Field Experiments of Current Concrete Pavement Surface Characteristics Practices: Iowa Data Collection and Analysis

National Concrete Pavement Technology Center

Tech Center

Final Report
December 2005

Sponsored by
the Federal Highway Administration (Project 15, Part 2),
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the Iowa Highway Research Board (IHRB Project TR-537)

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About the National Concrete Pavement Technology Center

The mission of the National Concrete Pavement Technology Center is to unite key transportation stakeholders around the central goal of advancing concrete pavement technology through research, tech transfer, and technology implementation.

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16. Abstract

One of the most important issues in portland cement concrete pavement research today is surface characteristics. The issue is one of balancing surface texture construction with the need for durability, skid resistance, and noise reduction. The National Concrete Pavement Technology Center at Iowa State University, in conjunction with the Federal Highway Administration, American Concrete Pavement Association, International Grinding and Grooving Association, Iowa Highway Research Board, and other states, have entered into a three-part National Surface Characteristics Program to resolve the balancing problem. As a portion of Part 2, this report documents the construction of 18 separate pavement surfaces for use in the first level of testing for the national project. It identifies the testing to be done and the limitations observed in the construction process. The results of the actual tests will be included in the subsequent national study reports.

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FIELD EXPERIMENTS OF CURRENT CONCRETE PAVEMENT SURFACE CHARACTERISTICS PRACTICES: IOWA DATA COLLECTION AND ANALYSIS

Final Report
December 2005

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EXECUTIVE SUMMARY

One of the most important issues in portland cement concrete pavement research today is surface characteristics. The issue is one of balancing surface texture construction with the need for durability, skid resistance, and noise reduction. The National Concrete Pavement Technology Center at Iowa State University, in conjunction with the Federal Highway Administration, American Concrete Pavement Association, International Grinding and Grooving Association, Iowa Highway Research Board, and other states, have entered into a three-part National Surface Characteristics Program to resolve the balancing problem. As a portion of Part 2, this report documents the construction of 18 separate pavement surfaces for use in the first level of testing for the national project. It identifies the testing to be done and the limitations observed in the construction process. The results of the actual tests will be included in the subsequent national study reports.

INTRODUCTION

The public reaction to pavement noise is increasing at the same time that highway agencies are being asked to construct long lasting pavements that have both durability and adequate frictional characteristics during wet weather. In addition, the pavement surface profile is expected to provide a smooth ride for vehicle occupants. The portland cement concrete (PCC) paving industry is searching for ways to optimize each of these public needs in an economical and constructible pavement surface.

BACKGROUND

In 2004, Iowa State University, through its National Concrete Pavement Technology Center (CP Tech Center) and at the request of a broad industry coalition, formally designated Concrete Pavement Surface Characteristics as a principal focus area for future research, technology development, and technology transfer. (Note: The CP Tech Center was known as the Center for Portland Cement Concrete Pavement Technology, or PCC Center, at the time this project was initiated; the new name is used here throughout for consistency.)

The Federal Highway Administration (FHWA) and the CP Tech Center recognized strength in partnering, and signed a cooperative agreement that called for mutual cooperation in addressing the issues related to concrete pavement surface characteristics. The agreement called for the development of a $325,000 comprehensive action plan for concrete pavements and identified pavement noise solutions that must not adversely affect smoothness, safety, life expectancy, or require excessive or continuous maintenance.

To execute the action plan, the FHWA/CP Tech Center mutually funded a three-phase program as follows and as shown in Table 1:

1. Develop a comprehensive strategic plan for surface characteristics, working with all appropriate parties. The FHWA and the CP Tech Center agree that without a plan, the application of research funds from a multitude of agencies may leave gaps, be duplicative, or be ineffective in finding solutions.
2. Prepare comprehensive documentation on all concrete pavement noise reduction trials, with a specific focus on European and U.S. methods. This investigation includes interviews with many of the innovators who have worked with these techniques first-hand. The report will compile information on design, bidding, construction, quality control, maintenance, and field evaluations. It will also include information collected over the course of the project about noise, ride, friction, spray, etc., to assure that the noise solution has been properly integrated with other surface characteristics.
3. Following the completion of the strategic plan, the CP Tech Center will provide continuous surface characteristics management services. This will include preparation of status reports, coordination, outreach efforts (including TRB presentation management), analyses of results as they relate to the goals and objectives, and adjustments and updates to the plan. Additionally, the CP Tech Center will develop and implement a comprehensive program to work with the American Concrete Pavement Association

(ACPA) and its chapters and members on field research to ensure that the ACPA is fully aware of and understands the initiatives, findings, and ongoing activities.

Table 1. Summary of current FHWA/CP Tech Center surface characteristics research (Part 1)

Task	Title	ISU FY 2004 federal appropriation	FHWA funding	Start date	End date
1	Strategic Plan	$175,000		7/2004	7/2005
2	Evaluate Europe and U.S. Methods and Results		$75,000	1/1/2005	8/30/2005
3	Strategic Plan Management		$75,000	1/1/2005	12/31/2005
Summary of FY 2004/2005 funding		**$175,000**	**$150,000**	**Total $325,000**	

PROPOSED RESEARCH FOR PART 2

In 2005, the ACPA joined the FHWA/CP Tech Center effort to form Part 2 of the National Surface Characteristics Field Experiment Plan. The ACPA has pledged financial and technical expertise and is helping to develop the national plan for concrete pavement texturing related to noise generation at the tire-pavement interface. Other partners have directly and indirectly pledged cooperation and support, including the California Department of Transportation (Caltrans), the International Grinding and Grooving Association, and the Iowa Concrete Paving Association.

The 2005/2006 National Surface Characteristics Field Experiment Plan called for the measurement and analysis of conventional texturing variations and grinding techniques. The construction, measurement, and analysis of new and innovative surfaces, such as exposed aggregate, will be developed in 2006/2007. The 2005/2006 national plan includes the simultaneous measurement of noise, smoothness, friction, and texture. The experiment is based on continuously measuring all four properties, identifying the rate of change in the properties, and then linking them all back to specific changes in noise.

The following funding was proposed for the 2005/2006 National Surface Characteristics Field Experiment Plan:

FHWA	$211,000
CP Tech Center federal appropriation	$150,000
ACPA	$261,000
Iowa Highway Research Board	$ 96,700
Total	**$718,700**

The 2005/2006 national experimental plan called for two “Type 1” sites for new construction using conventional texture variations, two “Type 1” sites with grinding variations, up to eight existing “Type 2” projects with comprehensive analysis, and 24 additional “Type 3” sites with noise and texture measurements only.

To meet the overall program schedule, the work was underway in the summer of 2005. However, monitoring was anticipated to continue for at least five years on an annual basis. The plan recommended a test section with a low traffic volume to facilitate measurements, but with high (possibly seasonal) traffic loads to accelerate texture wear. Furthermore, the plan recommended flat, tangent roadway geometrics, if possible, to eliminate bias and interference in the noise and friction measurements. The detailed plan included the recommended test layout and was a function of the specific project selected.

The Iowa Department of Transportation (DOT) project is identified as one of the two Type 1 construction sites selected for the 2005/2006 placement, evaluation, and monitoring of approximately ten texture configurations. It was proposed that the funding for this research come from the Iowa Highway Research Board. The configurations proposed for the Iowa project included conventional texture variations, specifically three transverse, five longitudinal, one turf, and one burlap.

Additional sites in Iowa for Types 2 and 3 evaluations were selected with the above referenced funding from the FHWA or ACPA.

OBJECTIVES

The objectives of the national study are as follows:

1. To design, procure, build, test, and evaluate various concrete pavement texture patterns that address noise reduction in relation to friction, smoothness, and texture, as well as the patterns' rates of change in service.
2. To analyze data from over 35 existing sites in the United States, benchmarking Iowa values.
3. To develop best practices guidance for Iowa for optimizing texturing, which includes balancing noise considerations with friction and smoothness.

The Iowa research was developed to include the construction of up to ten texture configurations: longitudinal and transverse tining, broom, and drag at one 6,000-foot site or possibly two 3,000-foot sites. Each texture was to include variations in geometry, such as width and depth. Initially, test sections of a minimum of 500 feet and intermediate gaps of 100 feet were considered for each texture configuration. The final length and number of texture types were reviewed with the Iowa DOT based on the project length, potential impact on costs, production sequencing, and coordination with the contractor.

The Iowa experiment called for noise data collection inside the vehicle, at the tire-pavement interface, and at the wayside, along with texture, smoothness, and friction data. This study distinguished itself from other studies by collecting mega-, macro-, and microtexture data using a variety of test equipment. Equipment identified to date includes inertial profiling, a dynamic friction tester, circular texture meter, advanced line laser-based texture equipment, friction (skid) trailers, and X-ray tomography. The study called for the collection of this data over the first seven days of operation and again for approximately one day, 30 and 60 days after construction, to better define the following: (1) the relationship between noise and texture and (2) the rate of change in texture, smoothness, friction, and noise over time.

EXPERIMENTAL PLAN

Accomplish the listed objectives required the application of various surface texturing methods in the course of a concrete paving project. The national study team developed a list of potential textures to be evaluated. This list was discussed with Iowa DOT representatives and representatives of the ACPA. The combined needs of all representatives resulted in 18 different combinations of tining, burlap drag, AstroTurf, and grinding texturing methods.

Each section was designed to be approximately 200 or more meters in length. Texture depth was to be measured at prescribed locations across the pavement and at 50-meter increments longitudinally. In addition, two weather stations were used at each end of the day's work to record the climate conditions during the placement. This data was collected to allow a review of the impact of weather on the ability to texture the pavement surface.

The Iowa DOT staff agreed to allow the project to be built on a section of US Highway 30 near LeGrand, Iowa. The contractor for the project was the Fred Carlson Co. of Decorah, Iowa.

SITE DESCRIPTION

The site for the research work was located on US Highway 30 approximately 2.41 km east of LeGrand, Iowa. It consists of a section of the eastbound lanes for a length of approximately 4.02 km through Iowa riverbottom area. The site is shown in Figure 1.

The pavement cross section consists of a monolithic slab that is 260 mm in depth and 7.8 m in width. The width is divided into a 3.6 m passing lane and a 4.2 m driving lane. The slab is constructed on a 260 mm thick granular base of well-graded crushed limestone that is 11 m in width. The median shoulder consists of a 1.8 m asphaltic concrete shoulder, of which 1.6 m is asphalt cement concrete (ACC) and 0.2 m is crushed stone. The outside shoulder is 2.4 m in top width, of which 1.6 m is ACC and 0.8 m is crushed stone. There are 6:1 slopes on the earth outside of each shoulder. Longitudinal subdrains are installed along the outside edge of the driving lane at a depth of 1.22 m (4 ft) in selected locations.

In 2001, the average daily traffic (ADT) on the two-lane section of US Highway 30 in the project area was 8,310. The design ADT for this route in year 2021 is 11,210, with 10% being trucks. The design loading is 9,920,190 equivalent single axle loads. A quarry, located 2.41 km north of the west end of the project, will provide a large number of heavy vehicles to the traffic mix that will use this pavement in the future. The quarry serves as a plant site for asphalt and portland cement concrete mobile operations in the area.

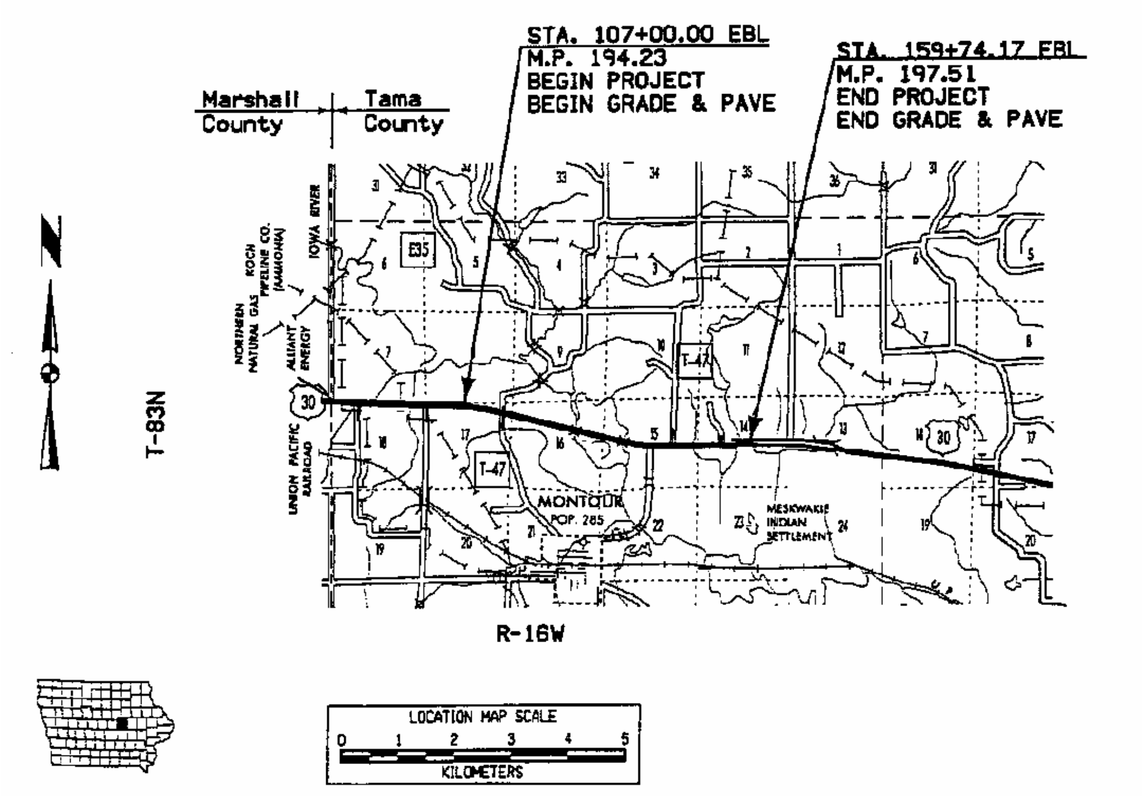

Figure 1. Site plan

DATA COLLECTION METHOD

The slab was constructed using conventional slipform paving equipment. The paving train consisted of a belt placer, followed by the full pavement width slipform paver, pre-texture bridge, and cure/texture machine, as shown in Figure 2. The various textures were obtained by making changes in the pre-texture material at the bridge location and changing the type, depth, and spacing of texture applied by the cure/texture machine. An additional special bridge was added at the rear of the train to allow for the collection of texture depth data. The entire spread of equipment is guided horizontally and vertically by stringlines on both sides of the pavement.

Figure 2. Paving train

Texture data for this project was collected by a four-person crew. One person was employed to observe the operations of the texture/cure machine (Figure 3). Two others were employed on the portable bridge behind the texture/cure machine to conduct texture depth measurements at prescribed locations across the slab, at each 50-meter increment in the test sections (Figure 4).

Figure 3. Tining machine operations

Figure 4. Portable bridge

The test sections were placed end to end where possible to reduce the chance for errors in construction and provide adequate project length to accommodate the 18 test sections. The beginning and ending of each section was identified with a paper pie plate attached to a lath (Figure 5). The plate provided the contractor and the research staff with advance notice of changes in texture, where equipment or methods needed to be modified prior to passing the marker. The 200-meter length also allowed for transitions between each section at each end of the test section (approximately 25 m on each end). These transitions allowed for an adequate sound measuring area in the middle of the test site and adequate distance on each end for the construction/research staff members to make texture changes during paving operations. The transitions also allowed those people to assure themselves that the desired texture was being obtained in the critical parts of the test section.

Figure 5. Paper pie plate marker

For this project, the depths of the tines placed in the concrete at the time of paving were recorded. There were 17 different texture patterns to place, each combining different pre-texture, texture materials, and methods for development. At the beginning of the project, the bridge that is normally attached to the back of tining machine was removed. Eight markers were placed on the bridge to show where data measurements were to be taken. Four markers were placed in each traffic lane: one on the outer edge of the lane, one in each of the two wheel paths, and one at the quarter-point of the lane. These markers were based on measurements of where the lane edges would be from the edge of the slab. The wheel path was measured eighteen inches in from the edge of the slab, and the quarter distance across the lane was the lane width divided by two.

As the pavement was placed, measurements were obtained at 50-meter increments, resulting in 5 measurements for each section (the section length was 200 m). The depths of the tines were measured using a tire tread gauge (obtained at a local auto parts store). Tining depths were recorded in thirty-secondths of an inch (0.794 mm) and converted to metric measures.

To gather data, the data collector lay down on the bridge (Figure 6) and placed the tire gauge (Figure 7) over the edge of the bridge, next to the markers. The tire gauge was placed as close to the marking on the bridge as possible to obtain accurate readings. In some instances, the tire gage had to be placed next to the marker instead of directly in front of it. Crumbs of paste may have covered the tines due to the pre-texture, which would affect the data reading. If the readings were abnormal for a particular tining groove, the data collector moved to the left or right one tining groove to obtain a better result.

Figure 6. Data collection from bridge

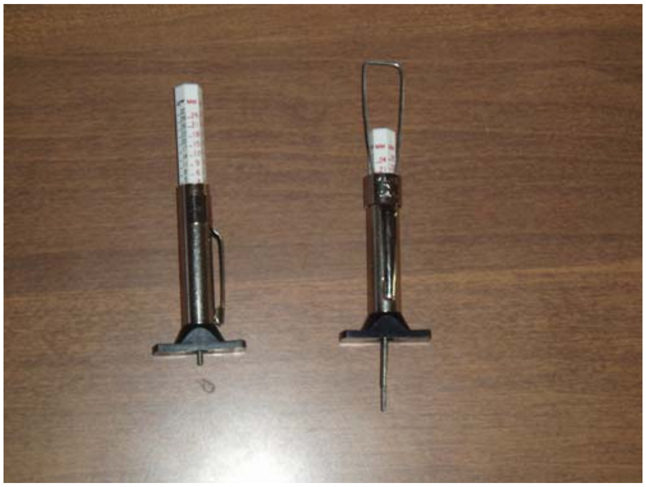

Figure 7. Tire gauge

Along with the tining depth measurements, weather data were collected during each test section. The pavement temperature in each wheel path, air temperature, relative humidity, wet bulb, and wind speed/direction were recorded directly behind the tining machine, during the tining data collection with the handheld devices, as shown in Figures 8 and 9. All measurements, including the depth of the tines, were taken after the curing compound was applied to the pavement. Weather data were also collected from two weather stations, placed at the beginning and end of each paving section for the day.

Figure 8. Weather data instrument

Figure 9. Wind speed instrument

The Iowa DOT Office of Materials was involved in the collection of profile data for each of the sections using the light weight profiler (LISA), shown in Figure 10. Tests were conducted immediately after construction where possible and on the entire project after opening to traffic. The results of these tests were forwarded to the Transtec Group for analysis and inclusion in the national report.

Figure 10. Iowa DOT LISA

The research staff also had the opportunity to use the CP Tech Center's Mobile Concrete Research Laboratory (Figure 11) to test the plastic and hardened concrete. To represent the mix being placed each day, air voids, slump, and compressive and flexural strengths were tested routinely during the project. The Fred Carlson Co. provided its paving mix design for use in the national analysis.

Figure 11. CP Tech Center's Mobile lab research staff

As an additional step in the data collection, photographs were taken of each pavement texture and a rubber mold of the texture was obtained for future demonstration purposes. Figure 12 illustrates the process of using a square mold to develop the negative of the texture in the field. The reverse of this process was used in the lab to create positive casts of each of the textures. In this way, others can see and feel the type of surface desired from the construction process.

Figure 12. Texture mold construction

TEXTURE DEVELOPMENT

Texture development incorporated different configurations of microtexture and macrotexture using a burlap or AstroTurf drag and longitudinal or transverse tining. A complete layout of the US 30 test sections can be seen in Table 2. A plan view of the test section layout can be seen in Figure 13.

Table 2. US 30 test section layout as built, 8/28/05

Day	Sect.	Texture	Spacing	Depth	Pre-texture	Length	Location (metric sta.)
1	008	Long. tine	25.4 mm	3.2 mm	Burlap	200 m	107+70 to 109+70
	101	Long. tine	19.0 mm	3.2 mm	Burlap	400 m	111+00 to 115+00
	004	Long. tine	12.7 mm	3.2 mm	Burlap	200 m	115+50 to 117+50
	009	Burlap	Std. wt.		None	190 m	117+50 to 119+40
2	006	Long. tine	19.0 mm	3.2 mm	None	200 m	120+00 to 122+00
	005	Long. tine	19.0 mm	3.2 mm	Burlap	200 m	122+00 to 124+00
	007	Long. tine	19.0 mm	6.4 mm	Burlap	200 m	124+00 to 126+00
3	204	Burlap	Hv. Wt.	- - - - -	None	200 m	130+00 to 132+00
	001	Transv. tine	12.7 mm	3.2 mm	Burlap	200 m	132+00 to 134+00
	Ia. D	Transv. tine	12.7 mm	1.6 mm	Burlap	200 m	134+00 to 136+00
	002	Transv. tine	25.4 mm	3.2 mm	Burlap	200 m	136+00 to 138+00
	003	Transv. tine	Random	3.2 mm	Burlap	200 m	138+00 to 140+00
4	010	AstroTurf	Std. wt.	- - - - -	None	172 m	140+00 to 141+72
	Special longitudinal grinding section					59 m	141+72 to 142+31
	205	Astrotruf	Hv. Wt.	- - - - -	None	169 m	142+31 to 144+00
	Ia. B	Long. tine	19.0 mm	1.6 mm	AstroTurf	200 m	144+00 to 146+00
	Ia. C	Long. tine	19.0 mm	3.2 mm	AstroTurf	200 m	146+00 to 148+00
	Ia. A	Long. tine	19.0 mm	1.6 mm	Burlap	200 m	148+00 to 150+00

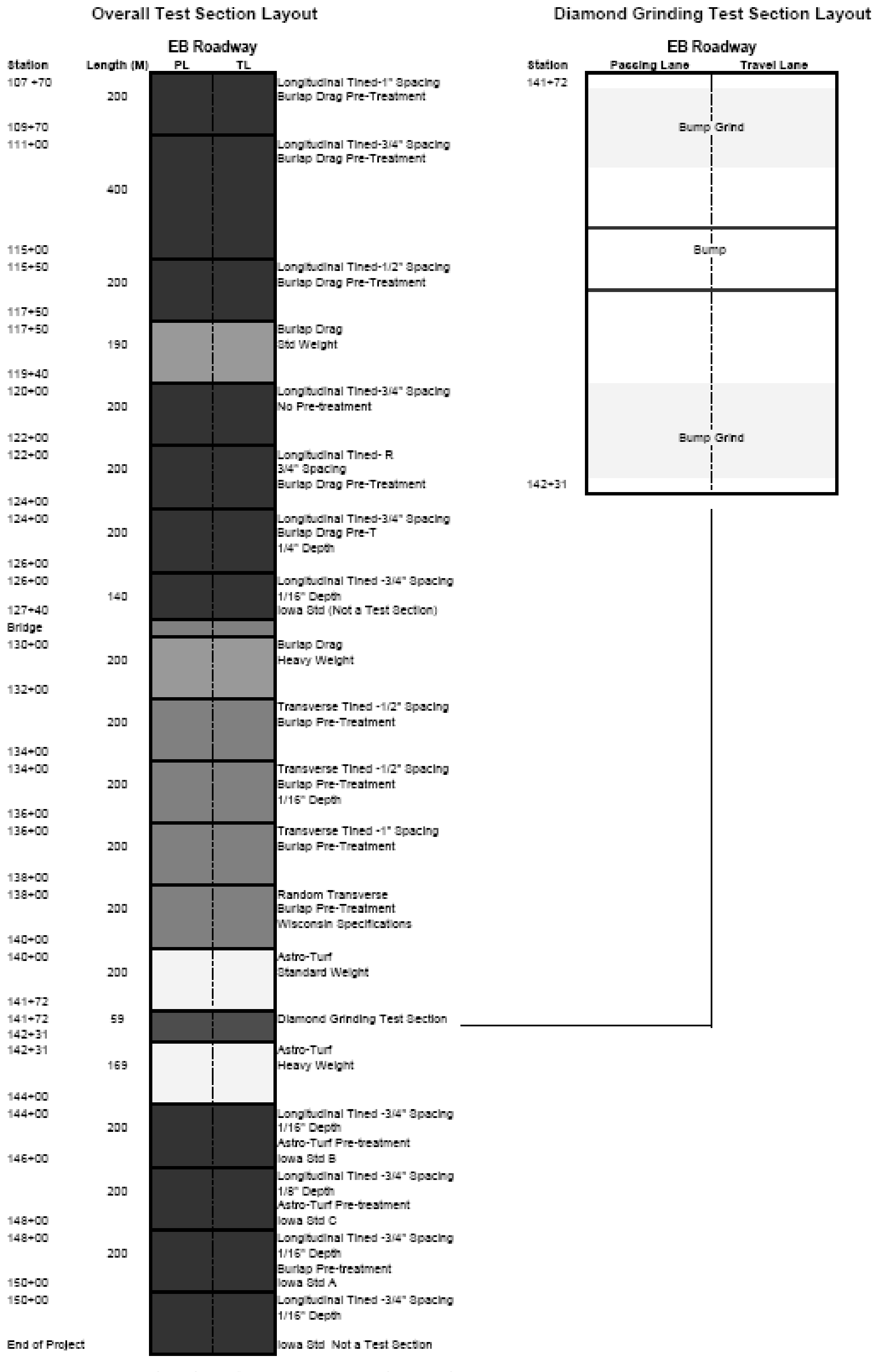

Figure 13. Iowa site 1, US 30 test sections

GENERAL OPERATIONS

Preliminary Texture

The pre-texture on this project was produced using either a burlap or AstroTurf drag. To create the dragging motion, a piece of material (burlap or AstroTurf) spanning the width of the concrete slab was attached to a construction bridge in tow behind the paving machine. Therefore, the application rate of the pre-texture was dependent upon the speed of the paver. As seen in Figures 14 and 15, approximately 0.75 m of pre-texture material was always in contact with the concrete slab.

Figure 14. Burlap drag

Figure 15. AstroTurf drag

Primary Texture

Three methods were used to develop the surface texture. The first two were variations of the burlap and AstroTurf drag, in which additional weight was added to the pre-texture material. The amount of weight added to the burlap was limited by the strength of the material. Extra weight consisted of four shovels of highly calibrated limestone and two 20 ft long #5 rebars, shown in Figures 16 and 17.

Figure 16. Heavy weight burlap texture

Figure 17. Heavy weight AstroTurf texture

Significant concrete buildup was noticed on the AstroTurf drag. The buildup tended to flake off and remain on the slab, making tining difficult (Figure 18).

Figure 18. AstroTurf cleaning problem

The third method was performed with the use of a tining machine. Tining was done in both the longitudinal and transverse directions. Achieving a good texture with the machine depends on the training, knowledge, and experience of the operator. General guidelines for obtaining a target texture include the visual inspection of the product coming out of the slipform paver (apparent moisture content). For a wetter concrete, more pressure is needed to obtain the required depth. To add more pressure, the overall elevation of the machine is lowered. The tining teeth are positioned at a larger angle away from the vertical. For a drier concrete, less pressure is needed and the machine's elevation is raised. The tining teeth are then adjusted to a position closer to vertical. Even pressure should be maintained across the tining broom. Curvatures of the teeth are a strong indication of how much pressure is being applied. Also, periodic cleaning of the broom teeth should be planned to assure uniformity in the depth and cross-section of the tined area.

Close attention should be paid to the speed, position, and master alignment of the tining machine with respect to the slipform paver and the stringline. If the rate of forward movement of the cure/texture machine is too fast, a wavy texture can occur, but the depth of the tining groove is not affected. If the slipform paver's position shifts, the tining machine should follow. The tining machine should be positioned closer to the slipform paver if the concrete shows visual signs of curing prior to tining. For transverse tining, the general operation of the machine does not change from that of the longitudinal tining, but the broom should be positioned so that the consecutive passes run parallel to each other and minimize the overlap. For a complete set of pictures of the test sections, see Figures C1 through C36 in Appendix C.

CONCLUSIONS

Limitations of Longitudinal and Transverse Tining

Although the tining machine is generally used to create the surface texture, there are some limitations to the machine's capabilities. If the concrete slab is too dry, it can be difficult to obtain a deep texture. If transverse tining is being applied, the broom angles can not be adjusted with current equipment designs. In this case, the depth of the tines will vary across the slab, with deeper tines at the crown. When applying longitudinal texturing in a transition to a super-elevation, the horizontal angle of the brooms should be adjusted continually to maintain a uniform tine depth across the slab.

Texture Development

Most of the tining values were lower than what was required for each section, despite adjustments to the tining machine. This could be due to several factors, such as aggregate being too close to the surface of the slab or the concrete being to dry to allow penetration of the tines.

Weather Data

The weather may have contributed to the shallow tining depths. On most days, the air was hot and humid, causing the concrete to set faster. This caused the surface of the slab to be too dry for the tines to be placed deeply enough.

The weather data was collected behind the tining machine, at the same time as the data collection. Weather stations were placed at the beginning of the project (BOP) and the end of the project (EOP) for each day of paving. Table B1 in Appendix B summarizes the weather data collected on the slab. Table B2 contains the average weather data for each day.

Data Collection

It is very difficult to place tines at required depths and maintain those depths throughout the test section. There are many factors to consider when tining, such as weather, paving train forward speed, length of haul of the concrete, and the moisture content of the concrete. The aggregate will also affect the tining depths by preventing the comb from sinking into the slab to the correct depth. For tining depth values, see Table B1 in Appendix B. The following was observed:

- For the sections in which only burlap or AstroTurf was applied, the depth of the texture was minimal, if present at all.
- It was difficult to obtain accurate values for the tining depths with the instruments because of the fresh concrete. The tire gauge needle was sharp enough that it would sink into the surface if placed too roughly.
- If the bridge was bumped or moved during a measurement, the motion affected the accuracy of the measurement.

RECOMMENDATIONS

When trying to achieve a certain tining depth, it is important to maintain a consistent concrete mixture and move the paving train forward constantly at a uniform rate of speed. Concrete batches that vary from each other in terms of moisture content can affect the depths of the tines. Uniformity in moisture content to meet the construction needs for pavement edge control and texturing and to account for atmospheric conditions is essential for good, consistent texturing.

The type of pre-texture and its application to the slab is important. If AstroTurf is used, it must remain clean so as not to leave buildup on the slab surface. This necessity may require several replacements during the day to allow for one drag to be cleaned while another applies the texture.

Uniformity in material moisture and the rate of delivery to the slipform paver is essential. It is also important to look at the type of tines (shape, length, and stiffness) to match them to the mix and field conditions. The goal is to leave a specified mark depth on the fresh concrete without dragging materials to the surface and increasing profile and noise values.

APPENDIX A

Table A1. Average tining depths per station (mm)

Sect.	Lt. edge	WP	¼ pt	WP	WP	¼ pt	WP	Rt. edge
008	3.37	2.59	2.95	2.84	3.52	3.37	3.17	3.38
101	2.41	2.69	2.45	2.56	3.01	2.83	2.91	2.88
004	2.89	2.78	2.70	2.67	2.87	2.68	2.68	2.87
009	1.10	1.18	1.57	1.29	1.14	0.94	0.98	1.03
006	2.02	2.78	3.37	2.67	2.48	2.48	2.06	2.24
005	2.13	3.10	2.60	2.59	2.51	2.62	2.40	2.30
007	4.41	3.92	3.80	3.95	3.95	3.57	3.73	3.10
204	0.78	1.06	1.06	0.73	0.86	0.84	0.58	0.81
001	2.30	2.02	2.10	2.54	2.91	2.29	2.13	2.46
Ia.D	1.57	1.89	1.64	1.65	1.76	1.54	1.73	1.83
002	1.79	1.87	1.94	2.46	1.92	1.73	1.94	1.91
003	2.37	2.24	2.30	2.43	2.87	2.38	2.48	2.78
010	1.91	1.79	1.98	1.67	1.67	1.13	1.67	1.30
205	1.14	1.08	1.32	0.97	0.81	0.98	0.98	0.98
Ia. B	1.91	1.45	1.49	1.86	1.87	1.59	1.48	1.46
Ia. C	2.06	2.00	1.90	2.11	1.70	2.18	1.59	1.57
Ia. A	1.79	1.88	2.06	1.73	2.03	1.99	2.06	1.52

APPENDIX B

Table B1. Weather data behind tining machine

Sect.	Pav. temp., °F		Relative humidity,	Air temp., °F	Wet bulb		Relative humidity, %		Wind spd.,
	Lt. WP	Rt. WP	%		%	°F	min	max	kph
008	74.94	76.63	45.71	91.26	45.73	73.35	37.06	54.25	4.33
101	78.76	80.74	33.01	101.88	34.88	77.36	28.17	39.60	4.55
004	78.68	78.88	36.9	98.28	38.82	77.02	32.1	46.58	5.02
009	76.30	75.88	45.10	94.45	45.45	76.18	39.58	52.10	3.70
006	82.70	82.84	73.26	83.22	74.14	74.88	69.58	76.96	0.93
005	86.68	87.58	43.84	94.9	44.36	76.16	41.34	50.22	2.14
007	85.32	85.48	33.34	102.42	37.52	77.16	29.70	46.56	1.61
204	82.84	82.56	65.28	83.72	69.14	74.14	65.7	75.08	1.48
001	87.10	87.66	46.04	97.46	48.04	80.34	44.82	51.56	4.31
Ia.D	88.20	89.02	42.78	100.44	43.74	80.02	40.12	37.96	7.88
002	90.18	90.32	35.84	107.08	37.70	83.18	33.68	43.06	3.75
003	89.44	89.38	35.46	103.48	35.74	77.56	33.26	40.16	4.47
010	77.96	77.86	71.8	73.3	71.26	66.58	66.66	81.18	0.00
205	80.68	80.78	37.56	95.24	38.32	32.86	32.86	47.02	2.61
Ia. B	80.16	80.02	29.20	100.06	32.14	73.26	28.16	38.20	7.40
Ia. C	67.25	81.7	29.78	97.94	30.56	72.74	23.7	33.42	6.89
Ia. A	79.02	79.20	31.68	94.62	33.04	71.68	27.90	34.68	6.44

Table B2. Average weather station data

Location	Date	Temperature, °F	Relative humidity, %	Wind speed, kph	Wind dir., degrees
BOP	7-13-05	84.32	56.17	6.69	60.05
	7-14-05	83.86	61.68	2.35	125.23
	7-15-05	88.98	57.20	3.39	224.74
	7-19-05	80.52	55.03	4.41	206.22
EOP	7-13-05	84.58	54.25	6.19	100.53
	7-14-05	82.90	62.23	1.90	206.88
	7-15-05	86.42	58.69	5.10	263.12
	7-19-05	78.7	54.84	7.08	233.39

APPENDIX C

The following are images of the test sections. All photos taken in the direction of travel on the road.

Figure C1. Iowa standard

Figure C2. Iowa standard

Figure C3. Iowa A

Figure C4. Iowa A

Figure C5. Iowa B

Figure C6. Iowa B

Figure C7. Iowa C

Figure C8. Iowa C

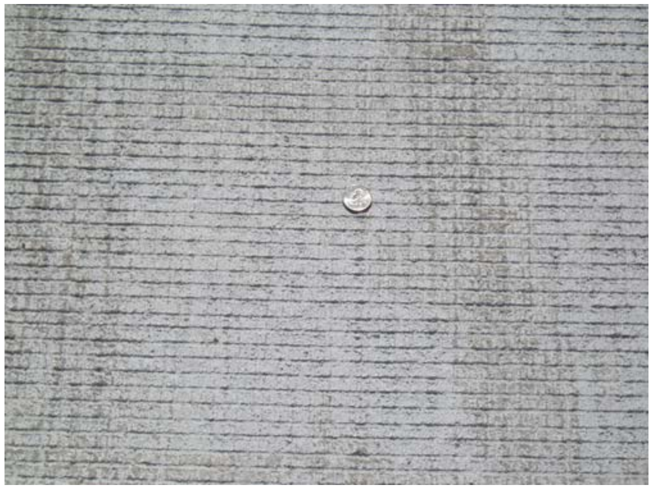

Figure C9. Iowa D

Figure C10. Iowa D

Figure C11. Section 010

Figure C12. Section 010

Figure C13. Section 205

Figure C14. Section 205

Figure C15. Section 004

Figure C16. Section 004

Figure C17. Section 008

Figure C18. Section 008

Figure C19. Section 101

Figure C20. Section 101

Figure C21. Section 001

Figure C22. Section 001

Figure C23. Section 002

Figure C24. Section 002

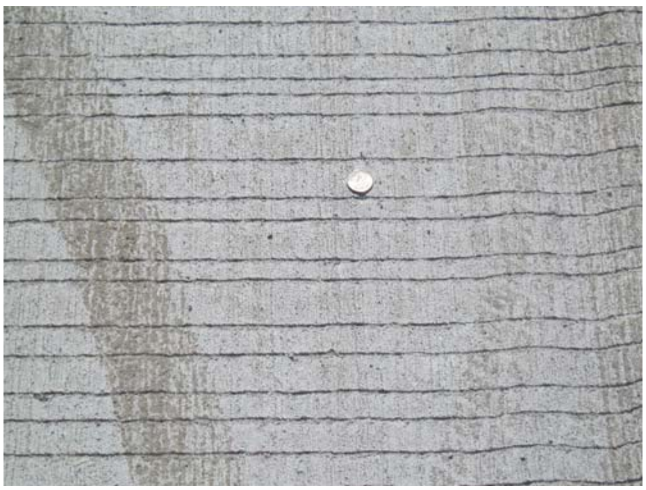

Figure C25. Section 003

Figure C26. Section 003

Figure C27. Section 005

Figure C28. Section 005

Figure C29. Section 006

Figure C30. Section 006

Figure C31. Section 007

Figure C32. Section 007

Figure C33. Section 009

Figure C34. Section 009

Figure C35. Section 204

Figure C36. Section 204

Figure C37. Diamond grinding

Figure C38. Diamond grinding