation of a specification for using International Roughness Index, using an inertial profiler, as a smoothness measure for new portland cement concrete pavements in Minnesota. This new specification represents a departure from the use of the Profile Index, using a California Profilometer, for concrete pavement smoothness.

In addition to providing recommendations to the Minnesota Department of Transportation regarding the implementation of the specification, the report contains additional information and analyses. These include a summary of the specifications in use by other states for measurement and incentive/disincentive payment for concrete pavement smoothness, an analysis of the effects of pavement surface characteristics on the International Roughness Index and the Profile Index, and a comparison of IRI-based concrete pavement smoothness specifications in use by other states.

The report concludes with several recommendations for the new specification and for its administration and enforcement by the Minnesota Department of Transportation.

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Implementation of an International Roughness Index for Mn/DOT Pavement Construction and Rehabilitation

Final Report

Prepared by:

Dr. W. James Wilde, P.E.
Department of Mechanical and Civil Engineering
Minnesota State University, Mankato

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Bernard Izevbekhai
Doug Schwartz
Curt Turgeon
Maria Masten
Ron Mulvaney
Joe Thomas

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EXECUTIVE SUMMARY

This report describes the work completed on an implementation project by Minnesota State University for the Minnesota Department of Transportation (Mn/DOT) to refine a new specification for measurement and payment of surface smoothness on new portland cement concrete (PCC) pavement construction. The report consists of four major components.

- A review of smoothness specifications for concrete pavement in use by other states in the Nation.
- An analysis of the effect on smoothness incentives, comparing the existing specification which uses profile index (PI), and the proposed specification using the international roughness index (IRI).
- An analysis of the effects of wavelength features in concrete pavement surfaces, and their potential effects on smoothness specifications
- Recommendations for modifying the 2006 pilot specification for international roughness index for portland cement concrete pavements in Minnesota.

The review of smoothness specifications in use by other states indicates that as of the end of 2005, only seven states were using IRI for PCC pavement surface smoothness, but that an increasing number of states would be using IRI in the near future. Several tables of information were developed to summarize the equipment, specifications, and incentives/disincentives used by the various state highway agencies.

The analysis of the effect of the measurement system (PI or IRI) showed that each index can be affected by difference wavelengths inherent in the concrete pavement surface. These wavelengths can be generated by components of the design, construction methods, or both. Generally, the wavelength that affects PI more than others is the 25-foot recurring feature, and the 15-foot feature affects IRI more than others. In summary, the same section of pavement can be measured by the same equipment, and the two different smoothness indices often depict the surface very differently. For this reason it is very difficult to compare the results of the PI and IRI measurements, and to make an equitable conversion from one index to another.

Other analyses conducted for evaluating the effects of changing from the PI to the IRI in the Mn/DOT specifications for PCC pavements include the following.

- The effect of 15-, 25-, and 50-foot features in the surface profile, index calculation, and incentive / disincentive payment computation.
- The effect of tining added into the surface profile.
- The effect of segment length for payment, incentive, and disincentive calculation purposes.

The resulting deliverable for this project include recommended modifications to the 2006 pilot specification for future use and a list of additional recommendations for Mn/DOT's consideration. A summary of the primary recommendations made by the researchers includes the following.

- Conduct a study or literature review on the long-term effects on durability of diamond grinding.
- In cases where excessive grinding occurs to achieve smoothness, the thickness of a PCC pavement should be checked in the ground area to ensure remaining thickness is within specification requirements.
- Implement a profile machine operator training and certification program. Several other states conduct this type of certification.
- Require that the profile machine itself be adjusted and/or calibrated according to manufacturers' recommendations prior to each day's testing.

Chapter 1. INTRODUCTION

The pavement contractor charged with building a high-quality, high-performance, smooth road with sometimes low budgets and lower-quality materials is faced with competing objectives. The pavement must be smooth for the driving public, but also cost-effective, strong, and must meet many other specifications required by the owner of the road – the state highway agency and ultimately the drivers who use the road. As an incentive to encourage contractors to optimize these competing objectives, states began offering bonuses to contractors who could resolve the technical problems associated with the task, and still achieve a smooth surface on which to drive. As a necessary complement to the bonuses, states also instituted penalties for rough pavements. Most states, including Minnesota, have recognized the benefit of offering incentives for smoother pavements. Although it may be that unit prices for pavements increase initially when such a specification is initiated, studies have shown that eventually the costs return to about the same level as before, but with an increase in quality – as contractors learn to produce better-quality pavement surfaces (1).

There are many aspects related to the surface characteristics of a pavement that can interfere with the proper and fair measurement of pavement roughness when calculating bonuses and penalties. The method in which the data is collected and processed, and the way it is reduced to a single statistic of "roughness" or "smoothness" representing a one-tenth mile section, one lane wide, has been cause for much discussion and even dispute across the Nation.

The primary objective of this project was to assist the Minnesota Department of Transportation (Mn/DOT) develop an implementable specification for the use of the International Roughness Index (IRI) for smoothness incentives and disincentives on portland cement concrete (PCC) pavements. This represents a change from the current use of Profile Index (PI) for incentives and disincentives. Although the Bituminous Office of Mn/DOT has previously made this change, differences inherent to the materials and types of pavements have prevented the parallel IRI specification from being implemented for PCC pavements.

This report documents the work completed on the implementation project funded by Mn/DOT and conducted by researchers at Minnesota State University, Mankato (MSU). One major component of the project was assisting the state in making the change from using the California Profilograph and Profile Index measurements to using inertial profilers (IP) and the International Roughness Index. The work conducted for this project, and this report consists of three major portions. These include:

- A review and survey of the initial ride specification requirements of other states within the United States, focusing on portland cement concrete pavements;
- Comparisons of the effects different features in concrete pavement surfaces on the resulting Profile Index and International Roughness Index;
- Recommendations for implementing a new specification for initial ride quality using IRI on PCC pavements in Minnesota.

Chapter 2. STATE OF THE PRACTICE

This chapter focuses on the various requirements, in terms of equipment, certifications, data collection and analysis, and incentive / disincentive payments in use by other states. This review of other states' specifications is not limited to the use of IRI, but includes all states and all requirements and specifications used.

Of the states using IRI for concrete pavements, an analysis is then made of several actual profiles measured on new PCC pavements in Minnesota to determine the financial incentive or disincentive that those pavements would have earned had they been in another state.

Ride Specification Review

Each state is responsible for the construction and maintenance of the roadways in its highway network. Each state, then, sets its own policy for achieving and paying for smooth road surfaces. This section summarizes the various methods used by the states to measure and encourage smoother pavements. Most of the methods used incorporate some type of incentive and/or disincentive adjustment of the bid price for smoothness measurements smoother or rougher than the basic requirement.

The American Concrete Pavement Association conducted a similar survey of state practices in 1999. Although the data in their database may be out of date, the ACPA is currently working to update their information.

The majority of states have a specification for pavement smoothness using some type of profiler – usually either California Profilograph or inertial profiler. Information for some states was not available, however, including New Jersey, Ohio, Rhode Island and Vermont. Where no specification or requirement exists, "None" has been entered into Table 2.1 through Table 2.5. Where information could not be found or obtained, a blank has been left in the table. In most cases, an attempt was made through e-mail to obtain the information from states where specifications could not be found online. It is likely that special provisions or supplemental specifications have been used in some states to implement a different type of ride specification than those shown in the standard specifications. This information is not included in the survey unless specific information from the state highway agency was obtained.

Among the information obtained from each states' standard specifications, the following categories are included.

- Use of blanking band
- Must-grind requirements
- Type of profile filters used
- Profile measuring equipment
- Ride specification type
- Smoothness measurement requirements
- Incentive/disincentive factors and requirements

The remaining sections summarize the data shown in Table 2.1 through Table 2.5.

IRI vs. Other Indices

The survey of the states showed that eight states had specifications for portland cement concrete pavement smoothness using IRI – Kentucky, Maine, Maryland, Michigan, New Mexico, Pennsylvania, Texas and Virginia. Of these eight states, only one (Maine) used m/km, the other seven states specifications were written using in/mi. Thirty-five states for which data were found use PI specifications with the remainder using some other form of measurement or having no data available. One state (Michigan) currently has a specification for both PI and IRI.

Type of Profiler

For PCC smoothness, the survey showed that ten states have specifications requiring or allowing the use of light weight (LW) or inertial profilers. The eight states with IRI specifications allow or require the use of LW or inertial profilers. A total of 32 states, including Minnesota, require or allow the use of a California type Profilometer. Of those, four states – Arkansas, Iowa, Minnesota and Oklahoma – allow the use of both a California type Profilometer as well as a light weight or inertial profiler.

Profile Index Blanking Band

Of the 35 states using PI for PCC smoothness, sixteen, including Minnesota, use a blanking band of 0.2 in. Eight states use a 0.0-in blanking band requirement in their specifications. The remainder of the states use a blanking band of 0.1 in or 2.5 mm.

Must-Grind

For PCC pavements, eighteen states including Minnesota have a must grind bump of 0.3 inches over 25 feet. Minnesota has a range from 0.3 to 0.4 inches over a distance of 25 feet where the engineer has discretion over the must grind requirement (for sections with a speed limit over 42 mph). Other states have similar "judgment" clauses. Seven other states have a must grind bump of 0.3 inches, but do not specify a distance. Four states have a must grind bump of 0.4 inches over 25 feet and two states have a must grind bump of 0.5 inches over 25 feet. Nineteen states have some other requirement for must grind, no requirement at all or no data was available.

Location of Profile Measurement

A total of 30 states require the profile measurement location to be in both wheel paths. Two states – Arkansas and Missouri, require the measurement to be taken at the center of the lane. The remainder require measurement at some other location, either the outside or inside wheel path or the centerline, or at engineers discretion. Minnesota requires the profile to be measured in the right wheel path.

Index Calculation Interval

Thirty-five states calculate the index at an interval of 0.1 mile. Two states (Kentucky and South Carolina) calculate the index at 1-mile intervals and Virginia measures at 0.01 mile. The remaining states measure the segment length at other variable lengths or no data was available.

Smoothness Calculation

Of the states that require PI, seven require the calculation of roughness to be done by hand. Eleven states allow the option of calculating roughness by hand or by using a computerized profilograph, which calculates the roughness automatically. Minnesota currently requires calculation by computer.

Agency vs. Contractor Measurements

Fifteen states require the profile to be measured using either the state's measuring equipment or equipment supplied by the contractor and approved by the state. Twenty-seven states require the contractor to perform the measurement using state-approved equipment, including Minnesota. Four of the remaining states allow or require both the contractor and the state to perform the measurement.

Incentives and Disincentives

Index ranges for incentive and disincentive adjustments vary greatly from state to state with very little consistency between states. Table 2.4 displays the ranges for 100 percent payment, incentive, disincentive and the method of calculating them. Fourteen states do not pay an incentive and the states that do pay incentives have ranges from 0 up to 52.2 inches per mile for which maximum incentive is paid (using various measuring techniques, blanking bands and filters). Seventeen states currently use a percentage of the unit bid price to award incentive with maximum incentives ranging from a 3 to 10 percent bonus. Seven states assign a specific dollar amount as a bonus in dollars per square yard. Seven other states assign a dollar amount per segment for incentive, the remaining use some other method of paying incentive.

In terms of PI, the highest roughness allowed varies greatly from state to state – from 5 in/mi in Florida and Nevada (0.2-in blanking band) to 44.4 inches per mile in Wisconsin (0-blanking band). Minnesota allows 8 inches per mile with a 0.2 inch blanking band using PI before corrective action is required.

The maximum roughness disincentive also varies greatly from state to state and even with the method of calculation and basis of payment reduction. Fifteen states do not reduce payment or have no payment reduction limit. Fifteen states reduce payment on a percentage basis with the worst reduction being zero percent payment at an IRI value greater than 160 in/mi in Virginia. Seven states reduce payment on a dollar per square yard basis, six use a dollars per segment basis. According to the special provisions in place since 2003, Minnesota uses a dollars per segment payment reduction, rather than dollars per square yard. There was no data available for the remaining states.

Table 2.1. Measuring Equipment and Index Used for PCC Pavements.

State	Smoothness Measuring Equipment	Roughness Index
AL	CA Profilograph	Profile Index (in/mi)
AK		
AZ	CA Profilograph	Profile Index (in/mi)
AR	CA Profilographs, LW Profilometer	Profile Index (in/mi)
CA	CA Profilograph	Profile Index (in/mi)
CO	Computerized Profilograph	Profile Index (in/mi)
CT	CA Profilograph	Profile Index (in/mi)
DE	CA Profilograph	Profile Index (in/mi)
FL	CA Profilograph, (Laser Profiler)	Profile Index (in/mi) (Ride Number RN)
GA	Rainhart Profilograph	Profile Index (in/mi)
HI	CA Profilograph	Profile Index (in/mi)
ID	CA Profilograph	Profile Index (in/0.1mi)
IL	CA Profilograph	Profile Index (in/mi)
IN	CA Profilograph, 10-ft/16-ft straightedge	Profile Index (in/0.1mi)
IA	CA Profilograph, Inertial Profiler	Profile Index (in/mi)
KS	CA Profilograph, 10-ft straightedge	Profile Index (in/mi)
KY	Noncontact profilometer (ASTM E 950 CL I)	IRI (in/mi)
LA	CA Profilograph	Profile Index (in/mi)
ME	Inertial Profiler (CL I or II)	IRI (m/km)
MD	LW Profilometer	IRI (in/mi)
MA		
MI	CA Profilograph/Equivalent	Profile Index or IRI (in/mi)
MN	CA Profilograph, LW Profilometer	Profile Index (in/mi)
MS	CA Profilograph	Profile Index (in/mi)
MO	CA Profilograph, 10-ft straightedge	Profile Index (in/mi)
MT	CA Profilograph	Profile Index (in/mi)
NE	CA Profilograph	Profile Index (in/mi)
NV	CA Profilograph	Profile Index (in/mi)
NH	None	None
NJ	10-ft Rolling Straight Edge	None
NM	Inertial Profiler	IRI (in/mi)
NY	CA Profilograph	Profile Index (in/mi)
NC	Rainhart Profilograph	Profile Index (in/mi)
ND	CA Profilograph	Profile Index (in/0.1mi)
OH	10-ft Rolling Straight Edge	None
OK	CA Profilograph, LW Inertial Profiler	Profile Index (in/mi)
OR	CA Profilograph	Profile Index (in/mi)
PA	Inertial Profiler	IRI (in/mi)
RI	10-ft straightedge	None
SC	Mays Ride Meter, 10-ft straightedge	Relative Roughness (in)
SD	CA Profilograph	Profile Index (in/0.1mi)
TN	Rainhart Profilograph	Profile Index (in/mi)
TX	LW Profiler, 10-ft straightedge	IRI (in/mi)
UT	CA Profilograph	Profile Index (in/mi)
VT	None	None
VA	Inertial Profiler (SD Type)	IRI (in/mi)
WA	CA Profilograph	Profile Index (in/mi)
WV	Inertial Profiler, Mays Ride Meter	Smoothness (in/mi)
WI	CA Profilograph	Profile Index (in/mi)
WY	CA Profilograph	Profile Index (in/mi)

Table 2.2. PI Blanking Band and Must Grind Requirements.

State	Blanking Band	Must Grind Bump	Filters Required
AL	0.0 in	0.3 in / 25 ft	
AK			
AZ	0.2 in	0.3 in / 25 ft	
AR	0.1 in	0.3 in / 25 ft, 1/8 in / 10 ft	
CA		0.3 in	
CO	0.1 in	0.4 in / 25 ft	
CT	0.2 in	0.5 in / 25 ft	
DE	0.2 in	0.3 in / 25 ft	
FL	0.2 in	0.3 in / 25 ft (5mm)	
GA	0.1 in	> 0.3 in	
HI	0.2 in	0.3 in	
ID	None	0.3 in	
IL		0.3 in / 25 ft	
IN	0.0 in	0.3 in / 25 ft	
IA	0.2 in	0.5 in / 25 ft	Butterworth
KS	0.0 in	0.3 in / 25 ft	
KY	---	---	---
LA	0.2 in	0.3 in / 25 ft	
ME	---		
MD	---		
MA			
MI	0.0 in	0.3 in / 25 ft	
MN	0.2 in	0.3 in / 25 ft	3rd Order Butterworth w/ 2 ft cutoff
MS	0.0 in	0.3 in / 25 ft	
MO	0.0 in	0.4 in / 25 ft	
MT	0.2 in	0.3 in / 25 ft	
NE	0.2 in	0.2 / 25 ft	
NV		0.3 in	
NH	None	None	
NJ	None	.125 in / 10 ft	
NM	---	>0.15 in / 25 ft	
NY	0 mm, 5 mm	10 mm / 7.6 m	
NC	0.0 in	0.3 in / 25 ft	
ND	0.2 in	0.3 in / 25 ft	3rd Order Butterworth w/ 2 ft cutoff
OH	None	.125 in / 10 ft	
OK	0.2 in	0.6 in / 25 ft	
OR	0.2 in	0.3 in	
PA	---	0.25 in	
RI	None	0.25 in / 10 ft	
SC	None	.125 in / 10 ft	
SD	0.2 in	0.3 in / 25 ft	3rd Order Butterworth w/ 2 ft cutoff
TN	0.1 in	0.4 in / 25 ft	
TX	---	.125 in / 10 ft	
UT	0.2 in	0.3 in / 25 ft	
VT	None	None	
VA	---	0.25 in	
WA		0.3 in	
WV	None		
WI	0.0 in	0.4 in / 25 ft	
WY	0.2 in	0.3 in / 25 ft	3rd Order Butterworth w/ 2 ft cutoff

Table 2.3. Smoothness Measurement Requirements for Concrete Pavements.

State	Profile Measurement Location	Length of Interval	How profile index calculated	Acceptance Measurement
AL	Engineers Discretion	0.1 mi	By Hand	State, Contractor
AK				
AZ	Both Wheel Paths	0.1 mi	By Hand, Computer	State
AR	Center of Lane	0.1 mi	By hand or Computer	State
CA	3 ft from edge/joint	0.1 mi	Computer	Contractor
CO	3 ft from edge/joint	0.1 mi	Computer	Contractor
CT	3 ft from edge/joint	0.1 mi	By Hand, Computer	State
DE	Both Wheel Paths	0.1 mile	Computer	State
FL	Both Wheel Paths	0.1 mi	Computer	Contractor
GA	Both Wheel Paths	0.25 mi	By Hand	Contractor
HI	3 ft from edge/joint	0.1 mi	By Hand, Computer	State
ID	3 ft from edge/joint	0.1 mi	By Hand, Computer	Contractor
IL	3 ft from outside edges	0.1 mi		State, Contractor
IN	Outer wheel paths	0.1 mi	By Hand	State, Contractor
IA	Both wheel paths of each lane	0.1 mi	By Hand, Computer, Digital Scan	Contractor
KS	Both wheel paths	0.1 mi	By hand or computer	Contractor
KY	Both Wheel Paths	1 mi	Computer	State
LA	Both Wheel Paths			State
ME	Both Wheel Paths	1000m (50M)	Computer, Digital Scan	
MD	Both Wheel Paths	0.1 mi	By Hand, Computer	Contractor
MA				
MI	3 ft from edge/joint	0.1 mi	By Hand or Computer	Contractor
MN	Right Wheel Path	0.1 mi	Computer	Contractor
MS	Both Wheel Paths	0.1 mi	By Hand or Computer	Contractor
MO	Center of Lane	0.1 mi	By hand or Computer	Contractor
MT	3 ft from outside edge	0.1 mi	By Hand or Computer	Contractor
NE	Right wheel path of all lanes	0.1 mi	Computer	Contractor
NV	3 ft from edge/joint	0.1 mi	Computer	Contractor
NH	None	None	None	None
NJ	Random	300 – 400 ft	By Hand	State
NM	3 ft from edge/joint	0.1 mi	Computer	Contractor
NY	Both Wheel Paths	160 m	Computer	Contractor
NC	3.5 ft from edge/joint	600 ft	By Hand	Contractor
ND	8 ft either side of centerline	0.1 mi	Computer	State
OH	3 ft from edge/ joint			Contractor
OK	Inside Wheel Path	0.1 mi	Computer	Contractor, State
OR	3 ft from edge/joint	0.1 mi	By Hand or Computer	Contractor
PA		0.1 mi	Computer	Contractor
RI	Centerline	10 ft	By Hand	Contractor
SC	Wheel Paths	1 mile	Computer	State
SD	Both Wheel Paths	0.1 mi	Computer	Contractor
TN	Both Wheel Paths	0.1 mi	By Hand	State
TX	Both Wheel Paths	0.1 mi	Computer	Contractor
UT	Both Wheel Paths	0.1 mi	Computer	State
VT	None	None	None	None
VA	Both Wheel Paths	0.01 mi	Computer	Contractor
WA	3 ft from edge/joint	0.1 mi	Computer	Contractor
WV	Both Wheel Paths	0.1 mi	Computer	State
WI	3 ft from each edge	0.1 mi	Computer	Contractor
WY	3 ft from each edge	0.1 mi	Computer	State

Table 2.4. Pay Factors and Maximum Incentives.

State	Index Range for 100% Payment	Index for Maximum Incentive	Maximum Incentive Possible
AL	10 - <20 (0.0 in bb)	0	105% unit bid price
AZ	7 (0.2 in bb)	0	$ / sq yd formula
AR	>4 – 5 (0.1 in bb)	<2	+ 6% unit bid price
CA			
CO	14.1 – 16 (0.1 in bb)	0 – 8	$1.40 / sq yd
CT	>10 – 12 (0.2 in bb)	0 - 6	106% unit bid price
DE	10 (0.2 in bb)	0 - 5	$1.50 / sq yd
FL	>2 – 5 (0.2 in bb)	< 2	103% unit bid price
GA	0 – 7 (0. 1 in bb)	None	None
HI	0 – 10 (0.2 in bb)	None	None
ID	>6.1 – 7.0	4.0 or less	$500 / 0.1 mi
IL	4.25 - 10	< 2.25	103% unit bid price
IN	>2.2 – 2.6 (0.0 in bb)	< 1.0	106 % unit bid price
IA	3.1 – 7.0 (0.2 in bb)	0 – 1.0	$750 / segment
KS	18.1 – 40.0 (0.0 in bb)	< 6.0	+$1200 / segment
KY	<53	<6 (PI)	103% unit bid price
LA	2.1 – 3.0 (0.2 in bb)	0 - 1	105% contract unit price / lot
ME	PF = 1	0	$ / sy formula
MD			Computer Program
MI	0 – 70 (IRI)	None	None
MN	0 – 4 (0.2 in bb)	0	$ / segment formula
MS	22.1 – 30 (0.0 in bb)	< 10	+$.26 / sy
MO	15.1 – 25 (0.0 in bb)	< 10	105% of contract price
MT	6 – 10 (0.2 in bb)	< 6	$0.50 / sy
NE	5.0 – 10.0 (0.2 in bb)	0 – 2.0	105% of contract price
NV	0 – 5	None	None
NH	None	None	None
NJ	0 – 5 ft lot length error	None	None
NM	61.4 – 62.3	<52.2	110% pay factor
NY	80 mm/km (5 mm bb)	0 - 16	5% / segment
NC	0 - 25 in/mi (0.0 in bb)	None	None
ND	0.3 – 0.5 / 0.1 mi (0.2. bb)	< 0.3 / 0.1 mi	$0.50 / sy
OH	None	None	None
OK	6.08 in/mi (0.2 in bb)	0 - 3	103% Contract Unit Price
OR	5 in/mi (0.2 in bb)	0 in/mi	3% unit price
PA	>60 – 70 in/mi	<35 in/mi	$1500 / section
RI	None	None	None
SC	<55 in/mi	None	None
SD	5 – 10.0 (0.2 in bb)	< 2.9	103.5% unit price
TN	< 10 (0.1 in bb)	< 10	None
TX	60 – 65	<31	$600 / section
UT	5 in/mi (0.2 in bb)	0 in/mi	$200 / section
VT	None	None	None
VA	55.1 – 70.0	<45.1	105% unit price
WA	>4 – 7.0	0 – 1.0	+4%
WV	0 – 65	None	None
WI	< 44.4 (0.0 in bb)		
WY	0 – 5 (0.2 in bb)	None	None

Table 2.5. Highest Acceptable Roughness.

State	Highest Acceptable Roughness	Maximum Roughness Disincentive
AL	50 in/mi	80% contract price
AZ	9 in/mi	-$1.00 / sq yd
AR	7 in/mi	-4% unit bid price
CA	7 in/mi	
CO	24.1 in/mi	-$1.40 / sq yd
CT	20 in/mi	92% unit bid price
DE	15 in/mi	-$1.50 / sq yd
FL	5 in/mi	100% unit bid price
GA	7 in/mi	100% unit bid price
HI	15 in/mi	90% unit price
ID	9.6 in/0.1mi	-$500 / 0.1 mi
IL	15 in/mi	90 % unit bid price
IN	3.0 in/0.1mi	92 % of unit bid price
IA	> 10.0 in/mi	$300 / segment
KS	40.1 in/mi	-$750 / segment
KY	> 10 in/mi (PI)	-$150/mi
LA	6	50% contract unit price / lot
ME	1.25 – 1.4 m/km	$ / sy formula (75% unit price)
MD		
MI	70 in/mi	None
MN	8 in/mi	$ / segment formula
MS	30 in / mi	None
MO	25 in/mi	100% of contract price
MT	15 in/mi	-$1.00/sy
NE	15 in/mi	90 % of contract price
NV	5 in/mi	None
NH	None	None
NJ	13.9 ft lot length error	-16% / lot
NM	72.8 in/mi	90.0% pay factor
NY	80	None
NC	25 in/mi	None
ND	< 0.90	Unit price-$4.00 / sy
OH	None	None
OK	16 in/mi	76.8% Contract Unit Price
OR	7 in/mi	None
PA	70 in/mi	None
RI	<. 25 in/10ft	None
SC	55 in/mi	None
SD	< 20.1	96.5% unit price
TN	15	90 % unit bid price
TX	95 in/mi	-$600 / section
UT		
VT	None	None
VA	100.0	0% payment (IRI > 160 after corrections)
WA	7 in/mi	-2%
WV	65 + 50%	-$ / sy formula
WI	< 45	
WY	5 in/mi	None

Smoothness Incentives/Disincentives by State

The method used by Minnesota to compute incentive and disincentive is unique among all states except for Alaska. It is one of only two states that uses two different equations as well as a zero incentive range on one payment schedule. Arizona, however uses an equation for a continuous segment of the incentive schedule, and two levels of disincentive in dollars per square yard in its payment schedule. Most other states use a payment that is linear when computing incentive based on mathematical equations. The other states that use equations to compute incentive for which data were available are Maine, Oregon and Utah. Most states use a payment schedule based on a lump sum paid per section, or they pay an adjustment on the unit bid price for each section.

States that use several levels of payment when using these schemes vary in how they pay the contractors incentive or assess disincentive. Some states have as few as three payment levels, these include Florida, New Jersey and Wisconsin with only one level paying no incentive, and two paying disincentive. However, some states such as Texas have very long and extensive tables outlining specific payments for a large range of smoothness values. Most states have several levels of incentive and disincentive, the most common between five and nine levels of incentive and disincentive.

The following sections include the incentives and disincentives for each state for which data were available. For most states, the formatting is as close as possible to the data in its original form.

Table 2.6 PCC Smoothness Incentive – Arizona [401-6; 401-4.02] – 2000.

TABLE 401-2 (Use when pavement **will not** be overlaid with Asphaltic concrete prior to opening to traffic.)	
Profile Index (P.I.) [inches per mile per 0.1 mile section]	**Unit Price Adjustment**
7.0 or Less	Plus ($0.20) x [7.0 - (P.I.*)] per square yard ($1.00 Maximum) (See Notes)
7.1 to 8.0	Minus $0.50 per square yard
8.1 to 9.0	Minus $1.00 per square yard
Notes: 1. P.I.* = Profile Index (P.I.) rounded to the nearest whole number. 2. The "plus" unit price adjustment will not be made for pavement placed within each 0.1-mile section which has grinding in excess of 1.5 percent of the area included in any traffic lane involved.	

Table 2.7. PCC Smoothness Incentive – Arkansas [501.05(m); 501.12] – 2003.

PROFILE INDEX		PRICE ADJUSTMENT % of payment of Unit Bid Price
In/Mi./0.1 Mi. section	mm/km/200 m section	
2 or less	30 or less	+ 6.0%
Over 2 to 3	Over 30 to 45	+4.0%
Over 3 to 4	Over 45 to 60	+2.0%
Over 4 to 5	Over 60 to 75	0
Over 5 to 6	Over 75 to 90	-2.0%
Over 6 to 7	Over 90 to 110	-4.0%
Over 7	Over 110	CORRECTIVE WORK REQUIRED

Table 2.8. PCC Smoothness Incentive – Connecticut [4.01.03(H); 4.01.04(A)] – 2004.

AVERAGE PROFILE INDEX		**CONTRACT UNIT PRICE ADJUSTMENT % of pavement of unit bid price**
Inches per mile per 0.1-mile section (Millimeters per kilometer per 150-meter section)		
0-6	(0-95)	106
over 6-8	(95-125)	104
over 8-10	(125-160)	102
over 10-12	(160-190)	100
over 12-14	(190-220)	98
over 14-16	(220-250)	96
over 16-18	(250-285)	94
over 18-20	(285-315)	92
over 20	(over 315)	Corrective Work Required

Table 2.9. PCC Smoothness Incentive – Florida [352-6] – 2004.

Average Profile Index (inches/mi) per 0.1 mi Section		**Contract Unit Price Adjustments Percent of Pavement Unit Bid Price**
Curvature Radius ≥2,000 ft	1,000 ft ≤ Curvature Radius < 2,000 ft	
PI ≤ 2	PI ≤ 4	103
2 < PI ≤ 5	4 < PI ≤ 7	100
PI > 5	PI > 7	Corrective work required

Table 2.10. PCC Smoothness Incentive – Idaho [409.05] – 2004.

English Schedule	
INITIAL PROFILE INDEX in. per 0.1 mi. section	**PAYMENT $ per 0.1 mi.**
0.20 or less	$1200.00
0.30 or less	$ 800.00
0.40 or less	$ 240.00
> 0.40 thru 0.50	No payment

Metric Schedule	
INITIAL PROFILE INDEX Mm per 100 m section	**PAYMENT $ per 100 m**
3.5 or less	$750.00
5 or less	$ 500.00
6.5 or less	$ 150.00
> 6.5 thru 8	No payment

Table 2.11. PCC Smoothness Incentive – Illinois [420.12] – 2002.

Price Adjustment Schedule	
Profile Index for Entire Project mm/km (in/mi)	**Percent of Unit Bid Price**
36 (2.25) or less	103
Over 36 (2.25) – 53 (3.25)	102
Over 53 (3.25) – 67 (4.25)	101

Profile Index for 160 m (0.1mi) Section mm/km (in/mi)	**Percent of Unit Bid Price**
Over 67 (4.25) – 160 (10)	100
Over 160 (10) – 175 (11)	98
Over 175 (11) – 190 (12)	96
Over 190 (12) – 205 (13)	94
Over 205 (13) – 220 (14)	92
Over 220 (14) – 235 (15)	90
Over 235 (15)	Corrective work required

Table 2.12. PCC Smoothness Incentive – Indiana [501.28(d)] – 2006.

SECTION PAY FACTORS FOR SMOOTHNESS ($PI_{0.0}$) ZERO BLANKING BAND	
Design Speed Greater Than 45 mph (70km/hr)	
Profile Index in/0.1mi. (mm/0.16 km)	**Pay Factor**
Over 0.00 - 1.00 in. (Over 0 - 25 mm)	1.06
Over 1.00 – 1.20 in. (Over 25 – 30 mm)	1.05
Over 1.20 – 1.40 in. (Over 30 – 35 mm)	1.04
Over 1.40 – 1.60 in. (Over 35 – 40 mm)	1.03
Over 1.60 – 1.80 in. (Over 40 – 45 mm)	1.02
Over 1.80 – 2.20 in. (Over 45 – 55 mm)	1.01
Over 2.20 – 2.60 in. (Over 55 – 65 mm)	1.00
Over 2.60 – 2.80 in. (Over 65 – 70 mm)	0.96
Over 2.80 – 3.00 in. (Over 70 – 75 mm)	0.92
All pavements with a Profile Index ($PI_{0.0}$) greater than 3.00 in (75mm) shall be corrected	

Note: Indiana uses $PI_{0.0}$ in *inches per 0.1 mile*, so the limiting values are smaller than if the unit was *inches per mile*.

Table 2.13. PCC Smoothness Incentive – Iowa [2316.08] – 2006.

INCENTIVES FOR PAVEMENT SMOOTHNESS						
INITIAL PROFILE INDEX	**SINGLE LIFT PAVEMENTS (5)**			**MULTI-LIFT PAVEMENTS (8)**		
Inches Per Mile (mm/km) Per Segment (1)	Interstate & Multi-Lane Divided Primary (2)	All Other Primary (3)	Non-Primary (4)	Interstate & Multi-Lane Divided Primary (6)	All Other Primary (6)	Non-Primary (7)
	Dollars Per Segment	Dollars Per Segment	Dollars Per Segment	Dollars Per Segment	Dollars Per Segment	Dollars Per Segment
0-1.0 1.1-2.0 2.1-3.0 3.1-7.0	650 550 450 Unit Price	550 450 350 Unit Price	200 150 100 Unit Price	300 250 200 Unit Price	200 150 100 Unit Price	75 50 25 Unit Price
(0-16) (16.1-32) (32.1-48) (48.1-110)	650 550 450 Unit Price	550 450 350 Unit Price	200 150 100 Unit Price	300 250 200 Unit Price	200 150 100 Unit Price	75 50 25 Unit Price

(1) For each segment of pavement that has an initial index, within the limits listed, with no grinding, the Contractor will receive an incentive payment as shown in the tabulation for the appropriate category.
(2) If all segments in a section of pavement in this category qualify for 100% payment with no grinding, the qualifying incentive payment will be increased by $100 per segment for each.
(3) If all segments in a section of pavement in this category qualify for 100% payment with no grinding, the qualifying incentive payment will be increased by $75 per segment for each segment in the section.
(4) If all segments in a section of pavement in this category qualify for 100% payment with no grinding, the qualifying incentive payment will be increased by $50 per segment for each segment in the section.
(5) If all segments in a project qualify for 100% payment with no grinding, the qualifying incentive payment as indicated in notes (2), (3), and (4) will be increased by $50 per segment for each segment in the project.
(6) If all segments in a section of pavement in this category qualify for 100% payment with no grinding, the qualifying incentive payment will be increased by $25 per segment for each segment in the section.
(7) If all segments in a section of pavement in this category qualify for 100% payment with no grinding, the qualifying incentive payment will be increased by $10 per segment for each segment in the section.
(8) If all segments in a project qualify for 100% payment with no grinding, the qualifying incentive payment as indicated in notes (6) and (7) will be increased by $25 per segment for each segment in the project.

Table 2.14. PCC Smoothness Incentive – Kansas [SP 90P-111-R10] – 2000 .

Schedule for Adjusted Payment		
Ave. Profile Index in. per mi. per 0.1mi section (greater than 45 mph)	**Ave. Profile Index in. per mi. per 0.1 mi section (45 mph or less & ramps)**	**Contract Price Adjustment per 0.1 mi. section per lane**
6.0 or less		+$1200.00
6.0 to 10.0	15.0 or less	+$1000.00
10.1 to 15.0		+$750.00
	15.1 to 25.0	+$500.00
15.1 to 18.0		+$375.00
18.1 to 30.0	25.1 to 45.0	+$0.00
30.1 to 40.0	45.1 to 65.0	+$0.00*
40.1 or more	65.1 or more	-$750.00*
* Correct to 25.0 in/mi (45.0 in/mi for 45 mph or less & ramps)		
2005		
Schedule for Adjusted Payment (Urban Type Projects)		
Ave. Profile Index inch per mile per 0.1 mile (mm per km per 0.1 km) section (greater than 45 mph)	**Ave. Profile Index inch per mile per 0.1 mile (mm per km per 0.1 km) section (45 mph or less & ramps)**	**Contract Price Adjustment per 0.1 mile (0.1 km) section per lane**
10.0 (160) or less	15.0 (240) or less	+$1690.00 (+$1060.00)
10.1 to 15.0 (161 to 240)		+$1260.00 (+$800.00)
	15.1 to 25.0 (241 to 400)	+$840.00 (+$530.00)
15.1 to 18.0 (241 to 285)		+$630.00 (+$400.00)
187.1 to 30.0 (286 to 475)	25.1 to 45.0 (401 to 710)	$0.00
30.1 to 45.0 (476 to 710)	45.1 to 65.0 (711 to 1025)	$0.00*
45.1 (711) or more	65.1 (1026) or more	-$1060.00 (-$670.00*)
* Correct to 30.0 inch/mile (475 mm/km) [45.0 inch/mile (710 mm/km) for 45 mph or less & ramps]		

Table 2.15. PCC Smoothness Incentive – Kentucky [501.05.02] – 2004.

RIDE QUALITY ADJUSTMENT SCHEDULE FOR ROADS POSTED GREATER THAN 45 MPH	
IRI	**Pay Value[(1)]**
53 or lower	+0.03
54 to 56	+0.02
57 to 60	+0.01
Average for PI (inches per mile)[(2)]	**Pay Value**
6 or lower	0.00
Over 6, up to 7	-0.02
Over 7, up to 8	-0.05
Over 8, up to 10	-0.08
Over 10	Corrective Work Required

RIDE QUALITY ADJUSTMENT SCHEDULE FOR ROADS POSTED LESS THAN 45 MPH	
IRI	**Pay Value**
56 or lower	+0.03
57 to 60	+0.02
61 to 64	+0.01
Average for PI (inches per mile)[(2)]	**Pay Value[(1)]**
8 or less	0.00
Over 8, up to 10	-0.02
Over 10,up to 12	-0.05
Over 12	Corrective Work Required

(1) Contractor may correct areas to achieve a positive adjustment. The Department will perform additional requested testing and retesting for corrective work at a cost of $150.00 per lane mile. The Department will deduct charges for requested additional testing and retesting for corrective work from monies due on the Contract.
(2) The Department will apply the unit bid price adjustment to the total area of the 1,000-foot section of the traffic lane represented by the Profile Index. The Department will not make payment in excess of 50 percent for any main line pavement that has an average Profile Index in excess of 10 inches per mile (12 inches per mile for 45 MPH or less) until the Contractor completes the corrective work and the Department reprofiles and verifies that the average Profile Index has been reduced to 10 inches per mile or less (12 inches per mile for 45 MPH or less)

Table 2.16. PCC Smoothness Incentive – Louisiana [601.21] – 2000.

	Payment (Percent of Contract Unit Price/Lot)				
	100	98	95	80	Correct or remove and replace
Category I[1] Average Profile Index inches/mile/lot (mm/km/lot)	6.0 (94) or less	6.1 to 7.0 (95 – 110)	7.1 to 8.0 (111 – 126)	-	Over 8.0 (126)
Category II[2] Average Profile Index inches/mile/lot (mm/km/lot)	12.0 (189) or less	12.1 to 13.0 (190 – 205)	13.1 to 14.0 (206 – 221)	-	Over 14.0 (221)
Category III[3] Average Profile Index inches/mile/lot (mm/km/lot)	20.0 (315) or less	20.1 to 22.0 (316 – 347)	22.1 to 24.0 (348 – 378)	24.1 to 26.0 (379 – 410)	Over 26.0 (410)

(1) Design Speed greater than 45 mph (70km/hr)
(2) Urban Areas using continuous paving operations with design speeds 45 mph (70km/hr) or less
(3) Urban Areas not using continuous paving operations with design speeds 45 mph (70km/hr) or less.

Table 2.17. PCC Smoothness Incentive – Minnesota.

Incentive Equation		
y = pay incentive in dollars / square yard (prior to 2003 special provisions, $/sy)		
Incentive for PI < 4 in/mi		
y = (4-x)*0.28	(x = PI calculated in in/mi)	
y = ((63.1-x)*0.0212	(x = PI calculated in mm/km)	
For PI from 4 to 6		
y = 0		
Reduction for PI > 6 in/mi		
$y = 2x^2/16 – 2x +7$	(x = PI calculated in in/mi)	
$y = 0.0006x^2 – 0.15156 + 8.372$	(x = PI calculated in mm/km)	
Removal and replacement or surface planing is required if PI >8.		
y = pay incentive in dollars / square yard (2003 special provisions, $/0.1-mile segment)		
Incentive for PI < 4 in/mi		
y = (4-x)*197.12	(x = PI calculated in in/mi)	
y = (63.1-x)*7.762	(x = PI calculated in mm/km)	
For PI from 4 to 6		
y = 0		
Reduction for PI > 6 in/mi		
$y = 88x^2 – 1408x + 4928$	(x = PI calculated in in/mi)	
$y = 0.2195x^2 – 55.43x + 3062$	(x = PI calculated in mm/km)	
Removal and replacement or surface planing is required if PI >8.		

Table 2.18. PCC Smoothness Incentive – Mississippi [501.05.3] – 2004.

Profile Index Inches Per Mile Per Segment	**Adjustment Price Per Square Yard Of PCC Pavement**
Less than 10.0	plus $0.26
10.0 to 14.0	plus $0.20
14.1 to 18.0	plus $ 0.13
18.1 to 22.0	plus $ 0.07
22.1 to 30.0	$ 0.00
Over 30.0	$ 0.00 (With Correction of PI ≤ 30.0)

Table 2.19. PCC Smoothness Incentive – Missouri [502.15.3.2] – 2004.

Table 1	
Profile Index, Inches Per Mile (mm/km)	**Percent of Contract Price**
10.0 (158) or less	105
10.1 – 15.0 (159 – 237)	103
15.1 – 25.0 (239 – 395)	100
25.1 (396) or greater	100[a]

Table II	
Profile Index, Inches Per Mile (mm/km)	**Percent of Contract Price**
20 (316) or less	103
20.1 – 45.0 (317 – 711)	100
45.1 (712) or greater	100[b]

[a] After correction to 25.0 inches per mile (395 mm/km) or less.
[b] After correction to 45.0 inches per mile (711 mm/km) or less.

Table 2.20. PCC Smoothness Incentive – Montana [501.03.14] – 2006.

ENGLISH	
Lane Average Profile Index (Inches per Mile-per 0.1 Mile)	**Contract Unit Price Adjustment**
Less than 6	$0.50 per square yard incentive pay
6 to 10	Contract Unit Price
10 to 15	$1.00 per square yard deduction
Over 15	Corrective work required
METRIC	
Lane Average Profile Index (mm per 1.6 km-per 161 m)	**Contract Unit Price Adjustment**
Less than 150 mm	$0.60 per 1 square meter incentive pay
150 mm to 255 mm	Contract Unit Price
255 mm to 380 mm	$1.20 per 1 square meter deduction
Over 380 mm	Corrective work required

Table 2.21. PCC Smoothness Incentive – Nebraska [602.08] – 1997.

Table 602.01	
Payment Adjustment Schedule	
Profile Index Inches Per Lane Mile	**Percent of Contract Prices**
0 to 2 inches	105
More than 2 to 3 inches	104
More than 3 to 4 inches	103
More than 4 to 5 inches	101
More than 5 to 10 inches	100
More than 10 to 11 inches	98
More than 11 to 12 inches	96
More than 12 to 13 inches	94
More than 13 to 14 inches	92
More than 14 to 15 inches	90
More than 15 inches	Corrective work required

Table 2.22. PCC Smoothness Incentive – New Mexico [401.323] – 2005.

Interstate and National Highway Routes		US (Non-NH) and NM Routes		Pay Factor (Percent)
IRI		IRI		
mm per 0.1-km	Inch per 0.1-mi	mm per 0.1-km	Inch per 0.1-mi	
<824	<52.2	<783	<49.6	110.0%
824 to 840	52.2 to 53.2	783 to 804	49.6 to 50.9	109.0%
841 to 856	53.3 to 54.2	805 to 822	51.0 to 52.1	108.0%
857 to 871	54.3 to 55.2	823 to 843	52.2 to 53.4	107.0%
872 to 887	55.3 to 56.2	844 to 864	53.5 to 54.7	106.0%
888 to 903	56.3 to 57.2	865 to 882	54.8 to 55.9	105.0%
904 to 919	57.3 to 58.2	883 to 903	56.0 to 57.2	104.0%
920 to 935	58.3 to 59.2	904 to 923	57.3 to 58.5	103.0%
936 to 950	59.3 to 60.2	924 to 944	58.6 to 59.8	102.0%
951 to 968	60.3 to 61.3	945 to 965	59.9 to 61.1	101.0%
969 to 983	61.4 to 62.3	966 to 985	61.2 to 61.4	100.0%
984 to 999	62.4 to 63.3	986 to 1,007	62.5 to 63.8	99.0%
1,000 to 1,017	63.4 to 64.4	1,008 to 1,028	63.9 to 65.1	98.0%
1,018 to 1,032	64.5 to 65.4	1,029 to 1,048	65.2 to 66.4	97.0%
1,033 to 1,048	65.5 to 66.4	1,049 to 1,070	66.5 to 67.8	96.0%
1,049 to 1,066	66.5 to 67.5	1,071 to 1,091	67.9 to 69.1	95.0%
1,067 to 1,081	67.6 to 68.5	1,092 to 1,113	69.2 to 70.5	94.0%
1,082 to 1,099	68.6 to 69.6	1,114 to 1,133	70.6 to 71.8	93.0%
1,100 to 1,116	69.7 to 70.7	1,134 to 1,156	71.9 to 73.2	92.0%
1,117 to 1,132	70.8 to 71.7	1,157 to 1,178	73.3 to 74.6	91.0%
1,133 to 1,149	71.8 to 72.8	1,179 to 1,200	74.7 to 76.0	90.0%
>1,149	> 72.8	> 1,200	> 76.0	Corrective Work Required

IRI Based Profile Pay Adjustment Schedule of PCC Pavements, Ramps, Tapers, and Holding Lanes (Based on an Initial Serviceability Index = 4.3)

Table 2.23. PCC Smoothness Incentive – New York [502-4.04] – 2002.

Table 502-4 Smoothness Adjustment Factors		
Final Profile Index (mm/km.)	Level 1 SAF	Level 2 SAF
0.0 – 16.0	1.05	1.05
16.1 – 32.0	1.04	1.04
32.1 – 48.0	1.03	1.03
48.1 – 64.0	1.02	1.02
64.1 – 79.9	1.01	1.01
80	1	1
80.0+	Grind	1
190.0 +	Not Applicable	Grind

Table 2.24. PCC Smoothness Incentive – North Dakota [550.04.P4] – 2002.

Profile Index Inches Per 0.1 Mile	Contract Unit Price Adjustment
Less than 0.30	$0.50/square yard bonus(a)
.30 to .50	Contract Unit Bid Price
.51 to .70	$1.00/square yard deducted(b)
.71 to .80	$2.00/square yard deducted(b)
.81 to .90	$3.00/square yard deducted(b)
Over .90	Corrective work required

a. Unit bid price adjustment will be paid only when both adjacent 12-foot driving lanes meet the indicated surface smoothness. To qualify for bonus payment, each lane must have a measured profile index of less that 0.30 inches per 1/10 (0.1) mile for five or more consecutive 0.1 mile increments. A length of 25 feet on each side of each transverse construction joint (header) will be exempted from this requirement. The bonus payment will apply to the total area of the 1/2 (0.5) mile or more segment (two lanes, 24 feet wide) minus the exempted areas at the headers. No bonus will be paid in any segment if there is any grinding outside of the exempted areas.

If a header exemption area has a deviation in excess of 0.3 inch per 25 feet, the Contractor shall remove the high points with a diamond grinding device.

b. Unit bid price adjustment will apply to the total area of the 0.1-mile segment of pavement, for the lane width represented by the profile (12 feet wide). A paving section less than 0.1 mile shall be added to the subsequent day's paving operation to total 0.1 mile.

Payment for any pavement which has an average Profile Index greater than 0.9 inch per 0.1 mile will be made at Contract Unit Price minus $4.00/square yard until corrective work has been completed and the pavement reprofiled to verify a reduction in the average Profile Index to 0.9 inch or less.

Table 2.25. PCC Smoothness Incentive – Oregon [00756.95] – 2002.

Metric
Bonus = 0.00038 x (80 – PI) x Quantity x Unit Price
PI = Average of the two profile indexes in the segment or partial segment (mm/km)
Quantity = the quantity (m^2) represented by the segment or partial segment
Unit Price = the unit price for the concrete pavement as shown in the Schedule of Items.
English
Bonus = 0.006 x (5.0 – PI) x Quantity x Unit Price
PI = Average of the two profile indexes in the segment or partial segment (in/mi)
Quantity = The quantity (square yards) represented by the segment or partial segment
Unit Price = The unit price for the concrete pavement as shown in the Schedule of Items.

Table 2.26. PCC Smoothness Incentive – Pennsylvania [507.4] – 2006.

TABLE A **Payment Schedule for Ride Quality Incentive**		
Type I Lots	**Type 2 Lots**	**Payment**
IRI mm/km/lot (inches/mile/lot)	IRI mm/km/lot (inches/mile/lot)	Amount
≤553 (35)	≤710 (45)	$1500
≤790 (50)	≤868 (55)	$1000
≤948 (60)	≤1105 (70)	$500
≤1105 (70)*	≤1420 (90)	$0
>1105 (70)	>1420 (90)	Corrective Action Required
*Maximum acceptable IRI		

Table 2.27. PCC Smoothness Incentive – South Dakota [SP for PCC Smoothness] – 2005.

Profile Index Inches/mile	**Profile Index mm/km**	**Price Adjustment % of Contract Unit Price**
0 to 2.9	0 to 46	103.5
3 to 3.9	47 to 62	102.4
4 to 4.9	63 to 78	101.2
5 to 10.0	79 to 158	100.0
10.1 to 12.9	159 to 204	98.8
13 to 15.9	205 to 251	97.7
16 to 20	252 to 315	96.5

Table 2.28. PCC Smoothness Incentive – Tennessee [501.26(b)] – 1995.

Mainline and Auxiliary Lanes	**Ramps**	
Profile Index	**Profile Index**	**Price Adjustment**
mm/km per 0.1 km (in/mi per mi) section	**mm/km per 0.1 km (in/mi per mi) section**	**Percent of pavement unit bid price**
160 or less (10 or less)	315 or less (20 or less)	100
Over 160 to 175 (Over 10 to 11)	Over 315 to 330 (Over 20 to 21)	98
Over 175 to 190 (Over 11 to 12)	Over 330 to 345 (Over 21 to 22)	96
Over 190 to 205 (Over 12 to 13)	Over 345 to 365 (Over 22 to 23)	94
Over 205 to 220 (Over 14 to 15)	Over 365 to 380 (Over 23 to 24)	92
Over 220 to 235 (Over 14 to 15)	Over 380 to 395 (Over 24 to 25)	90
Over 235 (Over 15)	Over 395 (Over 25)	Corrective work required

Table 2.29. PCC Smoothness Incentive – Texas [585.4] – 2004.

Table 1 **Pay Adjustment Schedule for Ride Quality**							
Average IRI for each 0.10 mi. of Traffic Lane (in/mi)	**Pay Adjustment $/0.10 mi. of Traffic Lane**			**Average IRI for each 0.10 mi. of Traffic Lane (in/mi)**	**Pay Adjustment $/0.10 mi. of Traffic Lane**		
	Sched. 1	**Sched. 2**	**Sched. 3**		**Sched. 1**	**Sched. 2**	**Sched. 3**
<30	600	600	300	63	0	0	0
30	600	600	300	64	0	0	0
31	580	580	290	65	0	0	0
32	560	560	280	66	-20	0	0
33	540	540	270	67	-40	0	0
34	520	520	260	68	-60	0	0
35	500	500	250	69	-80	0	0
36	480	480	240	70	-100	0	0
37	460	460	230	71	-120	0	0
38	440	440	220	72	-140	0	0
39	420	420	210	73	-160	0	0
40	400	400	200	74	-180	0	0
41	380	380	190	75	-200	0	0
42	360	360	180	76	-220	-20	0
43	340	340	170	77	-240	-40	0
44	320	320	160	78	-260	-60	0
45	300	300	150	79	-280	-80	0
46	280	280	140	80	-300	-100	0
47	260	260	130	81	-320	-120	0
48	240	240	120	82	-340	-140	0
49	220	220	110	83	-360	-160	0
50	200	200	100	84	-380	-180	0
51	180	180	90	85	-400	-200	0
52	160	160	80	86	-420	-220	0
53	140	140	70	87	-440	-240	0
54	120	120	60	88	-460	-260	0
55	100	100	50	89	-480	-280	0
56	80	80	40	90	-500	-300	0
57	60	60	30	91	-520	-320	0
58	40	40	20	92	-540	-340	0
59	20	20	10	93	-560	-360	0
60	0	0	0	94	-580	-380	0
61	0	0	0	95	-600	-400	0
62	0	0	0	>95	Corr. Action	Corr. Action	NA

Table 2.30. PCC Smoothness Incentive – Utah [01452-3.2] – 2005.

Table 4 PCCP	
Category	**Incentive/Disincentive per Section**
1	$200 x [(Required in/mi) - (PI)]
2	$125 x [(Required in/mi) - (PI)]

Table 2.31. PCC Smoothness Incentive – Virginia [Special Provision for 316.04(k)] – 2005.

IRI After Completion (Inches Per Mile)	**Contract Unit Price Adjustment (Percent of Pavement Unit Price)**
45.0 and Under	105
45.1 - 55.0	103
55.1 - 70.0	100
70.1 - 80.0	90
80.1 - 90.0	80
90.1 - 100.0	70
Over 100.0	Subject to Corrective Action
IRI After Correction (Inches Per Mile)	**Contract Unit Price Adjustment (Percent of Pavement Unit Price)**
100.1 – 120.0	60
120.1 – 140.0	40
140.1 – 160.0	20
Over 160.0	0

Corrective work shall be completed prior to determining pavement thickness.

Table 2.32. PCC Smoothness Incentive – Washington [5-05.5] – 2006.

Ride Smoothness Profile Index (Inches per mile)	**Compliance Adjustment (Percent adjustment)**
1.0 or less	+4
Over 1.0 to 2.0	+3
Over 2.0 to 3.0	+2
Over 3.0 to 4.0	+1
Over 4.0 to 7.0	0
Over 7.0	-2*

* Also requires correction to 7 in/mi.

Table 2.33. PCC Smoothness Incentive – Wisconsin [SP 440-005] – 2005.

Initial Profile Index (PRI)	**Pay Adjustment**
(Inches/Mile)	(Dollars per standard segment)
≥ 44.4 to <50.7	-230
≥50.7	-940

Minnesota Profiles by Other States' Standards

During the 2006 paving season, Mn/DOT used a pilot IRI specification for PCC pavement smoothness incentives and disincentives. This section analyzes the new pilot IRI specification with other states current IRI specifications for PCC pavements. For the purposes of this analysis, only two states will be compared to Minnesota's IRI pilot specification. The reason for this is that only Texas and Pennsylvania currently use an IRI specification that pays in dollars per segment. Other states currently using the IRI specification pay incentive based on dollars per square yard, which cannot be directly compared to Minnesota's payment schedule.

Comparing the incentive schedules of Texas and Pennsylvania with Minnesota, four profiles were selected from different projects, which had been given filenames 182335D1, 182461P1, 10405005, and 10405021 by the contractor's representative. Mn/DOT provided these profiles to MSU for analysis. Table 2.34 shows the results of the incentive payment analysis, and Table 2.1 through Table 2.5 show the incentive payment that would be earned (or penalty deducted) if those profiles had been measured on pavements constructed in each of the states. This information is based on only the calculated IRI value for each 0.1 mile segment for the first 10 segments of each profile. From the figures, it can be seen that Minnesota's incentive is generally between the amount paid by Texas and Pennsylvania. Minnesota generally pays more incentive than Texas and less than Pennsylvania. When IRI begins to increase, Minnesota's disincentive appears to be greater than Texas' as Minnesota's disincentive falls below Texas' disincentive for several segments in Figure 2.2.

Figure 2.5 compares the payment schedule of Minnesota to those of Utah and Iowa based on PI in inches per mile. Minnesota's incentive schedule is between the two of them, and perhaps slightly lower than the average of the two states. While Minnesota's incentive is slightly lower on average than Iowa and Utah, Minnesota also has a higher disincentive than the other states for corresponding roughness.

Figure 2.6 compares the payment schedules of Minnesota, Texas and Pennsylvania based on IRI in inches per mile. As in Figure 2.5, Minnesota's incentive payment is about average, being slightly higher than Texas and lower than Pennsylvania. The decrease in incentive is more dramatic than Texas however and when IRI nears 80 inches per mile, Minnesota begins charging a higher disincentive than Texas. Pennsylvania does not charge disincentive but requires correction. When looking at the lines representing maximum incentive for Texas and Minnesota, Minnesota's incentive levels off at approximately 50 inches per mile and does not increase beyond the amount paid at that level for any lower IRI value. Texas continues to pay more incentive, increasing to a maximum at 30 inches per mile. This may provide Texas contractors incentive to decrease their pavement roughness below that of their Minnesota counterparts. Because Minnesota's current pilot specification does not currently pay incentive below 50 inches per mile, there is no incentive to achieve a pavement smoothness lower than this amount, especially if there is increased cost associated with constructing a smoother pavement. In the future, if the lower limit on the IRI value which receives the initial maximum incentive is lowered below 50 in/mi, an increase in pavement smoothness may be measured and correlated to this.

Figure 2.7 compares the HMA incentive paid by Minnesota specifications with the pilot IRI incentive for PCC pavements. The higher incentive available for PCC pavements may be a result of the expected longer life of those pavements. It may be reasonable to assume that the pavement surface, as constructed, will have a longer expected life for PCC pavements, and thus the incentive would be paid at a much reduced frequency due to overlays and reconstruction.

Table 2.34. Incentive Comparison by Measurement Type and State.

	Comparison by PI				Comparison by IRI			
Proj. No	**PI**	**Minnesota**	**Iowa**	**Utah**	**IRI**	**Minnesota**	**Texas**	**Pennsylvania**
182335D1								
0	1.83	$ 428	$ 650	$ 834	63.6	$ 332	$ -	$ 500
528	0.69	$ 652	$ 550	$ 1,062	65.4	$ 259	$ -	$ 500
1056	0.19	$ 751	$ 650	$ 1,162	62.6	$ 373	$ -	$ 500
1584	2.63	$ 270	$ 450	$ 674	67.4	$ 177	$ (40)	$ 500
2112	0.31	$ 727	$ 650	$ 1,138	55.0	$ 685	$ 100	$ 1,000
2640	0.07	$ 775	$ 650	$ 1,186	47.3	$ 890	$ 260	$ 1,000
3168	0.31	$ 727	$ 650	$ 1,138	42.1	$ 890	$ 360	$ 1,000
3696	-	$ 788	$ 650	$ 1,200	37.0	$ 890	$ 460	$ 1,500
4224	-	$ 788	$ 650	$ 1,200	43.4	$ 890	$ 340	$ 1,000
4752	1.03	$ 585	$ 550	$ 994	48.6	$ 890	$ 220	$ 1,000
182461P1								
0	-	$ 788	$ 650	$ 1,200	50.5	$ 870	$ 180	$ 1,000
528	0.24	$ 741	$ 650	$ 1,152	41.5	$ 890	$ 360	$ 1,000
1056	-	$ 788	$ 650	$ 1,200	48.4	$ 890	$ 240	$ 1,000
1584	0.09	$ 771	$ 650	$ 1,182	57.7	$ 574	$ 40	$ 1,000
2112	3.48	$ 103	$ -	$ 504	83.5	$ (484)	$ (380)	$ -
2640	3.61	$ 77	$ -	$ 478	81.8	$ (414)	$ (340)	$ -
3168	1.94	$ 406	$ 550	$ 812	87.9	$ (664)	$ (460)	$ -
3696	-	$ 788	$ 650	$ 1,200	67.5	$ 173	$ (60)	$ 500
4224	0.32	$ 725	$ 650	$ 1,136	65.8	$ 242	$ (20)	$ 500
4752	1.38	$ 516	$ 550	$ 924	60.7	$ 451	$ -	$ 500
10405005								
0	-	$ 788	$ 650	$ 1,200	60.4	$ 464	$ -	$ 500
528	1.40	$ 513	$ 550	$ 920	69.0	$ 111	$ (80)	$ 500
1056	-	$ 788	$ 650	$ 1,200	58.4	$ 546	$ 40	$ 1,000
1584	1.12	$ 568	$ 550	$ 976	61.1	$ 435	$ -	$ 500
2112	-	$ 788	$ 650	$ 1,200	57.0	$ 603	$ 60	$ 1,000
2640	0.44	$ 702	$ 650	$ 1,112	57.9	$ 566	$ 40	$ 1,000
3168	0.19	$ 751	$ 650	$ 1,162	55.0	$ 685	$ 100	$ 1,000
3696	-	$ 788	$ 650	$ 1,200	49.4	$ 890	$ 220	$ 1,000
4224	-	$ 788	$ 650	$ 1,200	52.0	$ 808	$ 160	$ 1,000
4752	-	$ 788	$ 650	$ 1,200	47.7	$ 890	$ 240	$ 1,000
10405021								
0	1.80	$ 434	$ 550	$ 840	56.2	$ 636	$ 80	$ 1,000
528	0.22	$ 745	$ 650	$ 1,156	52.8	$ 775	$ 140	$ 1,000
1056	-	$ 788	$ 650	$ 1,200	50.3	$ 878	$ 200	$ 1,000
1584	-	$ 788	$ 650	$ 1,200	47.7	$ 890	$ 240	$ 1,000
2112	0.88	$ 615	$ 650	$ 1,024	56.0	$ 644	$ 80	$ 1,000
2640	-	$ 788	$ 650	$ 1,200	53.3	$ 755	$ 140	$ 1,000
3168	-	$ 788	$ 650	$ 1,200	48.5	$ 890	$ 220	$ 1,000
3696	-	$ 788	$ 650	$ 1,200	45.6	$ 890	$ 280	$ 1,000
4224	-	$ 788	$ 650	$ 1,200	38.7	$ 890	$ 420	$ 1,500
4752	0.84	$ 623	$ 650	$ 1,032	51.6	$ 824	$ 160	$ 1,000

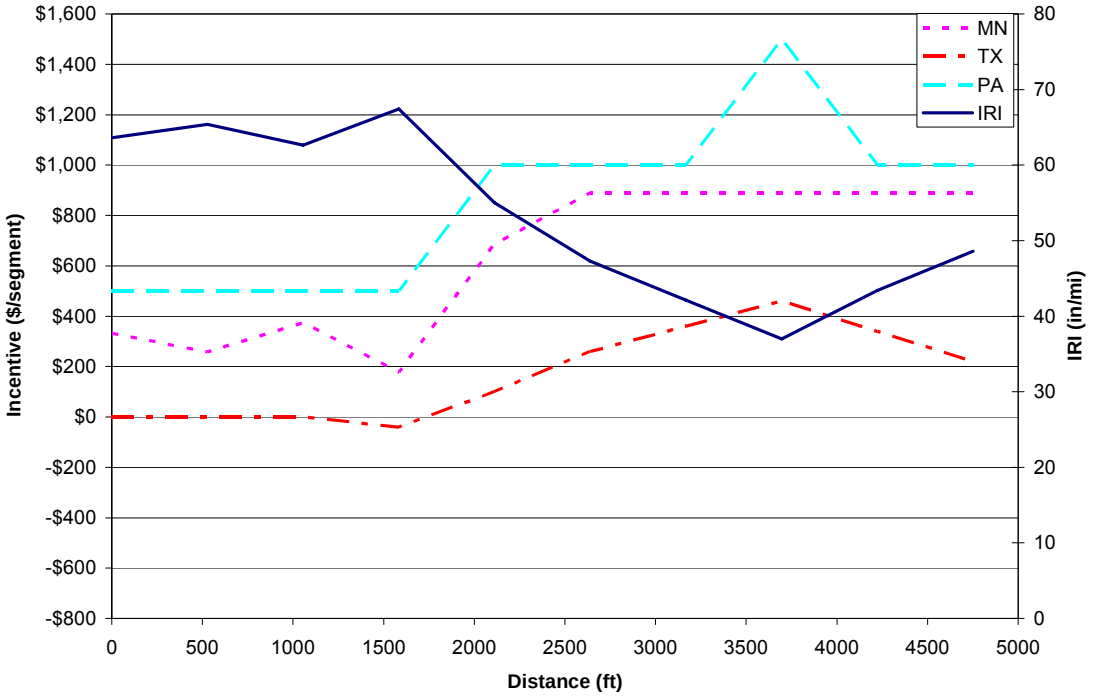

Figure 2.1. IRI incentive for Project Profile 182335D1.

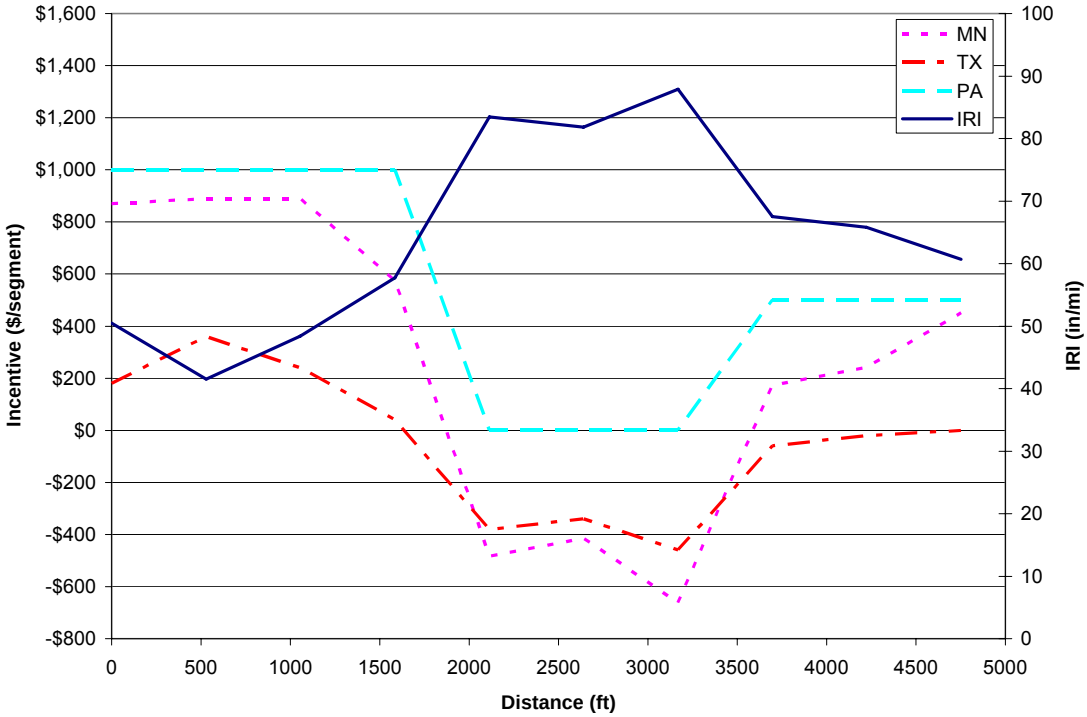

Figure 2.2. IRI Incentive for Project Profile 182461P1.

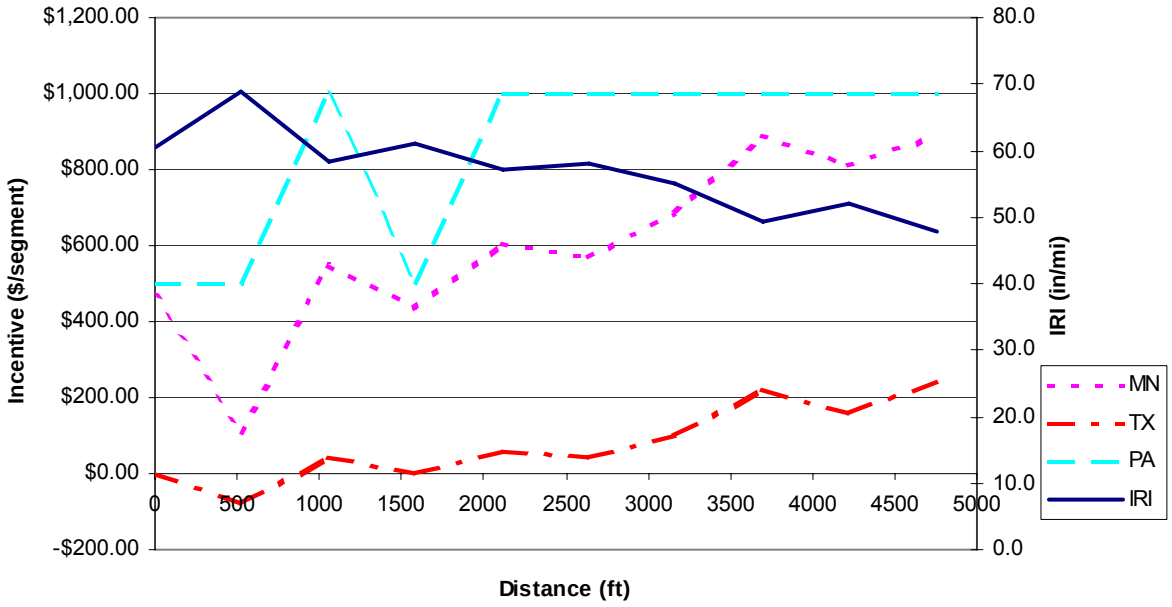

Figure 2.3. IRI Incentive for Project Profile 10405005.

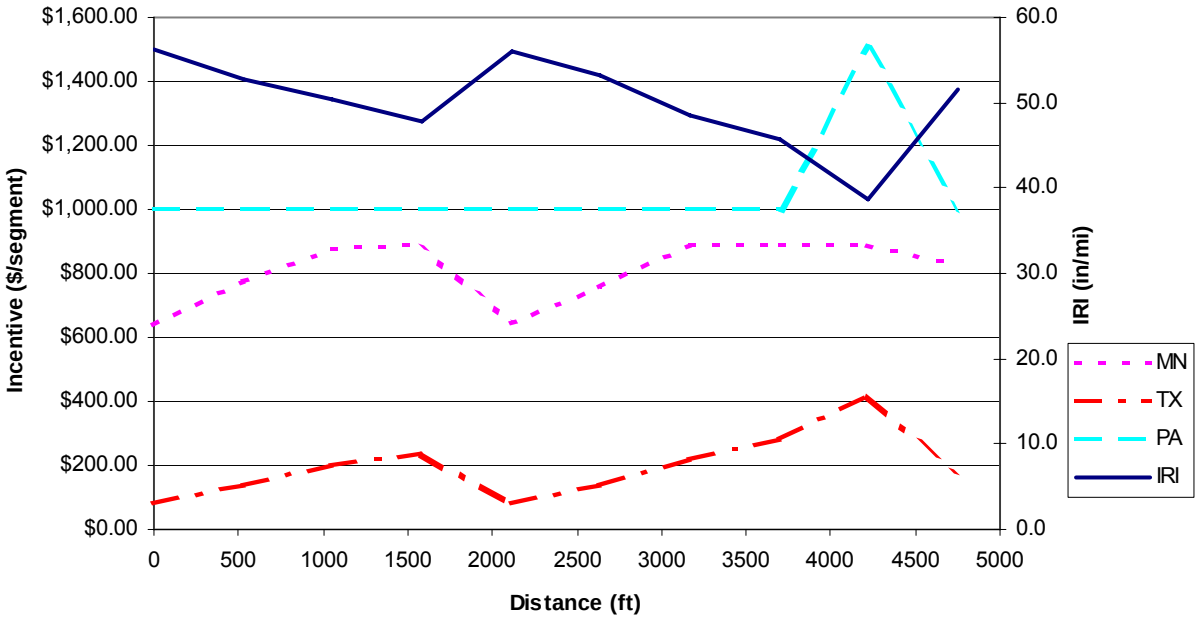

Figure 2.4. IRI Incentive for Project Profile 10405021.

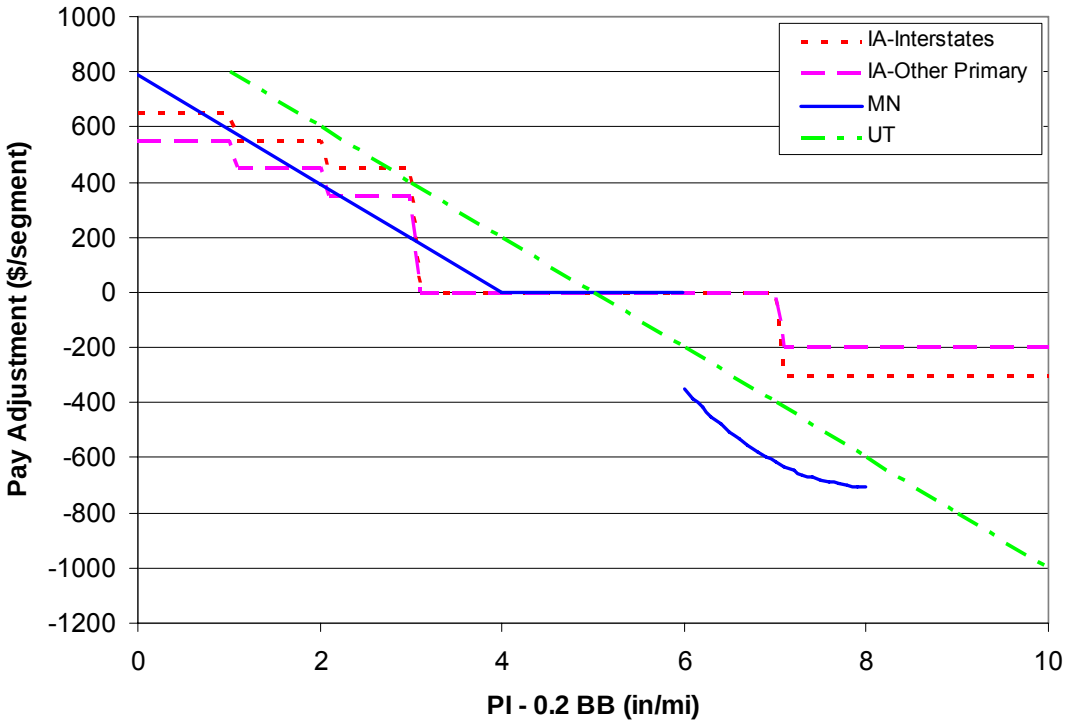

Figure 2.5. PI Incentive Comparison (0.2-in blanking band).

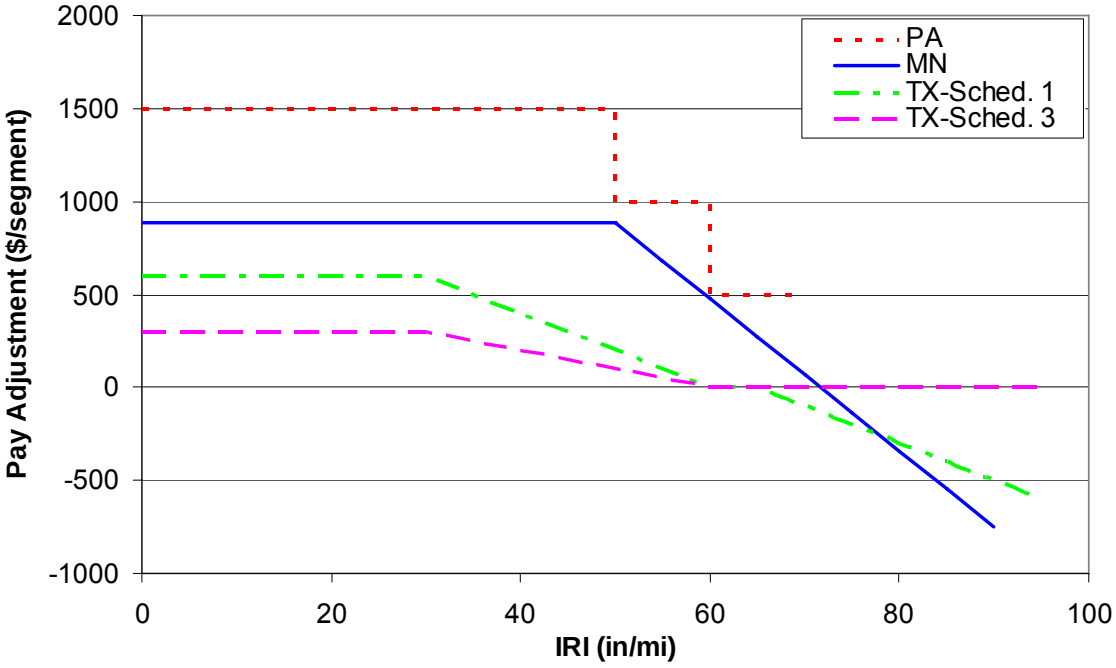

Figure 2.6. IRI Incentive Comparison.

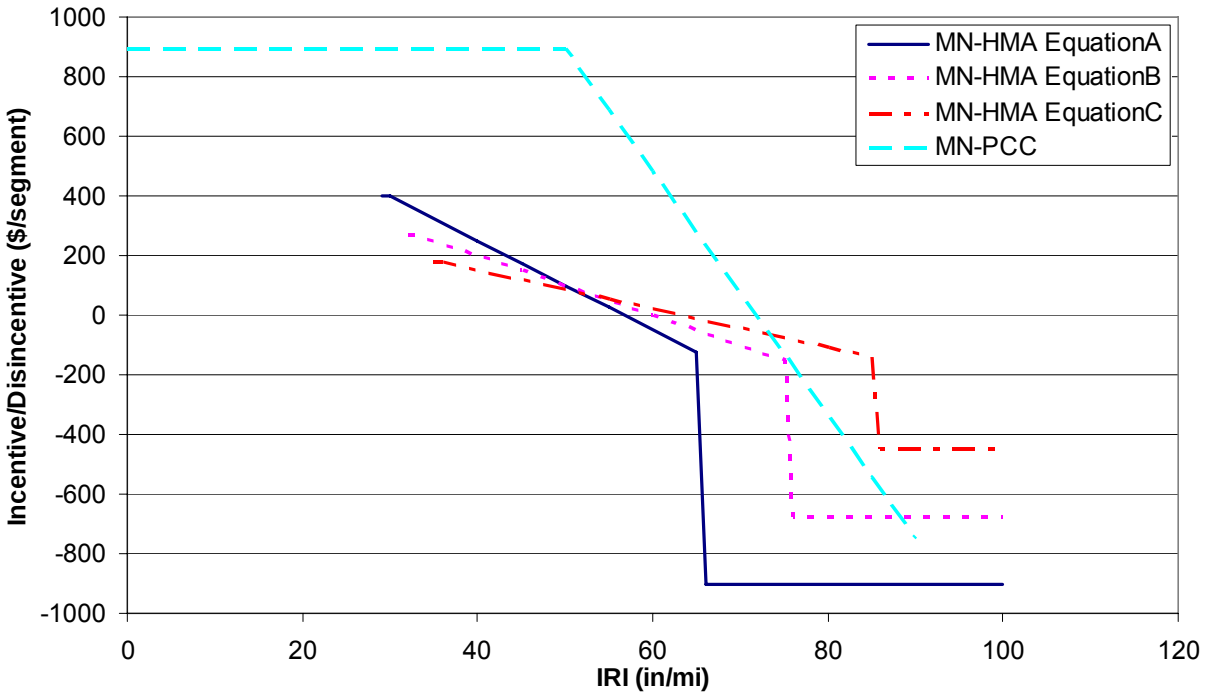

Figure 2.7. Comparison of Minnesota Payment Schedules for PCC and HMA.

Chapter 3. EFFECTS OF SURFACE FEATURES

This chapter consists of several analyses and comparisons of surface features often found in PCC pavements. The first is an analysis of randomly-generated pavement profiles with specific features added, which are then processed through the International Roughness Index and Profilograph Index filters. While a direct comparison between PI and IRI is not possible, some of the reasons for the discrepancies between them can be identified, and will be discussed in the next two sections. The first section also includes some analysis regarding the effect of different wavelength features on IRI and PI, and of tining in particular. The second section discusses specific profiles provided to the project team by Mn/DOT's Office of Materials. Within this section, a discussion of incentives and disincentives assessed for specific profiles will be presented. The third section presents a summary of the incentive and disincentive comparisons made in chapter 2 of this report and provides additional analysis and discussion of this topic.

Profile Analysis

The previous chapter discussed the PI and IRI measures of pavement roughness and their usage among the states. The primary focus of this section is to identify differences in the profiles based on the wavelength content – the dominant wavelengths present in many portland cement concrete pavement profiles in Minnesota. In order to avoid any inherent bias in the profiles used for this analysis, and to eliminate the potential confounding effects of other dominant wavelengths, generic profiles were generated using pseudo-random numbers based on a standard normal distribution. This was done using techniques reported in NCHRP Report 353: *Effects of Heavy-Vehicle Characteristics on Pavement Response and Performance* (2) and *Stringline Impacts on Concrete Pavement Construction* (3). These generic profiles do not have any dominant wavelengths, and thus are well-suited for this type of analysis. Originally, the researchers attempted to "remove" specific dominant wavelengths from actual pavement profiles. This proved difficult and ran the risk of removing other wavelengths besides those in question, and tended to smooth out the profile data too much, resulting in much lower roughness index values than would be expected. It was determined that beginning with a pseudo-random profile and *adding* a specific wavelength was a much better method.

After generating several random profiles to provide a statistical basis for the analysis, several "features" were added to them to generate more realistic profiles – in most cases with only a single dominant wavelength. These features include two types of repeating patterns – catenaries, which simulate the sag in a paving stringline, and sine waves, which are generic representations of repeating features similar to catenaries. Examples of catenaries and of sine waves are shown in Figure 3.1.

The analyses performed for this project were accomplished with the use of the ProVAL 2.6 software, developed through funding from the Federal Highway Administration. The analyses conducted with ProVAL include Ride Statistics (International Roughness Index), Profilograph Simulation, and Power Spectral Density.

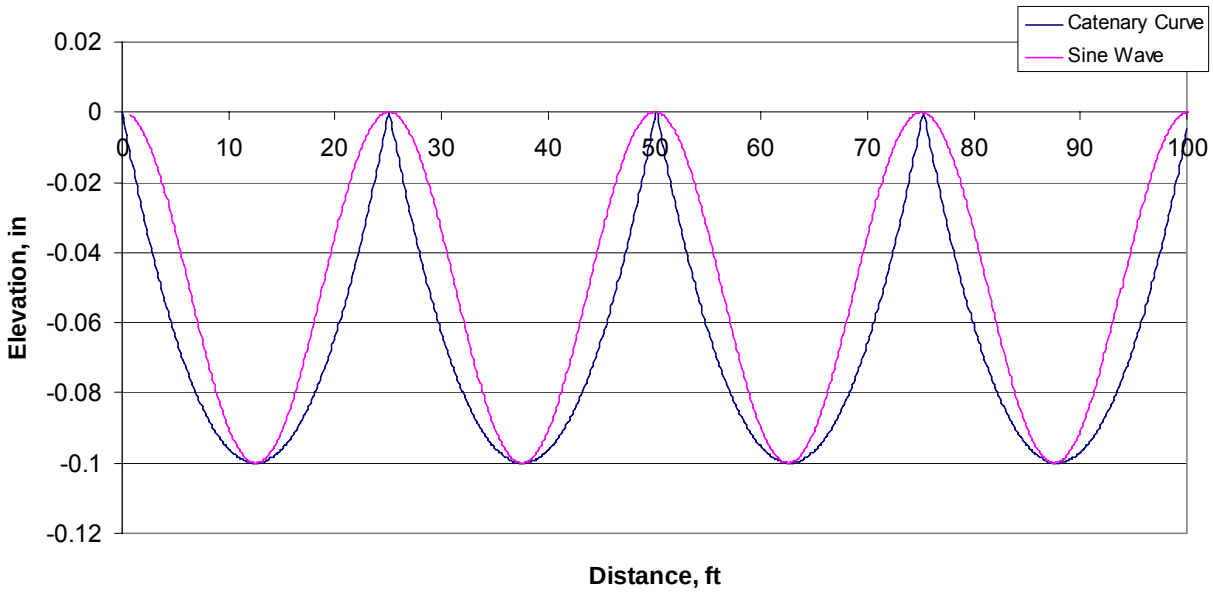

Figure 3.1. Examples of Catenaries and Sine Waves Added to the Generic Profiles.

IRI vs. PI

The purpose of the generic, random pavement profiles is to evaluate the effects of a single wavelength with the assurance that other wavelengths are not present. Originally the project team attempted to take existing profiles and filter out specific wavelengths, but as previously discussed, this was more difficult, and the effects of the filtering would have been greater than desired.

The first analysis comparing IRI and PI was to add specific wavelengths, one at a time, to a set of five randomly-generated profiles and then compute the average and standard deviation of the profile statistics determined by the ProVAL software. The features added to the random profiles included the following:

- 15-foot joint spacing, representing slightly upward curled slabs (catenary curve)
- 15-foot joint spacing, representing slightly downward curled slabs (catenary curve)
- 15-foot wavelength sine wave
- 25-foot stringline spacing (catenary curve)
- 25-foot wavelength sine wave
- 50-foot stringline spacing (catenary curve)
- 50-foot wavelength sine wave
- 15-foot upward curled slabs + 25-foot stringline spacing

One improvement to this analysis could be the shape of the curled slabs. In the current analysis, the curled slab shape is modeled as a catenary, as are the stringlines. A catenary curve is formed when a cable or string is supported by its ends only, and sags in the middle. The amount of sag is controlled by the tension in the cable. It is appropriate to model sagging stringlines in this way, but there is likely a better way of modeling the shape of curled slabs. Byrum (4) suggested modeling the shape of curled slabs with a constant curvature, but this also could be improved.

The exact shape is not significant, as can be seen in Table 3.1, the IRI and PI values computed using both catenaries and sine waves of the same wavelength are very similar.

Table 3.1 shows the average and standard deviation of the five random profiles and the additional components. The coefficients of variation are very small for IRI and $PI_{0.0}$ (up to 3.6% and 7.8%, respectively) and much larger for the $PI_{0.2}$ statistic (up to 71%).

Table 3.1. Average and standard deviation of random profiles and added features.

	Average, in/mi			Standard Deviation, in/mi		
	IRI	$PI_{0.2}$	$PI_{0.0}$	IRI	$PI_{0.2}$	$PI_{0.0}$
Random	63.1	0.41	29.9	2.2	0.29	1.2
Random+15-ft upward catenary	128.9	2.63	52.3	1.6	0.80	1.1
Random+15-ft downward catenary	130.2	2.53	50.4	1.7	0.78	1.4
Random+15-ft sine wave	135.8	2.68	50.3	1.9	0.65	1.0
Random+25-ft upward catenary	76.7	5.26	43.6	1.8	1.74	3.4
Random+25-ft sine wave	77.2	8.56	48.0	0.9	0.92	2.8
Random+50-ft upward catenary	68.9	1.91	29.2	1.4	0.47	1.4
Random+50-ft sine wave	68.6	1.70	28.9	2.1	0.59	1.4
Random+15-ft and 25-ft upward catenaries	137.3	9.70	57.3	1.8	1.69	1.1

Regardless of the random profile generated, as long as it was generated with the same input parameters to the random profile generator, the ride statistics were very close for IRI and both PI statistics. However, the $PI_{0.2}$ ride statistic is much more variable since it only considers the extreme values in the profile. The $PI_{0.2}$ will not be analyzed further in this section, but will be used later when comparing incentives and disincentives.

The important information to observe in Table 3.1 is the change in the ride statistic when certain features are added to the random profile. The 15-foot wavelength content added to the random profiles caused large increases in IRI when compared to the random profile (more than double), and the $PI_{0.0}$ statistic increased only about 70%. Table 3.2 shows the percent change in the three ride statistics over the unmodified random profile.

Table 3.2. Percent change in ride statistics over unmodified random profile.

	% Increase over Random		
	IRI	$PI_{0.2}$	$PI_{0.0}$
Random+15-ft upward catenary	104%	535%	75%
Random+15-ft downward catenary	106%	511%	69%
Random+15-ft sine wave	115%	548%	68%
Random+25-ft upward catenary	21%	1171%	46%
Random+25-ft sine wave	22%	1969%	61%
Random+50-ft upward catenary	9%	361%	-2%
Random+50-ft sine wave	9%	312%	-3%
Random+15-ft and 25-ft upward catenaries	118%	2243%	92%

In this table, it can be seen that the 15-foot wavelengths have the largest impact on IRI and that the 25-foot wavelengths have the largest impact on $PI_{0.0}$. Again, the $PI_{0.2}$ statistic is not included in any of the analysis in this section because of its inherent sensitivity to individual large peaks, but not to overall roughness within its 0.2-inch blanking band.

Effect of Added Wavelengths on IRI and $PI_{0.0}$

A second analysis was conducted after the analysis of specific wavelengths added to five random profiles and averaged to determine their effects on the ride statistics, and after seeing the very small coefficient of variation between the five random profiles. Since the variation is so small, the second analysis only used one of the random profiles, but attempted to see the relative difference in ride statistics when different wavelengths were added, individually, to the random profile. Figure 3.2 shows this sensitivity of IRI and $PI_{0.0}$ to variable added wavelengths. Figure 3.3 shows the same information, but highlighting the wavelength range from 0 to 1 ft. This is to show the effect of macrotexture on IRI and $PI_{0.0}$. The analysis conducted added a sine wave of the specified wavelength to one of the random profiles used in the previous analysis.

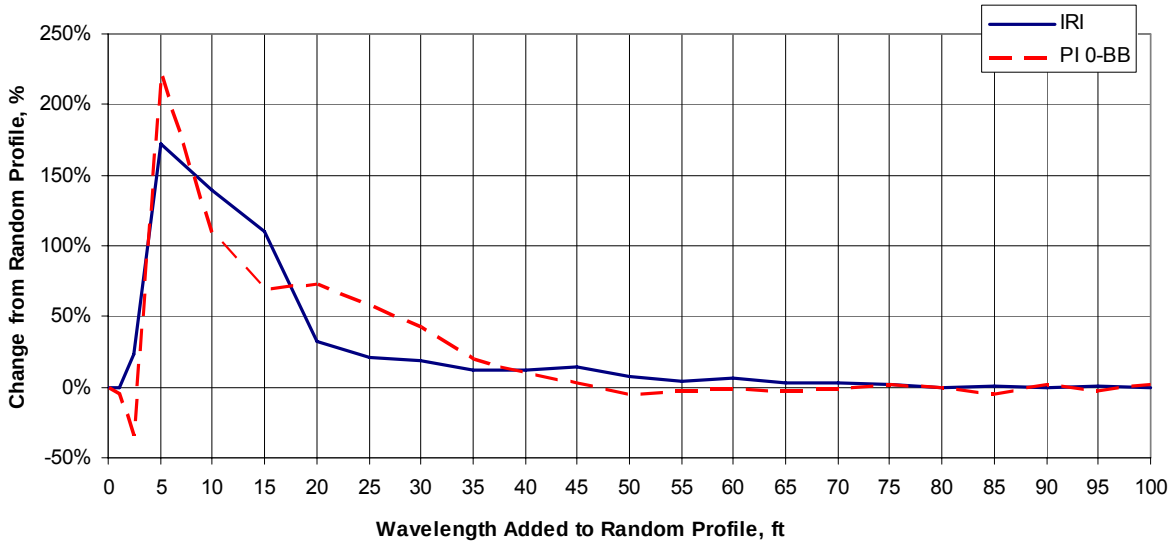

Figure 3.2. Sensitivity of IRI and $PI_{0.0}$ to Added Wavelengths.

Figure 3.2 shows that for wavelengths between about 5 and 8 feet and from about 17 to 40 feet, the PI analysis indicates a greater contribution to roughness than IRI, and that between 8 and 17 feet, the reverse is true. For wavelengths larger than 40 feet, both ride statistics tend not to show much increase with the addition of wavelength content in the profile. For wavelengths less than 40 feet, then, this means that the 15-foot wavelength (which is likely related to joint spacing) would affect the IRI more than the PI, and that the 25-foot wavelength (likely related to stringline spacing) would affect the PI more than the IRI. Thus, a change in pavement smoothness specifications from PI to IRI would likely favor the contractor (provide larger bonus) in terms of stringline sag, and would favor the highway agency (provide smaller bonus) in terms of the 15-foot joint spacing.

Figure 3.3 shows that the effect of tining and other macrotexture features in the pavement do not have an effect on the IRI calculations, as they do for $PI_{0.0}$. This does not mean that texture does not affect the driver and passengers in a vehicle, but simply that it does not affect the IRI calculations significantly.

The effect shown in Figure 3.2 and Figure 3.3 is indicative of the "gain" shown in Figure 3.4, which is an indication of how much the ride statistic increases or decreases the effect of specific wavelengths. These curves (PI gain and IRI gain) are taken from Kulakowski and Wambold (5), and Sayers and Karamihas (6), respectively.

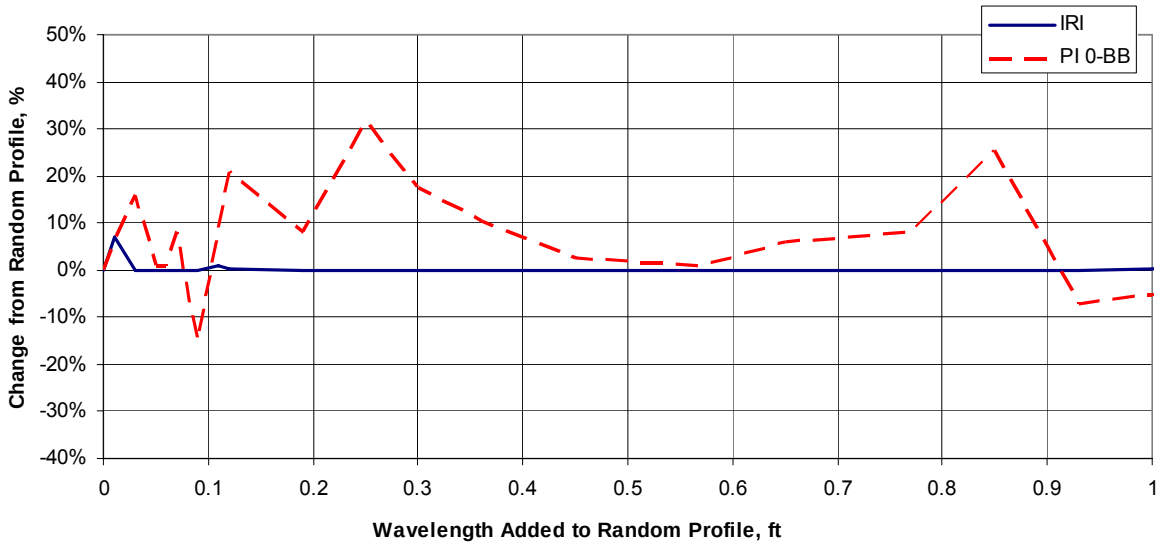

Figure 3.3. Sensitivity of IRI and $PI_{0.0}$ to Added Wavelengths, 0 to 1 ft.

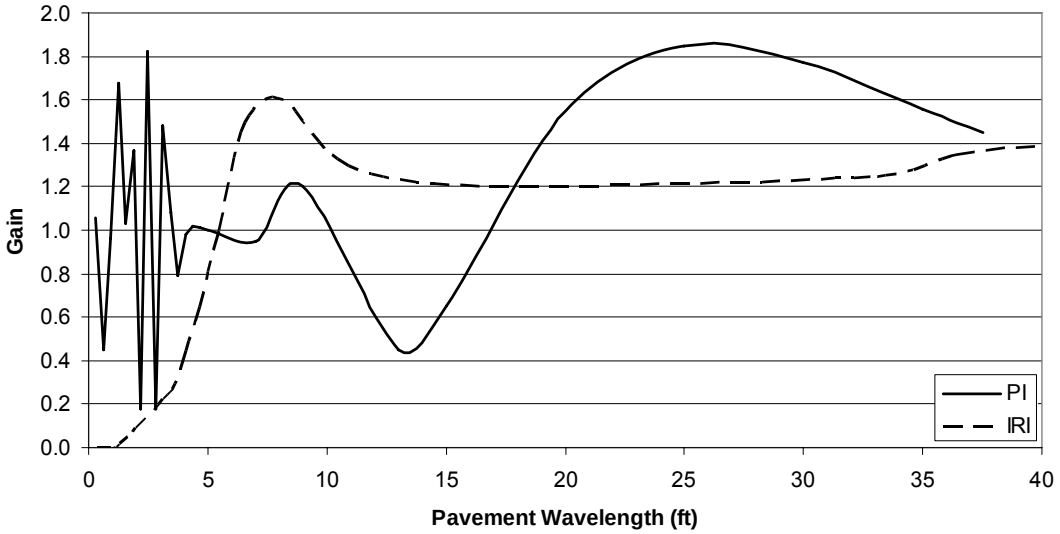

Figure 3.4. Pavement profile wavelength response.

Effect of Tining

A tining comb used in PCCP construction, according to Section 2301.3L of the Mn/DOT 2005 Standard Specifications (7), must have a "randomized spacing of 16-26 mm (approximately 5/8 – 1 inch)." The "required tine width is 2-3 mm (approximately 1/12 – 1/8 inch) and the required tine depth is 3-8 mm (approximately 1/8 – 5/16 inch). Using these parameters, and the same

random profile that was used in the analysis shown in Figure 3.2 and Figure 3.3, a random pavement profile with a reverse profile of a random tining comb was made. Since the tine spacing and width are very small, the reverse tining comb profile was resampled to a 0.1-ft spacing, to simulate the data collection of an inertial profiler, so that it could be added to the random profile produced in the 0.1-ft spacing ERD format. Due to the resampling, much of the tining comb profile was lost. Since this resampling simulates the data collection interval of a standard inertial profiler, the its result would be similar to the output of a profiler. The ERD file in 0.1-ft spacing does not see the changes in the profile between the sample points. It only measures the profile at the 0.1-ft interval.

The combined profile was analyzed with ProVAL. Again, the random profile used was the same as that used in the previous analysis, shown in Figure 3.2 and Figure 3.3. The spacing of the tines is purposefully random, but ranging between 0.052 and 0.083 ft. The ride values calculated by ProVAL are 64.3 in/mi IRI, and 36.7 in/mi $PI_{0.0}$. This corresponds to a negligible increase in IRI (0.3%), and a 25% increase in $PI_{0.0}$. The insignificant effect on IRI is to be expected, given the lack of change in the response curve in Figure 3.3 in the tining range.

While this specific example is based on randomly-generated pavement profiles and tining combs, the general effect seen would not be expected to change significantly. Factors that might change the effect include standard tining on a very smooth pavement surface (the relative effect of the tining would be larger than in this example) and a tined surface where the tine depth is greater than allowed in the standard specifications. If the tining is twice the allowable depth, the IRI in this example increases to 65.8 in/mi, and the $PI_{0.0}$ increases to 40.5 in/mi. Additionally, the process of tining sometimes raises some of the fresh concrete above the surface, which would have a greater effect on IRI.

Power Spectral Density

The power spectral density (PSD) analysis was used to identify dominant wavelengths in pavement profiles. For example, when a 15-foot joint spacing is used, there is often a dominant wavelength found at 15 feet per "cycle". The PSD analysis was originally used by the electrical power industry – thus its name. For the remainder of this report, units of wavelength will be reported in distances only, rather than distance per cycle. The dominant frequencies identified by the PSD analysis are features in the pavement profile that represent physical, repetitive components. Figure 3.5 and Figure 3.6 demonstrate this analysis.

Figure 3.5 is a profile of a pavement on a newly-constructed Minnesota highway. Figure 3.6 shows its component frequencies, or the "frequency content" of the profile. The range of wavelengths in Figure 3.6 is from about 1 to 200 feet. According to Karamihas (8), the range which most affects how a pavement feels to riders in a passenger car is between 1.4 and 220 feet. The profile in Figure 3.5, which was measured with an inertial profiler, was then analyzed using the PSD. The x-axis is a log scale of the wavelength, and the y-axis is a representation of the amplitude of the feature occurring at the particular frequency.

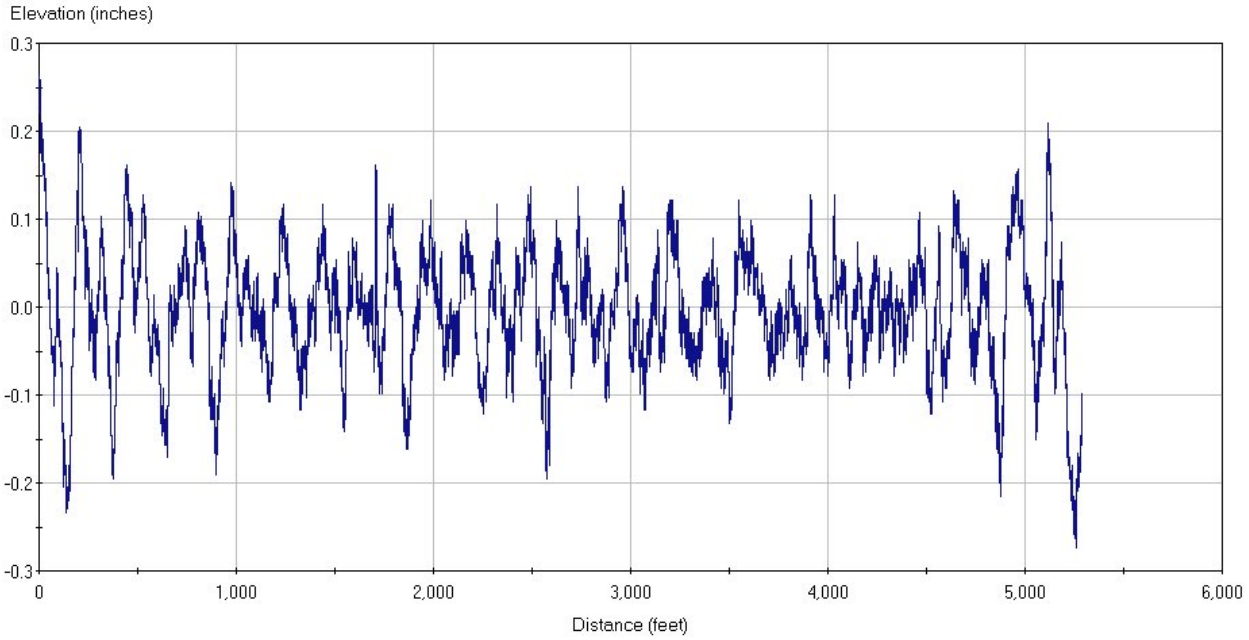

Figure 3.5. Sample pavement profile from a newly-constructed Minnesota highway.

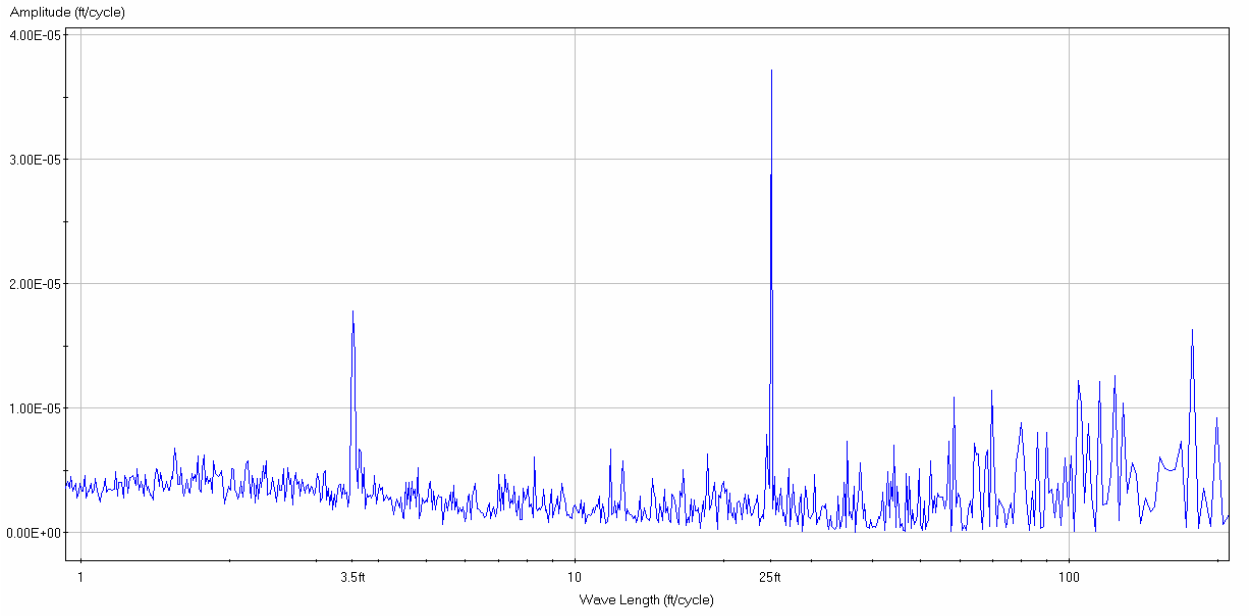

Figure 3.6. PSD analysis of profile in Figure 3.5.

The frequency plot shown in Figure 3.6 indicates two dominant wavelengths – one at 3.5 feet and one at 25 feet. At a speed of 75 mph, the 3.5-foot feature in the pavement would be felt at about 31 Hz and the 25-foot feature would be felt at about 4.4 Hz. At the proper amplitude, the feature with the 3.5-foot wavelengths is likely to produce the "chatter" or even the "whine" heard on some concrete pavements. The feature at the 25-foot wavelength is assumed to be the effect of stringline stake placement. Figure 3.7 shows a similar plot, with wavelengths also between 1 and 200 feet, with dominant frequencies at 7.5, 15, and 25 feet/cycle. The 15-foot wavelength

corresponds most likely with the 15-foot joint spacing, and the 7.5-foot wavelength is a higher-frequency harmonic of the 15-foot wavelength. The 25-foot wavelength likely corresponds with the stringline support spacing, similar to the pavement profile in Figure 3.6.

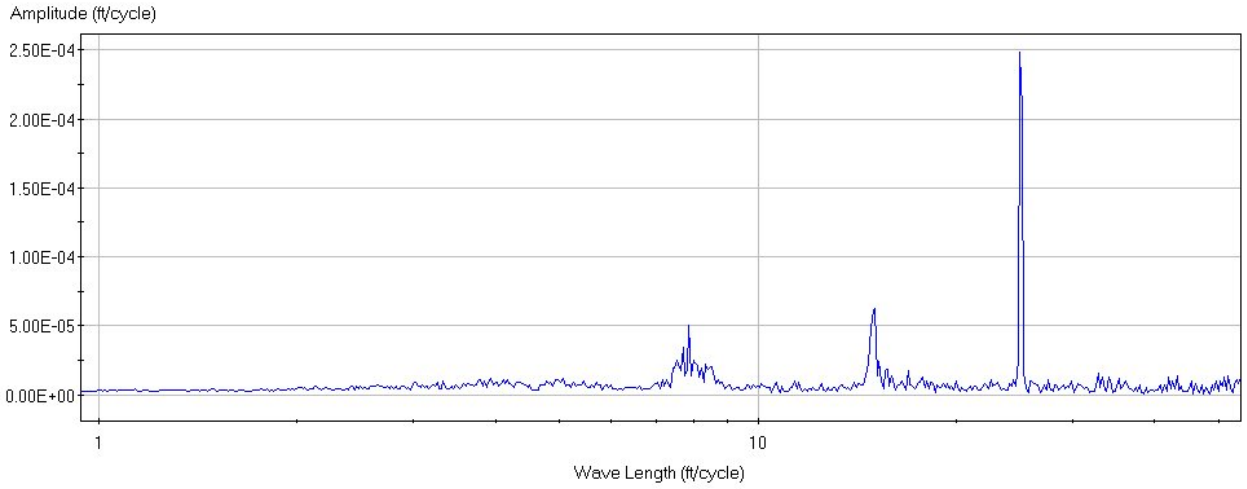

Figure 3.7. Sample PSD analysis – 7.5-, 15- and 25-foot wavelengths.

For contrast, to show a pavement without the 15-foot dominant wavelength due to joint spacing, Figure 3.8 is a PSD analysis of a continuously reinforced concrete pavement. This type of pavement does not have joints (except for construction headers), and it is interesting to note that the 25-foot wavelength is also absent. This is not to say that CRCP never includes the 25- or 50-foot feature, but that in the 7 sample CRCP profiles provided to the project staff from the Texas Department of Transportation, none showed the 25- or 50-foot wavelength. It is also significant to note that in a research report to the Federal Highway Administration (9) CRCP was distinguished for its ability to retain its initial smoothness over many years, as long as the pavement does not show excessive localized failure.

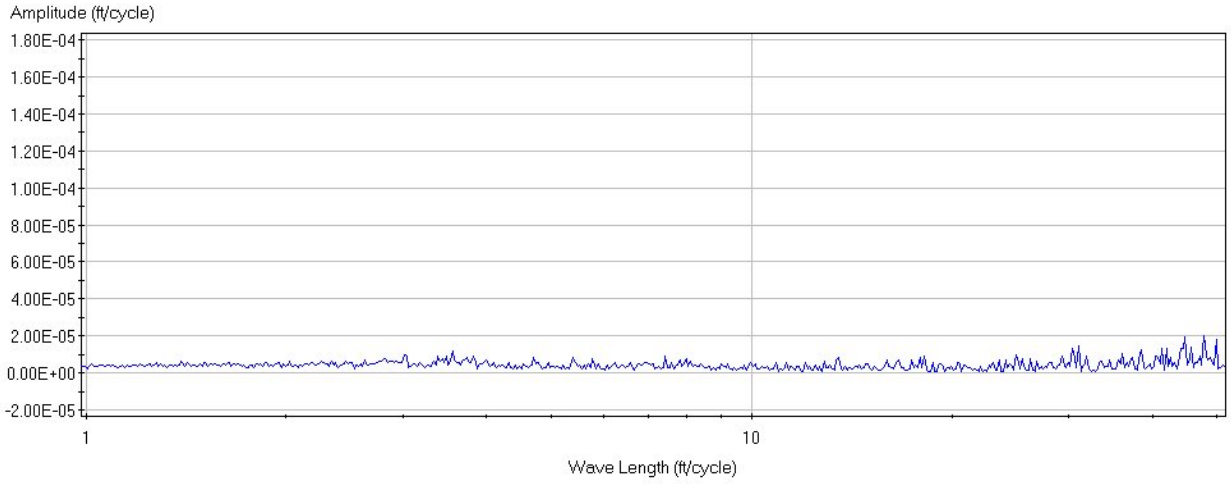

Figure 3.8. PSD analysis of a continuously reinforced concrete pavement.

The effect of the IRI analysis and its wavelength response can be seen in the following figure, which shows the power spectral density of the profile in Figure 3.5, which is similar to the PSD shown in Figure 3.6, except that in Figure 3.9 the IRI analysis, or filter, has been applied prior to the PSD. In this figure, the dominant wavelength at 3.5-feet has been eliminated due to the IRI "filter", and the 25-foot wavelength has been amplified. In addition, the wavelengths from about 7 – 10 feet has been increased slightly, as would be indicated by the response curve in Figure 3.4.

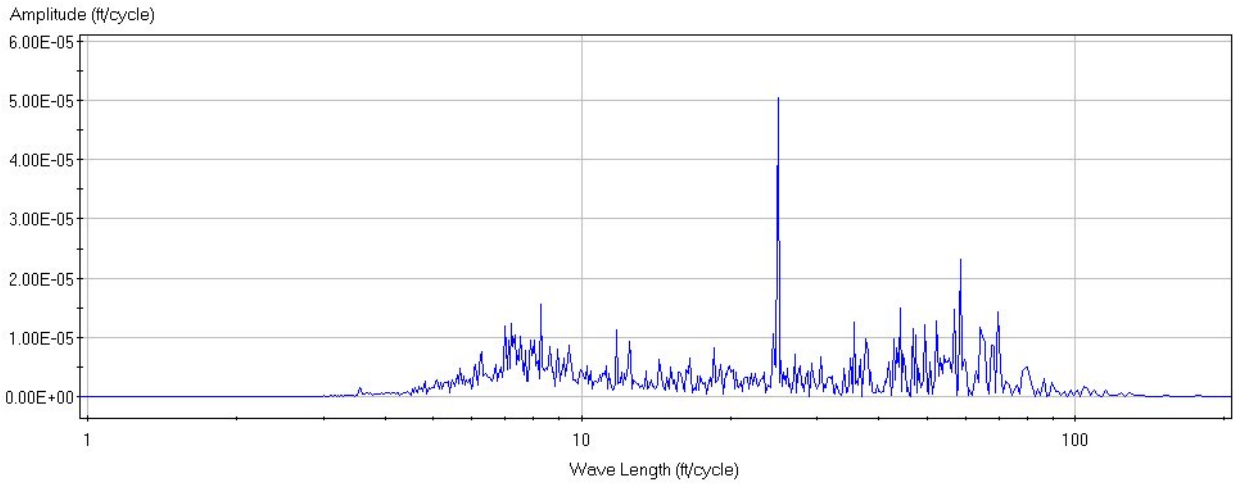

Figure 3.9. PSD of profile in Figure 3.5 after application of IRI filter.

Approximately 375 pavement profiles were provided to the project staff by Ms. Maria Masten and Mr. Bernard Izevbekhai of Mn/DOT. Using the ProVAL software, each profile was analyzed to identify dominant wavelengths. To enhance the resolution in the analysis results, the following settings were used in the ProVAL software: octave bands at 96 bands per octave, slope PSD calculation, and no preprocessor filter. The resulting PSD results were then examined to determine which wavelengths were dominant. A comprehensive list of the profiles along with dominant wavelengths and relative amplitude was assembled. Groups of profiles were chosen for each of the following common wavelength categories: No Dominant Wavelength, 15-ft, 25-ft, and 50-ft Dominant Wavelength. Other profiles that indicated several wavelengths and did not fit into any particular category were placed into the Multiple Dominant Wavelength category.

Table 3.3 shows a subset of all the profiles evaluated in the above analysis. These profiles have been divided into categories for additional analysis. Several additional columns are added to this table, showing some "shadow" wavelengths – one-quarter and one-half of the 15-foot wavelength, for example.

The relative dominance of the wavelengths, and other criteria including profile length and the exclusivity of the wavelength in the case of the 15, 25 and 50-ft wavelengths were used to determine the profiles that would be examined in the additional analyses. An attempt was made to use profiles from different projects when possible. The profile length is important because the results are averaged over more segments than in a shorter one, and the exclusivity of the wavelengths is important to determine as best as possible the contribution of the specific wavelength to the ride statistic.

Table 3.3. Summary of PSD results for pavement profiles on Minnesota highway projects.

	Dominant Wavelengths, ft						
	3.8	5	7.5	12.5	15	25	50
No Dominant Wavelength							
1050912H							•
1050912I							•
1050912J							
10500122	•						
10500164							
10500166	•						
15-foot Dominant Wavelength							
1050425A	•	•	•		•		•
1050606D	•	•	•		•		•
1050913C	•	•	•		•		•
1040242A			•		•		
10405005		•	•		•		
10500116			•	•			
25-foot Dominant Wavelength							
10500113	•					•	
10500121	•					•	
10500124						•	
10500151	•					•	
10500155	•					•	
10500165	•					•	
50-foot Dominant Wavelength							
1050601B							•
1050602G							•
1040536A							•
1040537A							•
1040542A							•
Multiple Dominant Wavelengths							
191759P1			•	•	•	•	
192694D2	•	•	•	•	•	•	
192694P1	•	•	•		•	•	
10204646					•	•	
10405005	•	•	•		•		
10405026	•	•	•		•	•	
10204648					•	•	
1050601A	•	•	•	•	•		•
1050602D	•	•	•		•	•	•
1050606M	•	•	•		•		
1050912C	•	•	•		•		•
1050926A	•	•	•		•	•	•
1050926F	•	•	•	•	•	•	•

Incentives / Disincentives – IRI vs. $PI_{0.2}$

Since the response of the ride statistics is different for the 15- and 25-foot wavelengths, it is understandable that the bonus or penalty assigned to a segment of highway would also be different. This is perhaps at the root of the differences which paving contractors concern themselves. Most contractors like to understand how they will be paid, and how incentives and disincentives will be assigned. If there is something the contractor can do to improve his bonus or to limit his penalty, he is likely to do it.

Table 3.4 shows a summary of the profiles selected for further analysis, their associated average roughness indices, and the average assigned incentives / disincentives, based on 0.1-mile segments. Also in this table are the change in incentive payment compared to the "no dominant wavelength" category of profiles analyzed. It should be considered, however, that these profiles are measured from actual pavements, and that the specific effect on the ride statistics will not be as consistent and predictable as for the randomly-generated profiles.

Table 3.4. Summary of Wavelength Contribution to Roughness.

	Average				Change in Incentive Over "None"	
Dominant Wavelength	**IRI**	**$PI_{0.2}$**	**IRI Incentive**	**$PI_{0.2}$ Incentive**	**IRI**	**$PI_{0.2}$**
None	60.07	1.31	523.91	542.87	0.0%	0.0%
15-foot	69.51	1.45	153.07	517.41	-70.8%	-4.7%
25-foot	47.92	0.39	842.25	711.89	60.8%	31.1%
50-foot	58.48	1.29	538.1	561.99	2.7%	3.5%
Multiple	68.35	1.66	252.33	566.85	-51.8%	4.4%

Figure 3.10 shows the value of the average incentive paid for each segment within the various wavelength categories. When no particular dominant wavelength is present in the profile, both IRI and PI pay about the same incentive (for the particular profiles used in this analysis). The figure also shows that when only a 50-foot wavelength is dominant in the data, both IRI and PI produce approximately the same incentive.

When comparing IRI and PI with respect to the 15-foot wavelength, The IRI analysis produces a much lower incentive value than the same profile analyzed in terms of PI. Conversely, with a 25-foot wavelength, the IRI incentive is greater than the PI incentive, although not as great a difference as with the 15-foot wavelength. These two differences are understandable when considering the differences in the frequency response of each roughness index, previously discussed.

There are many reasons why the IRI and PI analyses do not produce results consistent with each other. One major reason is the differences in how they each respond to the various frequencies present within individual profiles. These differences cannot be easily reconciled, if at all, and so it is not possible nor is it necessarily desirable to develop an IRI incentive algorithm that will always produce an incentive consistent with that computed by a PI algorithm. To do so would require analysis of the wavelengths present in the profiles and extensive adjustment of the

profiles themselves to "overcorrect" for the particular wavelengths that are attenuated or accentuated by the IRI or PI analysis. It is neither feasible, nor recommended to try to conduct such analyses or corrections. Comparisons in this section, then, are made between previous PI incentive values, the current pilot IRI incentive algorithm and other potential algorithms.

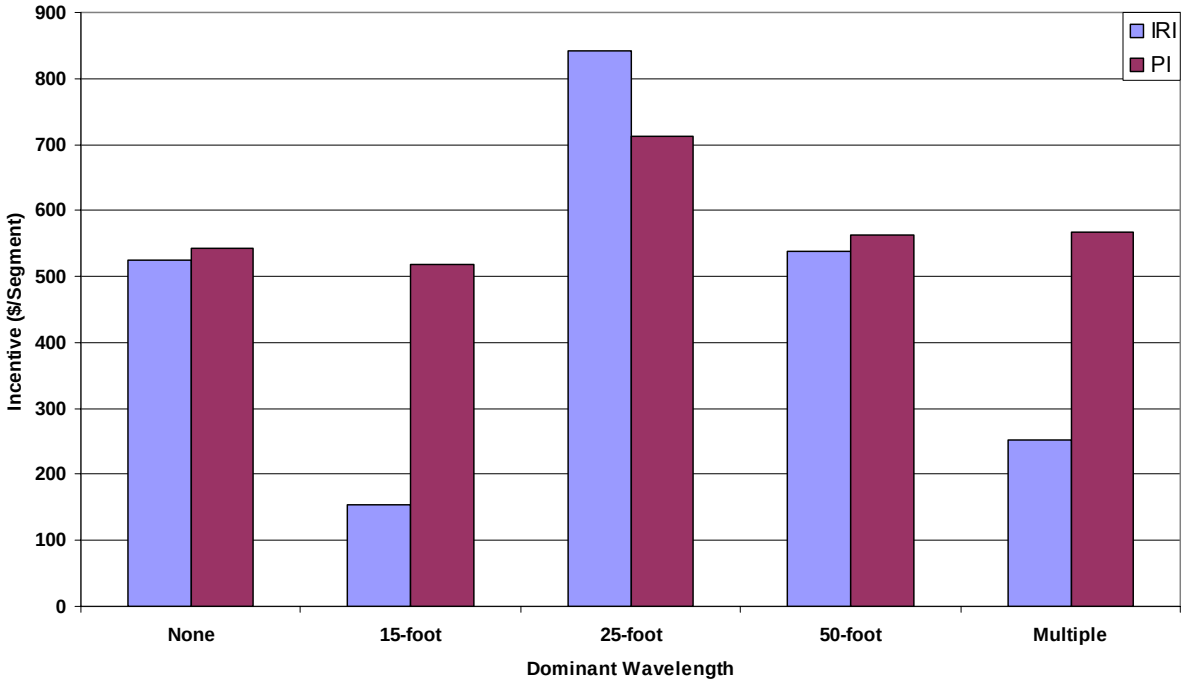

Figure 3.10. Average incentive by dominant wavelength.

As discussed in the previous section, the major difference between the incentive calculations with the PI and IRI analyses is the 15- and 25-foot wavelengths. Although the differences are not solely caused by these two wavelengths (other wavelengths where the two respond differently would also cause differences) these are some of few primary wavelengths found in the 375 profiles used in this analysis. These differences can be seen in Figure 3.10, where for the same profiles, the PI analysis and incentive algorithm calculates a higher incentive than the IRI analysis for those profiles where a 25-foot wavelength is present, and a lower incentive where a 15-foot wavelength is present.

IRI Incentive Algorithm

Figure 3.11 was presented previously in this section, and compares the Minnesota, Texas, and Pennsylvania payment schedules. Texas and Pennsylvania are the two states that had the most similar payment schedule (IRI with incentive per 0.1-mile segment), and the Minnesota IRI Pilot specification incentive schedule falls between them. There is a wide range between the three, however, with Pennsylvania paying up to $1500/segment, and the smallest maximum incentive paid by Texas as little as $300/segment. The Minnesota pilot specification currently pays up to $890/segment, but decreases more quickly than either Pennsylvania or Texas as IRI roughness increases. The incentive for smooth pavements ceases to increase at 50 in/mi in Pennsylvania and Minnesota, while in Texas the maximum incentive can be earned as low as 30 in/mi,

although that maximum is lower than the incentives paid by the other two states for higher IRI values.

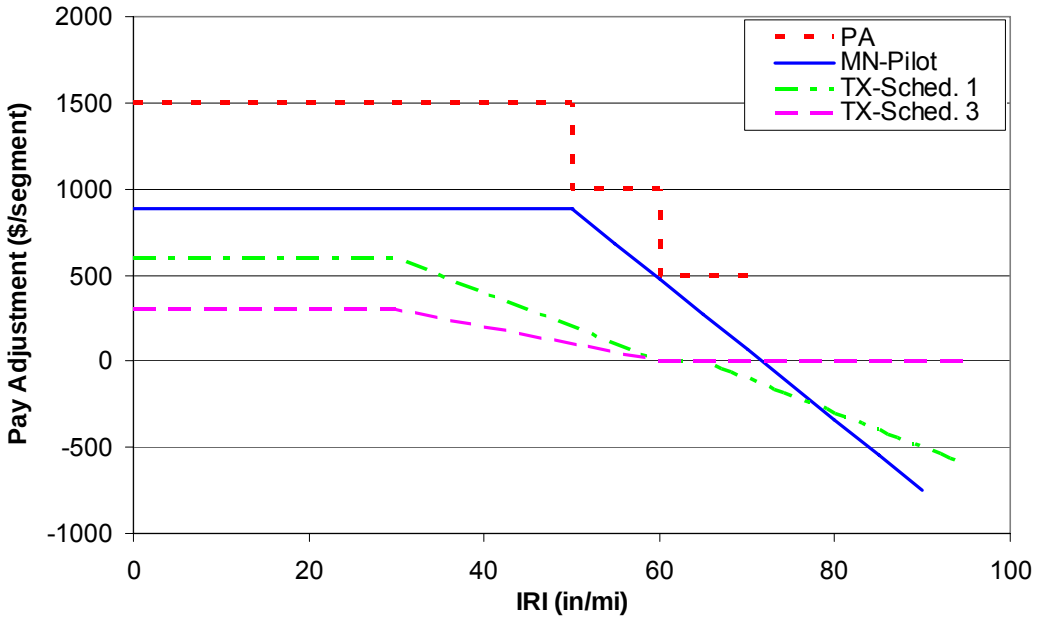

Figure 3.11. IRI Incentive Comparison between States.

In addition to leaving the current incentive algorithm in the Minnesota pilot specification unchanged, there are three recommendations to consider, which are presented in Figure 3.12. It is important to note that these options are simply suggestions, and the actual maximum, minimum, and slope values should be refined and determined by Mn/DOT.

- Option #1 Decrease the IRI level where the maximum incentive is paid (perhaps to 40 in/mi) and to leave the maximum value of the incentive unchanged. This essentially would mean flattening the slope of the incentive curve and decreasing the maximum incentive at the current minimum (50 in/mi).

- Option #2 Decrease the IRI level where the maximum incentive is paid, and to leave the slope of the incentive curve unchanged, thereby raising the amount of potential incentive for very smooth concrete pavements. This would result in much higher incentive payments ($1300/segment).

- Option #3 Break the slope of the curve, with a steeper slope between the maximum allowable IRI (currently 90 in/mi) and some level of IRI where incremental improvements in smoothness are not as valuable to the department. From that point, the slope would be less steep, arriving at the maximum incentive at a point where further smoothness is not considered of additional benefit.

The level of IRI below which additional smoothness would not be of benefit should be set as a matter of policy by Mn/DOT, with some technical guidance. The AASHTO Guide for Mechanistic-Empirical Design (10) indicates that initial IRI values are typically between 50 to

100 in/mi, and the mean value of initial IRI of 155 SPS-2 sections (doweled jointed plain concrete pavements) in the Long-Term Pavement Performance (LTPP) study is about 82 in/mi (11). According to Byrum (4) the *ideal, uncurled*, initial IRI based on an analysis of GPS-3 sections (jointed plain concrete pavements) in the LTPP database is about 32 in/mi. It is clear that there is a wide range of expectations in initial IRI.

Further investigation is suggested to determine a reasonable lower limit of initial IRI that is achievable by paving contractors, and if additional financial incentives could induce paving contractors to attempt to achieve those lower initial IRI values. Without this additional information, it is recommended that either the current minimum of 50 in/mi be maintained, or a trial period reducing the minimum to 40 in/mi be instituted.

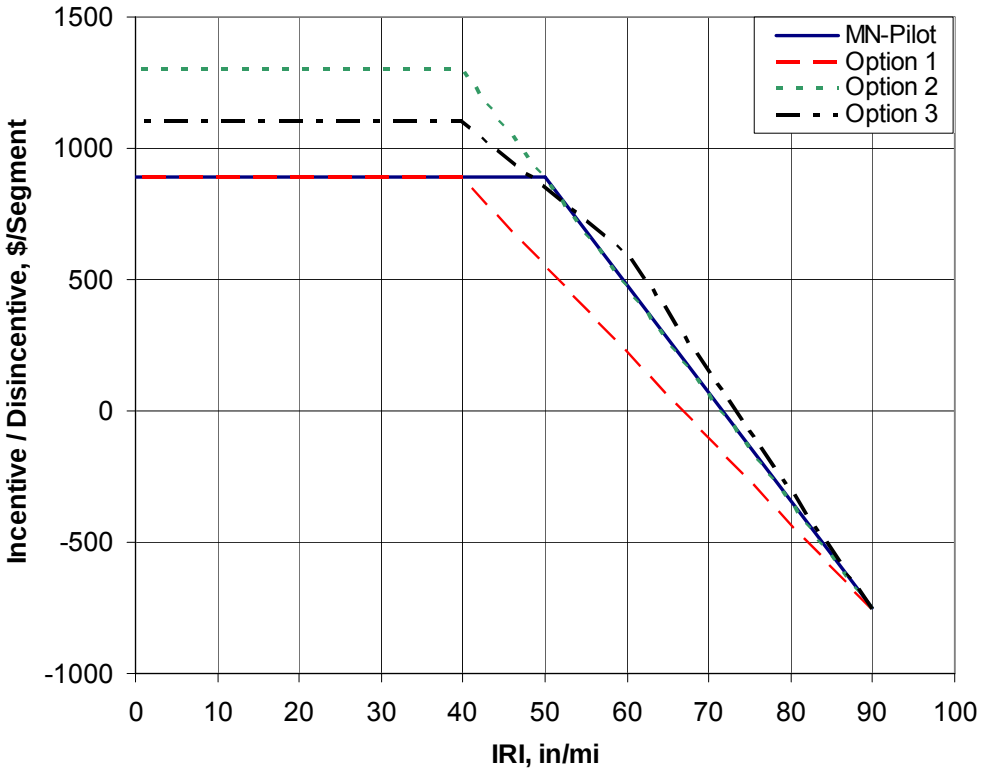

Figure 3.12. Current Minnesota Pilot IRI Incentive Schedule and Three Options.

Figure 3.13 shows the incentive payments for the various ride statistics and suggested payment schedule options discussed in this report. The incentive values are what were actually paid (for $PI_{0.2}$ or IRI Pilot) and would have been paid under the suggested options. It becomes obvious that any of the IRI incentive schedules, due primarily to the nature of the IRI analysis, dramatically decreases the payment for pavements which have a dominant 15-foot wavelength, and increases, to an extent, the payment for pavements which have a dominant 25-foot wavelength. The incentive payments for pavements with multiple dominant wavelengths are influenced by the component wavelengths.

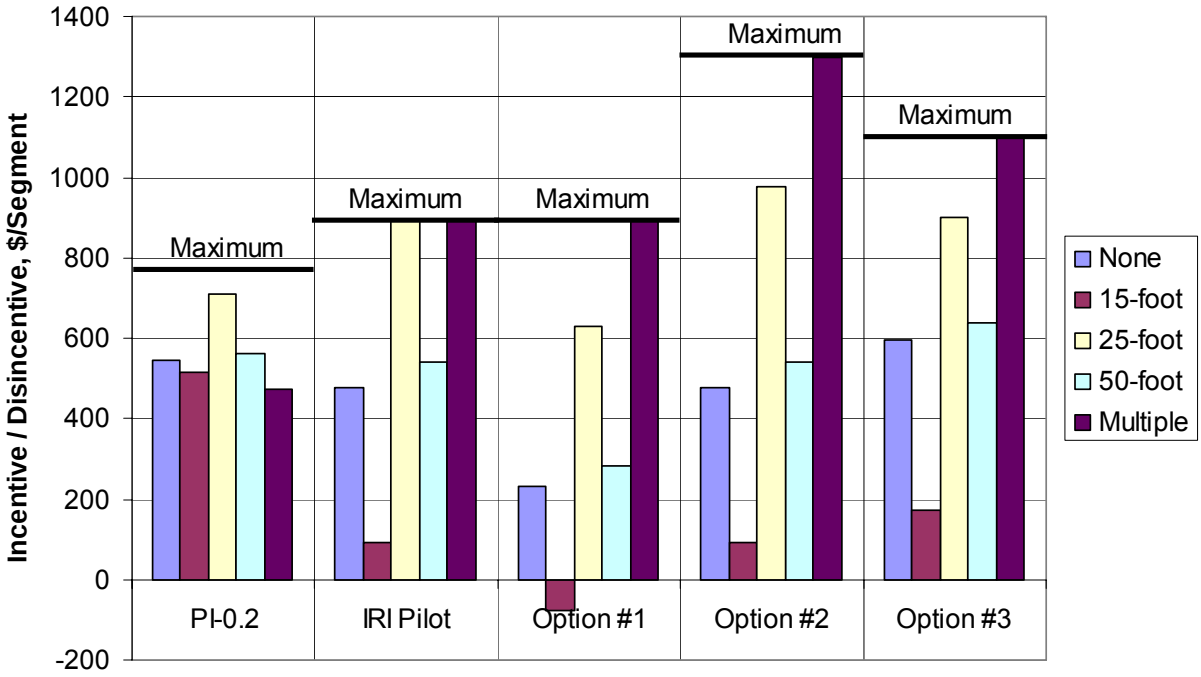

Figure 3.13. Summary of incentive payments for actual Minnesota highway profiles.

Effect of Segment Length

As found in the analysis reported in previous sections, the standard segment length for dividing lots is 0.1 mile. However, several states use segment lengths different than the standard 0.1-mile segment. The segment lengths specified by some other states vary between 52 to 1000 feet (0.01 to 0.19 mile). In order to evaluate the effect of segment length on IRI and the corresponding incentive / disincentive, three profiles were selected and analyzed using the ProVAL software with five different segment lengths – 0.01, 0.1, 0.25, 0.5, and 1.0 miles per segment. The 0.01-mile segment length corresponds to the segment length specified by Virginia.

Figure 3.14 shows the average and standard deviation of IRI for the three selected profiles. The average IRI for any segment length does not change significantly, although the standard deviation decreases as segment length increases. The largest improvement in standard deviation occurs between the 0.01- and 0.1-mile segment length.

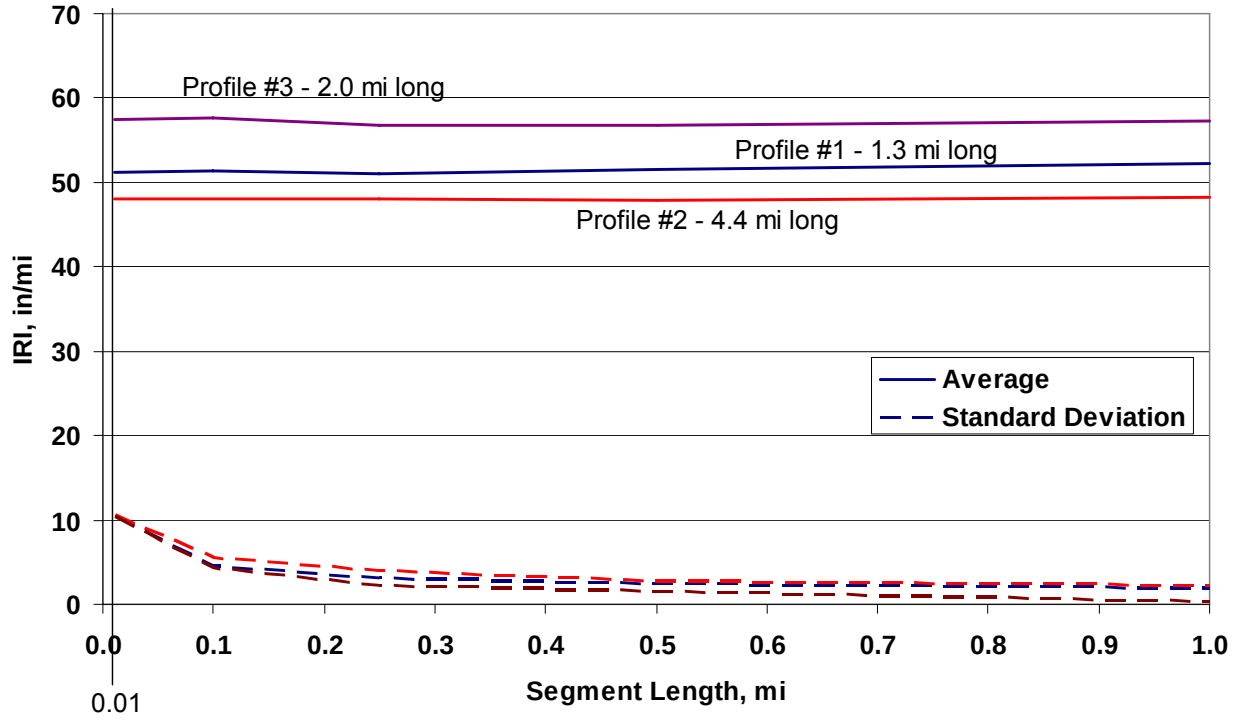

Figure 3.14. IRI Average and standard deviation with varying segment length.

Figure 3.15 shows the total incentive that would be paid by the current Mn/DOT 2006 IRI Pilot Specification for PCC pavements, normalized to dollars per mile of project length. Again, the largest change is between the 0.01- and 0.1-mile segment lengths. As segment length increases, there are only small increases in incentive payment.

It is recommended, therefore, that the segment length remain at 0.1 mile. Besides being a standard length specified by most states, it produces average IRI values virtually identical to those produced by other lengths. The standard deviation in the IRI values is much lower variability than in 0.01-mile segment length, and only slightly higher than with the longer segment lengths. The incentive calculated from IRI values with segment lengths less than 0.1-mile seem to take advantage of the large variability in the values to reduce the overall incentive for the project.

An argument could be made to specify 1.0-mile segments, with almost identical average IRI values as the 0.1-mile segment, lower variability in IRI between segments, and only slightly higher total incentive values. One drawback may be the psychological impact of offering an incentive of $8,900 per segment (for 1.0 mile) rather than $890 per segment (for 0.1 mile).

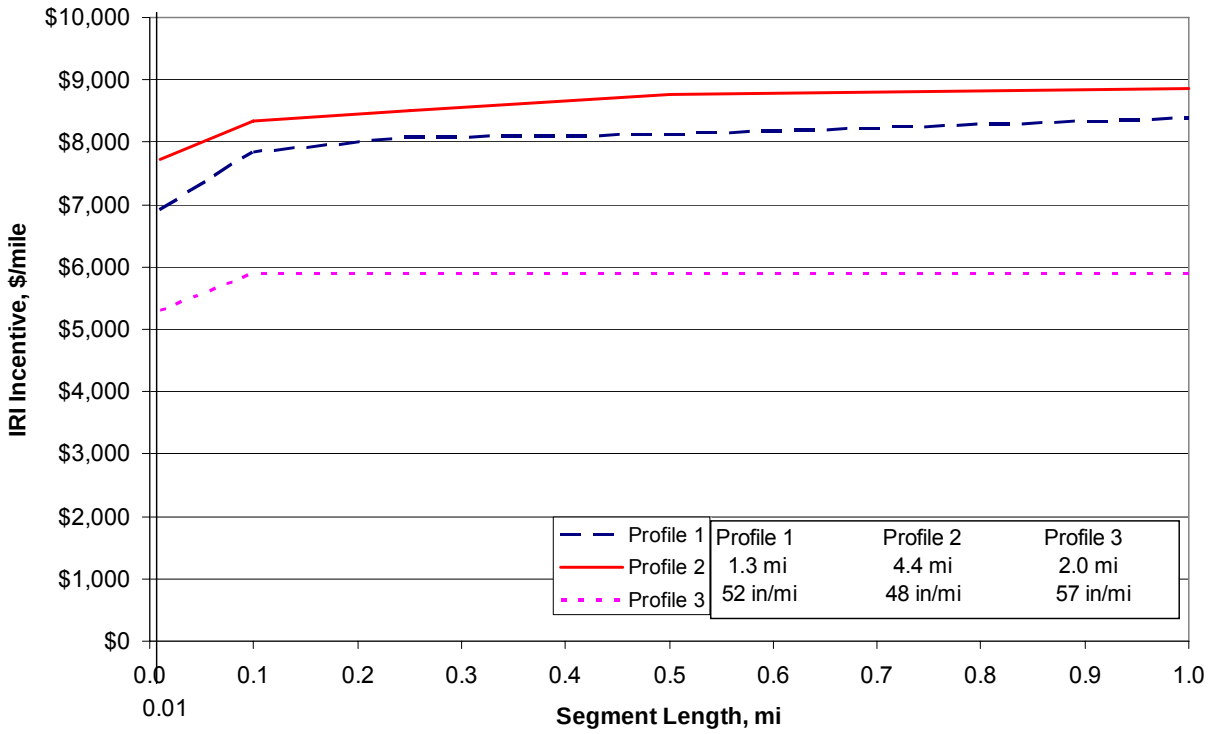

Figure 3.15. Total incentive payment with varying segment length.

Summary

This chapter presented analyses on theoretical, random, pavement profiles as well as on actual profiles measured on newly-constructed Minnesota highways. The relative effect of various component wavelengths on the PI and IRI analyses was discussed, and the resulting effect on the incentive and disincentive calculations was presented.

This chapter focused only on the effect of wavelengths on the PI and IRI incentive computations, and did not focus on the other aspects of smoothness specifications, which are addressed in the next chapter. Recommendations in the form of suggested options for modifying the incentive / disincentive computations in the current IRI Pilot specification are made at the end of this report. Although there is little difference in the resulting incentives between the current and the three suggested payment schedules, these are suggestions for the department to consider. Of the suggested options in this report, it is recommended that in some way the minimum IRI (where the incentive stops increasing) should be decreased to 40 in/mi. In association with this, the corresponding incentive payment for achieving such a smooth pavement surface should be increased. As recommended in the previous section, further investigation into paving contractors' abilities (or willingness) to achieve smoothness as low or lower than 40 in/mi should be conducted. Also, an assessment of contractors' expected costs and expectations for financial compensation for achieving lower initial IRI values should be conducted.

Chapter 4. REVIEW OF STATE PCC IRI SPECIFICATIONS

This chapter contains an analysis of International Roughness Index specifications for portland cement concrete pavements in use in seven states and Minnesota. The analysis compares the features of the IRI specifications in use by other states and the pilot IRI specification in use beginning in 2006. From this analysis a set of recommendations have been developed, and are presented in the next chapter of the report. The recommended features of Minnesota's final IRI specification have also been compared with the current hot-mix asphalt IRI specification in use by the Minnesota Department of Transportation.

Features of IRI Specifications

This section is divided into categories of IRI specification features. The other states that have implemented an IRI specification for PCCP include

- Kentucky
- Maryland
- Michigan
- New Mexico
- Pennsylvania
- Texas
- Virginia

The features of the PCCP smoothness specifications among the eight states include:

1. Type and location of profile measurement
2. Profile measurement equipment and testing parameters
3. Equipment and operator certifications
4. Calibration requirements
5. Who performs the testing
6. Lot size and definition, segment length
7. Exclusions
8. Timing of testing and data submission
9. QC/QA procedures
10. Required remedial action
11. Required correction plan
12. Pay adjustment method
13. Data analysis method
14. Surface preparation
15. Additional comments

State Specification References

Table 4.1 contains the references to smoothness specifications from each state. Some states have an entire specification section for pavement smoothness, and some include it in the overall concrete pavement specification.

Table 4.1. References to Smoothness Specifications by State.

State	Specification Reference
Kentucky	501.03.19 Ride Quality 501.04.07 Ride Quality 501.05.02 Ride Quality
Maryland	SP Section 535 Pavement Surface Profile
Michigan	Supplemental Specification DRAFT 0.8 08-27-04
New Mexico	401 Pavement Smoothness Measurement 450.352 Surfacing Smoothness Requirements 450.353 Straightedge Measurements
Pennsylvania	507 Evaluation of Concrete Pavement Ride Quality and Payment of Incentive
Texas	585 Ride Quality for Pavement Surfaces
Virginia	316 Hydraulic Cement Concrete Pavement
Minnesota	2301.3P1 Workmanship and Quality

Type and Location of Profile Measurement

Kentucky

If 12 feet wide or less, longitudinal profiles 3 feet from each edge. If wider than 12 feet, then longitudinal profiles 3 feet from each edge, and at planned longitudinal joints. In the direction of traffic.

Maryland

Stop 50 feet before a transverse joint, and include the 50 feet and the joint in the next section.

Michigan

IRI is calculated from the average IRI from left and right wheel paths. Wheel path is 3 feet from each edge of a lane. Contractor must mark beginning and end locations. In the direction of traffic. If initial run is <= 64 in/mi (IRI) then a single run is sufficient. If IRI is > 64 but <= 76 in/mi, then two additional runs are required. IRI is then the average of the three runs.

New Mexico

IRI for each wheel path, for each lane, using dual sensors. Three feet from pavement edges or lane lines. IRI is average of the two wheel paths. Distance between sensors (transversely) = 70.0 + or – 1.0 inch.

Pennsylvania

Both wheel paths, each lane. 3 ft from one edge, 5.75 ft from first.

Texas

Longitudinal and transverse. Both wheel paths.

Virginia

Both wheel paths, each lane.

Minnesota

Right wheel path. Each lane.

Profile Measurement Equipment and Testing Parameters

Kentucky

Profiles measured with profilograph. If PI is less than 6 in/mi (no specified blanking band but assume 0.2 in) then use a linear transform, as determined by ASTM E 1926, for the average of two profiles, to obtain IRI.

Short sections and exclusions are measured with a 10-foot straightedge. 1/8-inch longitudinal tolerance within 10 feet.

Michigan

Profiler must meet MTM 726 Michigan Test Method for Determining Ride Quality Using a GM Type Rapid Travel Profilometer.

New Mexico

Profile measurement equipment meets AASHTO MP 11 and PP 50.Cutoff wavelength of 91.4 m (300 ft). Profiles performed before longitudinal diamond grooving operations.

Pennsylvania

Provides specifications for profiler, in separate, referenced, test method.

Texas

High-speed or lightweight inertial profiler. Straightedge for excluded areas.

Virginia

"South Dakota type road profiling device". Tested in accordance with VTM-106.

Minnesota

ASTM Class 1, using optimum speed of the vehicle.

Equipment and Operator Certifications

Kentucky

The Engineer conducts all profile measurements. No statement of certification is made.

Michigan

"Furnish and operate a certified profiler…"

"Provide a certified profiler operator."

Certification by MTM 730 Michigan Test Method for Certification of Profilometers. Must display certification sticker on the equipment and provide a copy of operator certification to the Engineer.

New Mexico

Operator certified by Department's Technician Training and Certification Program. Demonstration of ability and written test.

Profiler certified by department. Must have current sticker.

Pennsylvania

Both must be certified by the department.

Texas

Equipment must be certified at the Texas Transportation Institute. Must display current decal. Operator must be on departments approved certified operator list.

Virginia

Department conducts testing.

Minnesota

Equipment must be certified by Concrete Engineering Unit according to procedures on file.

Operator must be "trained"

Calibration Requirements

Kentucky

No statement requiring calibration is made.

Michigan

Reference to MTM 726 and 730

New Mexico

Must calibrate before each use. If cannot be calibrated onsite, must remove equipment from the site until it can be recalibrated and recertified.

Pennsylvania

Must be calibrated. Distance and profile calibration each day.

Texas

Must be calibrated at the Texas Transportation Institute.

Virginia

No mention.

Minnesota

Special provisions.

Who Performs the Testing

Kentucky

The Engineer performs the testing. There is a statement that "The Department will be using the profilograph to test other project. Cooperate in the scheduling of testing as necessary in order that the testing can be performed efficiently on all projects."

Michigan

Contractor performs the run of record. Department performs verification runs. Independent profiler and operator, all certified and selected by the Engineer, performs referee runs.

New Mexico

Contractor performs testing. No mention of verification testing or referee testing.

Pennsylvania

Contractor conducts testing.

Texas

Contractor performs QC testing with straightedge, inertial profiler, profilograph, or other means. Contractor performs QA testing with high speed or lightweight inertial profiler. Engineer performs verification testing. Construction Division of TxDOT conducts referee testing.

Virginia

Department conducts the testing.

Minnesota

Contractor conducts testing in presence of engineer.

Lot Size and Definition, Segment Length

Kentucky

PI is determined for every "1,000 linear feet of full lane width pavement". For sections at the end of a lane that are less than 1,000 feet, they are included in the preceding full 1,000-foot section.

If the PI is less than 6 in/mi, the IRI is predicted based on the profilograph trace in 1-mile sections. Similar to PI, if a section is less than one mile long, it is included in an adjacent section.

Michigan

0.1-mile segments. Less than 0.1-mile segment are adjusted with a weighted average. Ride quality requirements are for total lane length, **and** for each 0.1-mile segment. Report IRI to nearest whole number.

New Mexico

0.1-km or 0.1-mi sections, or fractions thereof. Report IRI to nearest 0.1 in/mi.

Pennsylvania

528 ft., two types of lots, based on posted speed, > or <= to 45 mph.

Texas

0.1-mile sections.

Virginia

0.01-mile (52 feet.) sections.

Minnesota

IRI values to 2 decimal places. (0.00)

0.1-mile sections.

Exclusions

Kentucky

20 feet from any discontinuity such as a bridges. Straightedge requirements still apply.

Michigan

Predetermined – ramps other than freeway-to-freeway ramps, ramp tapers, shoulders, railroad crossings, bridges, loose material sampling areas. Contractor may propose other exclusions. Straightedge requirements still apply.

New Mexico

Shoulders, turnouts, median lanes, other areas less than 0.5 mile. PCCP slab removal and replacement, and intersections not paved integrally with the mainline.

Straightedge requirements apply to these areas – 1/8-in in 10 ft.

At transverse joints, back up 15 ft into previous placement.

Pennsylvania

Bridge decks, ramps less than 1,500 ft long, tapered pavements less than 12 ft wide, partial lots less than 100 feet long.

Texas

Service roads and ramps, short projects (< 2,500 ft), bridges, "leave-out sections", ends, shoulders or other layers.

Virginia

The 0.01-mile before a bridge, and the beginning and end 0.01 mile section. Exclusions must be tested with 10-ft straightedge. 0.25-inch over 10 ft. within 52 ft of manholes, bridge approach slabs, intersections, transition lanes, or less than 45 mph speed.

Minnesota

50 feet adjacent to construction header, bridge approach panels, <42 mph speed, ramps, loops, turn lanes, crossovers, panels adjacent to manholes, etc., intersections constructed under traffic including 100 ft away, undoweled shoulders < 10 ft wide, projects < 1000 ft long. Paving startup and end is not excluded.

¼-inch over 10-ft. straightedge.

Timing of Testing and Data submission

Kentucky

"… as soon as practical, preferably before the Contractor saws the final joint."

Straightedge measurements must be completed "as soon as the concrete has hardened sufficiently to support walking, but not later than 10:00 AM of the day following the placing of the concrete."

Michigan

None specified – when the profile must be measured. But Contractor must submit results to be paid. Must submit results within 3 working days of the measurement.

New Mexico

Traces are maintained by the contractor. IRI values are "submitted in a summarized format consistent with AASHTO PP 50 recommendations to the Project Manager". Must be submitted within 2 working days of data collection. If not, no incentives will be paid.

Pennsylvania

In the presence of the inspector. Must submit data to Representative immediately.

Texas

Within 7 days of receiving authorization for QA testing. Deliver results within 24 hours of testing. Submit all electronic data files.

Virginia

"as soon as practical and prior to opening to public traffic."

Minnesota

Must be submitted same day. If not, then incentives are not paid, but disincentives still apply. Must submit final summary report. Must submit ERD files and other documents. Initial testing must be conducted within 24 hours after sealing joints.

QC/QA Procedures

Kentucky

None specified.

Michigan

Extensive QC/QA requirements. Contractor does main testing. Department does verification testing. For dispute resolution, independent firm does referee testing.

Department conducts verification runs after paving is complete, or a the end of each year's paving season.

Run of record must meet specific limits.

Verification limit – the verification run is done on a randomly selected segment. Its IRI must be below 70+2s, where s is the repeatability standard deviation of the verification profiler.

Within the verification segment, the contractor's IRI must be within 6 in/mi of the verification IRI for the entire segment. Also, for each 0.1-mile segment, the two IRI values must be within 6 in/mi of each other.

If not, try to resolve differences – compare profilers, visually inspect traces, etc. If cannot be resolved, go to dispute resolution.

New Mexico

None specified.

Pennsylvania

None specified.

Texas

Basic QC/QA – contractor does QC and QA testing. Engineer does verification testing, and department does referee testing. If Engineer's IRI is < 3.0 in/mi higher than contractor's, they can decide which one to use, or to request referee testing. If the difference is more than 6.0 in/mi, referee testing is required.

Virginia

None specified.

Minnesota

Third party verification when requested by engineer.

Required Remedial Action

Kentucky

If PI > 10 in/mi, Engineer will suspend paving operations, and Department will require corrective work.

For PI between 6 and 10 in/mi, Contractor can make corrections to achieve a maximum of 6 in/mi, or accept an adjustment to the contract unit price.

Regardless of PI, "remove all areas represented by high points having deviations in excess of 0.3 inch in 25 feet or less"

The Contractor may request retesting, at a cost of $150 per lane mile.

Michigan

Corrective action requirements – Diamond grinding or remove and replace.

Must run initial test to identify areas for correction. Must submit corrective action plan to the engineer. Correct all segments containing areas exceeding the corrective limits prior to the run of record.

Must submit corrective action plan. Must repair areas where IRI > 70 in/mi.

New Mexico

Evaluated in 0.1-mile sections. If IRI falls into "corrective work" column in tables, must submit corrective action plan. If a section is in bonus area of tables, no additional corrective work is allowed for the purpose of increasing incentive payment. If pay factor is between 90% and 100%, the contractor may just accept the penalty.

Areas of localized roughness identified by software – 25-foot moving average. Deviations between moving average and each value of unfiltered data greater than 0.15 in must be corrected. Retest after corrective work. Use new profile for acceptance and payment.

Allowable actions – diamond grinding, remove and replace.

Must conduct corrective action, retest, etc.

Pennsylvania

Must grind – if ¼-inch over 10 feet. Carbide or diamond grinding. Perform corrective action before testing for pavement thickness. May be required to remove and replace.

Retest required.

Texas

Use new profile for acceptance and payment. Use diamond grinding "or other approved methods". Must do corrective action and retest, until engineer is satisfied, or assesses a

localized roughness penalty. Must do corrective action where a straightedge shows 1/8-inch deviation over 10 ft.

Virginia

Submitted for approval. May require extending the area of corrective action to maintain uniform cross-section. Will be retested, but no incentives allowed for sections that required retesting. Contractor has once chance at corrective action. If after that chance, pay factor is less than 70% (IRI < 100.0 in/mi.), then additional penalties are placed.

Minnesota

Extensive section on bumps and dips. Must submit corrective work plan. Diamond grinding.

Required correction plan

Kentucky

"…using methods the Engineer approves."

Michigan

Corrective action plan required prior to doing any corrective action.

New Mexico

Must have methods and procedures approved in writing.

Pennsylvania

None specified.

Texas

None specified.

Virginia

None specified.

Minnesota

Must be approved by engineer.

Pay Adjustment Method

Kentucky

Percent adjustment to unit bid price (JCP Pavement, Square Yard)

Michigan

No incentives or disincentives. Only approval or remove and replace. Corrective work must be done until it is approved, or until it is replaced.

New Mexico

Percentage basis of total thickness or area of PCCP for the actual lane width and roadway length. Based on PCCP pay item unit bid price.

Pennsylvania

Dollars per 0.1-mile segment.

Texas

Dollars per 0.1-mile section. Various tables for different types of construction.

Virginia

Percent of contract unit (pavement) price.

Minnesota

Dollars per 0.1-mile section.

Data Analysis Method

Kentucky

Measure profile with profilograph. Convert to IRI using ASTM E 1926 if PI is less than 6 in/mi.

Michigan

Computer programs referenced by AASHTO PP 37-00.

New Mexico

Approved computer program.

Pennsylvania

Provides requirements of the software in PTM-428.

Texas

Texas has its own software to analyze profiles.

Virginia

None specified.

Minnesota

Computer programs meeting World Bank requirements as described in NCHRP Report 228.

Surface Preparation

Kentucky

"Thoroughly clean the surface of all dirt and other foreign matter immediately before..."

Michigan

"Ensure that the pavement … is sufficiently clean prior to ride quality measurements."

New Mexico

"thoroughly sweep"

Pennsylvania

Clear path of loose material and foreign objects.

Texas

None specified.

Virginia

None specified.

Minnesota

"The Contractor shall remove all objects and foreign material on the pavement surface prior to surface evaluation."

Additional Comments

Kentucky

Incentive based on IRI (only is figured if PI is less than 6 in/mi). Disincentive is based on PI, if greater than 6 in/mi.

Somewhat confusing as to how the adjustment is made. The table is called "Ride Quality Adjustment Schedule for Roads Posted Greater (or less) than 45 MPH" There are no units on the adjustment column. It looks like it could be percentages (+0.03, -0.05, for example).

Michigan

Report values to nearest whole number using ASTM rounding method E 29.
Includes terminology section.
Requires ride quality measurement plan. Includes the following:

1. Equipment used to measure ride quality on the project
2. Method of measurement (IRI or PI)
3. Calibration schedule for the equipment used on the project
4. Length of the Run of Record
5. Proposed project specific excluded areas (see section (d) of this special provision)
6. Traffic control details
7. Method(s) to correct surface irregularities
8. Correction layout method
9. Ride quality testing and verification time frames in relation to paving and staging operations
10. Labeling format for the run of record
11. Predetermined excluded areas that apply to this project
12. Intermediate runs required due to project staging

Chapter 5. SUMMARY AND RECOMMENDATIONS

The following are recommendations for future consideration in the specification for portland cement concrete pavement smoothness incentives. The specification development effort balanced the inclusion of these recommendations with the desires of the Mn/DOT Office of Materials. These remaining items are not included in the recommended specification, but the researchers feel that they should be considered, and incorporated, in some way, into the specification.

1. Conduct a study or at least a literature review of the long-term durability effects on diamond-ground concrete pavement surfaces. Consider allowing "corrective work" sections to be included in incentive computations. Let the contractor decide if "grinding into bonus" is worth the cost. A cursory review indicates that an adverse impact has not been observed.
2. Thickness should be checked after diamond grinding. At least the payment for thickness should be determined after diamond grinding.
3. Clarify how the profiler is certified. Who does the certification?
4. Clarify how the operator is trained. A strong recommendation is to implement a Mn/DOT training and certification course for contractor and Mn/DOT personnel.
5. Include a requirement that the profiler be adjusted, tested, or calibrated according to the manufacturer recommendations prior to use.
6. Reassess the precision of units in the specification. In some cases distances are specified to the nearest 10 cm (0.1609 km), and the associated US Customary unit is to the nearest 528 ft (0.1 mi). This can cause disputes if a contractor would like to press an issue on how accurately a distance is measured. The nearest 0.1 mi could be rounded from a value between 0.05 and 0.14 mi, for example.
7. Define clearly when profiling should be conducted. For example, immediately after sawcutting for joint installation, or simply some time before the final product is accepted and it is opened to traffic.
8. Change the authority to make the decision on the $1500 penalty (Section 2301.3P1b(4) in the recommended specification, Appendix B) to the contractor. The field engineer should not be able to make monetary decisions that affect the contractor. If the agency would like to provide a choice of doing extra work or taking a penalty, it should be the contractor's choice. If the agency would rather force the extra work to be done, then it should not give the possibility of a choice.
9. Clarify that the profiler runs should be as long as possible, and then let the software or the contractor divide it into 0.1-mile segments. Currently, the specification could be interpreted such that each 0.1-mile section is profiled individually. It is more appropriate to measure one long run, and then evaluate it in segments.
10. Clarify the reporting requirements. It is recommended that after each profiling run, the segments be defined, smoothness statistics computed, and corrective work be identified in one summary document. This is currently in the recommended specification. In addition, a decision should be made regarding a final summary of all paving at the end of the paving project. If this is desired, it should be included in the specification. If not, it may be left as is.

11. Evaluate the current incentive/disincentive payment schedule and the three recommended schedules to determine which best represents the intent of the specification and the desires of the department. Consider increasing the maximum bonus for a corresponding decrease in initial IRI.

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Appendix A

2006 IRI Pilot Specification

2301.3P1b Smoothness Requirements

After completion of the initial curing period and prior to the opening of the roadway to traffic, the Contractor shall test all mainline pavement surfaces for smoothness.

2301.3P1b(1) Measurement

Smoothness will be measured with an Inertial Profiler (IP), which produces both an International Roughness Index (IRI) value and a profilogram (profile trace of the surface tested). Bumps and/or dips and magnitude will be based on California Test Method 526. Smoothness will be based on the International Roughness Index (IRI). Unless otherwise authorized by the Engineer, all testing shall be performed in the presence of the Engineer. The Engineer and the Contractor shall mutually agree upon scheduling of testing so that it can be observed. Any testing performed without the Engineer's presence, unless otherwise authorized, may be ordered retested at the Contractor's expense. **Perform initial testing within 24 hours after sealing joints.**

2301.3P1b(2) Smoothness Testing

The Contractor shall furnish a properly calibrated, documented, and Mn/DOT certified IP. The IP shall be equipped with automatic data reduction capabilities for determining IRI values. Computer programs used to calculate the IRI statistic from a longitudinal roadway profile shall follow the procedure developed by the World Bank for a quarter-car simulation as described in NCHRP Report 228.

The IP shall conform to the Class 1 requirements of ASTM E950-94 and must be certified according to the most recent procedure on file in the Concrete Engineering Unit. Certification documentation shall be provided to the Engineer on the first day the IP is used on the project. User selected profilograph and IP settings are on file in the Concrete Engineering Unit. The Contractor shall furnish a competent operator, trained in the operation of the IP and evaluation of both California Test Method 526 and IRI.

The Contractor shall remove all objects and foreign material on the pavement surface prior to surface evaluation.

For pavement evaluation, one pass shall be made in the right wheel path of each lane of the mainline pavement. The IP shall be run in the direction the traffic will be moving. Each lane shall be tested and evaluated separately. The Engineer shall determine the length in kilometers [**miles**] for each mainline traffic lane. The IP shall be operated at the optimum speed as defined by the manufacturer.

Make runs continuous and stop approximately 30 m [**100 feet**] prior to a construction header. Evaluate construction headers for smoothness on the next subsequent pass. Evaluate for smoothness all terminal headers that tie into the existing portland cement concrete pavement approximately 15 m [**50 feet**] adjacent to the terminal header. Bridge approach panels and

bridge surfaces are exempt from these requirements; however, paving start-up areas are not exempt.

An IRI value shall be calculated for each section of the final pavement surface. The IRI values shall be reported in units of m per km **[inches per mile]**. Both m per km and inches per mile shall be reported with two digits right of the decimal. Follow Mn/DOT rounding procedures per the Concrete Manual section 5-694.002.

The Contractor shall submit the graphical trace, a summary of the bump(s)/dip(s) locations, the magnitude of the bump(s)/dip(s) and each section IRI value with the signature of the Operator to the Engineer on the same day as the profiling was conducted. **If the actual data is not submitted by the Contractor to the Engineer on the same day as the profiling was conducted, the Department shall not pay incentives for those sections but the disincentives shall still apply.**

The pavement surface will be divided into sections that represent continuous placement. In the final pavement evaluation, construction headers will be included in the trace with no special consideration. Each lane will be separated into sections of 0.1609 km **[0.1 mile]**. Remaining subsections shorter than 0.1609 km [**0.1 mile**] are prorated for equivalency in smoothness. If a paving project doesn't connect into an existing pavement section, the Engineer has the authority to check the last 15.24m **[50 ft]** in length at the end of pavement section longitudinally with a 3.028 m **[10 ft]** straight edge. The surface should not deviate from a straight line by more than 6 mm in 3.028 m **[1/4 inch in 10 ft]**.

2301.3P1b(3) Smoothness Incentive/Disincentive

Incentive/disincentive payments will be based on the IRI determined for each section and will be based on the following equations:

Table 2301-P1

2301.3P1b (3) International Roughness Index (IRI)		
IRI m/km [inches/mile]	**Incentive/Disincentive $ per 0.1609 km section (Lane width may vary)**	**Incentive/Disincentive $ per 0.1 mile section (Lane width may vary)**
0.00 - 0.79 [0.00 – 50.00]	$890.00	$890.00
0.80 – 1.42 [50.01 – 90.00]	-2597.8*(IRI) + 2940 [1]	-41*(IRI) + 2940 [1]
>1.42 [>90.00]	Corrective Action**	Corrective Action**
**** Remove and Replace or Texture Plane to a IRI of 1.18 m/km [75.00 inches/mile] or less**		

[1] Since this is a pilot project, the disincentive for sections with an IRI values greater than 1.13 m/km **[71.7 inches/mile]**will be 75% of the calculated disincentive for those sections.

Texture planed areas of sections are not eligible for incentive bonuses.

2301.3P1b(4) Bump and Dip Requirements

Bumps and dips in the longitudinal direction will be determined in accordance with California Test Method 526. Bumps and dips in the transverse direction will be determined using a 0.9144 m [**3 foot**] straight edge. Bumps greater than 7.62 mm in a 7.62 m **[0.3 inch in a 25 foot]** span in the longitudinal direction or 7.62 mm in a 0.9144 m **[0.3 inch in a 3 foot]** span in the transverse direction shall be identified separately. Dips greater than 12.7 mm in a 7.62 m **[0.5 inch in a 25 foot]** span in the longitudinal direction or 12.7 mm in a 0.9144 m **[0.5 inch in a 3 foot]** span in the transverse direction shall be identified separately. When the profile trace shows a successive, uninterrupted bump, dip, or dip, bump combination (up to a maximum of 3 alternating trace deviations that relate to one bump or dip on the roadway), identify and evaluate these occurrences as one event. These combinations of deviations shall be counted only once for the purposes of calculating price deductions. One event is confined to a 9.144 m **[30 feet]** longitudinal section.

Bump Requirements

Bumps between 7.62 mm and 10.16 mm [**0.3 inches and 0.4 inches**] may remain in place without correction or penalty if the ride is satisfactory in the judgment of the Engineer. All bumps greater than 10.16 mm **[0.4 inches]** in the longitudinal or transverse direction shall be corrected. Corrected bumps will be considered satisfactory when the profilogram shows the deviations are less than or equal to 7.62 mm in a 7.62 m **[0.3 inch in a 25 foot]** span in the longitudinal direction or 7.62 mm in a 0.9144 m **[0.3 inch in a 3 foot]** span in the transverse direction.

Dip Requirements

Dips greater than 12.7 mm [**0.5 inch**] shall be corrected by removal and replacement of the pavement or by texture planing. Corrected dips will be considered satisfactory when the profilogram shows the deviations are less than or equal to 12.7 mm in a 7.62 m **[0.5 inch in a 25 foot]** span in the longitudinal direction or 12.7 mm in a 0.9144 m **[0.5 inch in a 3 foot]** span in the transverse direction**.** If the Engineer does not order corrective work for dips greater than 12.7 mm **[0.5 inch]** in the longitudinal or transverse direction the Contractor is assessed a $1500 penalty for each uncorrected dip. If dips exceed 25 mm **[1 inch]** in the longitudinal or transverse direction, the Contractor shall remove and replace the pavement represented by the dip.

2301.3P1b(5) Exceptions

The following Table 2301-P2 shows pavement surfaces that are excluded from 2301.3P1b(3) Smoothness Incentive/Disincentives. **However, modified bump and dip requirements still apply to Table 2301-P2. 2301.3P1b(4) Bump Requirements have been modified as shown below. 2301.3P1b(4) Dip Requirements shall apply. All other requirements in 2301.3P1 shall apply.**

Table 2301-P2

Portions of a paving project where the posted vehicle speed is anticipated to be less than 68 km/hr [**42 miles per hour**]
Bridge decks and approach panels (The occurrence of bridges shall not interrupt the continuity determination)
Ramps, loops, turn lanes, and crossovers
1 concrete panel on either side of obstructions such as manholes, water supply castings, etc.
Intersections Constructed under traffic – Begin and end exclusion 30.5 m **[100 feet]** from the intersection radius
Headers adjacent to colored concrete
Undoweled shoulders < 3 m **[10 ft] wide**
Projects less than 300 m **[1000 ft]** in length

Bumps greater than 12.7 mm in a 7.62 m **[0.5 inch in a 25 foot]** span in the longitudinal direction or 12.7 mm in a 0.9144 m **[0.5 inch in a 3 foot]** span in the transverse direction shall be identified separately.

Bumps greater than 12.7 mm [**0.5 inch**] shall be corrected by removal and replacement of the pavement or by texture planing. If the Engineer does not order corrective work for bumps greater than 12.7 mm in a 7.62 m [**0.5 inches in a 25 foot**] span in the longitudinal direction or 12.7 mm in a 0.9144 m **[0.5 inch in a 3 foot]** span in the transverse direction, the Contractor is assessed a $1500 penalty for each bump in each traffic lane.

2301.3P1c Blank

2301.3P1d Final Summary Report

The Contractor shall submit a **final** spreadsheet summary of the smoothness data to the Engineer within 5 calendar days after all mainline pavement placement prior to the commencement of corrective work, if any. The Contractor shall sign the summary report. The spreadsheet summary shall be in tabular form, with each 0.1609 km **[0.1 mile]** section occupying a row.

Each row shall include the following:

(1) The beginning and ending station for the section,
(2) The length of the section,
(3) The final IRI value for the section,
(4) The IRI based incentive/disincentive in dollars for the section, and
(5) The deductions for bumps/dips in dollars for the section.

Each continuous run will occupy a separate table and each table will have a header that includes the following:

(1) The project number,
(2) The roadway number or designation,
(3) A lane designation,

(4) The date of the final smoothness runs, and
(5) The beginning and ending station of the continuous run.

The following information shall be included at the bottom of each summary:
(1) A subtotal for the IRI based incentive/disincentive,
(2) A subtotal for the bump/dips deductions, and
(3) A total for incentive/disincentive for both IRI values and bumps/dips.

Software to summarize the data is available from the Mn/DOT Concrete Engineering Unit at www.mrr.dot.state.mn.us/pavement/concrete/concrete.asp. The Contractor shall also submit computer files in ERD format that represent the raw data from the each run.

The Contractor will be responsible for all traffic control associated with the testing and any corrective action (when applicable) that is required of the final pavement surface.

2301.3P1e Retesting

The Engineer may require any portion or the total project to be retested if the results are questioned. This includes both IRI values and bump/dip locations. The Engineer will decide whether Mn/DOT, an independent testing firm (ITF), or the Contractor will retest the roadway surface.

If the retested IRI values differ by more than 10% from the original IRI values, the retested values will be used as the basis for acceptance and any incentive/disincentive payments. In addition, bump/dip locations as shown by the retest will replace the original results.

If the Engineer directs the Contractor or an independent testing firm to perform retesting and the original results are found to be accurate, the Department will pay the Contractor or the independent testing firm $62.14 per lane km [$100 per lane mile] that is retested, with a minimum charge of $500.00. The Contractor will be responsible for any costs associated with retesting if the original values differ by more than 10% from the retested values.

2301.3P1f Corrective Work

The Contractor shall notify the Engineer prior to commencement of the corrective work. If corrective work is required, the Contractor shall submit a written corrective work proposal to the Engineer, which shall include the locations that will be texture planed. The Contractor shall not commence corrective work until the methods and procedures have been approved in writing by the Engineer. Unless otherwise approved by the Engineer, corrective work shall be by using an approved surface texture planing device consisting of multiple diamond blades. Pavement cross slope shall be maintained through corrective areas.

After the Contractor has completed the corrective work, the corrective area shall be re-measured within **48 hours** of completion of texture planing to verify compliance with specification requirements. All corrective action, including all necessary traffic control, shall be completed at no additional cost to the Department.

If permanent pavement marking are damaged or destroyed during surface correction activities, they will be replaced at no cost to the Department.

Joint sealant that has been damaged by texture planing on concrete pavement as determined by the Engineer shall be repaired and replaced at no expense to the Department.

Corrective work by texture planing may result in thin pavement sections. The Engineer shall determine if this condition needs to be verified by coring. Additional coring for thickness verification shall be at no cost to the Department.

All corrective work shall be subject to the approval of the Engineer. Within 5 calendar days after all required corrective work is completed a final section(s) IRI value and bump/dip tabulation shall be determined and submitted to the Engineer. Corrective work and re-evaluation shall be at the Contractor's expense.

2301.3P1g Payment

At no cost to the Agency, the Contractor shall remove all bumps and dips per 2301.3P1b(4) or 2301.3P1b(5), surface test and provide necessary additional corrective work to achieve the required smoothness.

All costs relative to Contractor providing the IP and the appropriate test results are included in the unit bid price for 2301.502, Concrete Pavement, Standard Width and Item 2301.503, Concrete Pavement, Irregular Widt

Appendix B

Recommended IRI Specification for PCC Pavements

2301.3P1b Pavement Smoothness – International Roughness Index

Pavement smoothness will be evaluated on the mainline and all other pavement surfaces, subject to the exclusions provided in Table 2301-P1. Incentives and disincentives will be computed using the International Roughness Index (IRI).

2301.3P1b(1) Equipment

Pavement smoothness shall be measured on the finished surface using an inertial profiler (IP) which conforms to the requirements for Class I profilers in the latest revision of ASTM E 950, and evaluated using the International Roughness Index as defined by the quarter-car simulation, described in NCHRP Report 228. The definition of bumps and/or dips will be based on California Test Method 526.

The contractor shall furnish a properly calibrated and documented IP which has been certified according to the most recent procedure on file in the Mn/DOT Concrete Engineering Unit. The IP shall be equipped with automatic data reduction capabilities for determining IRI values. Certification documentation shall be provided to the Engineer on the first day the IP is used on the project. User-selected IP operational and IRI computational settings for inertial profilers that have been previously certified are on file with the Concrete Engineering Unit.

2301.3P1b(2) Testing

Smoothness testing shall be conducted within 24 hours after sealing joints, and before opening to traffic. Unless otherwise authorized by the Engineer, all testing shall be performed in the presence of the Engineer. The Engineer and Contractor shall mutually agree upon scheduling of testing so that it can be observed. Any testing performed without the Engineer's presence, unless otherwise authorized, may be ordered retested at the Contractor's expense.

The Contractor shall furnish a competent operator, trained in the operation of the IP and in evaluation of both California Test Method 526 and in computation of IRI.

The Contractor shall remove all objects and foreign material on the pavement surface prior to surface profile measurement. All manufacturer requirements and recommendations for proper operation of the IP shall be followed by the Operator, including operational validation prior to each use and periodic maintenance, recalibration, and recertification.

Profile measurement shall consist of one pass made in the right wheel path of each lane of the mainline pavement (three feet from the edge of the lane) in the direction traffic will be moving. Each lane shall be tested and evaluated separately. The IP shall be operated at the proper testing speed as recommended by the manufacturer. The Engineer will determine the length of each mainline traffic lane.

Each run shall be made continuously, regardless of length, but shall not begin or end within 30 m [100 ft] of any construction headers. Subsequent runs shall begin at the same location as the end of the previous run. Terminal headers that tie into existing portland cement concrete pavement shall be evaluated, and smoothness measurements shall begin approximately 7.62 m [25 ft] before and end 7.62 m [25 ft] after terminal headers.

Exclusions from smoothness measurement are listed in Table 2301-P1, but any exclusions are still subject to the bump and dip requirements in Section 2301.3P1b(4).

Table 2301-P1 Pavement Smoothness Measurement Exclusions

Portions of a paving project where the posted vehicle speed is anticipated to be less than or equal to 70 km/hr [45 mph]
Bridge decks and approach panels, although the occurrence of bridges shall not interrupt the continuity determination
Ramps, loops, turn lanes, and crossovers
One concrete panel on either side of obstructions such as manholes, water supply castings, etc.
Intersections constructed under traffic – begin and end exclusion 30.5 m [100 feet] from the intersection radius
Headers adjacent to colored concrete
Undoweled shoulders less than 3 m [10 ft] wide
Projects less than 300 m [1000 ft] in length

The measured pavement surface profile will be divided into sections that represent continuous placement. Construction and terminal headers shall be included in the profile trace without special consideration. Each run will be separated into sections 0.1609 km [0.1 mi] in length. Final sections in a run that are less than 0.1609 km [0.1 mi] but that are longer than 7.62 m [25 ft] shall be evaluated as an independent section, but incentives/disincentives will be prorated for length. Segments 7.62 m [25 ft] long or less, and the first and last 7.62 m [25 ft] of projects that do not connect to an existing section may be evaluated by the Engineer using a 3.028-m [10-ft] straightedge. The vertical deviations from the surface using the straightedge shall not be greater than 6 mm in 3.028 m [1/4 inch in 10 ft].

The IRI value of each section shall be calculated and reported in units of m/km [in/mi] and shall be rounded to two digits to the right of the decimal, according to Mn/DOT rounding procedures in the Concrete Manual, Section 5-694.002.

On the same day the profiling is conducted, the Contractor shall submit the graphical trace, a summary of bump and dip locations and magnitudes (according to California Test Method 526), each segment's IRI value, with the signature of the Operator, to the Engineer. If this information is not submitted to the Engineer on the same day the profiling was conducted, the Department will not pay incentives for those sections, but disincentives will still apply.

Within 5 calendar days after the profiling is conducted, but before any corrective work is commenced, the Contractor shall submit a signed, spreadsheet summary of the smoothness data to the Engineer. The spreadsheet summary shall be in tabular form, with each 0.1609-km [0.1-mi] section occupying a row.

Each row shall include the following:

(1) The beginning and ending station for the section,

(2) The length of the section,
(3) The final IRI value for the section,
(4) The IRI based incentive/disincentive in dollars for the section, and
(5) The deductions for bumps/dips in dollars for the section.

Each continuous run will occupy a separate table and each table will have a header that includes the following:

(1) The project number,
(2) The roadway number or designation,
(3) A lane designation,
(4) The date of the final smoothness runs, and
(5) The beginning and ending station of the continuous run.

The following information shall be included at the bottom of each summary:

(1) A subtotal for the IRI based incentive/disincentive,
(2) A subtotal for the bump/dips deductions, and
(3) A total for incentive/disincentive for both IRI values and bumps/dips.

Software to summarize the data is available from the Mn/DOT Concrete Engineering Unit at www.mrr.dot.state.mn.us/pavement/concrete/concrete.asp. The Contractor shall submit computer files in ERD format that represent the raw data from the each run.

2301.3P1b(3) Incentive / Disincentive

Incentive payments and disincentive penalties will be applied to each section, based on the IRI value and the schedule shown in Table 2301-P2. Incentives and disincentives for short sections will be prorated based on the proportion, by length, of a full 0.1609-km [0.1-mi] section.

Table 2301-P2 IRI Incentive/Disincentive Calculation

IRI m/km [in/mi]	Incentive/Disincentive $ per 0.1609 km section (Lane width may vary)	Incentive/Disincentive $ per 0.1 mi section (Lane width may vary)
0.00 - 0.79 [0.00 – 50.00]	$890.00	$890.00
0.80 – 1.42 [50.01 – 90.00]	-$2597.8*(IRI) + $2940	-$41*(IRI) + $2940
> 1.42 [>90.00]	Corrective Action[1]	Corrective Action[1]

[1]Remove and Replace, or Texture Plane to an IRI of 1.18 m/km [75.00 in/mi] or less

2301.3P1b(4) Bump and Dip Requirements

Bumps and dips in the longitudinal direction shall be determined according to California Test Method 526. Bumps and dips in the transverse direction will be determined using a 0.9144-m [3-ft] straightedge. The location of transverse evaluation of bumps and dips will be at the discretion of the Engineer.

Bumps greater than 7.62 mm [0.3 in] vertical deviation in a 7.62-m [25-ft] span in the longitudinal direction or a 0.9144-m [3-ft] span in the transverse direction shall be identified separately. Dips greater than 12.7 mm [0.5 in] in a 7.62-m [25-ft] span in the longitudinal direction or a 0.9144-m [3-ft] span in the transverse direction shall be identified separately. When a profile trace shows a successive, uninterrupted bump-dip or dip-bump combination (up to a maximum of three alternating deviations), these occurrences will be identified and evaluated as one event. These combinations will be counted only once for the purposes of calculating payment deductions. One event is limited to a 9.144-m [30-ft] longitudinal section. However, bumps greater than 12.7 mm in a 7.62-m [0.5 inch in a 25-ft] span in the longitudinal direction or 12.7 mm in a 0.9144-m [0.5 inch in a 3-ft] span in the transverse direction shall be identified separately.

Bumps

Bumps between 7.62 mm [0.3 in] and 10.16 mm [0.4 in] may remain in place without correction or penalty if the ride is satisfactory in the judgment of the Engineer. Any bump greater than 10.2 mm [0.4 in] vertical deviation in the longitudinal or transverse direction shall be corrected by removal and replacement of the affected area, or by texture planing, at the Contractor's expense. However, if the Engineer does not order corrective work for bumps greater than 7.62 mm in a 7.62-m [0.5 inch in a 25-ft] span in the longitudinal direction or 12.7 mm in a 0.9144-m [0.5 inch in a 3-ft] span in the transverse direction, the Contractor shall be assessed a $1500 penalty for each bump in each traffic lane.

Corrected bumps will be considered satisfactory when the profile trace shows the deviations are within 7.62 mm [0.3 in] vertical deviation in a 7.62-m [25-ft] span in the longitudinal direction or 0.9144-m [3-ft] span in the transverse direction.

Dips

Dips greater than 12.7 mm [0.5 in] and less than 25 mm [1 in] shall be corrected by removal and replacement of the affected area, or by texture planing, at the Contractor's expense. Corrected dips will be considered satisfactory when the profile trace shows the deviations are within the tolerances specified in this section. Dips greater than 25 mm [1 in] in the longitudinal or transverse direction shall be removed and replaced at the Contractor's expense, so that the profile trace shows that the area of the dip is within 12.7 mm [0.5 in] in a 7.62-m [25-ft] span in the longitudinal direction or a 0.9144-m [3-ft] span in the transverse direction.

2301.3P1b(5) Corrective Work

If corrective work is required, the Contractor shall submit a written corrective work proposal to the Engineer, which shall include the locations that will be texture planed. The Contractor shall complete all corrective work before submitting the Final Summary Report to the Engineer, but shall not commence corrective work until the methods and procedures have been approved in writing by the Engineer. The Contractor shall notify the Engineer prior to commencement of the corrective work. Unless otherwise approved by the Engineer, corrective work shall be by using an approved surface texture planing device consisting of multiple diamond blades. Pavement cross slope shall be maintained through corrective areas.

Within 48 hours after completing the corrective work, the Contractor shall re-measure the affected sections to verify compliance with specification requirements. All corrective action, including any necessary traffic control, shall be completed at no additional cost to the Department.

If permanent pavement marking are damaged or destroyed during surface correction activities as determined by the Engineer, they will be replaced at no cost to the Department.

Joint sealant that has been damaged by texture planing on concrete pavement as determined by the Engineer shall be repaired and replaced at no expense to the Department.

Corrective work by texture planing may result in thin pavement sections. The Engineer shall determine if this condition needs to be verified by coring. Additional coring for thickness verification shall be at no cost to the Department.

All corrective work shall be subject to the approval of the Engineer. Within 5 calendar days after all required corrective work is completed, final profiling, IRI computation and bump/dip tabulation shall be determined and submitted to the Engineer. All corrective work, retesting, and re-evaluation shall be at the Contractor's expense.

2301.3P1b(6) Retesting

The Engineer may require any portion or the entire project to be retested if the results are questioned. This includes both IRI values and bump/dip locations. The Engineer will decide whether Mn/DOT, an independent testing firm, or the Contractor will retest the roadway surface.

If the retested IRI values differ by more than 10% from the original values, the retested values will be used as the basis for acceptance and any incentive/disincentive payments. In addition, bump/dip locations as shown by the retest will replace the original results.

If the Engineer directs the Contractor or an independent testing firm to perform retesting and the original results are found to be accurate, the Department will pay the Contractor or the independent testing firm $62.14 per lane km [$100 per lane mi] that is retested, with a minimum of $500.00. If the retested IRI values differ by more than 10% from the original values, the Contractor will be responsible for any costs associated with retesting.

2301.3P1b(7) Payment

All pavement surface profile measurement and IRI calculations will be considered incidental to Items 2301.501, Concrete Pavement, 2301.502, Concrete Pavement, Standard Width and 2301.503, Concrete Pavement, Irregular Width. At no cost to the Agency, the Contractor shall remove all bumps and dips per section 2301.3P1b(4), conduct additional surface tests, and provide necessary additional corrective work to achieve the required smoothness.

Appendix C.

State IRI Specifications for PCC Pavements

G) Temporary Seals. When using temporary seals, firmly embed them in the joint. Place the material 1/4 inch below the pavement surface. Provide a material that is sufficiently strong and durable to resist intrusion of incompressible materials, and to allow complete removal after its usefulness has ended.

501.03.19 Surface Tolerances and Testing Surface.

A) Edge Slump. Prevent and correct the slumping of the pavement, base, or shoulder edges. Ensure that edge slump does not exceed 1/8 inch when the Plans indicate the edge of the pavement, base, or shoulder being constructed is to be abutted by subsequently constructed pavement, base, or shoulders, either by this Contract or future contracts. Ensure that edge slump does not exceed 1/4 inch where the edge is not to be abutted by subsequent pavement, base, or shoulder. Measure the edge slump with a straightedge laid on the pavement, base, or shoulder perpendicular to the edge.

Use a planing device or a device consisting of multiple saws to perform corrective work. Use rotary grinders only on isolated irregularities less than 50 square feet. Prohibit the use of bush hammers or other impact devices. Texture all areas of the concrete corrected by grinding in the same manner as the undisturbed pavement, base, or shoulder. When the specified texture is the transverse grooves, texture the ground areas by sawing the transverse grooves. Provide a final surface comparable to the adjacent pavement that does not require corrective work for texture, appearance, or skid resistance. Complete all corrective work within a section before the Department checks the thickness tolerance of that section. The Department will allow corrective work by diamond grinding according to Subsection 503.03.

B) Ride Quality. When the Contract specifies that ride quality requirements apply, the Department will determine the ride quality of the pavement as in terms of a PI and IRI.

1) PI. The Engineer will test pavement surface with the profilograph as soon as practical, preferably before the Contractor saws the final joint. The Department will be using the profilograph to test other projects. Cooperate in the scheduling of testing as necessary in order that the testing can be performed efficiently on all projects.

When the pavement is 12 feet wide or less, the Department will take pavement profiles 3 feet from each edge and parallel thereto. When the pavement is placed wider than 12 feet, the Department will take profiles 3 feet from and parallel to each edge and at the approximate location of each planned longitudinal joint. The Engineer will exclude from testing all pavement within 20 feet of any discontinuity in the pavement such as bridges. However, the Engineer will require these excluded areas to meet the 1/8-inch longitudinal tolerance with a 10-foot straightedge.

The Engineer will determine an average PI for each section. The Department will consider a PI section to be 1,000 linear feet of full lane width pavement. When a test section at the end of a lane is less than 1,000 feet, the Department will include it in the preceding 1,000-foot test section. When an average PI of 10 inches per mile is exceeded in any section the Engineer will suspend the paving operation and will not allow paving to resume until the corrective action is taken. Regardless of the PI, remove all areas represented by high points having deviations in excess of 0.3 inch in 25 feet or less using methods the Engineer approves. The Engineer will determine deviations in excess of 0.3 inch from the profilograph.

When the section's average PI is between 6 and 10 inches per mile, correct pavement deviations to achieve a ride quality of a maximum PI

of 6 inches or accept an adjustment to the contract unit price. For sections with an average PI of 10 inches or greater per mile, the Department will require corrective work.

2) IRI. The Department will test the ride quality of the pavement for incentive payments when the PI is 6 or less and the Contractor either makes a request at least 2 weeks in advance or completes all main line paving.

The Department will determine the IRI by applying a linear transform, determined by correlation, to the values (average of 2 wheel paths) determined by ASTM E 1926. Thoroughly clean the surface of all dirt and other foreign matter immediately before the Department performs the testing.

The Department will divide and test each traffic lane using one-mile test sections starting at the beginning of the lane and proceeding in the direction of traffic. The Department will exclude discontinuities, such as a bridge, from the measurement. When a test section adjacent to a discontinuity or at the end of a lane is less than one mile long, the Department will include that section with the adjacent section. When requested, the Department will retest the pavement after any corrective work is completed. The Department will create a strip chart showing the elevation and distance traveled upon request.

When the Contract does not specify that ride quality requirements apply, straightedge the pavement or shoulder in the presence of the Engineer. Place a 10-foot straightedge parallel to the centerline to bridge all depressions and touch all high spots. Perform straight edging as soon as the concrete has hardened sufficiently to support walking, but not later than 10:00 AM of the day following the placing of the concrete. Plainly mark all high spots, indicated by a variation exceeding 1/8 inch from the straightedge, that are 6 inches or more from the pavement, base, or shoulder edge.

501.03.20 Opening to Public Traffic. Open the pavement, base, or shoulders to traffic anytime 3,000-psi strength is attained, except when curing with wet burlap. When curing with wet burlap, wait at least 72 hours before opening the pavement to traffic. If 3,000 psi is not attained within 28 days, the Department may allow opening according to KM 64-314.

Complete the construction of shoulders and thoroughly clean the pavement, base, or shoulders and seal all joints, as required, before opening the pavement to traffic other than construction equipment.

Prior to opening the pavement to traffic, other than the construction equipment, complete the construction of shoulders in a satisfactory manner.

When operating any equipment entirely or partially on the pavement, provide means to protect the pavement from damage regardless of its age. Either provide the equipment with rubber-tired wheels or operate the equipment over protective mats designed and constructed to prevent damage to the pavement surface and joints. Use mats consisting of wooden strips having a nominal thickness of 2 inches and a width of at least that of the treads. The Engineer may allow mats made of other suitable material. Sweep the pavement surface free of debris prior to placing the protective matting.

Construct a ramp of compacted earth, or other material of sufficient strength, to prevent undue stress in the pavement slab from equipment moving on and off the pavement.

Open residential entrances to traffic, on which only automobile traffic is expected, only at the end of the 72-hour curing period, or at an attained strength of 3,000 psi. Clean the pavement and seal all joints before opening the residential entrances to traffic.

501.03.21 Tolerance in Pavement Thickness. The Engineer will determine the thickness of the pavement and concrete shoulders according to KM 64-309. The Engineer

will evaluate areas of the pavement and shoulders found deficient in thickness by more than one inch. When the Engineer deems the areas warrant removal, remove and replace the areas with concrete of the thickness specified in the Plans.

501.04 MEASUREMENT.

501.04.01 JPC Pavement. The Department will measure the quantity in square yards according to the Plan dimensions as shown in the Record Plans. The Department will determine the final quantity based on the design quantity with increases or decreases by authorized adjustments. Authorized adjustments include changes in the Record Plan dimensions, additional areas not shown in the Record Plans, and errors and omissions in the design quantity in excess of one percent.

The Department will not measure reinforcing steel, load transfer assemblies, dowels, joint construction (including removal of concrete to accommodate a construction joint bulkhead), joint sealing, joint repair, form pins, texturing, additional work for drilling holes for form pins, texturing areas of the pavement that have been corrected by grinding, fly ash, Type IP cement, Type III cement, additional Type I cement for high early strength, formed rumbles strips, and all other items necessary to construct the pavement according to the Contract for payment and will consider them incidental to this item of work.

501.04.02 PCC Base. The Department will measure the quantity in square yards according to Subsection 501.04.01.

501.04.03 JPC Shoulders. The Department will measure the quantity in square yards according to Subsection 501.04.01. The Department will not measure rumble strips for payment, unless they are constructed in a separate operation because the shoulder was used to maintain traffic, and will consider them incidental to this item of work.

501.04.04 Rumble Strips, Type 3. The Department will measure the quantity in linear feet. The Department will not measure Type 3 rumble strips for payment unless they are constructed in a separate operation because the shoulder was used to maintain traffic.

501.04.05 Diamond Grinding. When listed as a bid item, the Department will measure the quantity according to Subsection 503.04. The Department will not measure diamond grinding for payment when it is performed at the Contractor's option or for corrective work and will consider it incidental to JPC Pavement.

501.04.06 Thickness. The Department will measure the pavement thickness tolerance in inches by coring according to KM 64-309. The Department will not measure the pavement thickness tolerance as a separate pay unit, but will use the pavement thickness tolerance to calculate an adjusted Contract unit price for JPC Pavement, PCC Base, or JPC Shoulders.

501.04.07 Ride Quality. The Department will not measure the PI or RI as a separate pay unit, but will use the RI or PI to calculate a ride quality adjustment for JPC Pavement. When the Contract specifies that the Department will measure the ride quality, the Department will use the RI for incentive payments and, if none, will use the PI for acceptance and disincentive payments.

501.05 PAYMENT. Department will make payment for the completed and accepted quantities under the following:

501.05.01 Thickness. The Department will adjust the Contract unit price for JPC Pavement, PCC Base, and JPC Shoulders by the Schedule for Adjusted Payment for Thickness Deficiency. The adjusted quantity is equal to the area of JPC Pavement, PCC Base, or JPC Shoulder specified in the Kentucky Method, multiplied by the Contract unit

price for the item and the Price Adjustment. The Department will not make additional payment for average thicknesses of pavement, base, or shoulders in excess of the specified thickness.

501.05.02 Ride Quality. The Department will apply a Ride Quality Adjustment for each section tested. The Department will calculate the Ride Quality Adjustments by multiplying JPC Pavement payment for each test section by its appropriate ride quality Pay Value found in the Ride Quality Adjustment Schedule.

Code	Pay Item	Pay Unit
2069-2071, 2073, 2075, 2084, 2086, 2088	JPC Pavement Non-Reinforced, thickness	Square Yard
2072, 2077, 2078, 2081-2083, 2087, 2089	JPC Pavement Non-Reinforced Shoulder, thickness	Square Yard
2061, 2064, 2065	PCC Base, thickness	Square Yard
2695	Rumble Strips, Type 3	Linear Foot
----	Rideability Testing	Each
2060	JPC Pavement Diamond Grinding	See Subsection 503.05

Schedule for Adjusted Payment for Thickness Deficiency

Thickness Deficiency (inches)	Price Adjustment (Percent of Contract Unit Bid Price)
0.00 to 0.20	100
0.21 to 0.30	80
0.31 to 0.40	72
0.41 to 0.50	68
0.51 to 0.75	57
0.76 to 1.00	50
Greater than 1.00	[1]

[1] *Remove and replace these areas with concrete of the specified thickness at no expense to the Department when the Engineer directs.*

RIDE QUALITY ADJUSTMENT SCHEDULE FOR ROADS POSTED GREATER THAN 45 MPH

IRI	**Pay Value[1]**
53 or lower	+0.03
54 to 56	+0.02
57 to 60	+0.01

Average for PI (inches per mile)[2]	**Pay Value**
6 or lower	0.00
over 6, up to 7	-0.02
over 7, up to 8	-0.05
over 8, up to 10	-0.08
over 10	Corrective work required

RIDE QUALITY ADJUSTMENT SCHEDULE FOR ROADS POSTED 45 MPH OR LESS

IRI	**Pay Value**[(1)]
56 or lower	+0.03
57 to 60	+0.02
61 to 64	+0.01

Average for PI (inches per mile)[(2)]	**Pay Value**
8 or less	0.00
over 8, up to 10	-0.02
over 10, up to 12	-0.05
over 12	Corrective work required

(1) *Contractor may correct areas to achieve a positive adjustment. The Department will perform additional requested testing and retesting for corrective work at a cost of $150.00 per lane mile. The Department will deduct charges for requested additional testing and retesting for corrective work from monies due on the Contract.*

(2) *The Department will apply the unit bid price adjustment to the total area of the 1,000-foot section of the traffic lane represented by the Profile Index. The Department will not make payment in excess of 50 percent for any main line pavement that has an average Profile Index in excess of 10 inches per mile (12 inches per mile for 45 MPH or less) until the Contractor completes the corrective work and the Department reprofiles and verifies that the average Profile Index has been reduced to 10 inches per mile or less (12 inches per mile for 45 MPH or less)*

The Department will consider payment as full compensation for all work required under this section.

General Information for Quality Control Testing to Meet Special Provisions Section 535 - Pavement Surface Profile

The following topics are covered in this document:

- Standardization Test Site Locations
- Setting-Up Test Sections on a Project
- Submitting Quality Control Data to Maryland State Highway Administration - Office of Materials and Technology (SHA-OMT)
- RideTool Pay Adjustment Program

STANDARDIZATION TEST SITE LOCATIONS:

The following two test sites each 0.2 miles in length are signed for use as Standardization Test Sites:

Baltimore County: IS-70 between IS-695 (Baltimore Beltway) and the Park and Ride at the east end of IS-70. Test section signs are posted in the Eastbound and Westbound directions along the median.

Allegany County: MD 144 (Old National Pike) east of Flintstone Elementary School. Off of IS-68 at exit #56 to MD 144 - National Pike : Flintstone. Test section signs are posted in the Eastbound direction.

Talbot County: MD 662 (Centreville Road) between Airport Road and Forest Street. Off of US 50 near the Easton Airport. Test section signs are posted in the Northbound direction.

SETTING-UP TEST SECTIONS ON A PROJECT - GUIDELINES:

1. When ready to profile a project, begin at the limit of paving, measure 50 ft in the direction of travel and mark the start of profiling. From the start of profiling, mark off 1/10 mile (528 ft) sections until you reach the other limit of profiling on the project (50 ft before the limit of paving). The sections should be marked out at regular 528 ft intervals, continue measuring and marking on bridge decks or other areas that will not be held to the ride quality specifications. Repeat this process for the other direction of travel on the project. Note that the section breaks may be at different locations for each direction of travel. The last section on the project in each direction of travel is the only section that might be a partial section, shorter than 528 ft, at this point. For dual lane or wider roadways mark the sections across all lanes in the same direction.

2. After completing marking 1/10 mile (528 ft) sections, mark off for bridges and structures, 50 ft on either side of each structure. Marking off these bridge areas may result in additional partial sections that are less the 528 ft long. Next determine if the partial sections, at bridges and profiling limits, that are left should stand alone or be added to an adjacent section. When the partial section is less than 159 ft long, add that partial section to the adjacent complete 528 ft section and report the PRI/IRI value

for the entire extended section length. When the partial section is 159 ft long or longer, designate that section as a separate stand alone section and report the PRI/IRI value for the reduced section length.

3. During the paving operation, when the paving for the day does not end at the project limits the following shall apply. If the end of a days production does not occur at the limit of work

or at a bridge deck then profile the resulting partial section, area less than 528 ft long, and the transverse joint with the next paving days production. The result will be PRI/IRI reported for full 1/10 mile (528 ft) sections with no partial sections.

4. If construction phasing dictates a paving start in the middle of a job or leaving the surface on a lane partially finished for an extended period of time, the Contractor has the option to split the 528 ft section that includes the break in paving. The 528 ft section, say section #6, shall be split into two sub-sections, section #6A and #6B, such that the combined length of sections #6A and #6B, equals 528 ft. In addition, the section that is paved first, say section #6A, shall end 50 ft away from the transverse joint so that the last 50 ft adjacent to a transverse joint and the transverse joint shall be profiled with the second paving operation.

SUBMITTING QUALITY CONTROL DATA TO SHA-OMT:

1. Send electronic data files for IRI data or PRI data to ridespec@sha.state.md.us. Please include the SHA contract number in the subject line of the e-mail message. The Data Input Template (instructions are in the spreadsheet) should be used for data not already in electronic format. Any other electronic data file formats must include all of the reporting information required under MSMT 559 or MSMT 563 in a DOS Text or ASCII file type.

2. PRI data may be submitted on paper as a data table or a copy of the profilograph tape summary section. Data should be faxed to 'OMT - Attention: Ride Spec' at the following fax number: 410-321-3099. IRI data must be submitted electronically under item 1 above (as indicated in MSMT 563.)

OBTAINING A COPY OF THE RIDETOOL PROGRAM:

RideTool is the in-house application OMT uses to review ride data and compute pay adjustments. To obtain a copy contact:

Vachel Davis or Jeff Withee
Office of Materials and Technology
2323 West Joppa Road
Brooklandville, MD 21022
Telephone: 410-321-3139 or 410-321-3115
Toll Free: 800-637-1290

MICHIGAN
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION
FOR
PAVEMENT RIDE QUALITY

a. Description. Furnish and operate a certified profiler or certified computerized profilograph to measure Ride Quality. Maintain the profiler or profilograph in calibration and good working order. Provide a certified profiler operator. Prepare and submit a Ride Quality Measurement Plan and, if required, a corrective action plan to the Engineer for acceptance. Complete all corrective action and perform all ride quality measurements as required by this special provision.

Ensure that the pavement on which ride quality measurements are taken, including the verification run conducted by the Engineer, is sufficiently clean prior to ride quality measurements.

This special provision deletes the longitudinal tolerances specified in the following subsections of the Standard Specifications for Construction:

Subsection 502.03.A.4, paragraph 4 (grade and slope control on HMA pavers)

Subsection 502.03.H (10 foot straightedge on HMA pavements)

Subsection 602.03.I (10 foot straightedge on concrete pavements)

b. Terminology.

Contractor Quality Control Run - Informational run(s) made by the Contractor to determine the ride quality acceptability, the need for corrective action, or the need for a process change. It can also include runs made after corrective action to determine if corrective action has been sufficient.

Correction Area - An area of the pavement which exceeds any of the correction limits for ride quality as defined in Table 1.

Project Specific Excluded Areas - Pavement identified in the accepted ride quality measurement plan where this Pavement Ride Quality special provision does not apply. Straightedge requirements will apply.

International Roughness Index (IRI) - a statistic used to determine the amount of roughness in a measured longitudinal profile. Computer programs to calculate the IRI statistic from a longitudinal profile are referenced in AASHTO PP 37-00

Predetermined Excluded Areas - Pavement within the project where this Pavement Ride Quality special provision does not apply. Straightedge requirements of subsection 502.03.H or 602.03.I of the standard specifications will apply as applicable. Predetermined excluded areas include:

- Ramps other than freeway-to-freeway ramps,

- All ramp tapers
- Shoulders
- Railroad crossings
- Bridges - The predetermined excluded area is that area between the two end reference lines or between the outermost limits of any structure expansion joint devices.
- Designated loose material sampling areas on the wearing course of HMA projects.

Profile - The elevation of a pavement along a line parallel to the centerline of the pavement. Also a two dimensional plot of the elevation of a pavement, taken in a longitudinal direction, and drawn to scale. Profiles are measured separately along each wheel path of a lane.

Profile Index (PI) - An index used to quantify the ride quality of a pavement. PI is based on the mechanical response of a California type profilograph to a pavement profile. PI is manually or mathematically determined in accordance with MTM 727 *Michigan Test Method for Manual Analysis of California Type Profilograms*.

Profiler - In general, a device that measures the elevation of a pavement and creates a profile. In particular, a device that meets the requirements for a General Motors type rapid travel profiler, as stated in MTM 726 *Michigan Test Method for Determining Ride Quality Using a GM Type Rapid Travel Profilometer*.

Profilograph - In general, a device that mechanically measures the elevation of a pavement using a contact sensor and creates a profile. In particular, a device that meets the requirements for a California type profilograph, as stated in MTM 725 *Michigan Test Method for Determining Ride Quality Using a California Type Profilograph*.

Referee Run – An independent ride quality measurement made to determine the ride quality value for the verification section. To be used in instances of dispute between the Contractor's and the Engineer's measurements on the verification section.

Ride Quality Certification – A formal process managed by the Department to assure that ride quality measuring equipment and operators are capable of measuring ride quality to the standards established in MTM 729 *Michigan Test Method for Certification of California Type Profilographs* or, MTM 730 *Michigan Test Method for Certification of Profilometers*. Display the equipment certification sticker indicating the expiration date of certification on the equipment used to measure ride quality on this project. Provide a copy of the operator certification to the Engineer.

Ride Quality Measurement Area - The traveled way, collector distributor roadways, freeway to freeway ramps, and other areas as shown on the plans.

Run of Record - The formal ride quality measurement submitted by the Contractor following any necessary corrective action. This includes both the initial and final measurements on a percent improvement project. A Run of Record is measured in the direction of travel. Each Run of Record must be labeled using a format approved by the Engineer.

Verification Run - A ride quality measurement made by the Engineer on a project or portion of a project to determine the ride quality for the verified section. A Verification Run is conducted and the results compared to the Contractor Run of Record on the same pavement area to determine if the Contractors entire Run of Record may be used as part of the acceptance decision. Verification Run value will be the average of three runs over the same area.

Verification Limit- Accounts for the expected variability of ride quality measurements taken by the same operator using the same piece of equipment. Run of record results are compared to the verification limit as part of the ride quality measurement verification. The Verification Limit is defined for the purpose of this special provision as the specification limit plus two times the repeatability standard deviation established during certification of ride quality testing equipment.

Wheel Path - The longitudinal locations three feet from each edge of a lane.

c. Ride Quality Measurement Plan. Submit a written ride quality measurement plan to the Engineer for review a minimum of 14 calendar days prior to the start of paving operations. Do not begin paving operations before acceptance of the ride quality measurement plan by the Engineer. The Engineer will notify the Contractor of any objections to the plan within 7 calendar days of receipt of the plan.

Include the following minimum details in the Ride Quality Measurement Plan:

1. Equipment used to measure ride quality on the project
2. Method of measurement (IRI or PI)
3. Calibration schedule for the equipment used on the project
4. Length of the Run of Record
5. Proposed project specific excluded areas (see section (d) of this special provision)
6. Traffic control details
7. Method(s) to correct surface irregularities
8. Correction layout method
9. Ride quality testing and verification time frames in relation to paving and staging operations
10. Labeling format for the run of record
11. Predetermined excluded areas that apply to this project
12. Intermediate runs required due to project staging

d. Project Specific Excluded Areas. Areas or circumstances, including physical features, that negatively impact ride quality may be proposed for exclusion from the ride quality requirements of this special provision provided that they are identified in the accepted Ride Quality Measurement Plan. These areas may include, but are not limited to, the following for freeway and non-freeway projects.

1. Freeway

    A. Areas where the constructed pavement must match grades of an existing feature (e.g. curb and gutter or an existing lane that will not be overlaid)

2. Non-Freeway

   A. Areas where the constructed pavement must match grades of an existing feature (e.g. curb and gutter or existing lane that will not be overlaid)

   B. Major at-grade intersections with part width or staged construction (where traffic flow is maintained during construction) may be considered for exclusion if listed as such in the ride quality measurement plan. The excluded area will extend between the approach and departure spring points of the intersection.

   C. In general, areas surrounding utility and drainage structures may be designated as excluded areas. The Engineer will review the locations and frequency of drainage and utility structures to determine if the proposed excluded area is acceptable.

   D. In general, gap areas may be designated as excluded areas. The Engineer will review the locations and extent of gap areas to determine if the proposed excluded area is acceptable.

e. General Ride Quality Measurement Requirements. Test in accordance with MTM 725 (for profilographs) or MTM 726 (for profilers). Mark, on the pavement surface or with stakes, the limits for ride quality measurement, including the POB, POE, and any excluded areas as specified in the accepted Ride Quality Measurement Plan. If the equipment used to measure ride quality excludes 16.25 feet at the beginning and end of each run, account for this when marking the actual starting and stopping locations.

Notify the Engineer a minimum of six hours prior to measuring a Run of Record, or performing any pavement corrections.

Perform each Run of Record on a length of pavement as long as practical and measure in the direction of travel. Label each Run of Record according to the approved format. Within 3 working days of the completion of a Run of Record, provide an electronic copy of all associated data files to the Engineer, as well as a paper copy of the Job Summary Table and Must Grind Table. Provide a paper copy of the California type profile plot, at a scale of 1:300, if requested by the Engineer.

If the initial Run of Record is less than or equal to 64 inches per mile for IRI (27 for PI_0) the run does not need to be repeated. If the initial Run of Record is greater than 64 but less than or equal to 76 inches per mile for IRI (27 to 33 for PI_0), conduct two additional runs, for a total of three runs. Average the value of the three runs to arrive at the Run of Record value.

f. Ride Quality Determination. Pavement acceptance will be determined by the Engineer based solely from the IRI or PI_0 for the final weighted average for both wheel path values within each lane for the entire project length minus excluded areas. Each tenth-mile segment of pavement falling outside the acceptable range for Ride Quality will be removed and replaced or corrected at the Contractor's expense.

Complete the Run of Record, any surface corrections, and re-measurement prior to any open-to-traffic or incentive dates specified in the contract documents.

1. **Unit of Measurement** - Calculate and report ride quality as International Roughness Index (IRI) or a zero vertical height blanking band Profile Index (PI_0). Calculate in accordance with

MTM 726 (IRI) and MTM 727 (PI_0). Select the index to be used (IRI or PI_0) prior to paving. Once selected, do not change the index without written authorization from the Engineer.

2. **Calculation Method** - Calculate and report an IRI or PI_0 value for each tenth-mile segment and for the entire length of each lane. Reported values will be the average of the left and right wheel path values. Report all ride quality values to the nearest whole number following the rounding method of ASTM E 29.

   Segments less than a tenth of a mile in length must be reported as partial segments and the IRI or PI_0 calculation must account for the shorter length. Use weighted averaging when individual measurement runs are shorter than the tenth-mile segment or the full lane length. Calculate the weighted average as follows:

$$WA = \sum \left[\frac{LLM}{TLL} \times RQ \right]$$

   where:

WA	=	Weighted Average
LLM	=	Length of Lane Measured
TLL	=	Total Length of Lane
RQ	=	Ride Quality Value

3. Ride Quality Requirements - Required ride quality values are given in Table 1. Each project must meet the criteria listed for both the entire length of the lane, and for each tenth-mile segment.

   Measure ride quality on two-course HMA overlay projects and diamond grinding projects, in IRI only, before and after construction. Compare before and after total lane values and tenth-mile values and calculate the change in ride quality as a percent rounded to the nearest whole percent following the rounding method of ASTM E 29.

4. **Corrective Action Requirements.** Examine the California profilograph type plot with the Engineer to identify surface irregularities (bumps or dips) following the guidance in MTM 727 and field check the locations to verify that correction is justified. Submit a corrective action plan to the Engineer for approval.

   Use a profilograph or profiler to locate and mark all surface irregularities requiring correction. Correct all segments containing areas exceeding the corrective limits shown in Table 1 prior to the Run of Record for that segment.

   Corrective action must consist of the following methods, in any combination depending on the irregularities to be corrected.

   A. Concrete or HMA pavement - Diamond grind in accordance with subsections 603.03.A.4 and 603.03.C of the standard specifications. Do not impair surface drainage or create any areas that allow water to pond.

B. HMA Pavement - Remove and replace a minimum of 1.5 inches of HMA one full lane width wide by the length required (a minimum of 100 feet). If necessary, diamond grind the surface after replacement.

g. Ride Quality Measurement Verification

1. Verification Run - The Engineer will notify the Contractor of the proposed verification schedule to allow for pavement cleaning as specified in section (a) of this special provision.

   Within seven calendar days of submittal of the Run of Record for the entire project, the Engineer will randomly select a segment (the verified segment) within the project and conduct a verification run. The verification run will, represent at least 10% of the total lane-miles subject to ride quality under this special provision. Verification Run results will be made available to the Contractor within 7 calendar days after completion of the run.

   On multi-year projects, the Engineer will complete all verification runs within 7 calendar days after seasonal shut down.

   NOTE: Refer to the accepted Ride Quality Measurement Plan if intermediate verification runs are required due to project staging.

2. Comparison of Run of Record and Verification Run Results - The Run of Record values will be used for acceptance and payment provided that all of the following criteria are met.

   A. The Run of Record value must meet the Ride Quality Requirements in Table 1.

   B. The Verification Run value must be below the Verification Limit established by the Department using the appropriate formula as follows

$$\text{IRI Verification Limit} = 70 + 2(s)$$

$$\text{PI}_o \text{ Verification Limit} = 30 + 2(s)$$

   where:

   s = Repeatability standard deviation for the verification profiler as published annually by the Department

   C. The shapes of the profile traces (bump heights and bump locations) must be similar.

   D. Within the verified segment

      (i) The Contractor's IRI value for the entire length must be within 6 inches per mile of the verification run value for the entire length or PI_0 must be within 3 inches per mile and

(ii) The Contractor's IRI value for each tenth-mile of the verified segment must be within 6 inches per mile of the Engineer's value for the companion tenth-mile or PI_0 must be within 3 inches per mile .

3. If the Run of Record values are not verified by the Verification Run, the Engineer and Contractor will attempt to resolve the differences to their mutual satisfaction by visually comparing the traces, running both profilers over a known profile, or evaluation or comparison of other available project information. If the differences cannot be resolved, then the dispute resolution procedures described in section (h) of this special provision will be applied.

h. Dispute Resolution. An independent certified profiler (equipment and operator) selected by the Engineer will conduct the referee testing.

Referee testing will be conducted using an inertial profiler that has been certified in accordance with MTM 729 or MTM 730. The certification must have been established within 30 days unless both parties agree in writing to accept prior certification of the equipment and/or operator.

The results will be compared to both the Contractor's run of record and the Engineer's verification run for the verified segment as follows.

1. The referee profiler will make five repeat runs of the verification section. The average of these five referee profiler result will be substituted for the Engineer's verification run results and the Contractors run of record will be re-evaluated as described in section (g.2) of this special provision with the exception that the repeatability standard deviation of the referee profiler will be used to compute the verification limit.

2. If the referee run validates the Contractor's run of record for the verification section, the Department will be responsible for all costs associated with the referee run and the Contractor's run of record results will be used for ride quality acceptance.

3. If the referee run does not validate the Contractor's run of record but validates the Engineer's verification run, all costs associated with the referee run will be the responsibility of the Contractor. Ride quality acceptance will be determined as follows:

   A. The total lane-miles subject to ride quality under this special provision will be remeasured by the Department according to section (f) of this special provision.

   B. If this measurement results in the need for additional corrective action, section (f.4) of this special provision will apply.

   C. The department will re-measure for ride quality after corrective action is complete and this measurement will be used for ride quality acceptance.

   D. All costs associated with the re-measurement(s) and any additional corrective action will be borne by the Contractor.

   E. No extension of time will be allowed for the time required to perform the re-measurement and/or additional corrective action, nor will delays to the project for completing this work be allowed as the basis of any claim.

4. If the referee run does not validate either the Contractor's run of record or the Engineer's verification run, Ride Quality acceptance will be determined as follows:

   A. The total lane-miles subject to ride quality under this special provision will be measured by the referee according to section (f) of this special provision.

   B. If this measurement results in the need for additional corrective action, section (f.4) of this special provision will apply. The Contractor must complete the corrective action and all costs associated with this additional corrective action will be borne by the Contractor.

   C. The referee will re-measure for ride quality after corrective action is complete and this measurement will be used for ride quality acceptance.

   D. All costs associated with the referee run and ride quality re-determination(s) will be shared equally by the Department and the Contractor.

The referee run will also be used to determine if either the Contractor or Department profiler exceeds the acceptable testing variability between two certified profilers as described in section (g) of this special provision. If either profiler exceeds the accepted testing variability, that profiler must immediately be taken out of service until it has been re-certified according to MTM 729 or MTM 730.

i. Measurement and Payment. Except as specified under Dispute Resolution in section (h) of this special provision, all costs associated with ride quality measurements, including all measurements required for construction and final acceptance, are included in other items of work and will not be paid for separately.

Ride quality measurements required by the Engineer in excluded areas will be measured by length in feet and paid for as extra work according to subsection 103.04 of the standard specifications.

All corrections within the limits of ride quality will be done at the Contractors expense. Corrections to areas outside the limits of ride quality or within excluded areas will be done under the direction of the Engineer and paid for using the following contract item (pay item).

Contract Item (Pay Item)	Pay Unit
Bump Grinding	Square Yard

Table 1: Ride Quality Requirements for Design Speeds Greater than 50 mph

	For Total Length of Lane				For Each Tenth-Mile Segment		Surface Irregularities Subject to Correction (c)
	Acceptable Range (IRI)	Correction Limit (IRI)	Acceptable Range (PI_0)	Correction Limit (PI_0)	Correction Limit (IRI)	Correction Limit (PI_0)	
HMA - Surface (a) (3 or more total lifts)	0-70 inch/mile	>70 inch/mile	0-30 inch/mile	>30 inch/mile	>70 inch/mile	> 3 inch	>0.3 in. in 25 ft.
HMA-Surface (a) (2 lifts total)	∃40% Improvement (b)	<40% Improvement (b)	NA	NA	<30% Improvement (b)	NA	>0.3 in. in 25 ft.
New Concrete Pavement	0-70 inch/mile	>70 inch/mile	0-30 inch/mile	>30 inch/mile	>70 inch/mile	>3 inch	>0.3 in. in 25 ft.
Diamond Grinding	>40% Improvement (b)	<40% Improvement (b)	NA	NA	<30% Improvement (b)	NA	>0.3 in. in 25 ft.

a. Any layer of new HMA material placed; any crush and shape operation; or any in-place recycling operation is considered a lift. Milling operations or wedging are not considered a lift.
b. Requirement waived if final IRI<70.
c. Based on California Type Profilograph Plot.

Table 2: Ride Quality Requirements for Design Speeds 30 - 50 mph

	For Total Length of Lane				For Each Tenth-Mile Segment		Surface Irregularities Subject to Correction (c)
	Acceptable Range (IRI)	Correction Limit (IRI)	Acceptable Range (PI_0)	Correction Limit (PI_0)	Correction Limit (IRI)	Correction Limit (PI_0)	
HMA - Surface (a) (3 or more total lifts)	0-120 inch/mile	>120 inch/mile	0-55 inch/mile	>55 inch/mile	>120 inch/mile	> 5.5 inch	>0.5 in. in 25 ft.
New Concrete Pavement	0-120 inch/mile	>120 inch/mile	0-55 inch/mile	>55 inch/mile	>120 inch/mile	>5.5 inch	>0.5 in. in 25 ft.

a. Any layer of new HMA material placed; any crush and shape operation; or any in-place recycling operation is considered a lift. Milling operations or wedging are not considered a lift.
b. Requirement waived if final IRI<70.
c. Based on California Type Profilograph Plot.

NEW MEXICO DEPARTMENT OF TRANSPORTATION
2005 INTERIM SPECIFICATIONS FOR

SECTION 401 - PAVEMENT SMOOTHNESS MEASUREMENT

401.1 DESCRIPTION.

401.11 This work shall consist of furnishing and utilizing profile testing equipment to perform pavement smoothness measurements, in accordance with requirements described herein using an International Roughness Index (IRI) profilometer that utilizes a Department State Materials Bureau approved computer program.

Note 1: This specification should be used on all new and reconstruction projects. However, for overlay, rehabilitation, and pavement preservation projects, it should only be used when two or more opportunities to achieve smoothness are provided to the Contractor. Examples of these types of opportunities are pavement surface milling followed by a PMBP overlay and projects where two or more lifts of PMBP will be constructed.

401.2 CONSTRUCTION REQUIREMENTS.

401.21 Straightedge Measurements. The final surface of all Plant-Mix Bituminous Pavement (PMBP), Stone Matrix Asphalt (SMA), Open-Graded Friction Course (OGFC), and Portland Cement Concrete Pavement (PCCP) not subject to profile measurement shall be tested using an approved 3.0-m (10-ft) straightedge at both right angles and parallel to the centerline. All surface deviations in excess of 3 mm in 3.0 m (1/8 in. in 10 ft) shall be corrected as directed by the Project Manager. The following are specifically excluded from profile measurement and shall be evaluated using a straightedge:

A. Shoulders, turnouts, median lanes and other areas less than 0.8-km (0.5 mile), as designated by the Project Manager during a pre-paving conference.

B. Concrete pavement slab removal and replacement, and intersections not paved integrally with the main line.

401.22 Profile Testing Equipment. The Contractor shall provide, operate, and maintain on the project a profile measurement device that will meet the requirements of AASHTOMP 11. The profile measurement device will utilize computer programs that are referenced in AASHTO PP 37 or an equal that has been given prior approval by the Department's State Materials Bureau.

401.23 Profile Measurements. The longitudinal smoothness of the final surface of OGFC, PMBP, SMA, or PCCP shall be tested using a profile measuring device and shall be performed per the requirements of AASHTO PP 50 using a cutoff wavelength of 91.4 meters (300 feet). On PMBP projects, all profile and corrective measurements shall be performed on the final surface of PMBP before the OGFC, if any, is allowed to be placed by the Project Manager. On PCCP projects, all profile and corrective measurements shall be performed on the finished surface of PCCP before longitudinal diamond grooving operations are allowed by the Project Manager. All profile measurements will be submitted to the Project Manager, in a format approved by the State Materials Bureau, within two (2) working days of actual data collection. If the actual data is not submitted by the Contractor to the Project Manager within two (2) working days of their actual collection, the Department shall not pay incentives greater than 100.0% for the section that this particular data represents per the criteria presented in Table 401-A, Table 401-B, Table 401-C, or Table 401-D.

401.24 Technician Certification. The Department's Technician Training and Certification Program (TTCP) shall certify all individuals performing profile measurement testing for acceptance and pay adjustment. The certification will be based on demonstration of ability and a written test. The term and expiration date of certification and requirements for renewal of certification shall be as established by the

TTCP. If a concern arises as to the competence of a certified individual, this concern must be documented in writing to the Department's State Materials Bureau Chief and the Assistant District Engineer. The Department's State Materials Bureau Chief, through the TTCP, will investigate the concern. If this investigation substantiates the concern, corrective action or de-certification will be implemented in accordance with procedures established by the TTCP Board of Directors.

401.25 Profile Measuring Device Calibration and Certification. The profile measuring device shall be certified in accordance with the Department's Standard Practice #002-03 "Certification of Inertial Profilers". The profile measuring device shall have a current TTCP calibration sticker or shall have a manufacturer's calibration and certification certificate which shall only be valid until the date of the next TTCP sponsored annual profile measuring device certification test.

The Contractor shall calibrate the profile measuring device. Both horizontal and vertical calibration shall be performed before each use. Additional calibrations or verifications may be required as directed by the Project Manager. Calibrations shall be performed in accordance with the manufacturer's approved procedures and the Contractor shall maintain copies of the calibration documentation and manufacturer's procedures with the machine.

If the profile measuring device does not meet manufacturer's calibration requirements, the contractor shall remove the machine from the project until adjustments can be made to bring the profile measurement device back into calibration requirements. The TTCP profile measuring device Certification Number shall be reported to the TTCP Administrator by the Project Manager in order to provide notification that the non-calibrated machine is not to be used on other projects until re-certification is obtained. Once the profile measurement device is re-certified by the manufacturer, a copy of the certificate shall be provided to the Department's TTCP Administrator.

401.26 Profile Measurement. The Contractor shall thoroughly sweep the roadway surface and then shall obtain the Project Manager's approval before beginning any profile operation.

The profile measuring device shall be operated per AASHTO PP 50 and in conformance with manufacturer's recommendations using a cutoff wavelength of 91.4 meters (300 feet). The profile measuring device shall be capable of maintaining the correct speed in accordance with the manufacturer's recommendations without interfering with traffic or the operation of the profile measuring device and shall be operated on the driving surface of the roadway.

The Contractor shall determine the International Roughness Index (IRI) for each lane, reported to the nearest mm per km (0.1-in./ mi), in accordance with the following:

A. The IRI shall be determined for each 0.1-km (0.1-mi) section or fraction thereof.

B. Profile traces shall be made for each wheel path, for each lane using dual-sensors. The traces shall be located 1.0 m (3.0 ft) from and parallel to the approximate location of pavement lane lines unless otherwise directed by the Project Manager. Additionally, the centerline distance between sensors shall be 1780 mm (70.0-inches) + 25.4 mm (1.0 inch).

C. At transverse joints, the profile traces shall commence 5.0 m (15 ft) into the previous placement.

D. The IRI used for evaluating each 0.1-km (0.1-mi) section shall be the average of the profile traces for each wheel path. This information shall be submitted in a summarized format consistent with AASHTO PP 50 recommendations to the Project Manager. The profile traces shall be maintained by the Contractor.

Additional profiles shall be taken to retest paved surfaces that have received corrective work, and as directed by the Project Manager, to check previously submitted data or to identify the limits of surface irregularities.

Each profile trace shall also include the following information:

A. Project number;
B. Date;
C. Lane profiled;
D. Beginning and ending stations;
E. Intermittent reference stations at least every 10 m (50 ft);
F. Horizontal equation stations;
G. Location of bridge abutments;
H. Net total linear meters (feet) of each lane; and
I. Operator's signature.

Profile testing is considered part of the paving operation. The proposed frequency for profile testing shall be included in the paving plan submitted by the Contractor at the pre-paving conference. Before any subsequent paving operation, the Project Manager shall approve the final pavement smoothness summary.

401.27 Evaluation for Corrective Work. For determining corrective work needed and pay adjustments, the pavement shall be evaluated in 0.1-km (0.1-mi) sections. When the measured smoothness value falls within the Table 401-A, Table 401-B, Table 401-C, or Table 401-D "Corrective Work Required" values, the pavement shall be evaluated by the Contractor in order to develop an appropriate corrective action plan. The corrective action plan, which may include diamond grinding, overlaying, or removing and replacing, shall be submitted to the Project Manager for review and approval. After the corrective action has been completed by the Contractor, the corrective area shall be re-profiled to verify compliance with specification requirements. All corrective action, including all necessary traffic control, shall be completed at no additional cost to the Department.

If the pay factor for any 0.1-km (0.1-mi) section meets or is greater than the Table 401-A, Table 401-B, Table 401-C, or Table 401-D 100.0% pay factor, additional corrective work for the purpose of reducing that reported measured smoothness value shall not be allowed by the Project Manager.

If the pay factor for any 0.1-km (0.1-mi) section is less than the Table 401-A, Table 401-B, Table 401-C, or Table 401-D 100.0% pay factor smoothness value and is equal to or greater than 90.0%, the Contractor may accept the designated pay factor. If the Contractor does not accept the designated pay factor and elects to develop a corrective action plan to further reduce the measured smoothness value to increase the designated pay factor, the Project Manager shall review the plan and if approved, shall allow such work. All elected corrective action, including all necessary traffic control, shall be completed at no additional cost to the Department.

Areas of localized roughness shall be identified through a 7.6 meter (25-feet) moving average filter. The difference between the 7.6 meter (25 foot) moving average and the reported relative elevation for every profile point will be determined by the Contractor in accordance with the method proposed in Transportation Research Board Report #02-4050 entitled "Application of Profile Data to Detect Localized Roughness", Transportation Research Record No. 1813 entitled "Construction 2002", pages 55 - 81. Reported deviations greater than 3.8 mm (0.15-in) shall be evaluated by the Contractor in order to develop an appropriate corrective action plan. Positive deviations shall be considered "bumps" and negative deviations shall be considered "dips".

The Project Manager shall determine which of these localized roughness areas, if any, need corrective action by the Contractor at no additional cost to the Department. If corrective action is required by the Project Manager, re-profile of the affected 0.1-km (0.1-mi) section will be required per Section 401.28.

401.28 Corrective Work. Corrective work shall be limited to diamond grinding, overlaying or removing and replacing. The Contractor shall submit a written corrective work proposal to the Project Manager that includes the methods and procedures that will be used. The Contractor shall not commence corrective

work until the methods and procedures have been approved in writing by the Project Manager. Approval by the Project Manager shall not relieve the Contractor of the responsibility of producing work in conformity with the specifications. All corrective work including all necessary traffic control shall be completed at no additional cost to the Department.

Corrective work shall conform to the following:

A. Diamond Grinding. Diamond grinding shall be performed by a roadway planing device to the extent necessary to bring the reported average measured smoothness value to an acceptable level per Table 401-A, Table 401-B, Table 401-C, or Table 401-D. The diamond grinding shall not reduce planned pavement thickness by more than 7.5 mm (0.3 in.) and shall be "daylighted" to produce a smooth finish. For PMBP, when an OGFC is not required as part of the contract, a fog seal shall be applied to the ground areas as approved by the Project Manager. For PCCP, additional diamond grinding shall be performed as necessary in the transverse direction such that the lateral limits are at a constant offset from and parallel to the nearest lane line or pavement edge and in the longitudinal direction such that the grinding begins and ends at lines normal to the pavement centerline. All diamond ground locations shall be neat rectangular areas of uniform appearance. The surface texture shall be such that the skid resistance is comparable to adjacent sections that do not require grinding. All damage to the curing membrane resulting from diamond grinding shall be repaired immediately. All diamond grinding work including necessary traffic control and curing membrane repair shall be completed at no additional cost to the Department.

B. Overlaying. When an additional lift of PMBP or SMA is used to correct a rough pavement, it shall meet all the requirements of the appropriate specification as specified in the contract. The overlay lift shall extend the full width of the underlying pavement surface and have a finished compacted thickness sufficient to correct the roughness and produce a final surface meeting all specification requirements. If the overlay does not meet the longitudinal smoothness requirement, a second overlay will not be allowed. Repairs to an overlay not meeting smoothness requirement shall be corrected by diamond grinding or removing and replacing as approved by the Project Manager.

C. Removing and Replacing. When repair of rough pavement is made by removing and replacing, the pavement shall be removed the full width of the lane and the full thickness of the course in areas requiring corrective work. The removal area shall begin and end with a transverse saw cut perpendicular to centerline. Replacement material shall be PMBP, SMA, or PCCP meeting all requirements of the contract.

D. OGFC Placement. If the measured average IRI of the OGFC is greater than the measured average IRI of the PMBP on the same 0.1-km (0.1-mi) section, the pay factor for the PMBP section shall be based on the OGFC's measured average IRI and not the PMBP's measured average IRI.

All 0.1-km (0.1-mi.) section of travel lane on which corrective work was performed shall be re-profiled and the re-profile reported measured smoothness data shall be used to represent that particular individual section. The previous section reported measured smoothness data shall be deleted for price adjustment purposes.

401.3 BASIS OF PAYMENT.

401.31 All surface smoothness testing and corrective work to bring the final surface within specification smoothness shall be included in the unit contract price for Plant-Mix Bituminous Pavement (PMBP), Stone Matrix Asphalt (SMA), or Portland Cement Concrete Pavement (PCCP). No separate payment will be paid for surface smoothness testing and corrective work.

401.32 Price Adjustment. A price adjustment will be calculated for each 0.1-km (0.1-mi) section of travel lane. The price adjustment shall apply to the total accepted quantity of the total thickness or area of PMBP or SMA as referenced by the contract, or to the total thickness or area of PCCP constructed under this contract for the actual lane width and roadway length represented by the price adjustment. Shoulder and turnout areas shall not be included for payment purposes. The price adjustment shall be determined by applying the appropriate percentage to the unit bid price for the pay item Plant Mix Bituminous Pavement (PMBP), Stone Matrix Asphalt (SMA), or Portland Cement Concrete Pavement (PCCP).

401.321 Price Adjustment for New or Reconstruction PMBP or SMA Projects. Price adjustments will be based on the final average IRI after any corrective work has been performed and measured per Table 401-A.

Table 401-A
IRI Based Profile Pay Adjustment Schedule For New or Reconstruction PMBP and/or SMA Pavements (Based on an Initial Serviceability Index = 4.3)

Type of Roadway						Pay Factor (Percent)
Interstate Routes IRI		National Highway Routes IRI		US (Non-NH) and NM Routes IRI		
mm per 0.1-km	inch per 0.1-mi	mm per 0.1-km	inch per 0.1-mi	mm per 0.1-km	inch per 0.1-mi	
<911	<57.7	<879	<55.7	<740	<46.9	110.0%
911 to 917	57.7 to 58.1	879 to 889	55.7 to 56.3	740 to 766	46.9 to 48.5	109.0%
918 to 925	58.2 to 58.6	890 to 900	56.4 to 57.0	767 to 789	48.6 to 50.0	108.0%
926 to931	58.7 to 59.0	901 to 909	57.1 to 57.6	790 to 813	50.1 to 51.5	107.0%
932 to 939	59.1 to 59.5	910 to 920	57.7 to 58.3	814 to 838	51.6 to 53.1	106.0%
940 to 947	59.6 to 60.0	921 to 930	58.4 to 58.9	839 to 862	53.2 to 54.6	105.0%
948 to 953	60.1 to 60.4	931 to 941	59.0 to 59.6	863 to 887	54.7 to 56.2	104.0%
954 to 961	60.5 to 60.9	942 to 950	59.7 to 60.2	888 to 912	56.3 to 57.8	103.0%
962 to 969	61.0 to 61.4	951 to 961	60.3 to 60.9	913 to 936	57.9 to 59.3	102.0%
970 to 976	61.5 to 61.8	962 to 972	61.0 to 61.6	937 to 961	59.4 to 60.9	101.0%
977 to 985	61.9 to 62.4	973 to 982	61.7 to 62.2	962 to 987	61.0 to 62.5	100.0%
986 to 991	62.5 to 62.8	983 to 993	62.3 to 62.9	988 to 1,012	62.6 to 64.1	99.0%
992 to 999	62.9 to 63.3	994 to 1,004	63.0 to 63.6	1,013 to 1,037	64.2 to 65.7	98.0%
1,000 to 1,007	63.4 to 63.8	1,005 to 1,015	63.7 to 64.3	1,038 to 1,062	65.8 to 67.3	97.0%
1,008 to 1,015	63.9 to 64.3	1,016 to 1,026	64.4 to 65.0	1,063 to 1,088	67.4 to 68.9	96.0%
1,016 to 1,023	64.4 to 64.8	1,027 to 1,037	65.1 to 65.7	1,089 to 1,115	69.0 to 70.6	95.0%
1,024 to 1,031	64.9 to 65.3	1,038 to 1,048	65.8 to 66.4	1,116 to 1,140	70.7 to 72.2	94.0%
1,032 to 1,039	65.4 to 65.8	1,049 to 1,059	66.5 to 67.1	1,141 to 1,165	72.3 to 73.8	93.0%
1,040 to 1,047	65.9 to 66.3	1,060 to 1,070	67.2 to 67.8	1,166 to 1,192	73.9 to 75.5	92.0%
1,048 to 1,055	66.4 to 66.8	1,071 to 1,081	67.9 to 68.5	1,193 to 1,217	75.6 to 77.1	91.0%
1,056 to 1,062	66.9 to 67.3	1,082 to 1,092	68.6 to 69.2	1,218 to 1,244	77.2 to 78.8	90.0%
> 1,062	> 67.3	> 1,092	> 69.2	> 1,244	> 78.8	Corrective Work Required

401.322 Price Adjustment for Rehabilitation and Overlay PMBP or SMA Projects. Price adjustments will be based on the final average IRI after any corrective work has been performed and measured per Table 401-B.

Table 401-B
IRI Based Profile Pay Adjustment Schedule For Rehabilitation or Overlay PMBP and/or SMA Pavements (Based on an Initial Serviceability Index = 4.2)

Type of Roadway						Pay Factor (Percent)
Interstate Routes IRI		National Highway Routes IRI		US (Non-NH) and NM Routes IRI		
mm per 0.1-km	inch per 0.1-mi	mm per 0.1-km	inch per 0.1-mi	mm per 0.1-km	inch per 0.1-mi	
<999	<63.6	<972	<61.6	<837	<53.0	110.0%
999 to 1,010	63.6 to 64.0	972 to 983	61.6 to 62.3	837 to 859	53.0 to 54.4	109.0%
1,011 to 1,018	64.1 to 64.5	984 to 993	62.4 to 62.9	860 to 882	54.5 to 55.9	108.0%
1,019 to 1,025	64.6 to 64.9	994 to 1,002	63.0 to 63.5	883 to 908	56.0 to 57.5	107.0%
1,026 to 1,031	65.0 to 65.3	1,003 to 1,012	63.6 to 64.1	909 to 931	57.6 to 59.0	106.0%
1,032 to 1,039	65.4 to 65.8	1,013 to 1,023	64.2 to 64.8	932 to 955	59.1 to 60.5	105.0%
1,040 to 1,045	65.9 to 66.2	1,024 to 1,032	64.9 to 65.4	956 to 979	60.6 to 62.0	104.0%
1,046 to 1,053	66.3 to 66.7	1,033 to 1,042	65.5 to 66.0	980 to 1,004	62.1 to 63.6	103.0%
1,054 to 1,059	66.8 to 67.1	1,043 to 1,053	66.1 to 66.7	1,005 to 1,028	63.7 to 65.1	102.0%
1,060 to 1,067	67.2 to 67.6	1,054 to 1,062	66.8 to 67.3	1,029 to 1,051	65.2 to 66.6	101.0%
1,068 to 1,073	67.7 to 68.0	1,063 to 1,073	67.4 to 68.0	1,052 to 1,077	66.7 to 68.2	100.0%
1,074 to 1,081	68.1 to 68.5	1,074 to 1,083	68.1 to 68.6	1,078 to 1,102	68.3 to 69.8	99.0%
1,082 to 1,089	68.6 to 69.0	1,084 to 1,094	68.9 to 69.3	1,103 to 1,126	69.9 to 71.3	98.0%
1,090 to 1,097	69.1 to 69.5	1,095 to 1,103	69.4 to 69.9	1,127 to 1,151	71.4 to 72.9	97.0%
1,098 to 1,103	69.6 to 69.9	1,104 to 1,115	70.0 to 70.6	1,152 to 1,176	73.0 to 74.5	96.0%
1,104 to 1,111	70.0 to 70.4	1,116 to 1,126	70.7 to 71.3	1,177 to 1,201	74.6 to 76.1	95.0%
1,112 to 1,119	70.5 to 70.9	1,127 to 1,135	71.4 to 71.9	1,202 to 1,227	76.2 to 77.7	94.0%
1,120 to 1,127	71.0 to 71.4	1,136 to 1,146	72.0 to 72.6	1,228 to 1,252	77.8 to 79.3	93.0%
1,128 to 1,133	71.5 to 71.8	1,147 to 1,157	72.7 to 73.3	1,253 to 1,277	79.4 to 80.9	92.0%
1,134 to 1,141	71.9 to 72.3	1,158 to 1,168	73.4 to 74.0	1,278 to 1,304	81.0 to 82.6	91.0%
1,142 to 1,149	72.4 to 72.8	1,169 to 1,178	74.1 to 74.6	1,305 to 1,329	82.7 to 84.2	90.0%
> 1,149	> 72.8	> 1,178	> 74.6	> 1,329	> 84.2	Corrective Work Required

401.323 Price Adjustment for PCCP Pavement, PCCP Ramps, PCCP Tapers, and PCCP Holding Lanes.
Price adjustments will be based on the final average IRI after any corrective work has been performed and measured per Table 401-C.

Table 401-C
IRI Based Profile Pay Adjustment Schedule for PCC Pavements, Ramps, Tapers, and Holding Lanes
(Based on an Initial Serviceability Index = 4.3)

Interstate and National Highway Routes		US (Non-NH) and NM Routes		Pay Factor (Percent)
IRI		IRI		
mm per 0.1-km	inch per 0.1-mi	mm per 0.1 km	inch per 0.1-mi	
<824	<52.2	<783	<49.6	110.0%
824 to 840	52.2 to 53.2	783 to 804	49.6 to 50.9	109.0%
841 to 856	53.3 to 54.2	805 to 822	51.0 to 52.1	108.0%
857 to 871	54.3 to 55.2	823 to 843	52.2 to 53.4	107.0%
872 to 887	55.3 to 56.2	844 to 864	53.5 to 54.7	106.0%
888 to 903	56.3 to 57.2	865 to 882	54.8 to 55.9	105.0%
904 to 919	57.3 to 58.2	883 to 903	56.0 to 57.2	104.0%
920 to 935	58.3 to 59.2	904 to 923	57.3 to 58.5	103.0%
936 to 950	59.3 to 60.2	924 to 944	58.6 to 59.8	102.0%
951 to 968	60.3 to 61.3	945 to 965	59.9 to 61.1	101.0%
969 to 983	61.4 to 62.3	966 to 985	61.2 to 62.4	100.0%
984 to 999	62.4 to 63.3	986 to 1,007	62.5 to 63.8	99.0%
1,000 to 1,017	63.4 to 64.4	1,008 to 1,028	63.9 to 65.1	98.0%
1,018 to 1,032	64.5 to 65.4	1,029 to 1,048	65.2 to 66.4	97.0%
1,033 to 1,048	65.5 to 66.4	1,049 to 1,070	66.5 to 67.8	96.0%
1,049 to 1,066	66.5 to 67.5	1,071 to 1,091	67.9 to 69.1	95.0%
1,067 to 1,081	67.6 to 68.5	1,092 to 1,113	69.2 to 70.5	94.0%
1,082 to 1,099	68.6 to 69.6	1,114 to 1,133	70.6 to 71.8	93.0%
1,100 to 1,116	69.7 to 70.7	1,134 to 1,156	71.9 to 73.2	92.0%
1,117 to 1,132	70.8 to 71.7	1,157 to 1,178	73.3 to 74.6	91.0%
1,133 to 1,149	71.8 to 72.8	1,179 to 1,200	74.7 to 76.0	90.0%
> 1,149	> 72.8	> 1,200	> 76.0	Corrective Work Required

401.324 Price Adjustment for Miscellaneous PMBP or SMA. Unit price adjustments will be made in accordance with Table 401-D for miscellaneous PMBP or SMA pavement to include ramps, tapers, and holding lanes that are greater than 0.8-km (0.5-mi) in length. All ramps, tapers, and holding lanes that are less than 0.8-km (0.5-mi) in length will be measured in accordance with 401.21.

Table 401-D
IRI Based Profile Pay Adjustment Schedule for PMBP and/or SMA Ramps, Tapers, and Holding Lanes (Based on an Initial Serviceability Index = 4.3)

Ramps, Tapers, and Holding Lanes IRI		Pay Factor (Percent)
mm per 0.1-km	inch per 0.1-mi	
< 849	< 53.8	110.0%
849 to 864	53.8 to 54.7	109.0%
865 to 876	54.8 to 55.5	108.0%
877 to 889	55.6 to 56.3	107.0%
890 to 901	56.4 to 57.1	106.0%
902 to 916	57.2 to 58.0	105.0%
917 to 928	58.1 to 58.8	104.0%
929 to 942	58.9 to 59.7	103.0%
943 to 955	59.8 to 60.5	102.0%
956 to 968	60.6 to 61.3	101.0%
969 to 982	61.4 to 62.2	100.0%
983 to 995	62.3 to 63.0	99.0%
996 to 1,009	63.1 to 63.9	98.0%
1,010 to 1,021	64.0 to 64.7	97.0%
1,022 to 1,034	64.8 t0 65.5	96.0%
1,035 to 1,048	65.6 to 66.4	95.0%
1,049 to 1,061	66.5 to 67.2	94.0%
1,062 to 1,075	67.3 to 68.1	93.0%
1,076 to 1,088	68.2 to 68.9	92.0%
1,089 to 1,102	69.0 to 69.8	91.0%
1,103 to 1,115	69.9 to 70.6	90.0%
> 1,115	> 70.6	Corrective Work Required

At the beginning and end of paving each day, the Contractor shall, with an approved stamp, indent the concrete surface near the right hand edge of the panel to indicate the date, month, and year of placement.

At 150-m (500-ft) intervals, the Contractor shall, with an approved stamp, indent the concrete surface near the right-hand edge of the pavement with the stationing of the roadway.

450.351 Protection of fresh Concrete. The Contractor shall have a sufficient quantity of polyethylene sheeting readily available to cover the entire pavement anticipated to be placed in three hours of maximum operation. This sheeting shall be reserved exclusively for the protection of the pavement in case of rain or other adverse conditions.

450.352 Surfacing Smoothness Requirements. The longitudinal smoothness of the finished surface of the PCCP in each through traffic lane and passing lane shall be tested with an approved profilograph, in accordance with SECTION 401 - PAVEMENT SMOOTHNESS MEASUREMENT. The following are specifically excluded from profilograph measurement and shall be evaluated using a straightedge in accordance with SECTION 401 - PAVEMENT SMOOTHNESS MEASUREMENT.

A. Horizontal curves with a centerline radius of curvature less than 300 m (1000 ft) and the super elevation transition to such curves.

B. Shoulders, ramps, tapers, holding lanes, turn-outs, medians, concrete pavement slab removal and replacement, intersections not paved integrally with the mainline, and other non-mainline pavement.

450.353 Straightedge Measurements. The surface of all PCCP not subject to profilograph measurements shall be tested using an approved 3-m (10-ft) straightedge at both right angles and parallel to the centerline. All surface deviations in excess of 6 mm (1/4 inch) in 3 m (10 ft) shall be corrected as directed by the Project Manager.

450.36 Curing. Immediately after finishing operations have been completed and as soon as marring of the concrete will not occur, the entire surface of the newly placed concrete shall be cured by applying a curing compound or by covering with sheeting material, at the Contractor's option, unless otherwise directed by the Project Manager. If curing compound is used, it shall be immediately reapplied over any control joints that were cut through previously applied coatings of curing compound.

450.361 Application of Curing Compound. Before placing the curing compound in the spray tank, it shall be thoroughly agitated by means of compressed air or other approved means, until the pigments in the original container are uniformly suspended. The compound shall not be diluted by the addition of solvents or altered in any manner.

All curing compound placed in the spray tanks shall be withdrawn directly from manufacturer's original containers bearing the manufacturer's name, brand, and lot number.

If the compound has become chilled to the extent that it is too viscous for proper stiffening or application or if portions of the vehicle have been precipitated from solution, it shall be heated to restore proper fluidity but it shall not be heated above 38 °C (100 °F).

Curing compound shall be applied to the entire area of the exposed surface of the concrete with an approved mechanical spray machine. The fog spray shall be protected from the wind with an adequate shield and shall be applied uniformly at a minimum rate of at least 0.3 L/m^2 (1 gal/150 ft^2).

The curing compound shall be applied immediately after the concrete has been finished and after surplus water that has collected on the surface has disappeared, or at a time designated by the Project Manager. The curing compound shall not be applied during or immediately after rainfall. If it becomes necessary to

SECTION 507—EVALUATION OF CONCRETE PAVEMENT RIDE QUALITY AND PAYMENT OF INCENTIVE

507.1 DESCRIPTION—This work is evaluating a concrete pavement surface profile and determining the ride-quality incentive associated with the pavement surface profile.

(a) General Requirements. Determine the ride quality of finished pavement surfaces, including approach slabs and pavement relief joints. In the presence of the Inspector, measure the pavement surface profile according to PTM No. 428. Provide the resultant International Roughness Index IRI data to the Representative. The Representative will determine payment for each ride-quality lot based on the IRI.

Measure the pavement surface of the following excluded areas separate from the pavement surface profile of ride-quality lots. The Representative will not include measurements from excluded areas to determine lot incentive payment.

- Bridge decks.
- Ramps less than 457 m (1,500 feet) in length.
- Tapered pavements less than 3.6 m (12 feet) wide.
- Shoulders, medians, and other pavement surfaces indicated.
- Partial lots less than 30 m (100 feet).

(b) Lot Size. A full lot is 161 m (528 feet) of a single pavement lane with the same lot type. The lot types are Type 1 (posted speed limit greater than 70 km/hour (45 miles per hour)) and Type 2 (posted speed limit less than or equal to 70 km/hour (45 miles per hour)). The Representative will designate lots starting at the beginning limit of paving and continuing to the ending limit of paving for each pavement lane and ramp that is 3.6 m (12 feet) or wider. Do not include the length of excluded areas in the 161 m (528 feet). If the lot type changes, end the lot and begin a new lot.

The Representative will designate a partial lot at the ending limit of paving, at a change in the lot type, and at an excluded area, when the lot length is less than 161 m (528 feet). The Representative will evaluate a partial lot as a percentage of a full lot.

507.3 CONSTRUCTION—

(a) Equipment and Operator. Provide pavement surface profile measuring equipment that has been verified by the Department according to PTM No. 428. In the presence of the Inspector, calibrate the distance sensor and check the profile system calibration before each day's testing.

Provide an operator that is Department certified according to PTM No. 428.

(b) Testing.

1. Lots. Provide the traffic control and station marking necessary to accommodate testing. Remove objects and equipment from the surface and sweep the surface as necessary to remove debris. In the presence of the Inspector, determine the pavement surface profile for each lot according to PTM No. 428. At the completion of testing, immediately submit the lot IRI data, as defined in PTM No. 428, to the Representative.

2. Excluded Areas. Provide traffic control necessary to accommodate testing. Test the entire surface of each excluded area in stages using a 3 m (10-foot) straightedge. At each stage, hold the straightedge in contact with the surface and parallel to the road centerline and, in successive positions, test the pavement surface profile from one side of the excluded area to the other. Advance the test location to the next stage by moving the straightedge along the roadway centerline not more than 1.5 m (5 feet).

(c) Acceptance.

1. Lots. The Representative will compare the lot IRI to Table A in Section 507.4 to determine if the lot requires corrective action. Additionally, perform corrective action on any individual bump (must grind) where the irregularity is more than 6 mm (1/4 inch) when tested with a 3 m (10-foot) straightedge.

2. Excluded Areas. Perform corrective action where irregularities are more than 6 mm (1/4 inch) when tested with a 3 m (10-foot) straightedge. Correct longitudinal joints not conforming to the requirements specified in Section 501.3(o)1. To improve the ride quality and at the Department's expense, the Representative may require grinding of excluded areas that conform to the acceptable straightedge surface tolerances specified in Section 507.3(c).

(d) Corrective Action.

1. Do not produce a deviation, such as a ridge or valley with the adjacent pavement, of more than 3 mm (1/8 inch) when measured on the transverse profile. Correct a sufficient length of pavement to correct the pavement surface profile without producing additional high or low points. Retest the lots and excluded areas after completing corrective action. Perform additional measurements of the pavement surface profile, as necessary, for the Representative to determine which lots do not require additional corrective action. Correct surfaces to a uniform texture and cross section.

2. Perform all corrective action before testing for pavement depth. If protective coating was applied before grinding, reapply to ground area. Use one or more of the following methods:

2.a. Carbide Grinding. Use carbide grinding for correcting areas 4.5 m (15 feet) in length or less. Use grinders of the walk-behind type that have cutting heads of carbide tipped shackles, stars, or blades and have a locking depth control to produce a uniform pavement surface texture.

Provide a pavement surface texture consisting of parallel grooves between 2 mm and 6 mm (3/32 inch and 1/4 inch) wide width a "land area" between grooves 2 mm and 5 mm (1/16 inch and 3/16 inch). Operate the grinder by making multiple passes if necessary, with a maximum depth of any single pass of 3 mm (1/8 inch). Grind longitudinally or transversely across the pavement surface.

2.b. Diamond Grinding. As specified in Section 514.3 and modified as follows:

(d) Tolerance. Delete this section.

Unless otherwise approved, grind the entire lane width.

2.c. Removal and Replacement. Remove and replace a minimum of 3 m (10 feet) of pavement between transverse joints of reinforced cement concrete pavements or an entire panel of plain cement concrete pavement. Where replacement extends to an existing transverse joint, replace the joint in kind as directed. Construct transverse joints at other locations resulting from removal of defective pavement using the methods for joining pavements shown on the Standard Drawings.

(e) Defective Work. A ride-quality pavement lot is defective if:

- The IRI of the lot exceeds the maximum acceptable IRI specified in Table A of Section 507.4.
- Any individual bump (must grind) exists in the lot where the irregularity is more than 6.5 mm (1/4 inch) when tested with a 3 m (10-foot) straightedge.

- The surface adjacent to another ride-quality lot contains a ridge or valley of more than 3 mm (1/8 inch).

- The specifications for pavement construction require removal and replacement of pavement within the ride-quality lot.

Unless the Department and Contractor agree to leave a defective lot in place as specified in Section 507.4, remove and replace defective areas and retest the ride-quality lot.

507.4 MEASUREMENT AND PAYMENT—Dollar

The proposal will include an item and a predetermined amount of money for Evaluation Of Bituminous Concrete Pavement Ride Quality And Payment Of Incentive. The contract item will have a unit of measure of DOLLAR, a unit price of $1.00, and a quantity equal to the predetermined amount.

Due to the incentive or bonus status of the payment being made, the provisions of Section 110.02(d) are not applicable to this item.

Measured and paid for, under the Evaluation Of Bituminous Pavement Ride Quality And Payment Of Incentive item as follows:

If the lot is not defective, Table A and the IRI for each lot will be used to determine the incentive payment for ride quality.

The incentive payment for a lot subjected to corrective action will be determined using Table A and the IRI for the lot after the Contractor completes corrective action.

The incentive payment for a partial lot will be determined as a percentage of a full lot.

After corrective action, the Contractor may leave a defective lot in place if the District Executive provides written approval and the Contractor accepts a $4,000 downward adjustment (rebate) of the amount paid for the lot.

Costs associated with evaluating pavement ride quality will not be paid for separately.

TABLE A
Payment Schedule for Ride Quality Incentive

Type 1 Lots	
IRI mm/km/lot (inches/mile/lot)	**Amount**
≤ 553 (35)	$1,500
≤ 790 (50)	$1,000
≤ 948 (60)	$500
≤ 1105 (70)*	$0
> 1105 (70)	Corrective Action Required
* Maximum acceptable IRI	

Type 2 Lots	
IRI mm/km/lot (inches/mile/lot)	**Amount**
≤ 710 (45)	$1,500
≤ 868 (55)	$1,000
≤ 1105 (70)	$500
≤ 1420 (90)*	$0
> 1420 (90)	Corrective Action Required
* Maximum acceptable IRI	

ITEM 585
RIDE QUALITY FOR PAVEMENT SURFACES

585.1. Description. Measure and evaluate the ride quality of pavement surfaces.

585.2. Equipment.

A. Surface Test Type A. Provide a 10-ft. straightedge.

B. Surface Test Type B. Provide a high-speed or lightweight inertial profiler, certified at the Texas Transportation Institute. Provide the Engineer with equipment certification documentation. Display a current decal on the equipment indicating the certification expiration date.

Use a certified profiler operator from the Construction Division's approved list. When requested, furnish the Engineer documentation for the person certified to operate the profiler.

C. Diamond Grinding Equipment. When grinding is required, provide self-propelled powered grinding equipment that is specifically designed to smooth and texture pavements using circular diamond blades. Provide equipment with automatic grade control capable of grinding at least 3 ft. of width longitudinally in each pass without damaging the pavement.

585.3. Work Methods. Measure and evaluate profiles using Surface Test Types A and B on surfaces as described below unless otherwise shown on the plans.

A. Transverse Profile. Measure the transverse profile of the finished riding surface in accordance with Surface Test Type A.

B. Longitudinal Profile. Measure the longitudinal profile of the surface, including horizontal curves.

1. **Travel Lanes.** Unless otherwise shown on the plans, use Surface Test Type B on the finished riding surface of all travel lanes except as follows.

   a. **Service Roads and Ramps.** Use Surface Test Type A on service roads and ramps unless Surface Test Type B is shown on the plans.

   b. **Short Projects.** Use Surface Test Type A when project pavement length is less than 2,500 ft. unless otherwise shown on the plans.

c. **Bridge Structures.** For span type bridge structures, approach slabs, and the 100 ft. leading into and away from such structures, measure the profile in accordance with the pertinent item or use Surface Test Type A.

d. **Leave-out Sections.** Use Surface Test Type A for areas listed on the plans as leave-out sections.

e. **Ends.** Use Surface Test Type A on the first and last 100 ft. of the project pavement length.

2. **Shoulders and Other Areas.** Use Surface Test Type A for shoulders and all other areas including intermediate pavement layers.

C. **Profile Measurements.** Measure the finished surface in accordance with Surface Test Type A or B in accordance with Section 585.3.A, "Transverse Profile"; Section 585.3.B, "Longitudinal Profile"; and the plans.

1. **Surface Test Type A.** Test the surface with a 10-ft. straightedge at locations selected by the Engineer.

2. **Surface Test Type B.**

a. **Quality Control (QC) Testing.** Perform QC tests on a daily basis throughout the duration of the project. Use a 10-ft. straightedge, inertial profiler, profilograph, or any other means to perform QC tests.

b. **Quality Assurance (QA) Testing.** Perform QA tests using either a high-speed or lightweight inertial profiler. Coordinate with and obtain authorization from the Engineer before starting QA testing. Perform QA tests on the finished surface of the completed project or at the completion of a major stage of construction as approved by the Engineer. Perform QA tests within 7 days after receiving authorization.

The Engineer may require QA testing to be performed at times of off-peak traffic flow. Operate the inertial profiler in a manner that does not unduly disrupt traffic flow as determined by the Engineer. When using a lightweight inertial profiler to measure a surface that is open to traffic, use a moving traffic control plan in accordance with Part 6 of the TMUTCD and the plans.

In accordance with Tex-1001-S, operate the inertial profiler and deliver test results to the Engineer within 24 hr. of testing.

Provide all profile measurements to the Engineer in electronic data files using the format specified in Tex-1001-S.

(1) Verification Testing. Within 10 working days after the Contractor's QA testing is completed for the project or major stage of construction, the Engineer may perform ride quality verification testing. When the Department's profiler produces an overall average international roughness index (IRI) value that is more than 3.0 in. per mile higher than the value calculated using Contractor data, the Engineer will decide whether to accept the Contractor's data, use the Department's data, use an average of both party's data, or request a referee test. Referee testing is mandatory if the difference is greater than 6.0 in. per mile.

(2) Referee Testing. The Construction Division will conduct referee testing, and their results are final. The Construction Division may require recertification for the Contractor's or Department's inertial profiler.

D. Acceptance Plan and Pay Adjustments. The Engineer will evaluate profiles for determining acceptance, bonus, penalty, and corrective action.

1. Surface Test Type A. Use diamond grinding or other methods approved by the Engineer to correct surface areas that have more than 1/8-in. variation between any 2 contacts on a 10-ft. straightedge. For asphalt concrete pavements, fog seal the aggregate exposed from diamond grinding. Following correction, retest the area to verify compliance with this Item.

2. Surface Test Type B. The Engineer will use the QA test results and the corresponding values in Table 1 to determine pay adjustments for ride quality using Department software. IRI values will be calculated using the average of both wheel paths. When taking corrective actions to improve a deficient 0.1-mi. section, pay adjustments will be based on the data obtained from reprofiling the corrected area.

a. IRI Pay Adjustment for 0.1-mi. Sections. Unless pay adjustment Schedule 1 or 2 is shown on the plans, Schedule 3 from Table 1 will be used to determine the level of bonus or penalty for each 0.1-mi. section on the project.

When Schedule 3 is specified, no associated bonuses will be paid for any 0.1-mi. section that contains localized roughness.

b. IRI Deficient 0.1-mi. Sections. When pay adjustment Schedule 1 or 2 is specified, use diamond grinding or other approved work methods to correct any 0.1-mi. section with an average IRI over 95.0 in. per mile (IRI deficient). Correct the deficient section to an IRI of 65 in. per mile or less when Schedule 1 is specified and to an IRI of 75 in. per mile or less when Schedule 2 is specified. After making corrections, reprofile the pavement section to verify that corrections have produced the required improvements. Associated bonuses apply when successful corrective action improves the IRI of a deficient 0.1-mi. section.

(1) Hydraulic Concrete Pavement. Use diamond grinding to correct deficient 0.1-mi. sections.

(2) Asphalt Concrete Pavement. For asphalt concrete pavement, the Engineer may assess a $3,000 penalty per 0.1-mi. section instead of requiring corrective action. Use diamond grinding or other approved methods to correct deficient 0.1-mi. sections. If corrective action does not produce the required improvement, the Engineer may require continued corrective action, assess the pertinent schedule penalty if the reprofiled IRI is 95 in. per mile or less, or assess the $3,000 penalty if the reprofiled IRI is greater than 95 in. per mile. Fog seal the aggregate exposed from diamond grinding or other corrective methods allowed.

c. Localized Roughness. Localized roughness will be measured using an inertial profiler in accordance with Tex-1001-S. The Engineer will determine areas of localized roughness using the average profile from both wheel paths.

The Engineer may waive localized roughness requirements for deficiencies resulting from manholes or other similar appurtenances near the wheel path.

(1) Corrective Action. When Schedule 1 or 2 is specified, use diamond grinding or other approved methods to remove localized roughness.

When Schedule 3 is specified, use a 10-ft. straightedge to further evaluate areas with localized roughness, and use

diamond grinding or other approved methods to correct areas that have more than 1/8-in. variation between any 2 contacts on the straightedge.

For asphalt concrete pavements, fog-seal the aggregate exposed from diamond grinding.

Reprofile the corrected area, and provide the Engineer the results that show the corrective action was successful. For asphalt concrete pavement, if the corrective action is not successful, the Engineer will require continued corrective action or assess a localized roughness penalty.

(2) Localized Roughness Penalty Assessed. For asphalt concrete pavement, in lieu of corrective action, the Engineer may assess a penalty for each occurrence of localized roughness. No more than 1 penalty will be assessed for any 5 ft. of longitudinal distance. No localized roughness penalties will be assessed in deficient 0.1-mi. sections where the Engineer elects to asses the $3,000 penalty instead of corrective action. For Schedule 1, a localized roughness penalty of $500 per occurrence will be assessed. For Schedule 2, a localized roughness penalty of $250 per occurrence will be assessed. For Schedule 3, localized roughness penalties will not be assessed.

585.4. Measurement and Payment. The work performed, materials furnished, certification and recertification, traffic control for all testing, materials and work needed for corrective action, equipment, labor, tools, and incidentals will not be measured or paid for directly but will be subsidiary to pertinent Items. Sections shorter than 0.1 mi. and longer than 50 ft. will be prorated in accordance with Tex-1001-S.

Table 1
Pay Adjustment Schedules for Ride Quality

Average IRI for each 0.10 mi. of Traffic Lane (in. / mi.)	Pay Adjustment $/0.10 mi. of Traffic Lane		
	Schedule 1	Schedule 2	Schedule 3
< 30	600	600	300
30	600	600	300
31	580	580	290
32	560	560	280
33	540	540	270
34	520	520	260
35	500	500	250
36	480	480	240
37	460	460	230
38	440	440	220
39	420	420	210
40	400	400	200
41	380	380	190
42	360	360	180
43	340	340	170
44	320	320	160
45	300	300	150
46	280	280	140
47	260	260	130
48	240	240	120
49	220	220	110
50	200	200	100
51	180	180	90
52	160	160	80
53	140	140	70
54	120	120	60
55	100	100	50
56	80	80	40
57	60	60	30
58	40	40	20
59	20	20	10
60	0	0	0
61	0	0	0

Table 1 (continued)
Pay Adjustment Schedules for Ride Quality

Average IRI for each 0.10 mi. of Traffic Lane (in./mi.)	Pay Adjustment $/0.10 mi. of Traffic Lane		
	Schedule 1	Schedule 2	Schedule 3
62	0	0	0
63	0	0	0
64	0	0	0
65	0	0	0
66	–20	0	0
67	–40	0	0
68	–60	0	0
69	–80	0	0
70	–100	0	0
71	–120	0	0
72	–140	0	0
73	–160	0	0
74	–180	0	0
75	–200	0	0
76	–220	–20	0
77	–240	–40	0
78	–260	–60	0
79	–280	–80	0
80	–300	–100	0
81	–320	–120	0
82	–340	–140	0
83	–360	–160	0
84	–380	–180	0
85	–400	–200	0
86	–420	–220	0
87	–440	–240	0
88	–460	–260	0
89	–480	–280	0
90	–500	–300	0
91	–520	–320	0
92	–540	–340	0
93	–560	–360	0
94	-580	-380	0

Table 1 (continued)
Pay Adjustment Schedules for Ride Quality

Average IRI for each 0.10 mi. of Traffic Lane (in./mi.)	Pay Adjustment $/0.10 mi. of Traffic Lane		
	Schedule 1	Schedule 2	Schedule 3
95	–600	–400	0
> 95	Corrective Action	Corrective Action	Not Applicable

S316B0B-1202

VIRGINIA DEPARTMENT OF TRANSPORTATION
SPECIAL PROVISION FOR
SECTION 316—RIDEABILITY

August 13, 2002c

SECTION 316—HYDRAULIC CEMENT CONCRETE PAVEMENT of the Specifications is amended as follows:

Section 316.04(k) Surface test is amended to include the following:

Pavement smoothness will be determined by a profiler on designated lanes having a design speed of 45 miles per hour or higher as specified herein. Intersections, transition lanes, and pavement within 52 feet of bridge approach slabs or manholes will be tested by a straightedge.

Except as noted hereinbefore, the surface ride quality acceptance will be based on the lowest average International Roughness Index (IRI) for each 0.01-mile section produced by a minimum of two test runs, using a South Dakota type road profiling device and reported for each travel lane. The device shall measure both wheelpaths with laser height sensing instruments. The Department shall conduct the testing as soon as practical and prior to opening to public traffic, providing the Contractor can allow unimpeded access to the paved surface for constant highway speed test runs. Testing shall be conducted in accordance with the requirements of VTM – 106.

Acceptance

An IRI number in inches per mile will be established for each 0.01-mile section for each travel lane of the surface. The 0.01-mile section before and after a bridge, and the beginning and end 0.01-mile sections of the surface will not be subject to a pay adjustment.

Areas excluded from testing by the profiler will be tested using a 10-foot straightedge. The variation of the surface from the testing edge of the straightedge between any two contacts with the surface shall not be more than 1/4 inch. Humps and depressions exceeding the specified tolerance shall be subject to correction as directed by the Engineer, at no additional cost to the Department.

The following table provides the acceptance quality rating scale of pavement based on the final rideability determination. The pay incentive/disincentive schedule will be applied to the final surface area. The surface area, in square yards, shall be calculated based on the tested section length and lane width as shown on the plans.

IRI After Completion (Inches Per Mile)	**Contract Unit Price Adjustment (Percent of Pavement Unit Price)**
45.0 and Under	105
45.1-55.0	103
55.1-70.0	100
70.1-80.0	90
80.1-90.0	80
90.1-100.0	70
Over 100.0	Subject To Corrective Action

This contract unit price adjustment will apply to the hydraulic cement concrete's unit price for the total area of the 0.01-mi section for the lane width.

When corrections to the pavement surface are required, the Contractor's method of correction shall be submitted for approval by the Engineer. In order to produce a uniform cross section, the Engineer may require correction to the adjoining traffic lanes or shoulders. Corrections to the pavement surface and/or the adjoining traffic lanes and shoulders will be at no cost to the Department.

Where corrections are made after the official Department test, the pavement will be retested by the Department to verify that corrections have produced the acceptable ride surface. No incentives will be provided for sections on which corrective actions have been required. The Contractor will have one opportunity to perform corrective action(s). In the event the corrective action(s) do not result in a minimum of 70% payment, then the Contractor will be assessed the corresponding percent payment based on the following table.

IRI After Correction (Inches Per Mile)	**Contract Unit Price Adjustment (Percent of Pavement Unit Price)**
100.1 – 120.0	60
120.1 – 140.0	40
140.1 – 160.0	20
Over 160.0	0

Corrective work shall be completed prior to determining pavement thickness.

C4 Trench Rollers

Trench rollers shall be self propelled and have a mass of not less than 4 400 kg per meter [**2,960 pounds per foot**] of width.

C5 Mixture Temperature Controls

If compaction is obtained by the ordinary compaction method, the minimum laydown temperature in all courses (as measured behind the paver or spreading machine) of the asphalt mixture shall be in accordance with the temperature requirements of Table 2360.6-C5. Unless directed by the Engineer in writing, no paving is allowed under the Ordinary Compaction Method when the air temperature is below 0°C [**32°F**].

Table 2360.6-C5
Mixture Temperature Control

Air Temperature	**Compacted Mat Thickness, mm (A)**			
°C [**°F**]	25 mm [**1 inch**]	40 mm [**1-1/2 inch**]	50 mm [**2 inch**]	≥75 mm [**3 inch**]
+0-5 [**32-40**]	--	129 (B) [**265**]	124 [**255**]	121 [**250**]
+ 6-10 [**41-50**]	130 (B) [**270**]	127 [**260**]	121 [**250**]	118 [**245**]
+ 11-15 [**51-60**]	127 (B) [**260**]	124 [**255**]	118 [**245**]	115 [**240**]
+ 16-21 [**61-70**]	121 (B) [**250**]	118 [**245**]	115 [**240**]	113 [**235**]
+ 22-27 [**71-80**]	118 [**245**]	115 [**240**]	113 [**235**]	113 [**235**]
+ 28-32 [**81-90**]	113 [**235**]	110 [**230**]	110 [**230**]	110 [**230**]
+ 33 [**91+**]	110 [**230**]	110 [**230**]	110 [**230**]	107 [**225**]

(A) Based on approved or specified compacted lift thickness.

(B) A minimum of one pneumatic-tire roller shall be used for intermediate rolling unless otherwise directed by the Engineer. The Engineer may specify or modify in writing (with concurrence from the Department Bituminous Engineer) a minimum laydown temperature.

2360.7 THICKNESS AND SURFACE SMOOTHNESS REQUIREMENTS

A Thickness

After compaction the thickness of each lift shall be within a tolerance of 6 mm [**1/4 inch**] of the thickness shown in the Plans, except that, if automatic grade controls are used, this thickness requirement will not apply to the first lift placed. This thickness requirement will not apply to a leveling lift whether or not automatic grade controls are required. The Engineer may require removal and replacement, at the Contractor's expense, of any part of any lift that is constructed to less than the minimum required thickness.

Cores taken for density determination shall be measured for thickness also. Each core shall be measured 3 times for thickness prior to sawing. Report the average of these three measurements. Each lot's average core thickness shall be documented and submitted to the Engineer. If the average of the two Contractor cores exceed the specified tolerance, an additional two cores may be taken in the lot in question. The average of all core thickness measurements per day per lift will be used to determine daily compliance with thickness specifications.

On that portion of any lift constructed to more than the maximum permissible thickness, the materials used in the excess mixture above that required to construct that portion of the lift to the Plan thickness plus 6 mm [**1/4 inch**] may be excluded from the pay quantities and at the discretion of the Engineer and at the Contractor's expense may be required to be removed and replaced.

B Surface Requirements

After compaction, the finished surface of each lift shall be reasonably free of segregated, open and torn sections, and shall be smooth and true to the grade and cross section shown on the Plans with the following tolerances:

(1) Where a leveling lift is specified, it shall be constructed to within a tolerance of 15 mm [**1/2 inch**] of the elevations and grades established by the Engineer. This requirement shall also apply to the first lift placed other than leveling when automatic controls are used.

(2) The surface of the final two lifts placed shall show no variation greater than 6 mm [**1/4 inch**] from the edge of a 3 m [**10 foot**] straightedge laid parallel to or at right angles to the centerline. Shoulder surfacing and surfacing on temporary connections and bypasses shall show no variations greater than 6 mm [**1/4 inch**] from the edge of a 3 m [**10 foot**] straightedge laid parallel to the centerline.

(3) After final compaction, all final lift asphalt wearing surfaces adjacent to concrete pavements shall be slightly higher (but not to exceed 6 mm [**1/4 inch**] than the concrete surface.

After final compaction, all asphalt surfaces adjacent to gutters, manholes, pavement headers, or other fixed structures shall be slightly higher (but not to exceed 6 mm [**1/4 inch**] than the surface of the structure.

(4) Transverse joints (construction joints), at the beginning and end of a project, at paving exceptions, or caused by suspension of daily paving operations, shall show no variation greater than 6 mm [**1/4 inch**] from the edge of a 3 m [**10 foot**] straightedge centered longitudinally across the transverse joint. The Engineer may require correction by diamond grinding when material is placed outside the above described limitations.

(5) The transverse slope of the surface of each lift, exclusive of the shoulder wearing lift, shall not vary from the slope shown in the Plans by more than 0.4 percent.

(6) The distance between the edge of each lift and the established centerline shall be no less than the Plan distance nor more than 75 mm [**3 inches**] greater than the Plan distance. In addition, the edge alignment of the wearing lift on tangent sections and on curve sections of 3 degrees or less shall not deviate from the established alignment by more than 25 mm [**1 inch**] in any 7.5 m [**25 foot**] section.

(7) The finished surface of each lift shall be reasonably free of segregated and open and torn sections.

Any material placed outside the above described limitations shall be removed and replaced after being cut or sawed at no expense to the Department or with the approval of the Engineer, allowed to remain inplace at a reduced cost calculated at $12 per square meter [**$10 per square yard**].

C Pavement Smoothness Specification – IRI (International Roughness Index)

C1 General

Pavement smoothness will be evaluated on the final mainline pavement surface using an Inertial Profiler (IP) and the International Roughness Index (IRI). Unless otherwise authorized by the Engineer, all smoothness testing shall be performed in the presence of the Engineer. The Engineer and the Contractor shall mutually agree upon scheduling of smoothness testing so that testing can be observed. Any testing performed without the Engineer's presence, unless otherwise authorized, may be ordered retested at the Contractor's expense. The following Table 2360.7-A (IRI) shows pavement surfaces that are excluded from smoothness testing but subject to 2360.7B surface requirements.

Table 2360.7 – A (IRI)
Testing Exclusions

50 feet either side of obstructions such as manholes, water supply castings, etc.*
Ramps, Loops, Climbing lanes
Side Streets, Side Connections
Turn Lanes, Storage Lanes, Crossovers, Bypass Lanes
Shoulders
Intersections constructed under traffic – Begin and end the exclusion 30.5m [**100 feet**] from the intersection radius
Sections less than 15.24m **[50 ft]** in length
Acceleration, Deceleration Lanes
Projects less than 300m [**1000 feet**] in length
Mainline paving where the normally posted regulatory speed is less than or equal to 70 km/hr [**45 miles per hour**]
Begin the exclusion at the sign
Single lift overlays over concrete

*Mainline shall be included in profiling if obstructions are located in auxiliary or parking lanes

C1A Smoothness Requirements

Pavement smoothness requirements will be evaluated by the International Roughness Index (IRI) Equation A, Equation B, or Equation C. The pavement smoothness Equation will be identified in the Special Provisions of the proposal. Location of bumps and/or dips and magnitude will be based on California Test Method 526.

C2 Measurement

Smoothness will be measured with an IP, which produces both an IRI value and a profilogram (profile trace of the surface tested). The IP shall conform to the Class 1 requirements of ASTM E950-94 and must be certified according to the most recent procedure on file in the Bituminous Office. For pavement evaluation, one pass will be made in each lane, 2.74 m [**9 feet**] from centerline. The IP shall be run in the direction the traffic will be moving. Each lane will be tested and evaluated separately. The Engineer will determine the length in kilometers [**miles**] for each mainline traffic lane. The IP shall be operated at the optimum speed as defined by the manufacturer.

C3 Smoothness testing

The Contractor shall furnish a properly calibrated, documented, and MnDOT certified IP. The IP shall be equipped with automatic data reduction capabilities. Computer programs used to calculate the IRI statistic from a longitudinal roadway profile shall follow the procedure developed by the World Bank for a quarter-car simulation as described in NCHRP report 228.

Mn/DOT certification documentation shall be provided to the Engineer on the first day the IP is used on the project. IP settings are on file in the Bituminous Office. The Contractor shall furnish a competent operator, trained in the operation of the IP and evaluation of both California Test Method 526 and the International Roughness Index.

The Contractor shall remove all objects and foreign material on the pavement surface prior to surface evaluation by power brooming.

The pavement surface will be divided into sections which represent continuous placement. A section will terminate 15.24m **[50 ft]** before a bridge approach panel, bridge surface, manhole or similar interruption. In the final pavement evaluation, a day's work joint will be included in the trace with no special consideration. A section will be separated into segments of 0.1 km **[0.1 mi]**. A segment will be in one traffic lane only.

An IRI value shall be computed for each segment of 15.24m **[50 ft]** or more. The IRI value will include the 15.24 m **[50 ft]** at the ends of the section only when the Contractor is responsible for the adjoining surface.

End of run areas not included in the IRI value and any sections of pavement less than 15.24m **[50 ft]** in length shall be checked longitudinally with a 3.028 m **[10 ft]** straight edge and the surface shall not deviate from a straight line by more than 6 mm in 3.028 m **[1/4 inch in 10 ft]**. Transverse joints shall be evaluated by centering the straightedge longitudinally across the transverse joint.

The Contractor shall submit the graphical trace, a summary of the bump(s)/dip(s) locations, the magnitude of the bump(s)/dip(s) and each segment IRI value on the same day as the profiling was conducted.

The Contractor shall submit a final spreadsheet summary of the smoothness data to the Engineer within five calendar days after all mainline pavement placement. The summary shall be signed by the Contractor. The spreadsheet summary shall be in tabular form, with each 0.1 km **[0.1 mile]** segment occupying a row. Each row shall include the beginning and ending station for the segment, the length of the segment, the final IRI value for the segment~~,~~ the IRI based incentive/disincentive in dollars for the segment, and the deductions for bump(s)/dip(s) in dollars for the segment. Each continuous run will occupy a separate table and each table will have a header that includes the following: the project number, the roadway number or designation, a lane designation, the mix type of the final lift, the PG binder of the final lift, the date of the final smoothness runs, and the beginning and ending station of the continuous run. The following information shall be included at the bottom of each summary: a subtotal for the IRI based incentive/disincentive, a subtotal for the bump deductions, and a total for incentive/disincentive for both IRI values and bumps. Software to summarize the data is available from the Mn/DOT Bituminous Office at www.mrr.dot.state.mn.us/pavement/bituminous/bituminous.asp.

The Contractor will be responsible for all traffic control associated with the smoothness testing and any corrective action (when applicable) that is required of the final pavement surface.

C3A Retesting

The Engineer may require any portion or the total project to be retested if the results are questioned. This includes both IRI values and bump/dip locations. The Engineer will decide whether Mn/DOT, an independent testing firm (ITF), or the Contractor will retest the roadway surface.

If the retested IRI values differ by more than 10% from the original IRI values, the retested values will be used as the basis for acceptance and any incentive/disincentive payments. In addition, bump/dip locations as shown by the retest will replace the original results.

If the Engineer directs the Contractor or an independent testing firm to perform retesting and the original results are found to be accurate, the Department will pay the Contractor or the independent testing firm $62.14 per lane km [$100 per lane mile] that is retested, with a minimum charge of $500.00. The Contractor will be responsible for any costs associated with retesting if the original values differ by more than 10% from the retested values.

C4 IRI Values

The IP shall be equipped with automatic data reduction capabilities for determining the IRI values. An IRI value shall be calculated for each segment of the final pavement surface. The IRI values shall be determined by following NCHRP report 228. The IRI values shall be reported in units of m per km **[inches per mile]**. Both m per km and inches per mile shall be reported with two digits right of the decimal. Follow Mn/DOT rounding procedures per the Bituminous Manual section 5-693.730.

When there is a segment equal to or less than 76.2 m **[250 ft]** in length at the end of a lane of paving, the IRI value for that segment shall be mathematically weighted and added to and included in the evaluation of the adjacent segment. Segments greater than 76.2 m **[250 ft]** in length will be evaluated individually.

C4a Bumps and Dips – IRI Equation A and IRI Equation B

Bump/dip location will be determined in accordance with California Method 526. Bumps and dips equal to or exceeding 10.2 mm in a 7.62 m **[0.4 inch in a 25 ft]** span shall be identified separately. When the profile trace shows a successive, uninterrupted bump, dip; or dip, bump combination (up to a maximum of 3 alternating trace deviations that relate to one bump or dip on the roadway), identify and evaluate these occurrences as one event.

The Contractor shall correct, by diamond grinding, all areas represented by bumps or dips of 10.2 mm **[0.4 inch]** or more as measured by California Test Method 526. However, the Engineer may allow bumps or dips of 10.2 mm to 15.2 mm **[0.4 inches to 0.6 inches]** in a 7.62 m **[25 foot]** span to be left uncorrected, and in such case, the contractor will be assessed a price deduct as specified in section C6 ("Payment") of this special provision.

Corrected dips or bumps will be considered satisfactory when the profilogram shows the deviations are less than 10.2 mm in a 7.62 m **[0.4 inch in a 25 foot]** span.

C4b Bumps and Dips – IRI Equation C

Bump/dip location will be determined in accordance with California Method 526. Bumps and dips equal to or exceeding 12.7 mm in a 7.62 m **[0.5 inch in a 25 ft]** span shall be identified separately. When the profile trace shows a successive, uninterrupted bump, dip; or dip, bump combination (up to a maximum of 3 alternating trace deviations that relate to one bump or dip on the roadway), identify and evaluate these occurrences as one event.

The Contractor shall correct, by diamond grinding, all areas represented by bumps or dips of 12.7 mm **[0.5 inch]** or more as measured by California Test Method 526. However, the Engineer may allow bumps or dips of 12.7 mm to 17.8 mm **[0.5 inches to 0.7 inches]** in a 7.62 m **[25 foot]** span to be left uncorrected, and in such case, the contractor will be assessed a price deduct as specified in section C6 ("Payment") of this special provision.

Corrected dips or bumps will be considered satisfactory when the profilogram shows the deviations are less than 12.7 mm in a 7.62 m **[0.5 inch in a 25 foot]** span.

C5 Surface Correction

Unless otherwise approved by the Engineer, corrective work shall be by diamond grinding. Other methods may include; overlaying the area, or replacing the area by milling and inlaying. The Engineer shall approve of the Contractor's method of correcting segment(s) prior to the Contractor starting corrective work. Any corrective actions by milling and inlay or overlay shall meet the specifications for ride quality over the entire length of the correction, including the first and last 15 m [**50 feet**]. Bumps or dips in excess of 10.2 mm [**0.4 inches]** where evaluation is by Equation A or B or bumps or dips in excess of 12.7 mm **[0.5 inch]** where evaluation is by Equation C that are located at transverse joints at areas of corrective actions utilizing overlay or milling and inlay, shall be removed by diamond grinding. The Contractor shall notify the Engineer prior to commencement of the corrective action. If the surface is corrected by overlay, inlay or replacement, the surface correction shall begin and end with a transverse saw cut. Surface corrections shall be made prior to placing permanent pavement markings. In the event that permanent pavement marking are damaged or destroyed during surface correction activities, they will be replaced at no cost to the Agency.

When pavement smoothness evaluation by Equation A is specified the Engineer may require that the Contractor, at no expense to the Department, correct segments with an IRI greater than 1.03 m per km **[65 inches/mile] or the** Engineer may assess a $560 per 0.1 km **[$900 per 0.1 mile]** penalty in lieu of requiring corrective work.

When pavement smoothness evaluation by Equation B is specified the Engineer may require that the Contractor, at no expense to the Department, correct segments with an IRI greater than 1.18 m per km

[75 inches/mile] or the Engineer may assess a $420 per 0.1 km **[$675 per 0.1 mile]** penalty in lieu of requiring corrective work.

When pavement smoothness evaluation by Equation C is specified the Engineer may require that the Contractor, at no expense to the Department, correct segments with an IRI greater than 1.34 m per km **[85 inches/mile] or the** Engineer may assess a $280 per 0.1 km **[$280 per 0.1 mile]** penalty in lieu of requiring corrective work.

Bump, dip, and smoothness correction work shall be for the entire traffic lane width. Pavement cross slope shall be maintained through corrective areas.

All corrective work shall be subject to the approval of the Engineer. After all required corrective work is completed a final segment(s) IRI value and bump/dip tabulation shall be determined and submitted to the Engineer. Corrective work and re-evaluation shall be at the Contractor's expense.

Segments requiring grinding will be re-profiled within two working days of completion of grinding. Individual bumps/dips and segments requiring grinding shall be completed with 15 working days of notification.

C6 Payment

The cost of traffic control for certified smoothness testing and/or any corrective work is incidental to the cost of the Wear course mixture.

The Contractor may receive an incentive payment or be assessed a penalty based on the number of segments and the IRI value. The total ride incentive shall not exceed 10% of the total mix price for pavement smoothness evaluated under IRI Equation A, 5% of the total mix price for pavement smoothness evaluated under Equation B, or 5% of the total mix price for pavement smoothness evaluated under Equation C. Total mix shall be defined as **all** mixture placed on the project. Pay adjustments for incentives will only be based on the segment IRI value before any corrective work has been performed. Any segment that contains corrective action for IRI value or bumps is not eligible for incentive pay.

The Contractor will not receive a net incentive payment for ride if more than 25% of all density lots for the project fail to meet minimum density requirements.

For pavement smoothness evaluated under Equation A uncorrected bumps or dips greater than or equal to 10.2 mm **[0.4 inches]** in a 7.62 m **[25 foot]** span will be assessed a price deduction of $900 per event.

For pavement smoothness evaluated under Equation B uncorrected bumps or dips greater than or equal to 10.2 mm **[0.4 inches]** in a 7.62 m **[25 foot]** span will be assessed a price deduction of $675 per event.

For pavement smoothness evaluated under Equation C uncorrected deviations (bumps or dips) greater than or equal to 12.7 mm **[0.5 inches]** in a 7.62 m **[25 foot]** span will be assessed a price deduction of $450 per event.

Combinations of bumps and dips which arise from the same single bump or dip are considered to be one event, and shall be counted only once for the purposes of calculating price deductions. Typically, bump-dip-bump combinations, or dip-bump-dip combinations, that are confined to a 30 feet longitudinal segment are considered to be one event.

Bumps or dips resulting from a construction joint will be assessed a $900 penalty, regardless of the IRI Equation used for evaluation or pavement smoothness.

Incentive/disincentive payments will be based on the IRI determined for each segment and will be based on the following equations and criteria.

C6a IRI Equation A*

IRI m/km **[inches/mile]**	Incentive/Disincentive $/0.1km **[$/0.1mile]**
< 0.47 m/km **[< 30 inches/mile]**	$249 **[$400]**
0.47 m/km to 1.03 m/km **[30 inches/mile to 65 inches/mile]**	$523 – (IRI x 584) **[$850 – (IRI x 15)]**
1.03 m/km **[> 65 inches/mile]**	-$560 **[-$900]**

* Typically, 3-lift minimum construction

C6b IRI Equation B*

IRI m/km **[inches/mile]**	Incentive/Disincentive $/0.1km **[$/0.1mile]**
< 0.52 m/km **[< 33 inches/mile]**	$168 **[$270]**
0.52 m/km to 1.18 m/km **[33 inches/mile to 75 inches/mile]**	$373 – (IRI x 395) **[$600 – (IRI x 10)]**
1.18 m/km **[> 75 inches/mile]**	-$420 **[-$675]**

* Typically, 2-lift construction

C6c IRI Equation C*

IRI m/km **[inches/mile]**	Incentive/Disincentive $/0.1km **[$/0.1mile]**
< 0.57 m/km **[< 36 inches/mile]**	$112 **[$180]**
0.57 m/km to 1.34 m/km **[36 inches/mile to 85 inches/mile]**	$258 – (IRI x 257) **[$414 – (IRI x 6.5)]**
1.34 m/km **[> 85 inches/mile]**	-$280 **[-$450]**

* Typically, single lift construction

2360.8 METHOD OF MEASUREMENT

A Asphalt Mixture

Asphalt mixture of each type will be measured separately by mass, based on the total quantity of material hauled from the mixing plant, with no deductions being made for the asphalt materials.

B Blank

C Asphalt Mixtures Measured by the Square Meter [Square Yard] per Specified (mm [inch]) and for Mixtures Measured by the [Square Yard inch]

Asphalt mixture of each type and for each specific lift will be measured separately by area and by thickness on the basis of actual final dimensions placed. The constructed thickness shall meet tolerances set forth in Sections 2360.7A.