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Final Report

PCCP TEXTURING METHODS

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January 2005

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH

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16. Abstract:

This report presents a 5-year evaluation and construction details of nine test sections with varying textural characteristics. Included in the report is an overview of the methodologies used to texture concrete pavement surfaces and a discussion of frictional attributes of various textures at different speeds and their impact on noise properties. Also included are descriptions of texture-measuring devices and texture-installing equipment, a description of the state-of-the-art equipment used to acquire sound pressure levels, plus a thorough discussion of data acquisition/analysis.

Frictional characteristics of the individual test sections were evaluated using the ASTM E 274 skid test procedure. Ribbed-tire and smooth-tire friction tests were conducted to acquire skid numbers at three different speeds of 40, 50, and 65 mph. To examine the noise properties of the test sections, noise measurements were acquired to acoustically asses the impact of various surface textures at three different locations:

- Inside the test vehicle
- 25 feet from the centerline (3 feet away from the right shoulder)
- Near the right rear tire of the test vehicle, away from the exhaust pipe.

Implementation:

The results of this study indicated that longitudinal tining, in addition to possessing adequate frictional properties, is easier to install and, more importantly, produces a much lower noise level than transverse tining. CDOT has adopted longitudinal tining as the preferred method of texturing concrete pavements.

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by

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Sponsored by the
Colorado Department of Transportation
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EXECUTIVE SUMMARY

This report presents the final results of the "PCCP Texturing Methods" research study, documenting the noise properties and the frictional characteristics of various concrete pavement textures. The report describes the testing and construction details of nine test sections with varying textural characteristics. Included in this report is an overview of the methodologies used to texture concrete pavement surface and a discussion of frictional attributes of various surface textures at different speeds and their impact on noise properties. Also included in the report is a description of the state-of-the-art equipment used to acquire sound pressure levels, texture-measuring devices and texture installing equipment, plus a discussion of data acquisition/analysis.

To evaluate the frictional characteristics of individual test sections, skid numbers were acquired according to ASTM E 274 skid testing procedure. Ribbed-tire (ASTM E 501) and Smooth-tire (ASTM E 524) friction tests were conducted to obtain skid numbers at 40, 50, and 65 mph for all the test sections. Five skid resistance tests were conducted for each test section, as required by the standard ASTM procedure E 274. The arithmetic averages of the skid resistance tests were then used to indicate the skid number (SN) for individual test sections at a specified speed.

Review of the acquired data revealed a definite relationship between speed, types of surface texture, and the magnitude of skid numbers. As speed increased, the skid numbers declined. This relationship was clearly more pronounced and consistent using the smooth tire. Skid numbers acquired with the smooth tire clearly showed a distinct difference in magnitude for surfaces with macrotexture and microtexture. The difference in skid numbers for microtexture and macrotexture were not as evident or consistent using the ribbed tire. This phenomenon confirmed the findings of many research papers, revealing the insensitivity of the ribbed-tire towards macrotexture.

Numerous texture-measuring devices provided by FHWA were used to quantitatively measure texture depth. The various methods used to measure the depth of textures included: Texture van, Texture Beam with an LVDT and a Laser Stylus, Outflow Meter, Tire Tread Gauge and the standard Sand-Patch test. Explanations of these innovative techniques are presented in the body of the report.

Noise measurements were acquired as a joint effort between the CDOT's Research Branch and a local noise consultant, David L. Adams Associates, Inc. The primary purpose of the measurements was to acoustically assess the impact of various surface textures installed in the test sections. Sound pressure levels (SPL) were acquired at the following three locations:

- Inside the test vehicle
- 25 feet from the center line (3 feet away from the right shoulder)
- Near the right rear tire of the test vehicle, away from the exhaust pipe

The sound pressure levels generated at the control section were normalized to represent a datum (zero SPL), and were compared with SPL taken from other test sections. Longitudinal macrotexture and microtexture were the most quiet surfaces based on the SPL taken at the shoulder, inside the test vehicle and at the rear tire. State standard section (combination of uniform 1-inch spacing) exhibited the highest noise level among all the test sections, with the microphone at the rear tire position.

Implementation Statement

The results of this study indicated that longitudinal tining, in addition to possessing adequate frictional properties, provides the following advantages over the traditional CDOT's standard transverse tining:

- Lower noise level
- Ease of installation
- Lower costs

CDOT has already adopted the longitudinal tining as a preferred method of texturing concrete pavements.

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1.0 INTRODUCTION

Surface texture in rigid pavements plays an important role in providing safety (providing skid resistant surfaces) for the travelling public. The depth, spacing, and orientation (transverse or longitudinal) of the surface texture can significantly affect the frictional characteristics, noise properties, and quality of ride.

In general, transverse tining has been the only permitted method of texturing used by the Colorado Department of Transportation (CDOT) and the majority of the other transportation agencies. There are a few states that use longitudinal tining or sawing to texture their pavements on a regular basis and are quite satisfied with its performance. Among them is the State of California, which has continued to this date to longitudinally texture concrete pavements.

The frictional characteristics of the concrete pavement surface can be divided into two general groups: microtexture and macrotexture. Microtexture comes primarily from exposing the sand particles in the mortar (1), while macrotexture refers to grooves and channels formed in the plastic and/or in the hardened concrete. Forster (2), in the Transportation Research Record 1215, defines microtexture as those "surface asperities less than 0.5 mm in height and macrotexture as those with surface asperities of greater than 0.5 mm in height".

Macrotexture, with its channels and grooves, provides a drainage system that allows water to escape from under the tire, and consequently plays an important role in reducing the likelihood of hydroplaning. As discussed by the American Concrete Institute Committee (3), the term "hydroplaning" refers to the separation of tire contact from the pavement surface by a layer of water which causes loss of steering and braking control of the vehicle. This phenomenon is complex and is a function of water depth, vehicle speed, tire-inflation pressure, pavement texture and tire-tread depth and design.

The type and quality of fine aggregate used in a concrete mix plays an important role in maintaining adequate skid resistance characteristics. As discussed in the FHWA Technical Advisory T 5050.17 (4), "regardless of the finishing or texturing method used, adequate durable skid resistance characteristics cannot be attained unless the fine aggregate has suitable wear and polish resistance characteristics".

Research by the Portland Cement Association indicates that the siliceous particle content of the fine aggregate should be greater than 25 percent in order to maintain longer lasting skid resistance characteristics. However, it should be noted that the presence of siliceous particles in a concrete mix might pose the possibility of alkali-silica reactions (ASR). Remedial measures should be taken to overcome the ASR reactions.

The most widely used method (indirect method) of acquiring frictional data (skid numbers) in the United States is the ASTM E 274 skid testing procedure with a ribbed tire (ASTM E 501). According to many of the papers reviewed on the subject of the skid testing, the ribbed tire lacks sensitivity to draining capability of pavement macrotexture, while it shows high sensitivity to pavement microtexture.

The primary reason for the ribbed tire's insensitivity to macrotexture is its deep grooves, which provide drainage for water regardless of pavement macrotexture. On the other hand, tests with the smooth-tire (ASTM E 524) have produced skid-resistance data which are sensitive to both macrotexture and microtexture (5). Another advantage of using a smooth tire is that the influence of tire wear on the friction data is eliminated (6). Photograph 1 compares the ribbed and the smooth tires.

In general, skid numbers are acquired with a skid trailer by the ASTM method E 274 in the United States. These numbers are used by the states as guidelines for evaluating the frictional characteristics of pavements. However, as discussed in the National Cooperative Highway Research Program (NCHRP) report number 104, "no state establishes statutory requirements for

Photo 1: View of the ribbed tire (ASTM E 501 and
The smooth tire (ASTM E524)

minimum skid resistance" (7). Liability implications may be the primary reason for not establishing such statutory requirements for minimum skid resistance.

Reported skid number (SN) guidelines, range from 30 to 40 for interstate highways and all highways with legal speeds in excess of 40 mph (65 km/h). Lower skid numbers are generally acceptable for urban areas where speed limits are less than 40 mph and for roads with the average daily traffic (ADT) of less than 3000 vehicles (7).

There are numerous direct methods available to quantitatively measure texture. Among the ones that were used for this study were: the Texture van; the Texture Beam consisting of an LVDT (Linear Voltage Differential Transducer) and a Commercial Laser Stylus; the Outflow Meter (indirect method); the Tire Tread Depth Gauge; and the standard Sand Patch Method. A complete description of all these methods is presented in section 5.2.

The pavement surface texture not only impacts the frictional characteristics, but also plays a major role on the magnitude of the noise generated at the interface of the tire and pavement surface. To examine the noise characteristics of the various surface textures, noise data were acquired at the following three locations:

1. Inside the test vehicle
2. 25 feet from the center line (3 feet away from the right shoulder)
3. Near the right rear tire of the test vehicle away from the exhaust pipe

Noise data acquisition was conducted as a joint effort between the CDOT's Research Branch and a local noise consultant, David L. Adams Associates, INC. The test vehicle used was a 1994 Oldsmobile Cutlass Sierra station wagon provided by CDOT. A thorough analysis of the acquired noise data is presented in section 5.3.

2.0 BACKGROUND

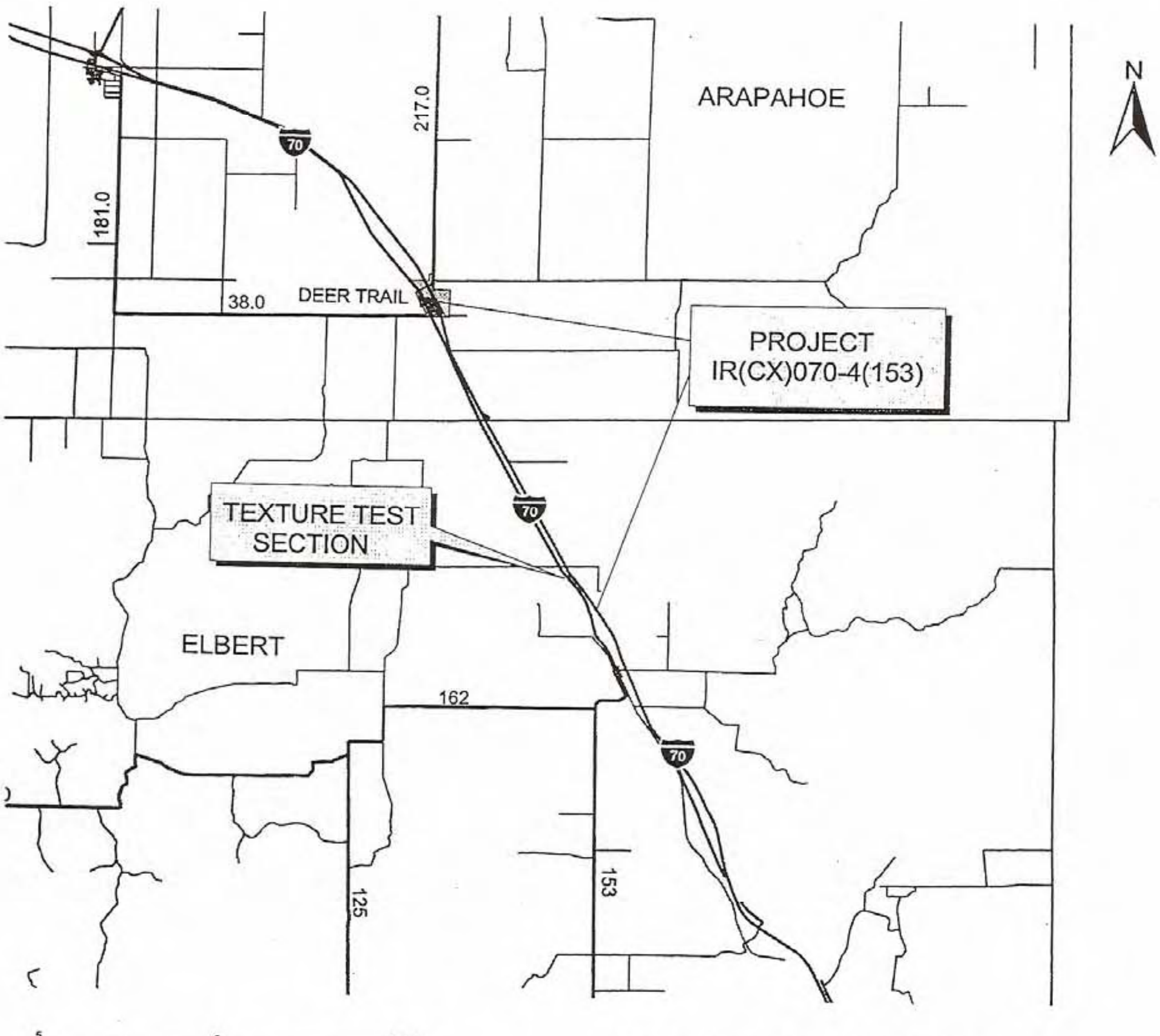
There are a number of methods used to texture the surface of Portland cement concrete pavements. The effects of these texturing methods are not well defined. Some pavement engineers feel that texturing especially formed when the concrete is in the plastic state has an adverse effect on the long-term performance of rigid pavements. Some, on the other hand believe that texturing plays an important role in providing a drainage system for the surface water and creating a skid resistance surface with adequate friction for the travelling public.

There is also the noise issue, both in the urban and rural areas. Some recent research papers have indicated that a change in the surface texture can have a profound effect on the traffic induced noise characteristics. Very little is known about the effectiveness of various texturing methods used by the Colorado Department of Transportation (CDOT) and other transportation agencies.

Questions have been raised regarding constructability, cost, and the performance of various surface textures in rigid pavements. What are the impacts of various texturing methods on the frictional characteristics, noise properties, and on the ride quality of the rigid pavements? Based on the recommendations of the American Concrete Pavement Association (ACPA) and CDOT Oversight Group, and in an attempt to answer some of these questions, the Research Branch of CDOT in cooperation with Region I Materials, initiated a study to examine the pros and cons of various texturing methods.

The ultimate goal of was to develop guidelines and specifications for future construction. To achieve the objectives of this study, nine test sections with various textures were installed on a stretch of Interstate 70, 50 miles east of Denver, Colorado (Figure 1). This final report describes the construction, data collection and data analysis for all the test sections.

Figure 1



Date Produced: November 18, 1999

3.0 OBJECTIVES

The primary objectives of this study were:

1. To document the constructability, costs, and the functional practicability of several PCCP surface textures installed on I-70 for the project IR (CX)70 - 4 (153) in Colorado.

2. To assess the long-term impacts of various surface textures on the frictional characteristics, noise properties, and the ride quality of concrete pavements.

3. To identify the best performing surface texture that is cost-effective, minimizes tire noise and provides adequate frictional characteristics over a long period.

4.0 PCCP TEXTURING METHODS

4.1 Site Description

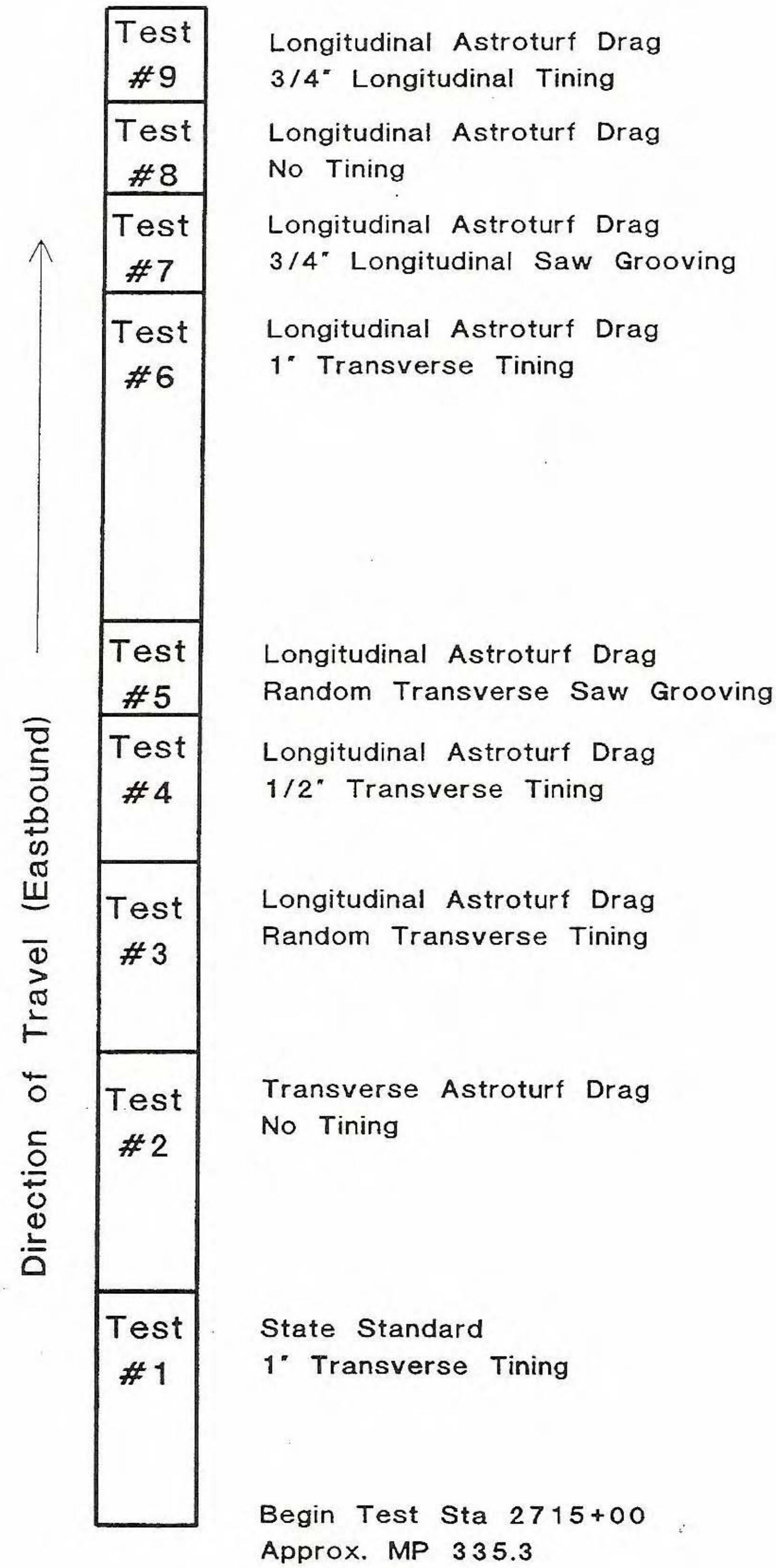
The subject research site is located on I-70, "Project IR (CX) 070 -4", approximately 60 miles east of Denver. It has an average daily traffic (ADT) of 6600 vehicles, with 40 percent of that consisting of heavy vehicles. The construction consisted of paving 10 miles of I-70 from Deer Trail East, beginning at about milepost 328. The 30-year design called for a full depth overlay of concrete Class P with a nominal thickness of 11 inches over the badly deteriorated existing concrete pavement.

The siliceous particle content of the fine aggregate was measured at approximately 96 percent using the ASTM test D 3042. This is well over the limit of 25 percent recommended by the Portland Cement Association indicating a very polish resistant fine aggregate with very little carbonates. This divided four-lane interstate highway will receive an accumulated 18-K ESAL of 21,300,000 over the next 30 years.

The details of the concrete mix design, including the test results from the siliceous particle content of the fine aggregate, are presented in Appendix C. The following is the description of all the test sections:

Stations	Texturing Method Used	Length in ft.
1) 2715 - 2743	transverse tining 1"/ state standard	2800
2) 2743 - 2768	trans. astro-turf/ no tining	2500
3) 2768 - 2789	long. astro-turf/ trans. tining random	2100
4) 2789 - 2806	long. astro-turf/ trans. tining 1/2"	1700
5) 442 - 452	long. astro-turf/ trans. sawing random	1000
6) 452 - 480	long. astro-turf/ trans. tining 1"	2800
7) 480 - 490	long. astro-turf/ long. sawing 3/4"	1000
8) 490 - 500	long. astro-turf/ no tining	1000
9) 500 - 510	long. astro-turf/ long. tining 3/4"	1000

Figure 2
CONCRETE TEXTURING STUDY on I 70 at DEER TRAIL
TEST SECTION LAYOUT
(Length is to scale)



Note: Burlap drag was applied to all test sections immediately behind the paver as shown in Photograph 2. The depth and the width of all the tining and sawing were specified at 1/8" ± 1/16".

Figure 2 shows the sequence of the test sections as constructed.

4.2 Construction of Test Sections

The construction of the test sections began with paving the eastbound lanes from the east end westerly, beginning at station 510. The first test section (section 9) installed was textured with longitudinal astro-turf, followed by longitudinal tining. The tines were uniformly spaced at 3/4-inch intervals. To install longitudinal tining, the tining operator had to modify the tining equipment (bridge). The tining springs were assembled on the bottom of a steel truss, which in turn was secured to the bottom of the tining bridge.

Photograph 3 illustrates the entire tining assembly. Sensors at the four corners of the tining bridge were used to adjust the elevation and to achieve proper compression on the tining springs.

The tining-bridge was also used to drag astro-turf in the front and to apply curing compound from the back. During the installation of the longitudinal tining, the tines rolled the concrete paste (mortar) into popcorn-like balls all over the surface of the pavement (Photograph 4). However, once the concrete cured, these mortar balls were crushed by the traffic at the construction site and then easily removed by brooming.

Every time the tining operation was stopped, the tines formed a transverse indentation across the pavement surface as shown in Photograph 5. For future longitudinal tining, the contractor should be required to make provisions for raising the tines when the tining operation is stopped. This should prevent indentation of the plastic concrete surface.

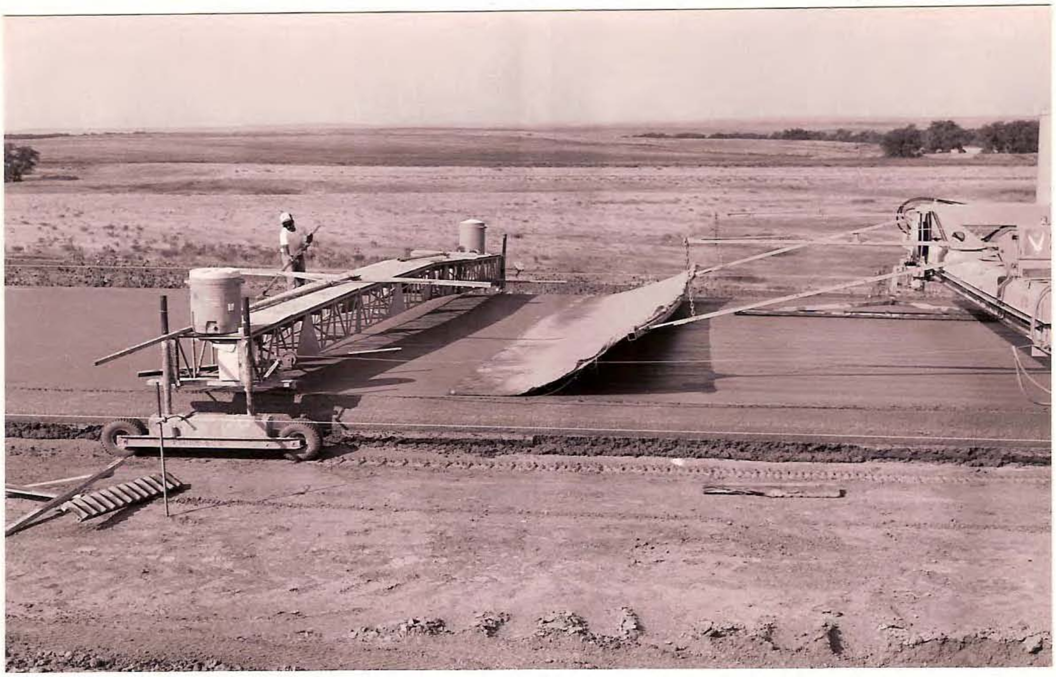


Photo 2: Burlap drag was applied to all test sections

Photo 3: View of the longitudinal tining assembly

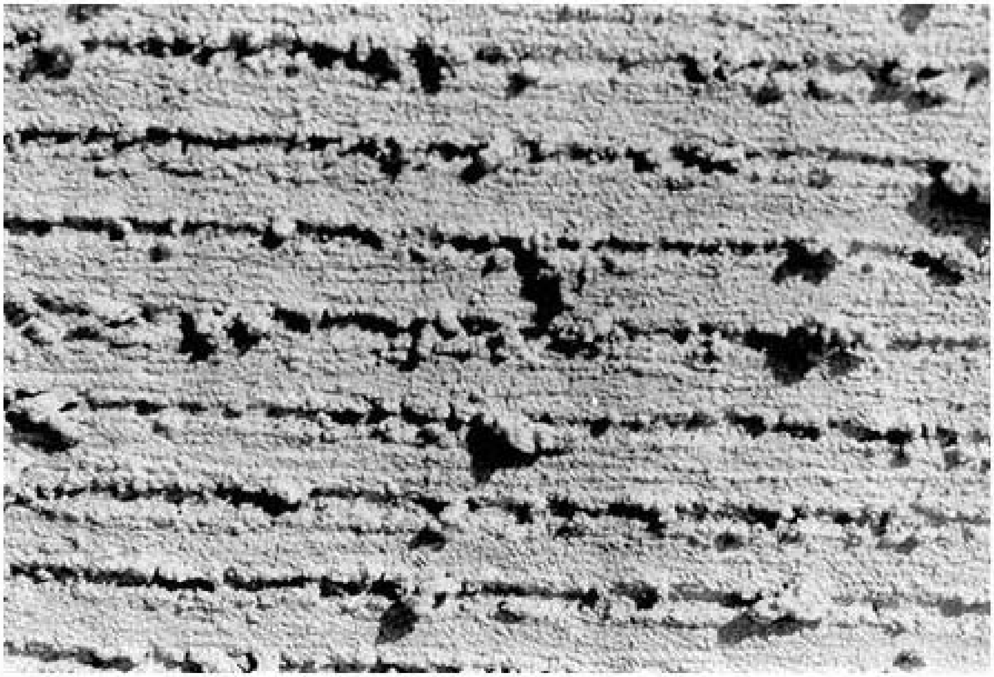


Photo 4: Popcorn-like mortar balls (longitudinal tining)

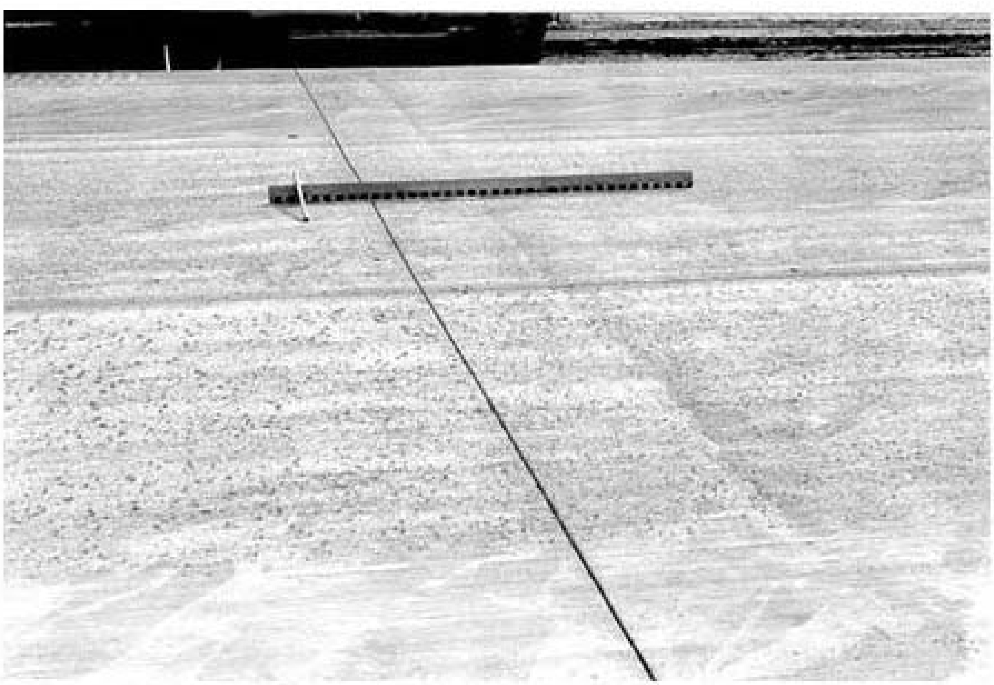


Photo 5: Transverse indentation of plastic concrete

The longitudinal astro-turf drag was applied from the front of the bridge simultaneously with longitudinal tining. The astor-turf used was 38 feet wide, covering the entire width of the pavement surface and 5.8 feet long, of which 4.8 feet contacted the surface. Due to a very stiff mix (slump of less than 1") the astro-turf was not capable of forming deep enough texture. To make the texturing more pronounced, several boards were placed on the astro-turf as shown in Photograph 6. Occasionally, the surface of the contact area became plugged with mortar (Photograph 7) and the tining operator had to raise the astro-turf and shake out the excess grout.

Photograph 8 shows the installation of transverse astro-turf texture. The set-up used was similar to that of transverse tining. A 12 foot wide, 2 foot long piece of astro-turf was folded in half and nailed to a 2" x 2" x 12 foot long piece of wood. The entire unit was then attached to the tining bridge in a manner similar to transverse tines.

Prior to installing transverse astro-turf test section the Principal Investigator (P.I), the Region I Materials Engineer, and the contractor met to discuss the possibility of encountering problems with the transverse texturing operation. It was decided to texture only the first 100 feet of the day's paving with this method to determine its feasibility and its possible continuation for the entire day's paving. If it was determined that transverse astro-turf was not adequately texturing the pavement surface, the contractor could then be directed to convert from transverse astro-turf texturing to longitudinal astro-turf texturing. However, as it can be seen in Photograph 9, the astro-turf adequately textured the pavement surface and as a result, transverse astro-turf texturing was continued for the entire day.

Photograph 10 shows a typical transverse tining operation. The state standard test section (control) which uses combination of burlap drag and 1" uniform transverse tining is shown in Photograph 11. Photograph 12 shows the combination of astro-turf drag with transverse tining of 1/2" uniform spacing. Transverse tining with random spacing of 5/8", 7/8" and 3/4" is shown in Photograph 13.

Photo 6: View of the astro-turf drag with planks for added weight

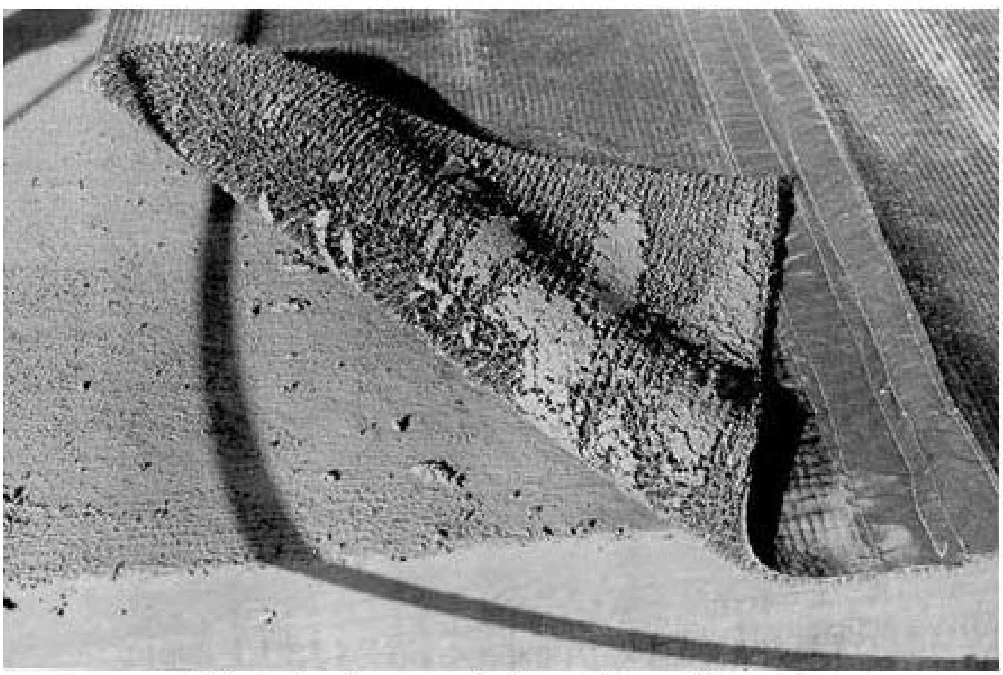


Photo 7: Astro-turf plugged up with grout

Photo 8: Installation of transverse astro-turf texture

Photo 9: Close-up of transverse astro-turf texture

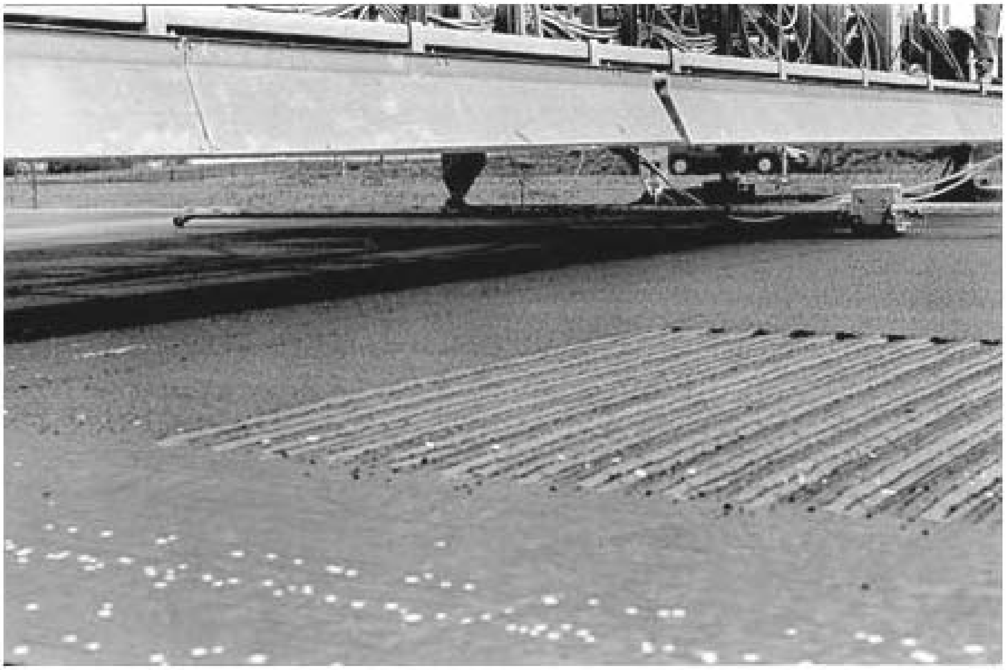


Photo 10: Typical transverse tining operation

Photo 11: 1-inch uniform spaced transverse tining (state standard)

Photo 12: 1/2-inch uniform spaced transverse tining

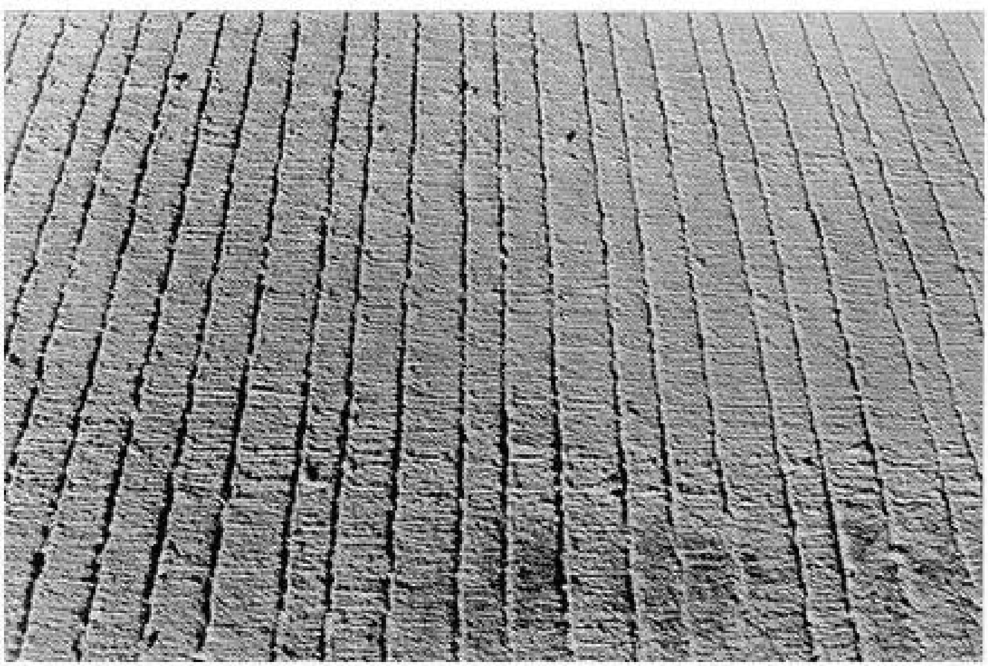


Photo 13: Random transverse tining with 5/8”, 7/8”, and 3/4” spacing

A self- propelled sawing machine (CUSHIN CUT, HG-130) was used to install the longitudinal grooves with uniform spacing of 3/4 of an inch (Photograph 14). The grooving machine was equipped with 46 blades, 14 inches in diameter each, and had a total effective cutting width of 34-1/2 inches. The machine, which had an approximate cutting rate of 1000 linear feet per hour, required 12 passes to groove the entire test section. Photograph 15 shows a close-up view of the longitudinal grooving. The rumble-strips on both the left and the right shoulders were also grooved. Photograph 16 shows a grooved rumble strip on the right shoulder.

A self propelled Transverse Bridge Deck Groover (TBDG) was used to install the transverse grooves with random spacing of 5/8, 7/8, and 3/4 of an inch, as shown in Photograph 17. The transverse grooving machine was equipped with a moving head, with 38 blades, 14 inches in diameter each, and with a total effective cutting width of 29 inches. A close-up view of the transverse grooving is shown in Photograph 18.

In general, transverse and longitudinal grooving appeared orderly, and aesthetically more pleasing than transverse and longitudinal tining. However, the extra costs associated with these types of texturing may make them economically undesirable. Nevertheless, the longer life that can be achieved with grooved textures may offset their extra initial costs.

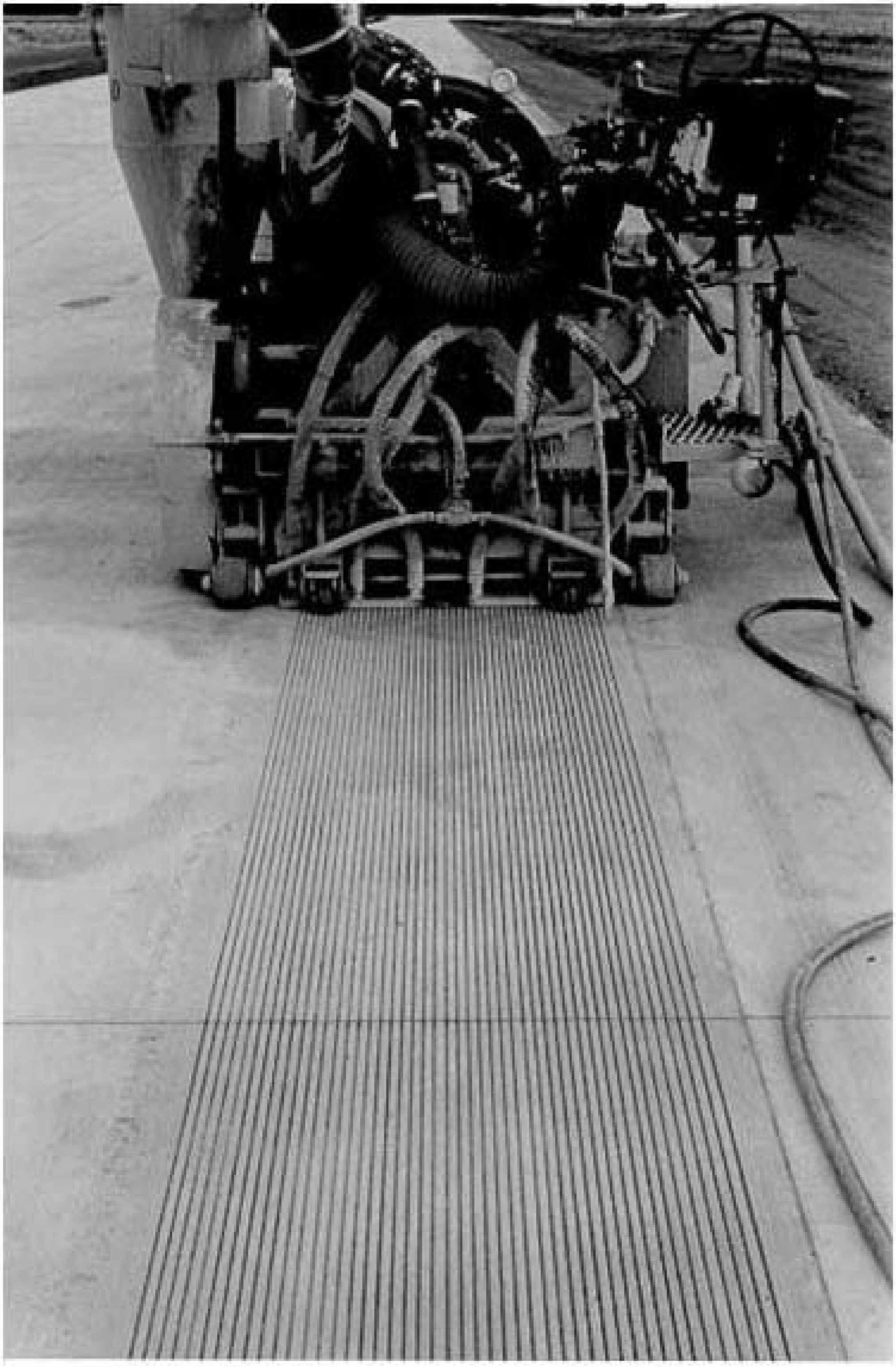


Photo 14: Installation of the longitudinal grooves

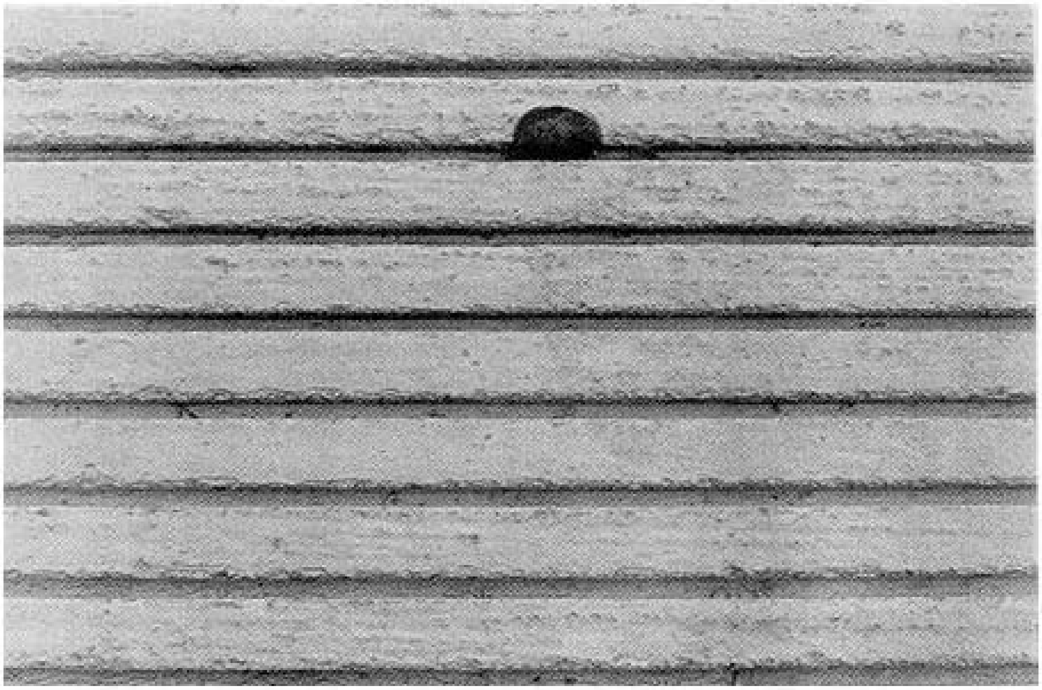


Photo 15: Close up view of longitudinal grooves

Photo 16: Grooved rumble strip in the right shoulder

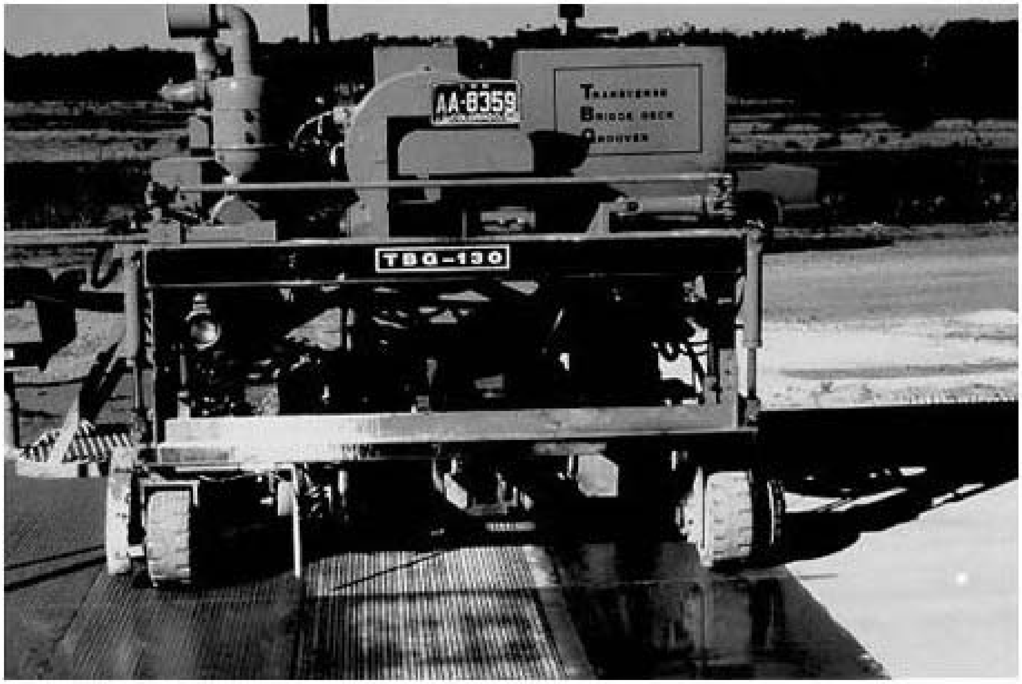


Photo 17: Installation of transverse grooves

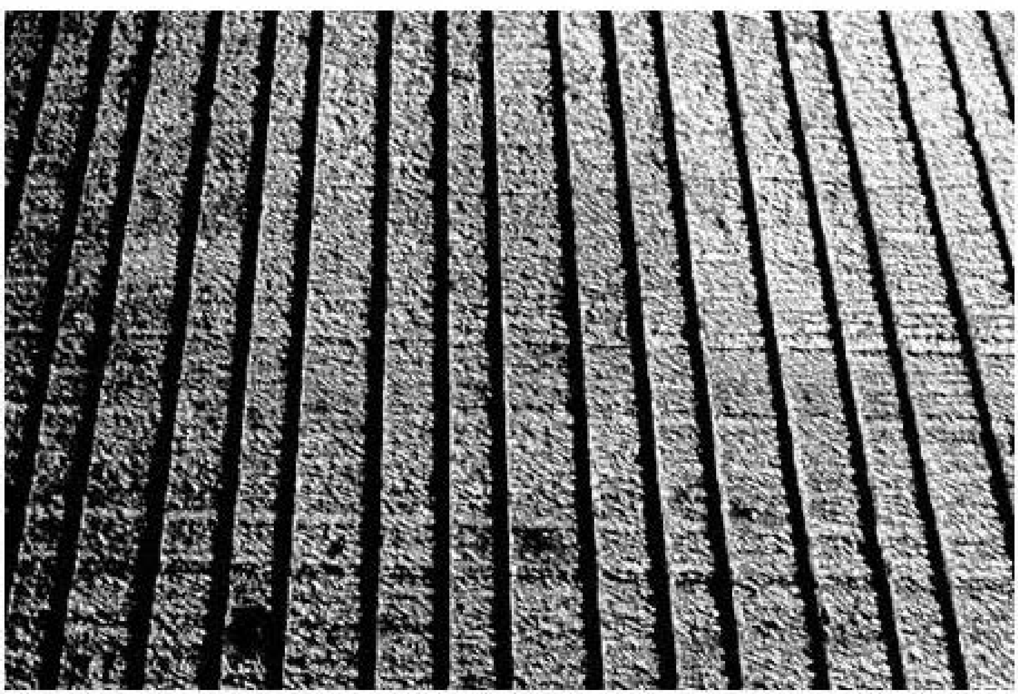


Photo 18: Close-up view of random transverse grooves with 5/8", 7/8", and 3/4" spacing

5.0 DATA ACQUISTION AND ANALYSIS

5.1 Frictional Data

To evaluate the frictional characteristics of individual test sections, skid numbers were acquired according to ASTM skid testing procedure E 274. This procedure measures the locked-wheel frictional forces between a tire of standardized design, size, and inflation pressure, and the wetted road surface at a constant speed of 40 miles per hour (7). Skid number is determined from the force required to slide the locked test tire at a stated speed, divided by the effective wheel load and multiplied by 100 (8).

Ribbed-tire (ASTM E 501) and Smooth-tire (ASTM E 524) tests were used to obtain skid numbers at 40, 50, and 65 mph for all the test sections. Five skid resistance tests were conducted for each test section, as required by the standard ASTM procedure E 274. The arithmetic averages of the skid resistance tests were then used to indicate the skid number (SN) for individual test sections at a specified speed. ASTM E 501 and ASTM E 524 skid numbers were acquired at 40, 50, and 65 mph in October of 1994, and the results were plotted in Figure 3 and Figure 4.

A glance at these figures quickly revealed a definite relationship between speed, types of surface texture, and the magnitude of skid numbers. As speed increased, the skid numbers declined. However, this relationship was clearly more pronounced and consistent using the smooth tire. Skid numbers acquired using the smooth tire clearly showed a distinct difference in magnitude for surfaces with macrotexture and microtexture. For example, the smooth tire showed significantly lower skid numbers for test sections 2 and 8, which received only transverse and longitudinal astro-turf (microtexture), and showed higher skid numbers for the rest of the test sections with macrotexture surfaces.

The difference in skid numbers for microtexture and macrotexture were not as evident or consistent using the ribbed tire. This phenomenon confirms the findings of many research papers, revealing the insensitivity of the ribbed-tire towards macrotexture. The primary reason for the

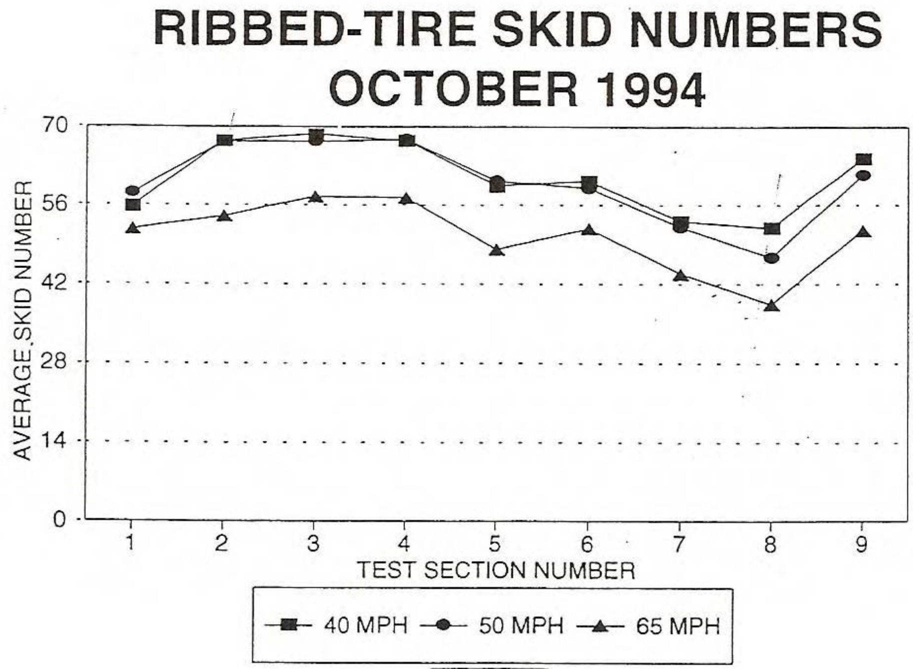


Figure 3

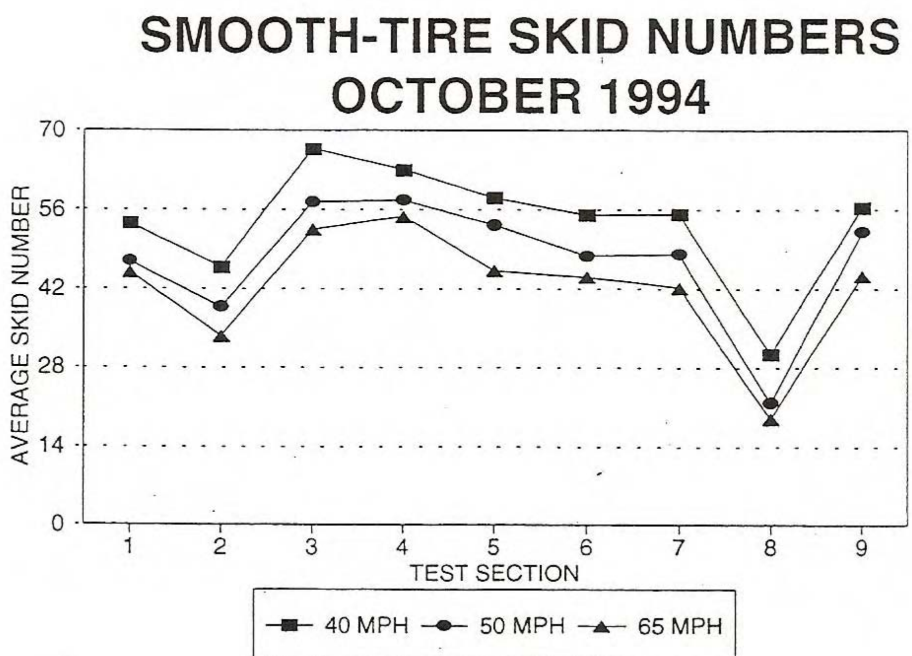


Figure 4

ribbed-tire's insensitivity to macrotexture is its deep grooves, which provide drainage or water and somewhat ignores the drainage capability of the sawed or tined surfaces.

Figure 5 through 8 show the ribbed and smooth-tire skid numbers at 40 and 65 mph for years 1994 through 1999. The skid numbers taken in 1995 showed appreciable decline in magnitude in comparison with the skid numbers taken in 1994. For example, skid numbers taken with ribbed tire at 40 mph (SN40R) in 1995 were an average of seven points lower than those taken in 1994. The SN40R for test sections number 2 (textured with astro-turf in the longitudinal direction) showed the highest drop in magnitude, approximately 15 points.

It should be noted however, that even though the 1995 SN40R were much lower than the 1994 SN40R, they were still much higher than the skid number of 35, which is being used by many states as their minimum acceptable limit. The drop in the magnitude of 1995 skid numbers taken with smooth-tire at 40 mph (SN40S) was even more pronounced. The 1995 SN40S were an average of 11 points lower than their corresponding 1994 SN40S. As before, test section 2 showed the highest drop, approximately 24 points.

Skid numbers kept declining during the 1996; However, the rate of drop in skid numbers magnitude from 1995 to 1996 were significantly lower than the rate of drop in skid number from 1994 to 1995. For example, skid numbers taken with ribbed-tire at 40 mph were an average of seven points lower than those taken in 1994. The average drop in skid numbers magnitude from 1995 to 1996 measured to be less than 1 point (0.77 to be exact). All the test sections including the microtexture test sections (sections 2 and 8) showed more than adequate skid numbers (SN40R = 49.9).

The rate of reduction in skid numbers for the smooth-tire were also minimal. The drop in the skid numbers magnitude from 1995 to 1996 averaged less than 1 point (.80 to be exact), while the rate of drop from 1994 to 1995 averaged 11 points. As before, the two microtexture test sections (test sections 2 and 8) showed very low skid numbers, SN40S = 20.6 and SN40S = 20.4

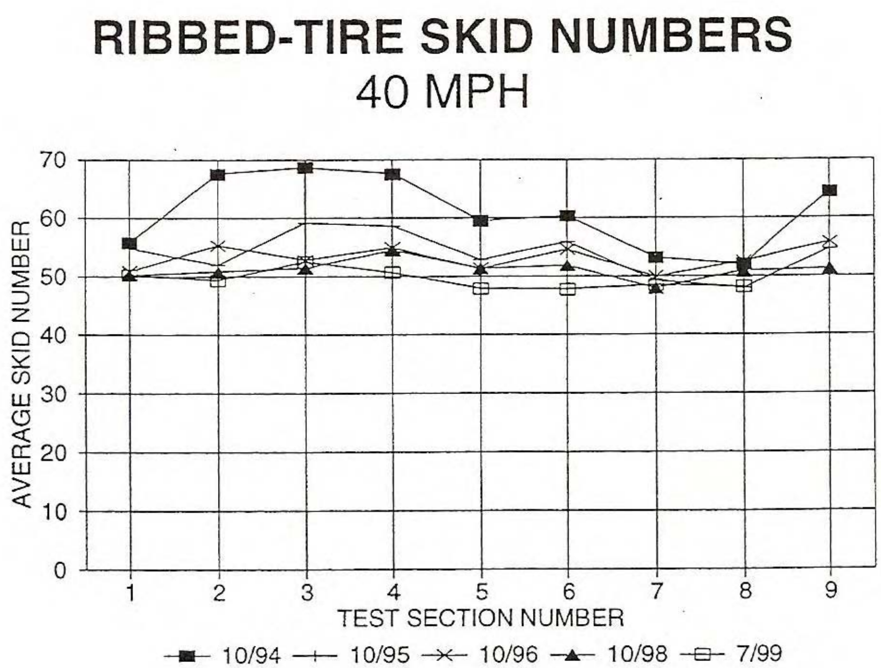


Figure 5

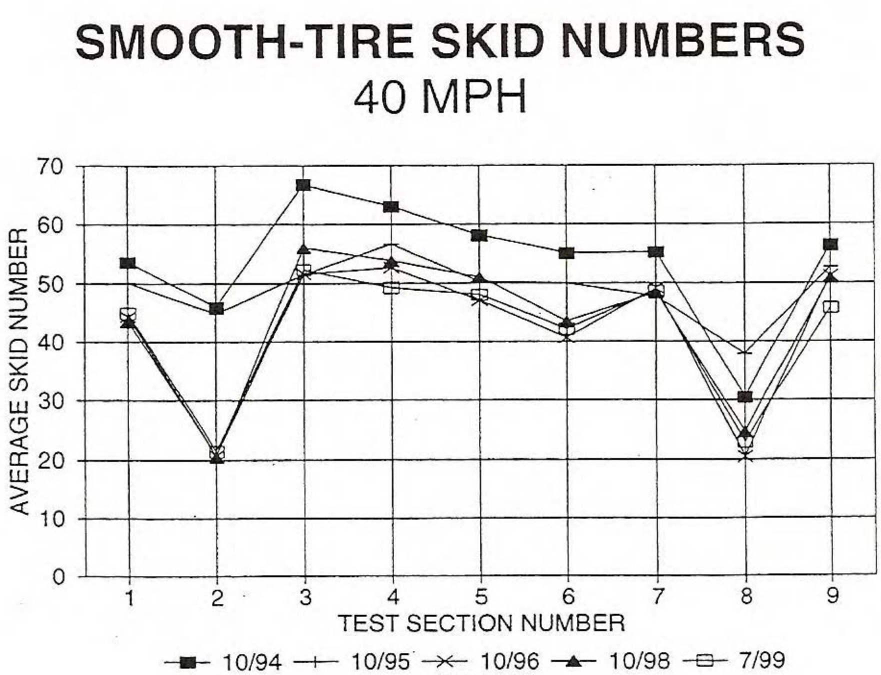


Figure 6

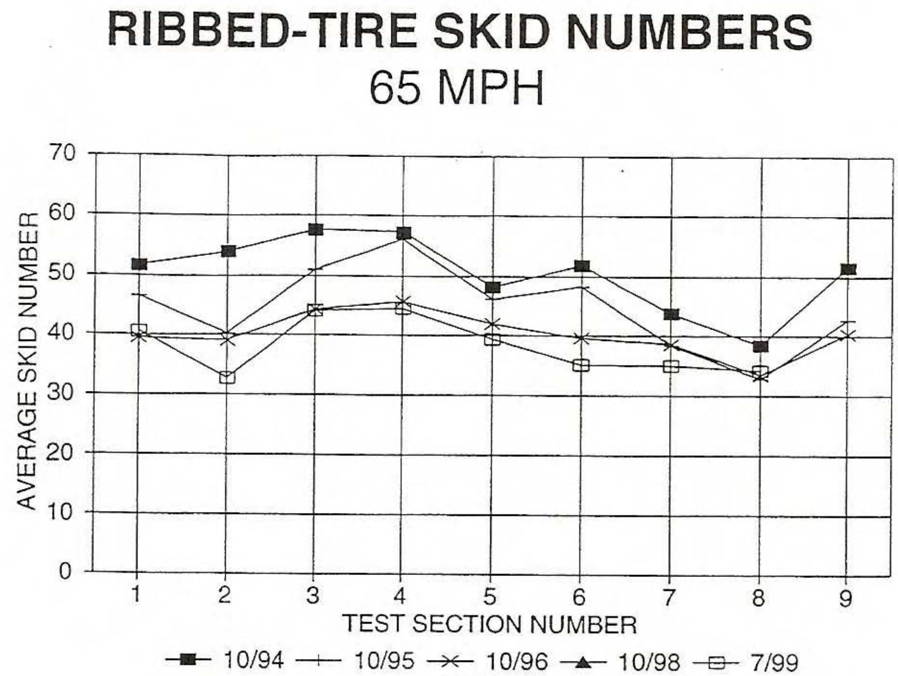


Figure 7

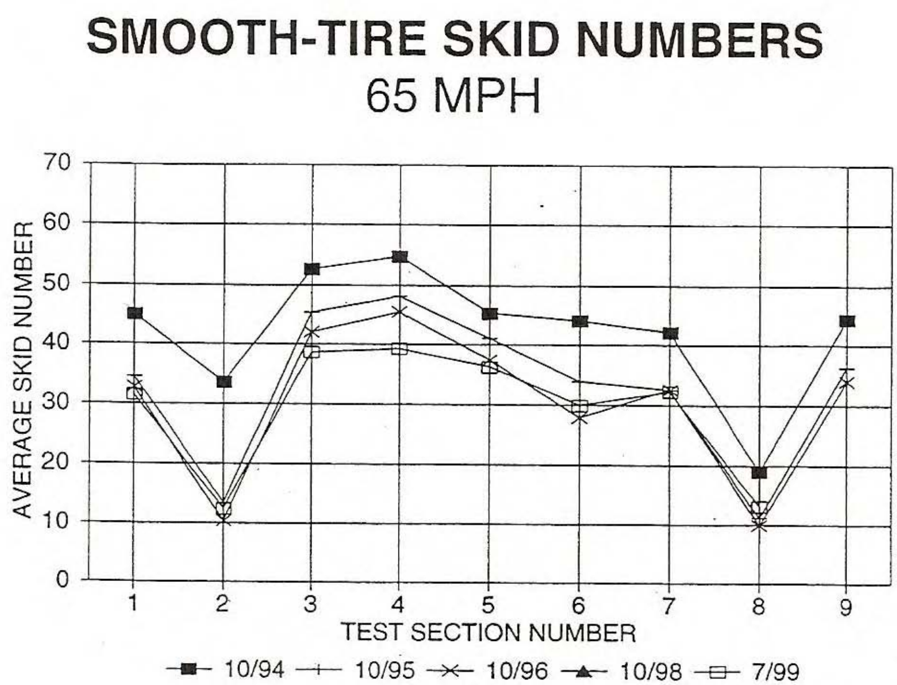


Figure 8

respectively.   Overall, the skid numbers showed no appreciable change in magnitude after 1995 through 1999. For complete view of skid numbers at different speed refer to Appendix A.

The smooth-tire and the ribbed-tire speed gradient for the individual test sections are shown in Figure 9. As shown in Figure 9, the relationship between the skid numbers and the speed appeared to be approximately linear for the smooth-tire. However, this relationship was not as linear for most of the test sections using the ribbed-tire. The speed gradient variations between 40 and 50 mph were minimal and inconsistent using the ribbed-tire. On the other hand, all the test sections tested with the smooth-tire showed a consistent drop in gradients as the speed increased.
In general, the smooth-tire gradients were steeper than their corresponding ribbed tire gradients. For more analysis on the relationship between the variables refer to scatter charts in Appendix A.

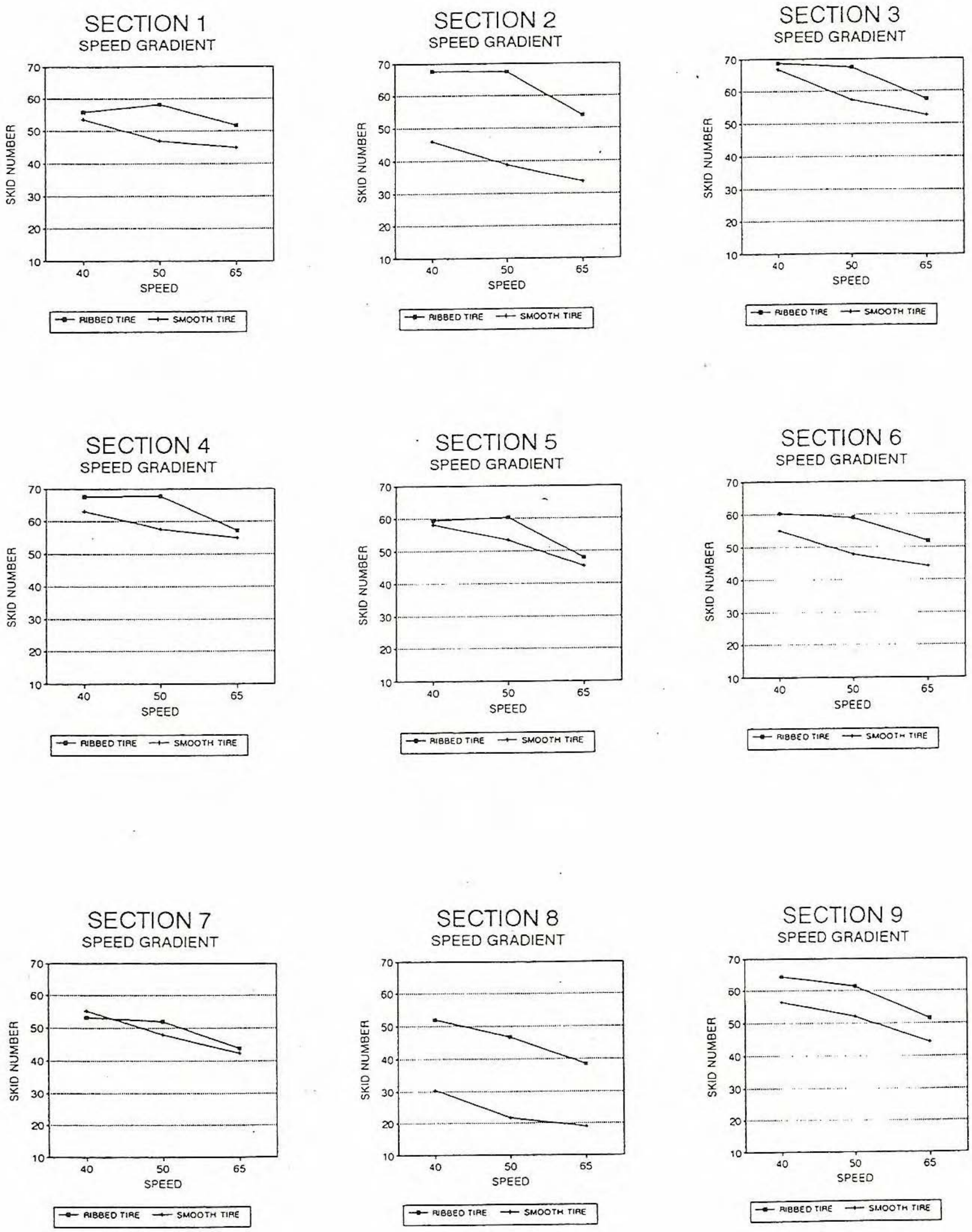
5.2 Texture Measurement

Several different types of texture measuring devices were utilized to measure the amount of texture in each of the test sections. The following is the summary of the data acquired and the description of the equipment used. Equipment descriptions were provided by the FHWA, Pavement Division (9).

5.2.1 Texture Van (Laser Van)

The texture van equipment (Photograph 19) can measure texture at travel speeds and does not interfere with normal traffic. It uses a television camera to take snapshots of a small pavement section in the wheel track (about 4 inches long). It takes a pre-selected number of exposures spaced about 50 feet apart at 50 miles per hour. To assure image sharpness the exposure time is given by a strobe light, and an infrared sensor assures that the field of view is in focus. A slit mask forms the images over the lens, giving two profile edges at every exposure.

An rms (root mean square) value is computed for each of the two profiles. The final output is an average rms value for the test section. Figure 10 compares the average rms values for the


SECTION 1
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE
SECTION 2
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE
SECTION 3
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE
SECTION 4
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE
SECTION 5
SPEED GRADIENT
SKID NUMBER
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SMOOTH TIRE
SECTION 6
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE
SECTION 7
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE
SECTION 8
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE
SECTION 9
SPEED GRADIENT
SKID NUMBER
SPEED
RIBBED TIRE
SMOOTH TIRE

Figure 9

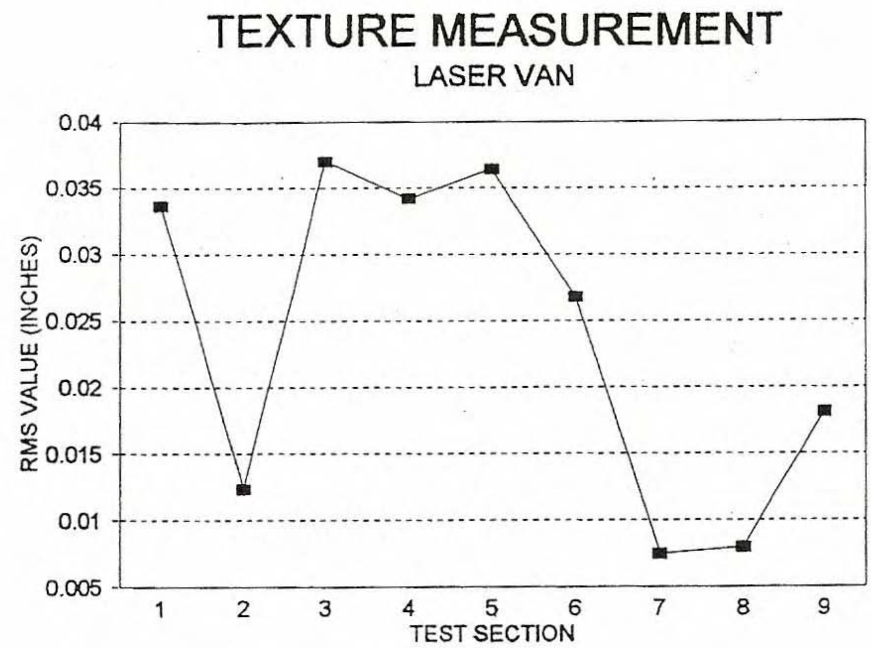

Figure 10

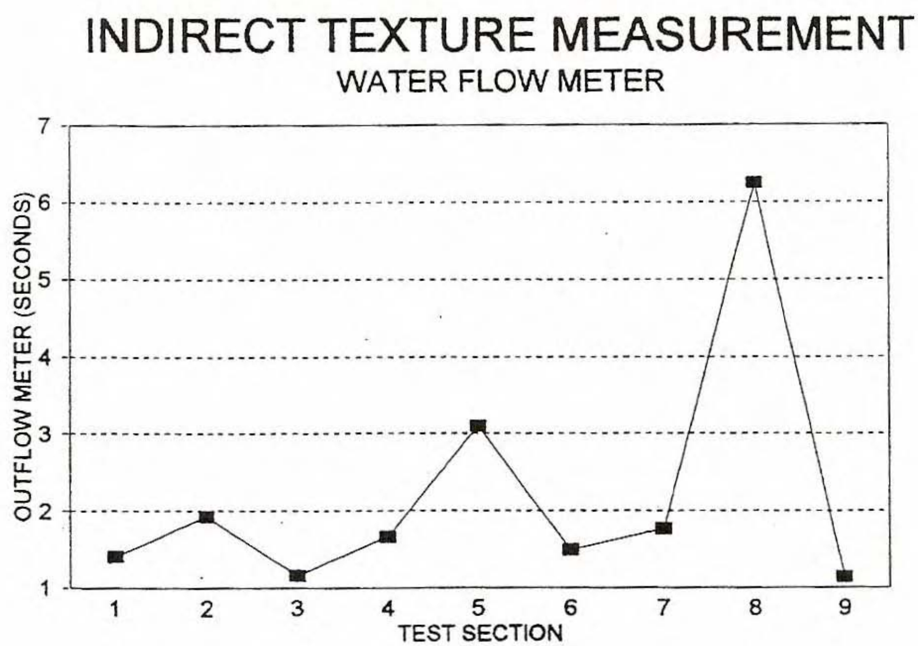

Figure 11

Photo 19: Inside of a texture measuring van

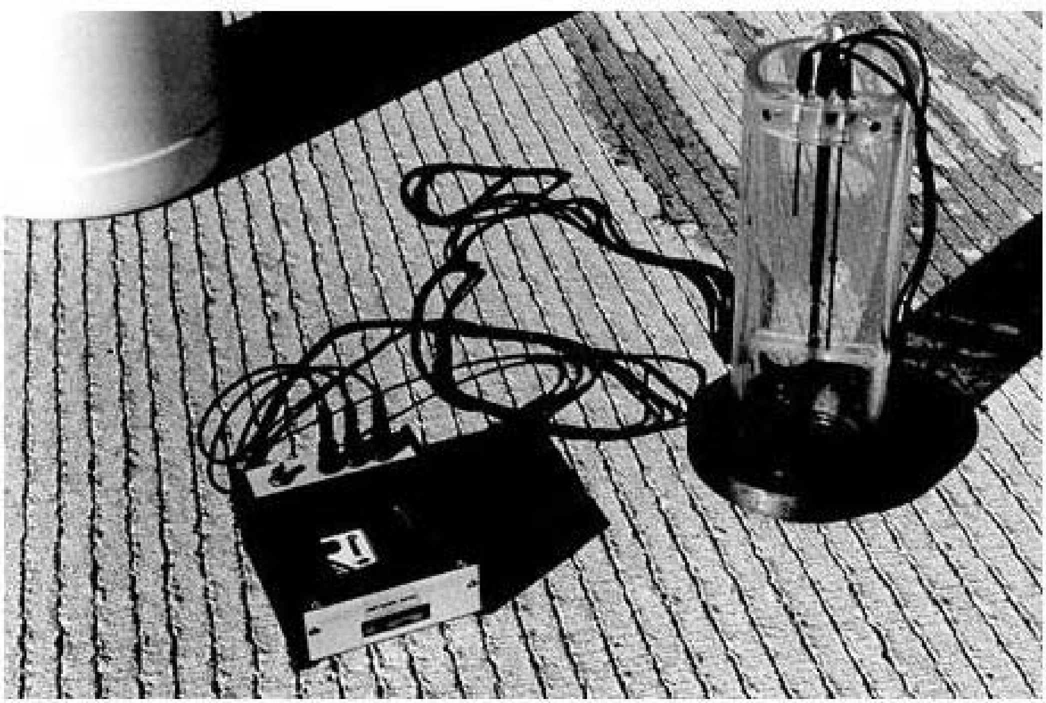

Photo 20: View of an outflow meter

individual test sections. As expected, the texture van showed lower values for sections 2 and 8 with microtexture; however, it also showed low values for longitudinal sawing (test section 7) and for longitudinal tining (test section 9). This may indicate that the laser van is more sensitive to the transverse texture than to the longitudinal texture. It should also be noted that, of the two microtexture (section 2 and 8), section 2 with the transverse orientation showed higher rms values.

5.2.2 Outflow Meter

This is an indirect measure of texture (Photograph 20). A cylinder with rubber seals on its lower end is placed on the surface and loaded by weights to assure good contact. An electric timer is connected to probes inside the cylinder. The cylinder is filled with water. To start the test, the plunger sealing of the outlet is lifted and the water escapes between the rubber seals and the pavement surface. The time for the water to escape is a measure of texture. Deep textured surfaces will allow fast escape of water; i.e. the outflow time for deep textured surfaces is shorter than the outflow time for shallow textured surfaces.

Figure 11 shows the rate of the dissipation of water in seconds for all the test sections. Section 8 with longitudinal astro-turf (microtexture) took the longest to dissipate the water. The fastest draining texture appeared to be test section 9 (longitudinal tining) and test 3 (random transverse tining). In general, the time of water dissipation was less than 2 seconds for most of the test sections.

5.2.3 Texture Beam

The texture beam shown on photograph 21 is capable of tracing texture over a straight line up to two feet long. A motor driven carriage carries two texture sensors. One is a mechanical stylus. The vertical motion is transmitted to an LVDT (Linear Variable Differential Transformer) and the output is recorded via a digitizing board on a computer.

The second sensor is a commercial laser stylus with its power supply and signal processor. The output is treated the same way as the LVDT output. The resulting texture traces can be displayed and processed. An rms value (similar to the texture van) can be computed. The profile can also be processed to display a texture spectrum. Figures 12 and 13 show the average rms values for both the LVDT and the commercial laser stylus. The only questionable rms value detected was for test section 1 (state standard, macrotexture with 1" transverse tining), for which measurements were lower than for the rms values of test section 2 and 8 with microtexture.

5.2.4 Sand patch Method

This method is a volumetric measurement using the ASTM procedure E-965. A given amount of fine sand or glass beads particles (1.5 cubic inches) are poured over a selected spot on the pavement surface. The particles are then spread carefully in a circular pattern until all of them are below the texture peaks. Photograph 22 illustrates texture depth measurement using the sand patch test method. The covered area is estimated by measuring and averaging several diameters. The sand patch texture depth is given by dividing the known volume of glass beads or sand by the estimated area. TD (texture depth) = volume/area.

The results of the sand patch test appeared to be more consistent and realistic than the previously described methods. As shown in figure 14, the two microtexture test sections (test sections 2 and 8) showed lower texture depth than the macrotexture test sections. The average TD for sections 2 and 8 measured to be 0.03 and 0.02 inches respectively, while the average TD of the macrotexture test sections measured from a low of 0.036 inches for section 1 (state standard) to a high of 0.048 inches for section 9 (longitudinal tining).

The sand patch texture depth results correlated favorably with the smooth-tire skid numbers, indicating a linear relationship between the two methods with a correlation factor of r = 0.88. The similarity between the orientation of Figure 4 and Figure 14 further illustrates a good correlation between these two methods.

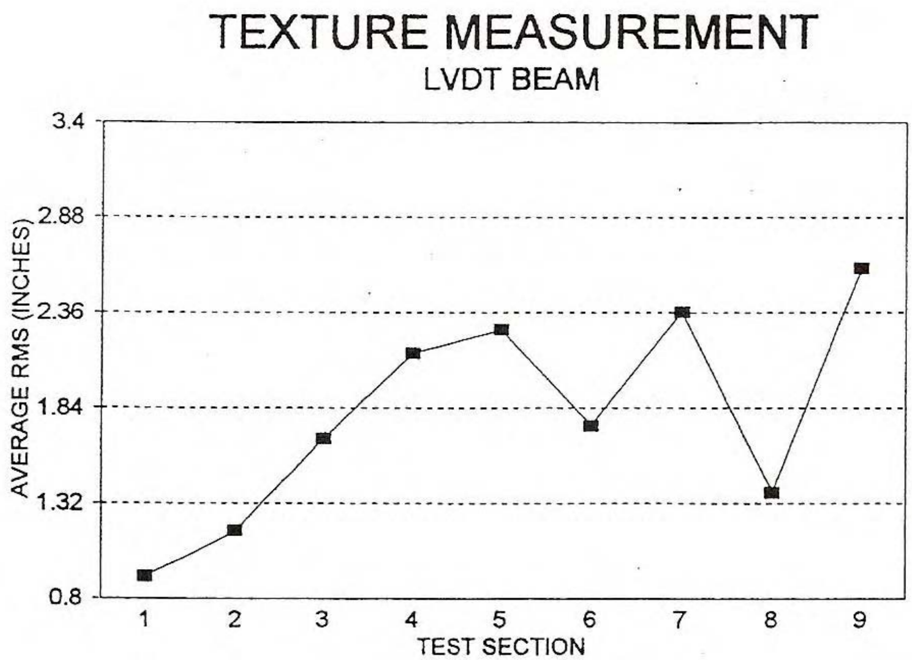

Figure 12

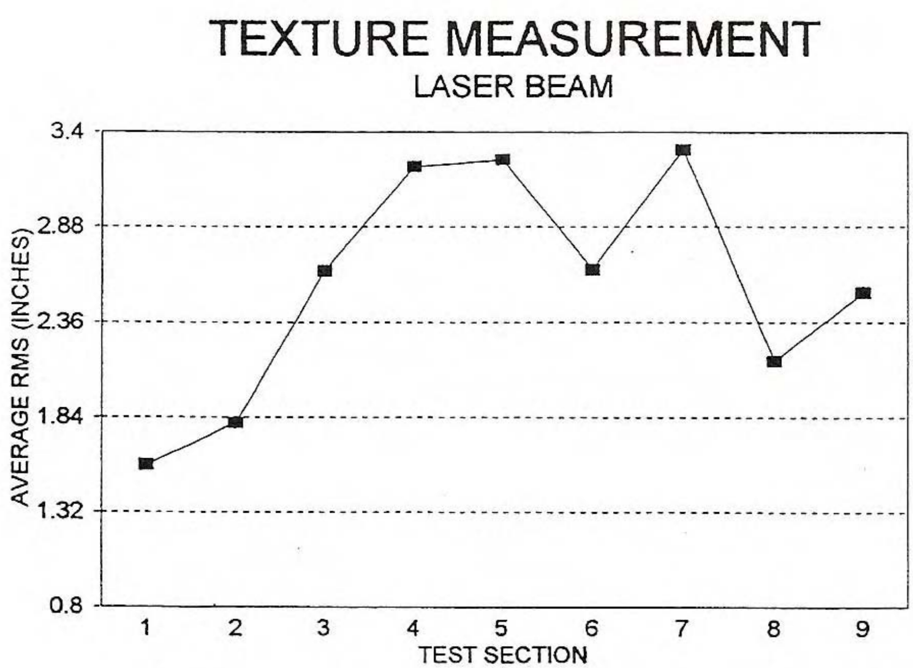

Figure 13

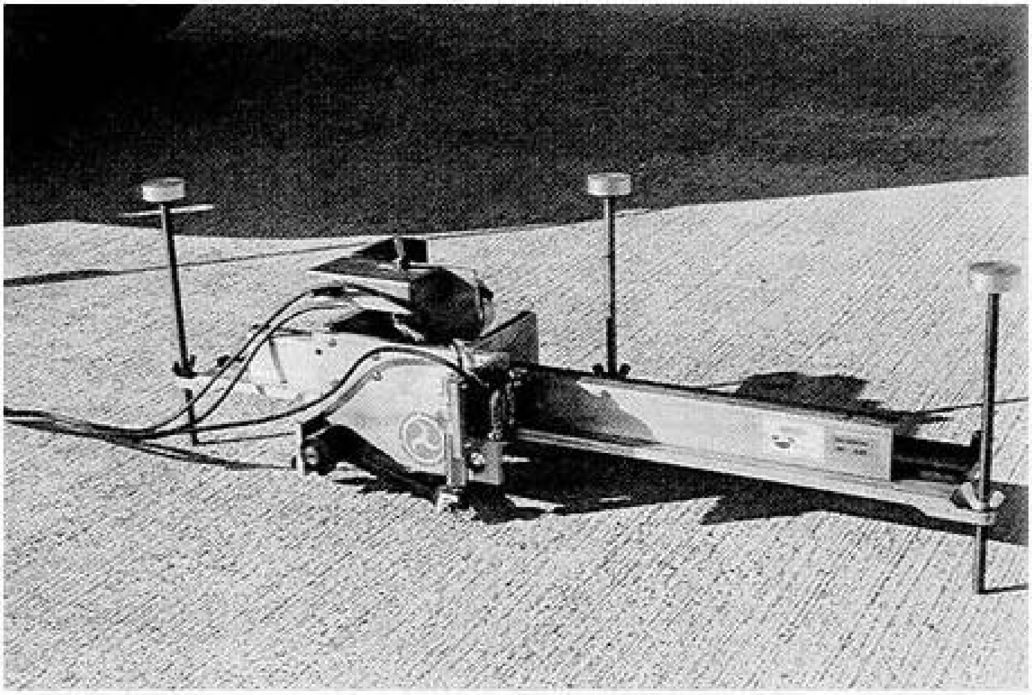

Photo 21: Texture beam, equipped with an LVDT and a laser stylus

Photo 22: Sand patch test for measuring texture depth

TEXTURE MEASUREMENT
SAND PATCH METHOD

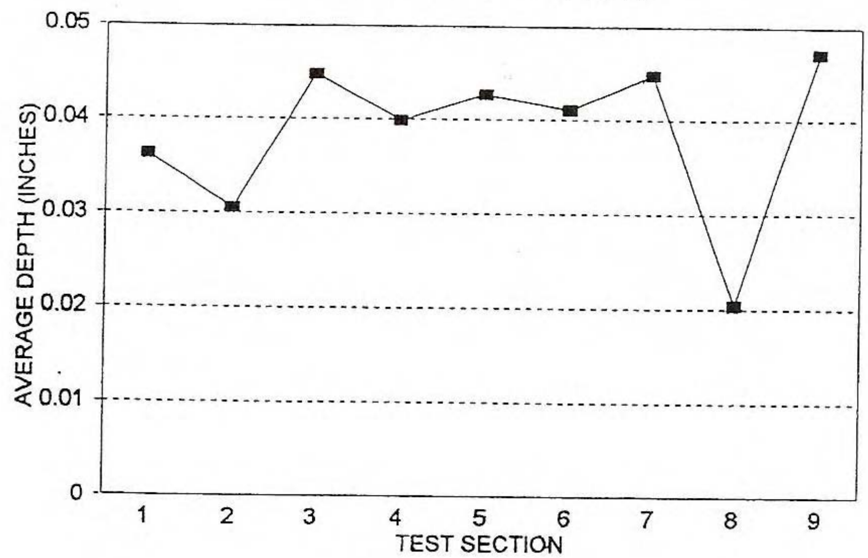

Figure 14

TEXTURE MEASUREMENT
TIRE GAUGE

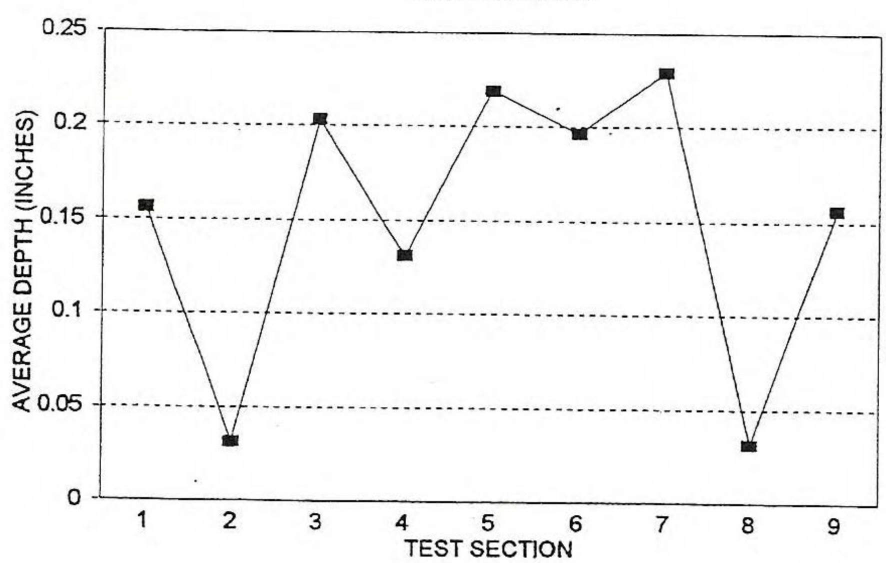

Figure 15

Photo 23: Texture depth measurement using a tire tread depth gauge

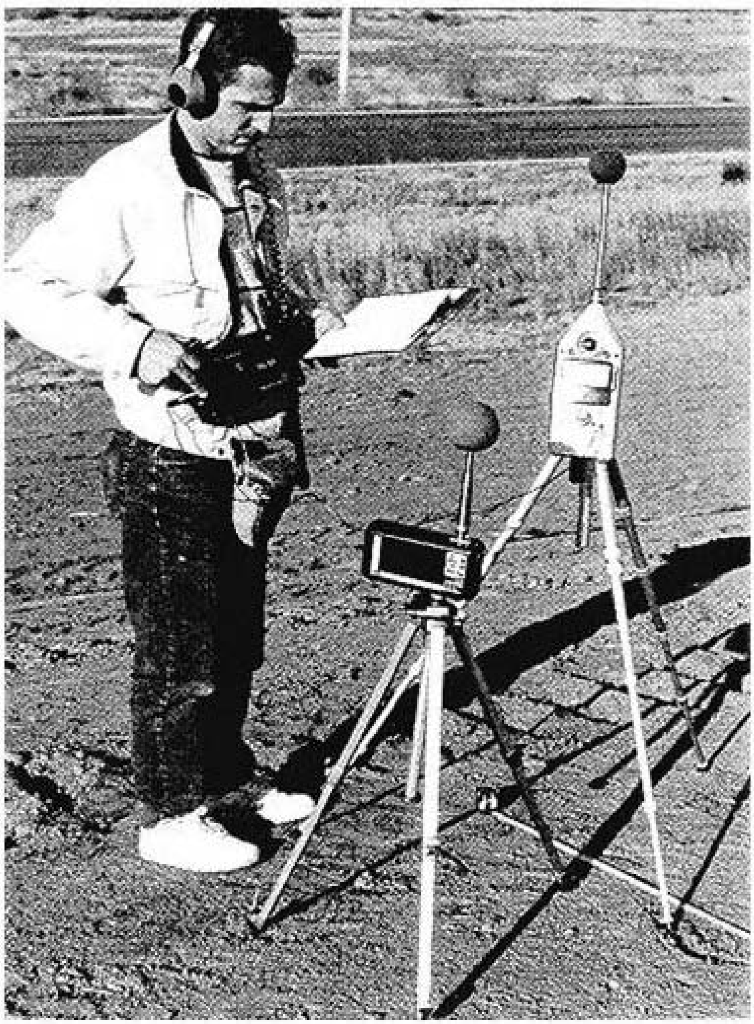

Photo 24: SPL measurement at the roadside

5.2.5 Tire Gauge

A tire tread depth gauge with an accuracy of 1/32 of an inch was also used to measure texture depth (Photograph 23). Five texture depth measurements were taken and averaged at the same spot that the sand patch tests were taken. The results of the tire gauge measurements are shown in Figure 15. These measurements appeared to have a linear relationship with those of the sand patch tests with a correlation factor of r = 0.89. For an in-depth look at the test results and the relationships between various variables refer to scatter charts in Appendix A.

5.3 Noise Measurement

Noise measurements were acquired as a joint effort between the CDOT's Research Branch and a local noise consultant, David L. Adams Associates, INC. The primary purpose of the measurements was to acoustically assess the impact of various surface textures installed in the test sections.

The test vehicle used was a 1994 Oldsmobile Cutlass station wagon provided by CDOT. Sound pressure level (SPL) measurements were recorded through a sound level meter to a digital tape recorder. The data extracted from the recordings were A-weighted sound levels, as well as 1/3-octave SPL with frequencies between 100 and 5000 Hz. The description of the equipment used in the assessment was as follows:

Equipment	Manufacturer	Model No.
Impulse Precision Sound Level Meter	Bruel & Kjaer	2209
Strip Chart Recorder Level	Bruel & Kjaer	2306
Digital Audio Recorder	Panasonic	SV-250

Noise data were acquired in the following three conditions:

1. SPL measurements were acquired at 25 feet from the centerline of the test sections. The microphone was placed on a tripod just beyond the shoulder of the road at a height of 4.5 feet (Photograph 24). The Oldsmobile station wagon was traveling in the driving lane at a

speed of 65 miles per hour. In an effort to minimize the impact of engine noise, the station wagon coasted out of gear while passing the measurement station.

However, it should be noted that measurements taken with the engine on and with the engine off produced the same SPL, indicating that the tire noise was predominately louder than the engine noise. Figure 16 compares the change in SPL measurements of all the test sections relative to control section (state standard) at the shoulder. The sound generated at the control section was normalized to represent a datum (zero sound level pressure). Except for test section 3 (random transverse tining), all the other test sections showed lower decibels (dB) than the control section. Section 8 showed the lowest sound level pressure (6 dB lower than control).

The following table (reference 10) shows an approximation of human sensitivity to changes in sound level.

Change in Sound Level (dB)	Change in Apparent Loudness
1	Imperceptible
3	Just barely perceptible
6	Clearly noticeable
10	About twice (or half) as loud
20	About 4 times (or one-forth) as loud

2. SPL measurements were acquired inside the test vehicle with the microphone positioned at ear height at the center of the front seat. These SPL measurements, which were taken at the coasting speed of 65 mph, represent the average SPL measurements over individual test sections.

Figure 17 compares the change in SPL measurements of all the test sections relative to the control section (state standard) at the driver's ear height. The sound generated at the control section was normalized to represent a datum (zero sound pressure level). As shown in Figure 13, the SPL measurements for all the test sections showed lower dB or the same dB levels as the control section. However, the lowest SPL measured, was only 2 dB lower than the control section.

3. A mounting bracket was constructed and installed to allow SPL measurements to be taken near the right rear tire away from the exhaust pipe (Photograph 25). Figure 18 compares the change in SPL measurements for all the test sections relative to control section (state standard) at the rear tire. As previously mentioned, the sound generated at the control section was normalized to represent a datum (zero SPL).

All the test sections showed lower sound levels than the control section as shown in Figure 18. Section 7 and 8 showed the lowest dB, 5 1/2 dB lower than the control section. It should be noted that for all the conditions mentioned above, 3 sets of data were acquired and then averaged. Figure 19 compares the A-weighted SPL measurements of all the three conditions. As expected, the SPL measurements taken near the rear tire and inside the test vehicle showed the highest and lowest dB respectively.

The three Figures in Appendix B show the SPL frequency distribution for all the test sections in all three conditions. The data are presented in a 1/3 octave band format. According to Chalupnik and Anderson (11) (12), noise components in the mid to upper frequencies between 1,000 Hz to 4,000 Hz are more annoying than the lower frequencies. These figures show that SPL generated in the control section (near tire and at the roadside) to be higher than the other sections at the 1,000 - 1250 frequencies. The lowest SPL generated at the same frequencies was at sections 8 (longitudinal astro-turf, no tining) followed by section 7 (longitudinal sawing).

Figure 20 compares SPL Frequency distribution of a semi-truck with the test vehicle in a 1/3-octave band format (100 – 5000 Hz), as well as A-weighted SPL at the roadside. As it can be

SPL AT THE SHOULDER
COMPARED TO STATE STANDARD SECTION

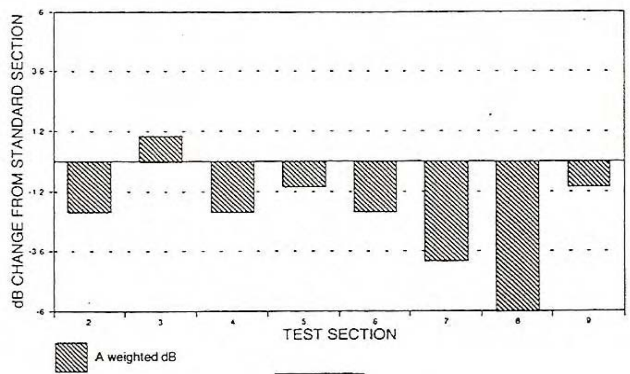

Figure 16

SPL INSIDE TEST VEHICLE
COMPARED TO STATE STANDARD SECTION

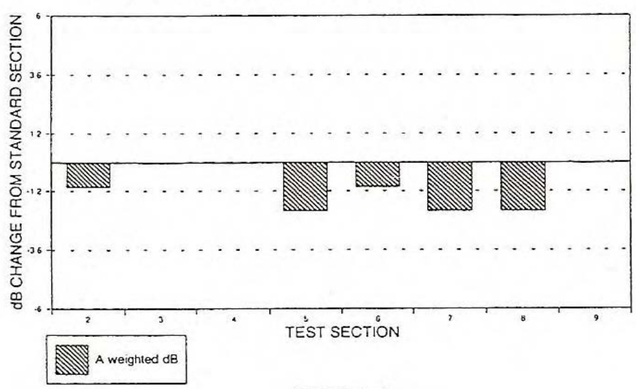

Figure 17

SPL AT REAR TIRE
COMPARED TO STATE STANDARD SECTION

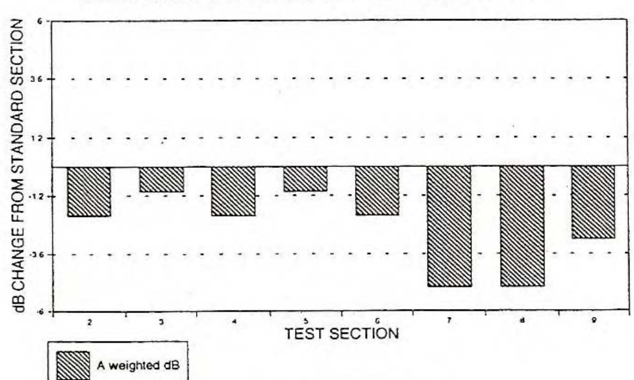

Figure 18

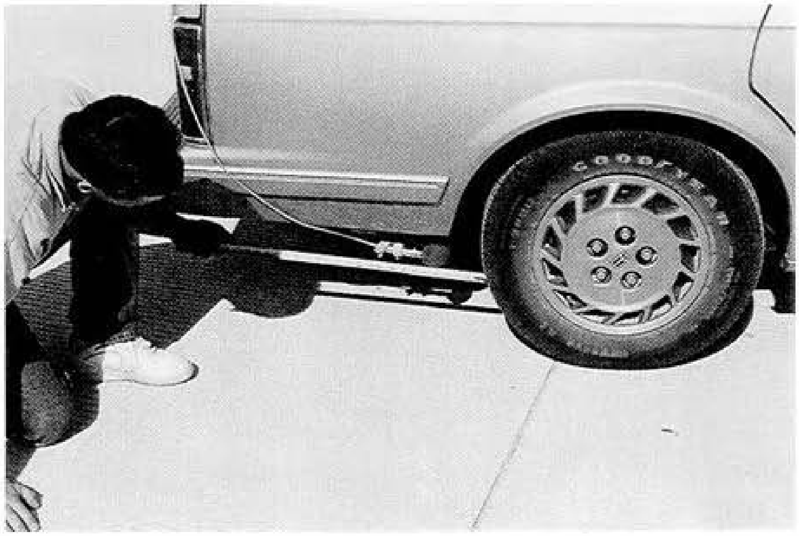

Photo 25: View of the microphone behind the rear tire

Photo 26: Acquiring truck noise levels at the roadside

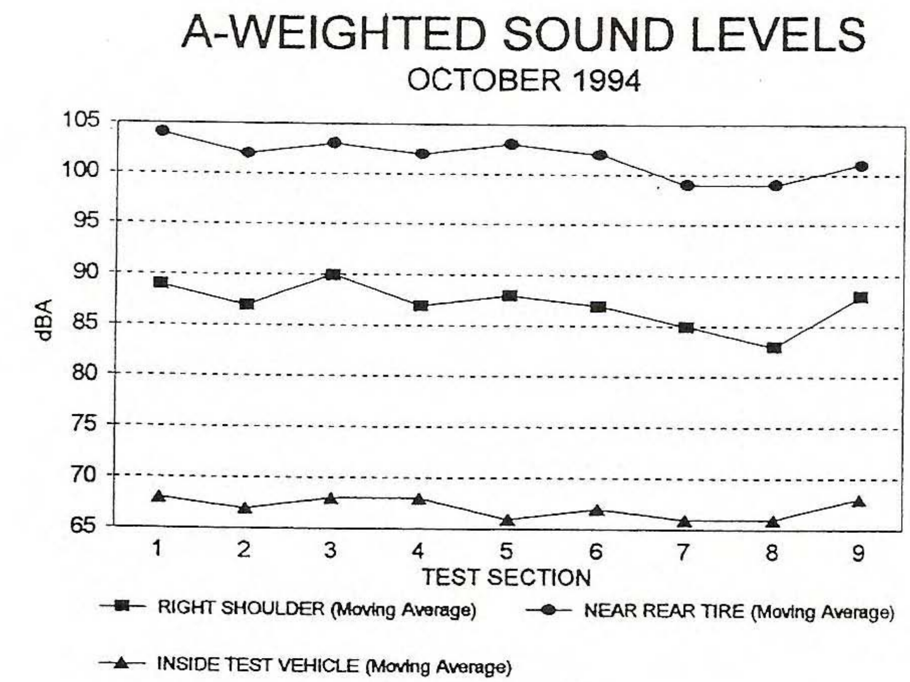

Figure 19

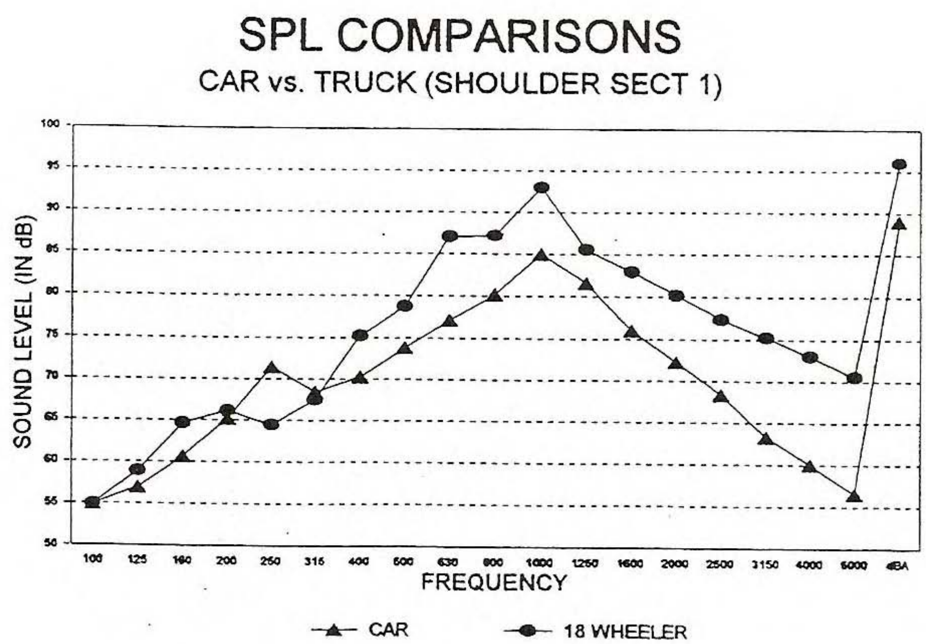

Figure 20

seen in this figure, the SPL for both the truck and the test vehicle peaked at 1000 Hz. However, the figure shows the noise from the truck (Photograph 26) to be at the higher annoyance range (by about 8 dB) than the noise from the test vehicle. The A-weighted dB for the truck was also 7 dB higher than the A- weighted dB of the test vehicle.

5.4 Roughness Data

Figure 21 compares the average right- and left-wheel-path roughness data for all the test sections.

Test section 6, which was textured using a combination of longitudinal astro-turf and 1-inch uniform tining, exhibited the highest roughness. It should be noted that dynamic effects that act on suspension systems and generate vibrations inside vehicles are primarily due to megatexture or small-scale roughness (explained below). The influence of surface texture on ride quality, with the exception of noise level, is minimal.

The Technical Committee Report on Surface Characteristics in Belgium (13), defines the various surface irregularities based on their wavelengths as follows:

Wavelength < 0.5 mm	Microtexture
Wavelength 0.5 mm - 50 mm	Macrotexture
Wavelength 50 mm - 500 mm	Megatexture
Wavelength 0.5 m - 50 m	Roughness

Based on the findings of the above mentioned report, it appears that irregularities with wavelengths greater than 50 mm and smaller than 150 mm (megatexture) have the most adverse effects on the quality of ride. Microtexture and macrotexture, with the exception of noise levels, have only beneficial effect (14).

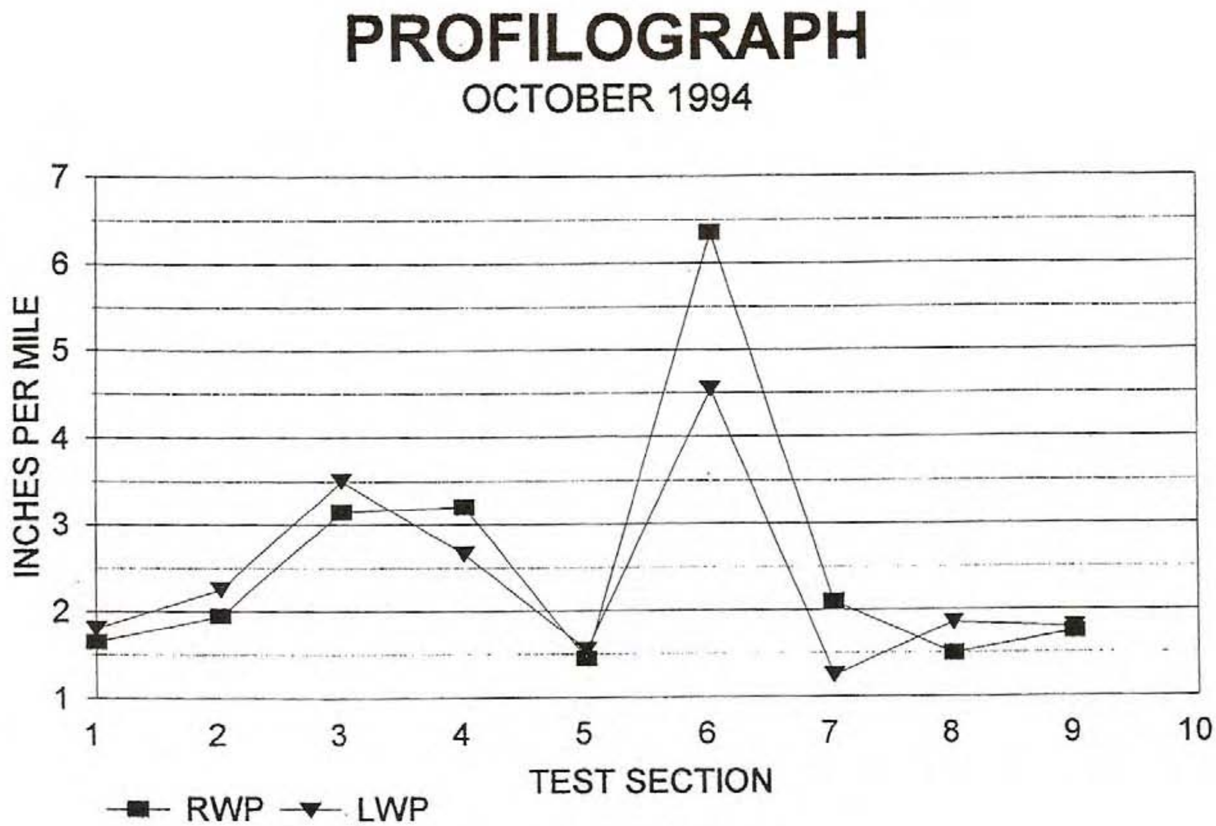
PROFILOGRAPH
OCTOBER 1994
7
6
5
4
3
2
1
INCHES PER MILE
1
2
3
4
5
6
7
8
9
10
TEST SECTION
RWP
LWP

Figure 21

6.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations presented here are based on the data that were acquired prior to opening to traffic in 1994 and the subsequent data that were acquired thereafter through 1999. The conclusions are also based in part on a national study called, “Noise and Texture on PCC Pavements”. This study was sponsored by FHWA and conducted by Marquette University (15). As part of this national study, Colorado, Iowa, Michigan, Minnesota, North Dakota and Wisconsin provided 57 test sections to study the noise properties and the frictional characteristics of several different PCC textures.

6.1 Conclusions

- The PCC surface texture has a profound effect on the traffic-induced noise characteristics generated at the interface of the tire and the pavement surface. The change in PCC surface texture also has a major effect on the frictional properties.

- Texture depth taken with various texture-measuring devices correlated favorably with the smooth-tire skid numbers taken at 40, 50, and 65 mph, indicating a linear relationship with excellent correlation factors. The results were not as linear with the ribbed-tire skid numbers. For a thorough view of the scatter diagrams (relationship between various variables) refer to Appendix A.

- Section 3 (combination of longitudinal astro-turf and random transverse tining) and section 8 (longitudinal astro-turf) showed the highest and lowest skid numbers respectively, using both the ribbed- and the smooth-tire.

- The highest drop in skid numbers occurred between the first year and the second year. The change in the magnitude of the skid numbers for both the smooth and the ribbed-tire significantly leveled off after the second year.

- The relationship between the skid numbers and the speed appeared to be approximately linear for the smooth-tire, and not as linear for the ribbed-tire. In general, the smooth-tire speed gradients were steeper than the ribbed-tire speed gradients.

- Longitudinal macrotexture and microtexture were the most quiet surfaces based on the sound pressure levels (SPL) taken at the shoulder, inside the test vehicle, and at the rear tire.

- State standard section (combination of burlap drag and uniform 1" spacing) exhibited the highest noise level among all the test sections with the microphone at the rear tire position.

- SPL taken at the shoulder showed the A-weighted dB of a semi- truck to be approximately 7 dB higher than the A-weighted dB of the test vehicle.

- The influence of surface texture on ride quality is minimal.

6.2 Recommendations

- The use of smooth-tire over the ribbed-tire as a method of acquiring skid numbers is recommended. The smooth-tire (ASTM E 524) showed more sensitivity to both microtexture and macrotexture than the corresponding ribbed-tire (ASTM E 521). The primary reason for the ribbed-tire's insensitivity to macrotexture is its deep grooves, which provide drainage for water and somewhat ignores the drainage capability of the sawed or tined surfaces.

- Longitudinally tinned PCC Pavements exhibit the lowest noise level and provide adequate friction. Their use is highly recommended.

- The use of the sand patch test method as a texture-depth measuring device is highly recommended. Excellent correlations were achieved using the sand patch test method and smooth-tire skid numbers (Appendix A).

- To ensure proper friction and to minimize noise, quality control for tine spacing and tine depth needs to be improved. Deeper tines generate louder sound levels.

- A research study to document the effects of various surface textures on safety in wet weather conditions is highly recommended.

7.0 FUTURE RESEARCH

CDOT has been receiving complaints concerning the handling of vehicles on newly paved concrete pavements textured with longitudinal tining. In an attempt to address the problems associated with longitudinal tining, CDOT has initiated two studies as follow:

1. **Alternate Longitudinal Texturing Methods to address Vehicle handling-** This study will evaluate various uniformly and randomly spaced longitudinal tining configurations including saw-grooving and grinding textures. The ultimate goal of the study is identifying the best longitudinally textured pavements that eliminates vehicle handling problems. A site has already been selected and constructed in region IV of CDOT with 6 different test sections as follows:

   - Standard longitudinal tining. Tining shall produce grooves of $^{1}/_{8}$ inch x $^{1}/_{8}$ inch spaced $^{3}/_{4}$ inch apart and parallel to the longitudinal joint.
   - Standard longitudinal tining without Astroturf (California spec). Tining shall produce grooves of $^{1}/_{8}$ inch x $^{1}/_{8}$ inch spaced $^{3}/_{4}$ inch apart and parallel to the longitudinal joint.
   - Longitudinal sawing. Sawing shall produce grooves of $^{1}/_{8}$ inch x $^{1}/_{8}$ inch spaced $^{3}/_{4}$ inch apart and parallel to the longitudinal joint.
   - Random pattern longitudinal tining. Tines shall be ⅛” x ⅛” placed at the following spacing repeated every 38”: 1¼”, ⅞”, 1¼”, ¾”, ⅝”, 1⅜”, 1⅛”, ⅝”, 1¼”, ¾”, 1½”, 1½”, ⅞”, ⅝”, 1⅜”, 1⅛”, ⅝”, 1⅜”, ⅞”, 1⅛”, ⅝”, 1”, 1”, 1½”, ¾”, ⅞”, ¾”, 1”, 1⅜”, 1¼”, 1”, 1½”, 1⅛”.
   - Meandering longitudinal tining. Tines shall be ⅛” x ⅛” placed as a sinusoidal wave with a wavelength of 16” ± 2” and amplitude of 8” ± 2”.
   - Grinding.

2. **Frictional Properties of PCC Pavements Textured with Astro-turf Vs. Longitudinal Tining-** The ultimate goal of this study is to evaluate an aggressive

Astroturf drag as a texturing method and determine if it provides safe and durable surface with adequate surface friction and low noise levels

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