

PCCP Texturing Methods

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16. Abstract This report describes the testing, and construction details of nine test sections with varying textural characteristics. The impacts of various surface textures (sawed vs. tined, longitudinal vs. transverse, and random vs. uniform spacing) on the frictional and noise characteristics of pavement surface were examined. Skid numbers were acquired according to ASTM E 274 procedure with ribbed- and smooth-tire (ASTM E 501, and 524) at 40, 50, and 65 mph for all the test sections. Six different types of texture measuring devices were used to measure and compare the amount of texture in each of the test sections. To examine the noise properties of the test sections, noise data were acquired in three different locations: inside of the test vehicle, 25 feet from the center line, and near the right rear tire of the test vehicle away from the exhaust pipe. Implementation: The smooth-tire showed more sensitivity to both micro- and macrotexture than the ribbed-tire. Longitudinal textures are more quite than transverse textures.			
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PCCP Texturing Methods
Project IR (CX) 070 -4 (153)
Deer trail - East

Interim Report
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I. 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 effect the frictional characteristics, noise, and quality of ride.

In general, transverse tining has been the only permitted method of texturing used by Colorado Department of Transportation (CDOT) and 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 which 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-tread depth and design, tire-inflation pressure, and pavement texture.

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 may 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 said to be attributed to 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 A 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 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).



Photo A: View of the ribbed tire (ASTM E 501), and the smooth tire (ASTM E 524).

There are numerous direct methods available to quantitatively measure texture. Among the ones that were used for this study are: the Texture van, the Texture Beam consisting of an LVTD (Linear Variable 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 are presented in section V-B.

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 in the following three locations: inside of the test vehicle, 25 feet from the center line (3 feet away from the right shoulder), and 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 V-C.

II. 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 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?

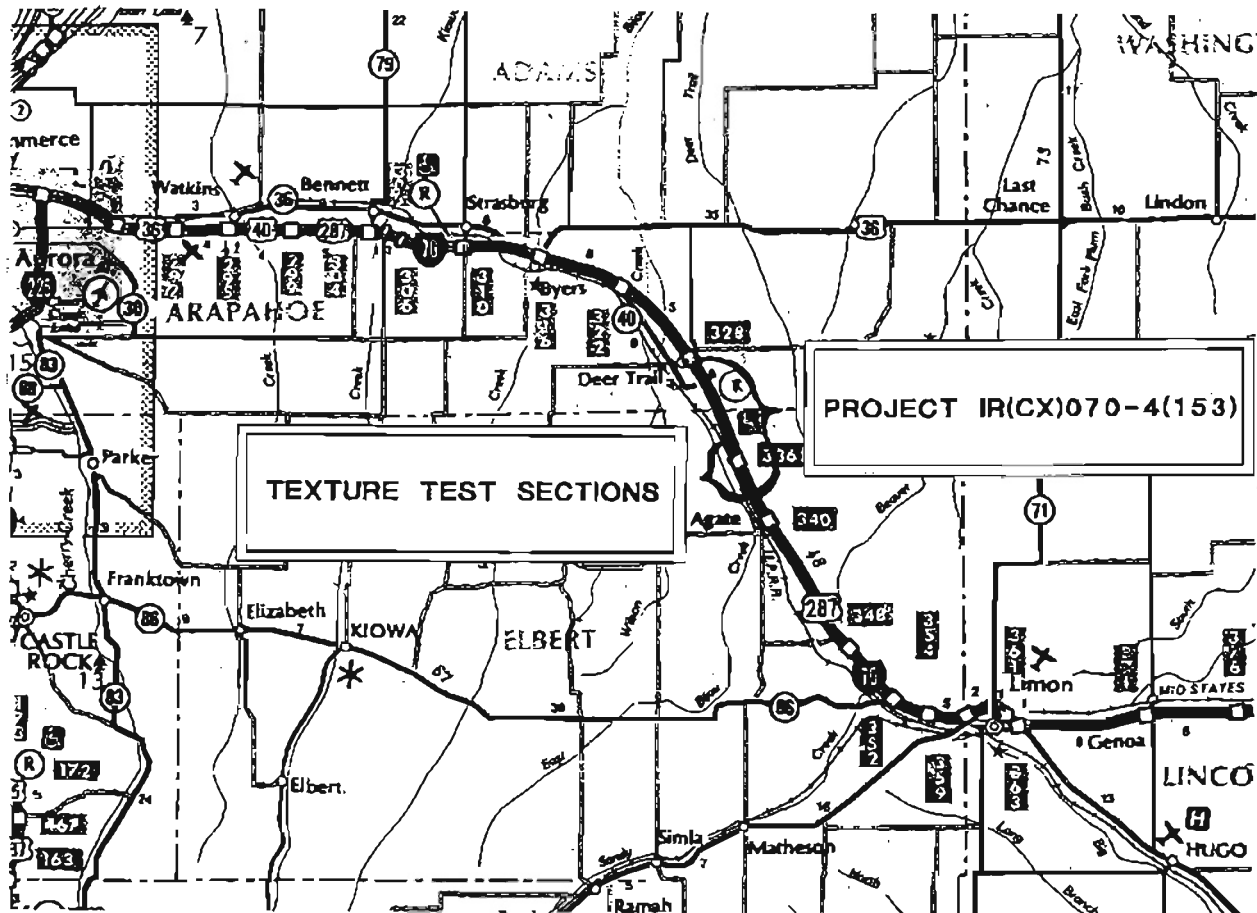
Based on the recommendation of the American Concrete Pavement Association (ACPA)/CDOT Oversight Group, and In an attempt to answer some of these questions, CDOT's Research Branch, in cooperation with Region I Materials, initiated a study to examine the pros and cons of various texturing methods, and 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 I-70, 50 miles east of Denver, Colorado (Figure 1). This report describes the construction and the first round of data collection and data analysis for all the test sections.

III. Objective

The primary objectives of this study were:

- 1- To document the constructability, costs, and the functional practicability of several PCC surface textures installed on I-70 for the project IR (CX)70 - 4 (153) in Colorado.
- 2- To assess the impacts of various surface textures on the frictional characteristics, noise, and the ride quality of concrete pavements over next 4 years.
- 3- To identify the best performing surface texture which is cost-effective, provides adequate frictional characteristics over a long period, and minimizes tire noise.

Figure 1



IV. PCCP Texturing Methods

A. 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 mile post 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 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

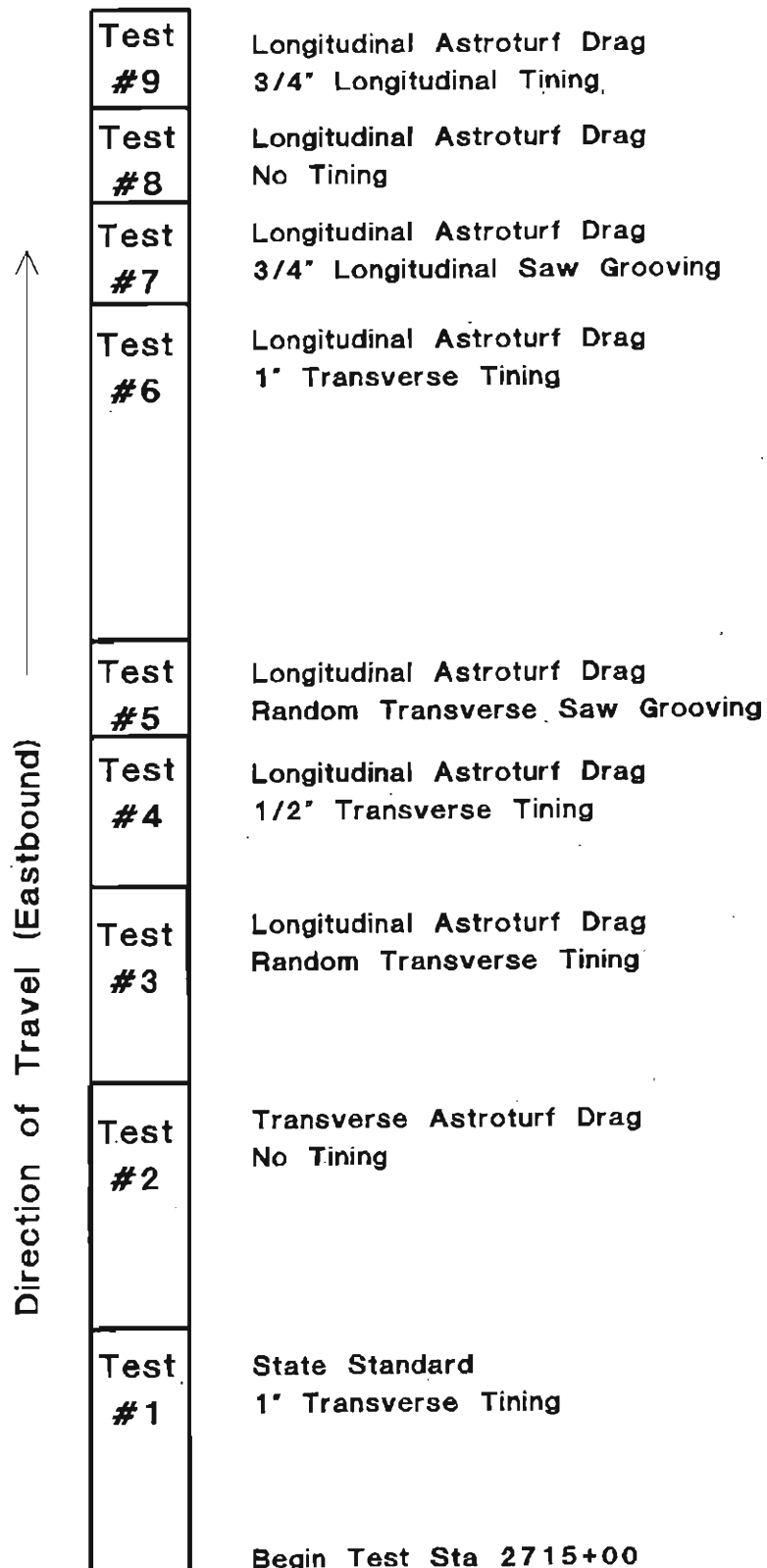
Note: Burlap drag was applied to all test sections immediately behind the paver as shown in Photograph 1. The depth and the width of all the tining and sawing were specified at $1/8" \pm 1/16"$.

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

B. 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 2 illustrates the entire

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



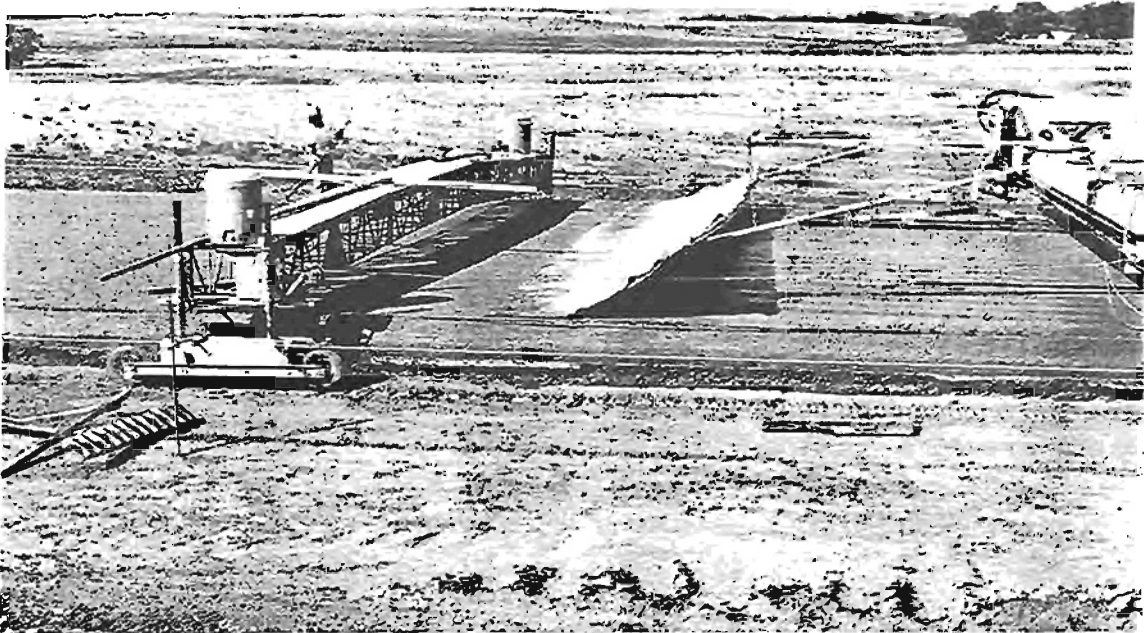


Photo 1: Burlap drag was applied to all test sections

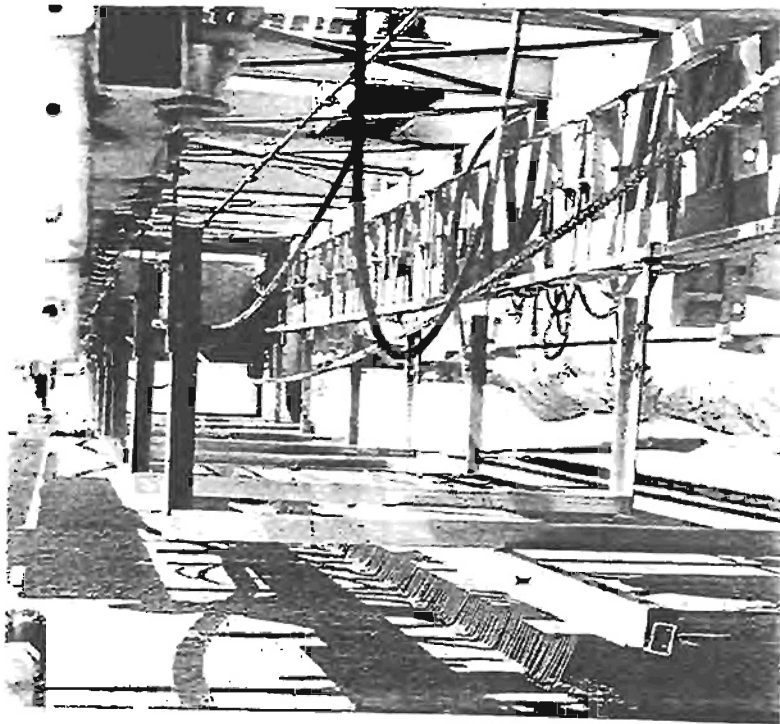


Photo 2: View of the longitudinal tining assembly

ting 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 3). 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 stopped, the tines formed a transverse indentation across the pavement surface as shown in Photograph 4. 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 or minimize indentation of the plastic concrete surface.

The longitudinal astro-turf drag was applied from the front of the bridge simultaneously with longitudinal tining. The astro-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

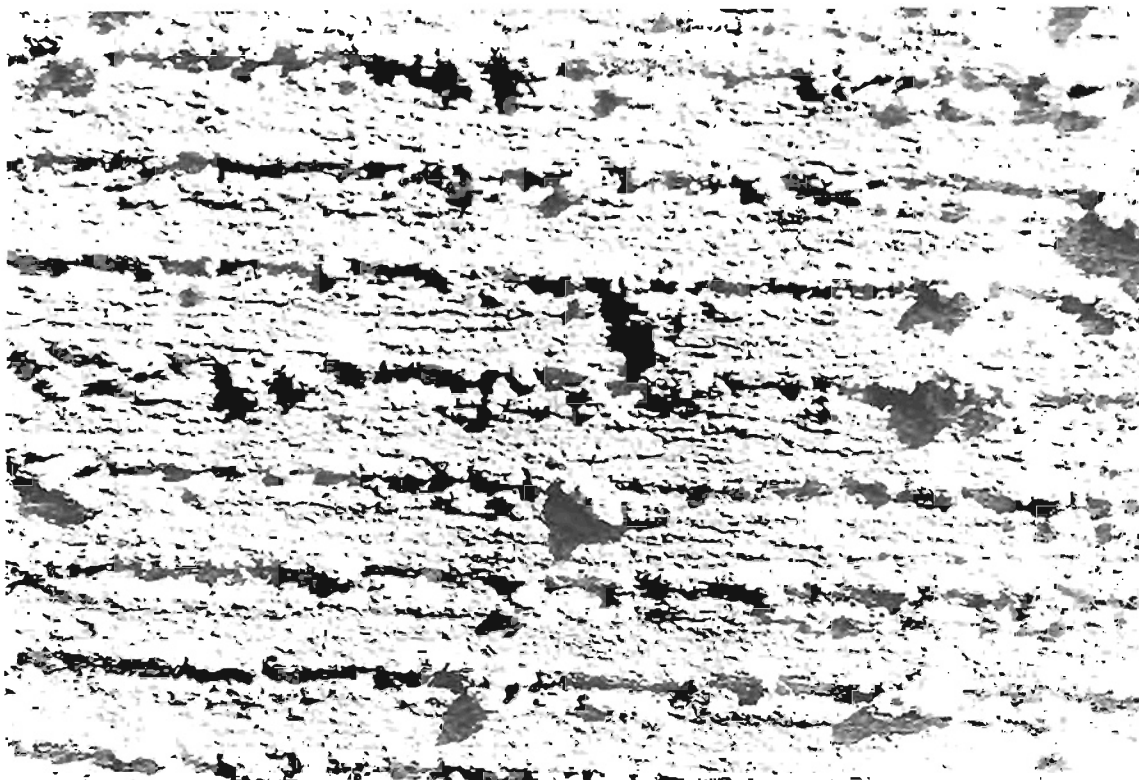


Photo 3: Popcorn-like mortar balls (longitudinal tining)

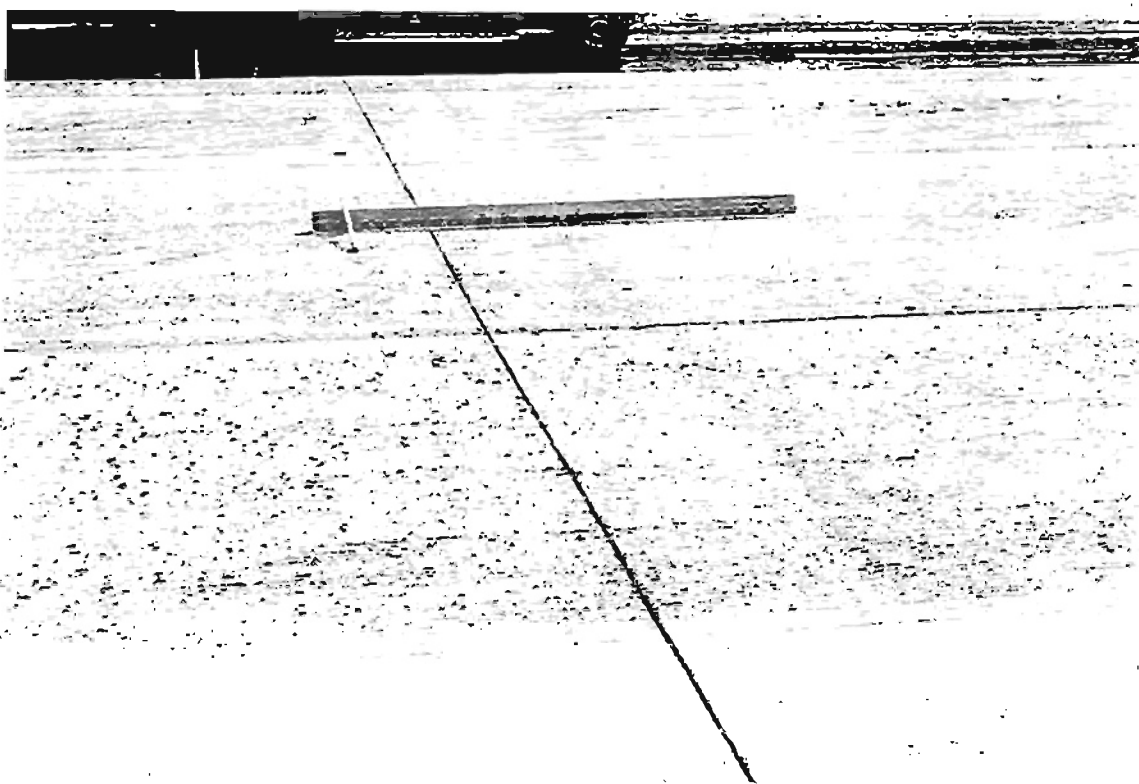


Photo 4: Transverse indentation of plastic concrete

make the texturing more pronounced, several boards were placed on the astro-turf as shown in Photograph 5. Occasionally, the surface of the contact area plugged with mortar (Photograph 6) and the tining operator had to raise the astro-turf and shake out the excess grout.

Photograph 7 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. They decided to texture only the first 100 feet of the day's paving with this method to determine its feasibility and its 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 8, the astro-turf adequately textured the pavement surface and as a result, transverse astro-turf texturing was continued for the entire day.

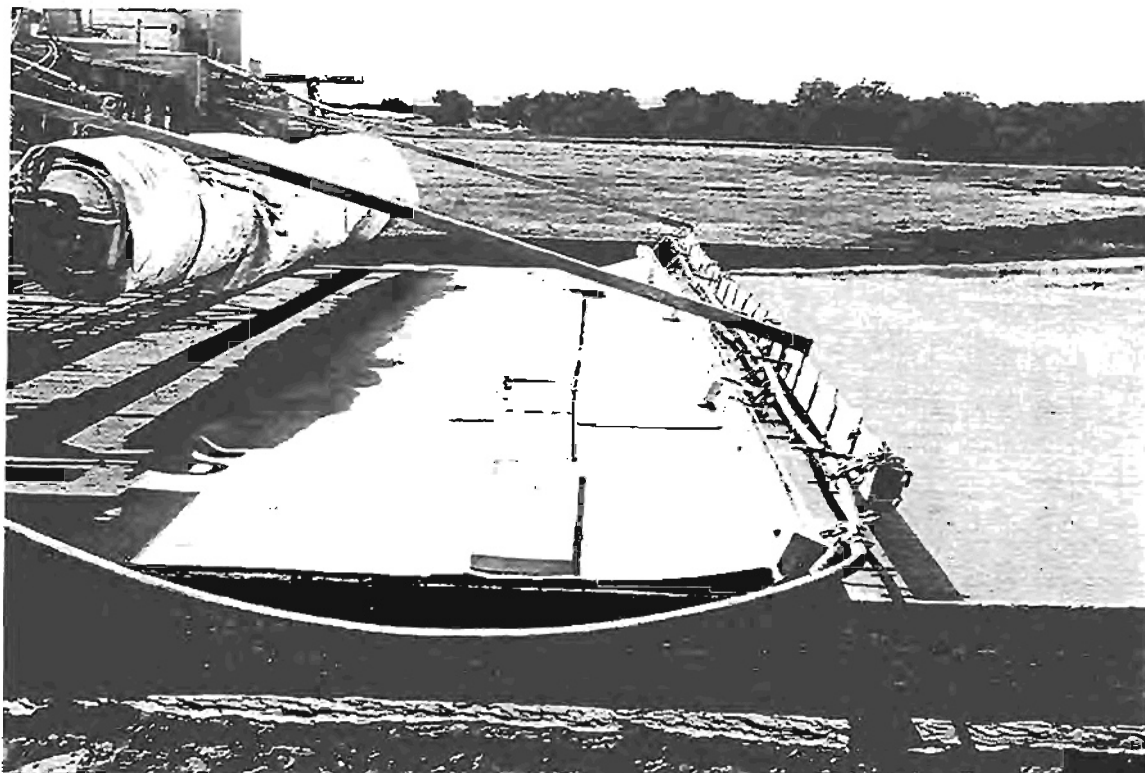


Photo 5: View of the astro-turf drag with planks for added weight

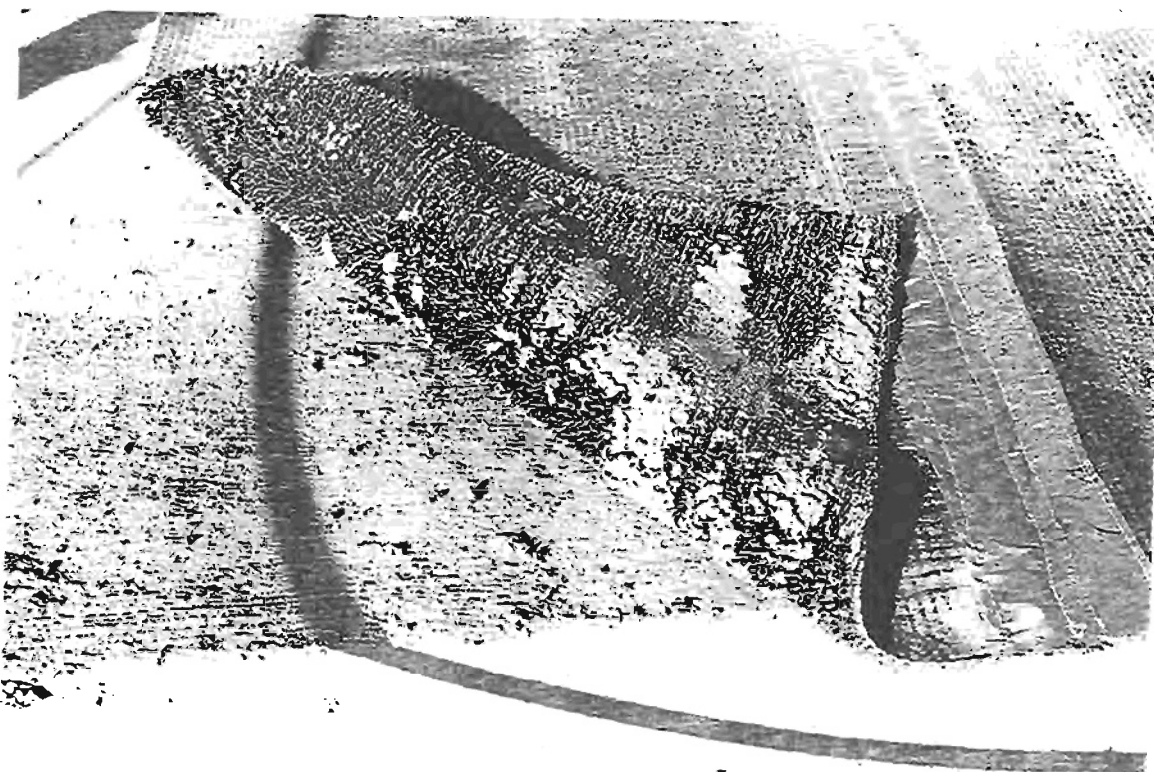


Photo 6: Astro-turf plugged up with grout



Photo 7 & 8: Installation and close-up view of transverse astro-turf texture

Photograph 9 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 10. Photograph 11, 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 12.

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 13). 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 14 shows a close-up view of the longitudinal grooving. The rumble-strips on both, the left, and the right shoulder were also grooved. Photograph 15 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 16. The transverse grooving machine was equipped with a moving head, with

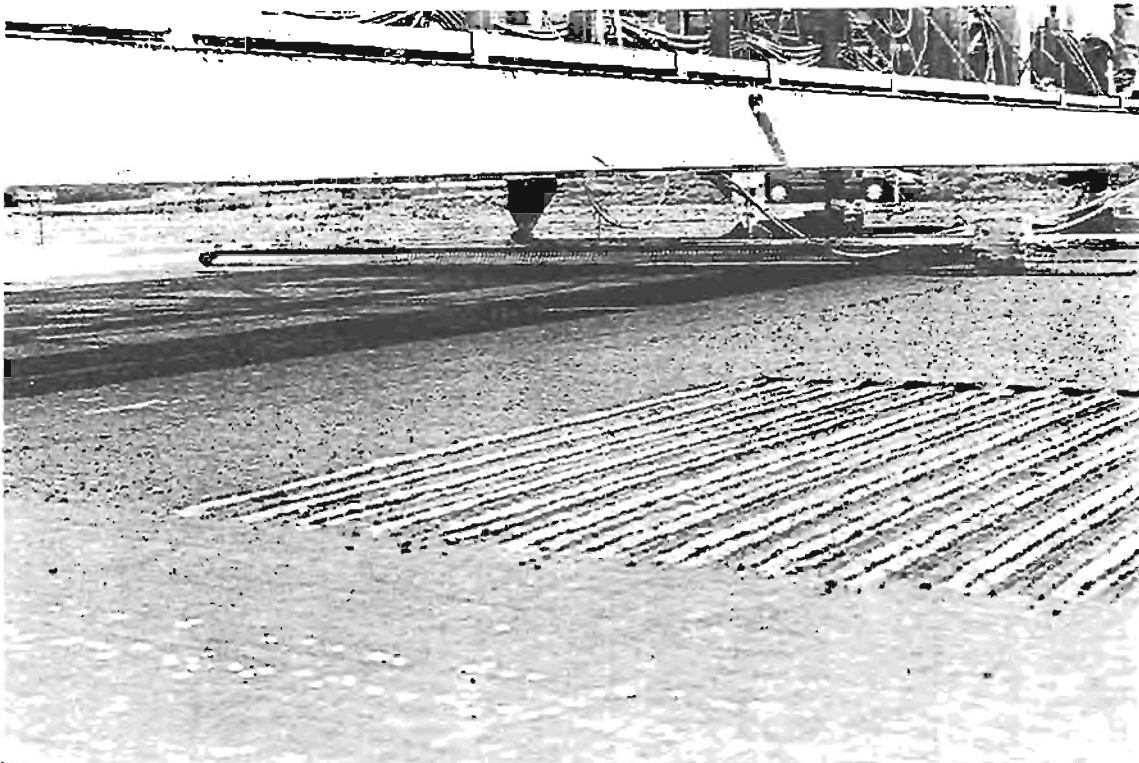


Photo 9: Typical transverse tining operation

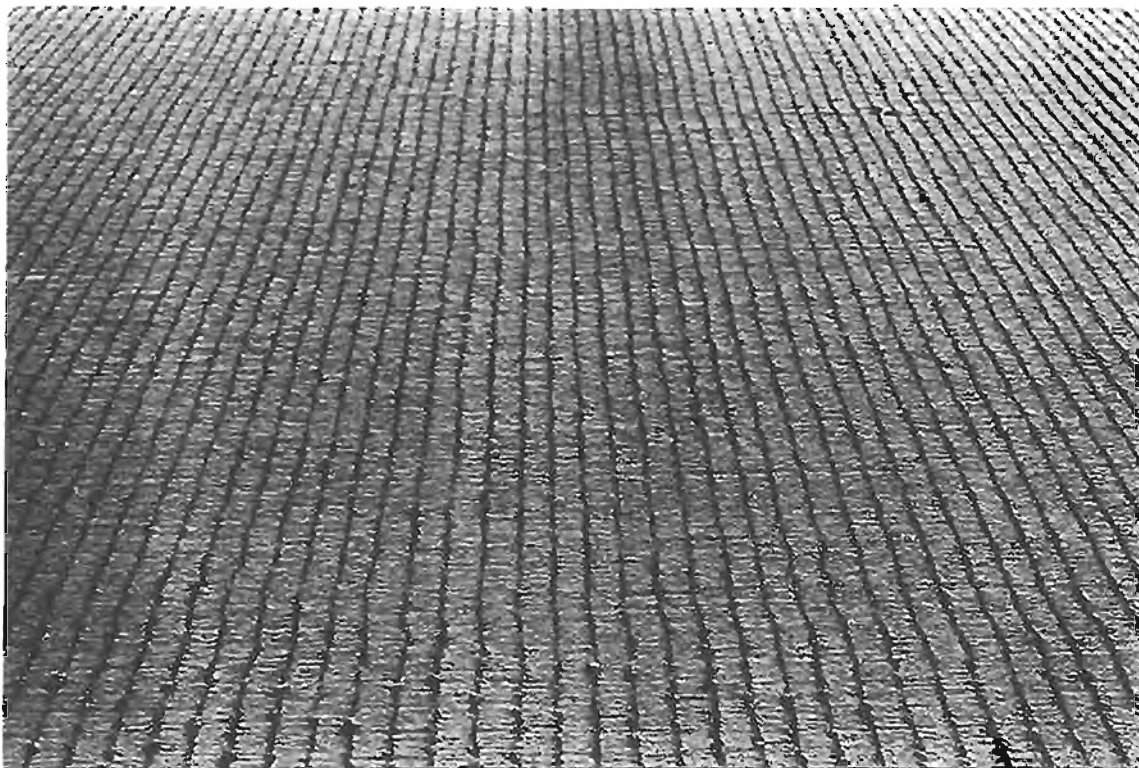


Photo 10: 1" uniform spaced transverse tining (state standard)



Photo 11: 1/2" uniform spaced transverse tining

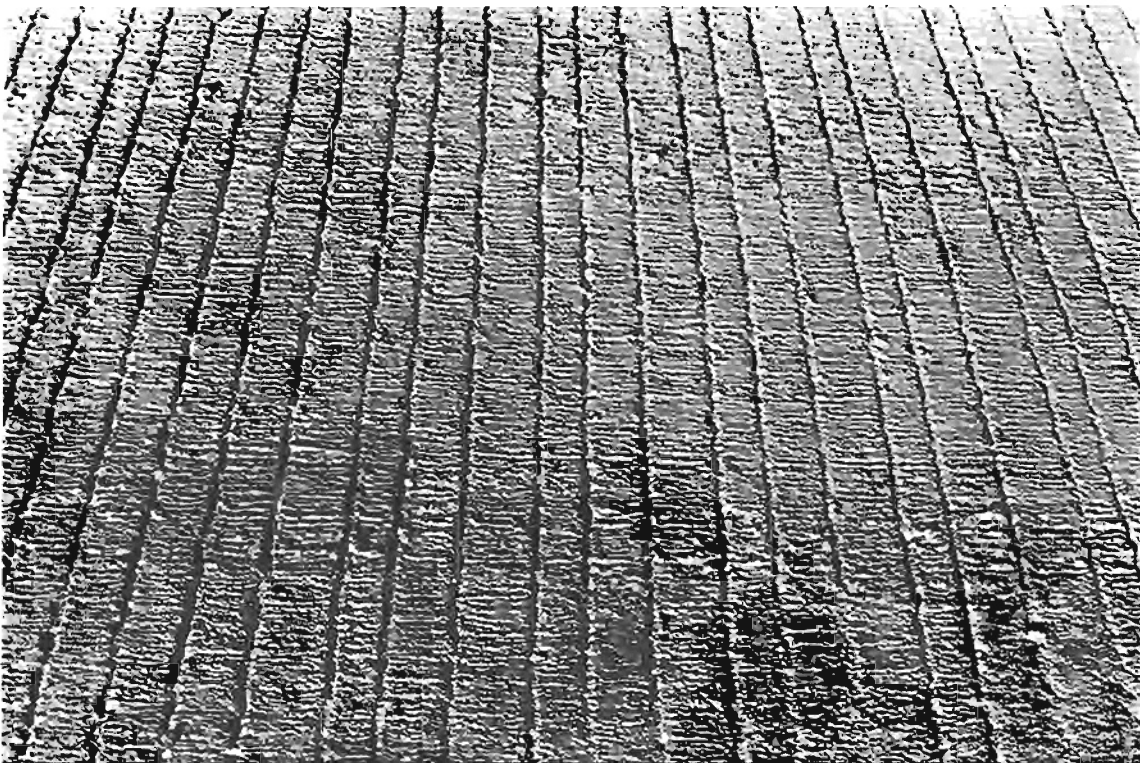


Photo 12: Random transverse tining with 5/8", 7/8", and 3/4" spacing

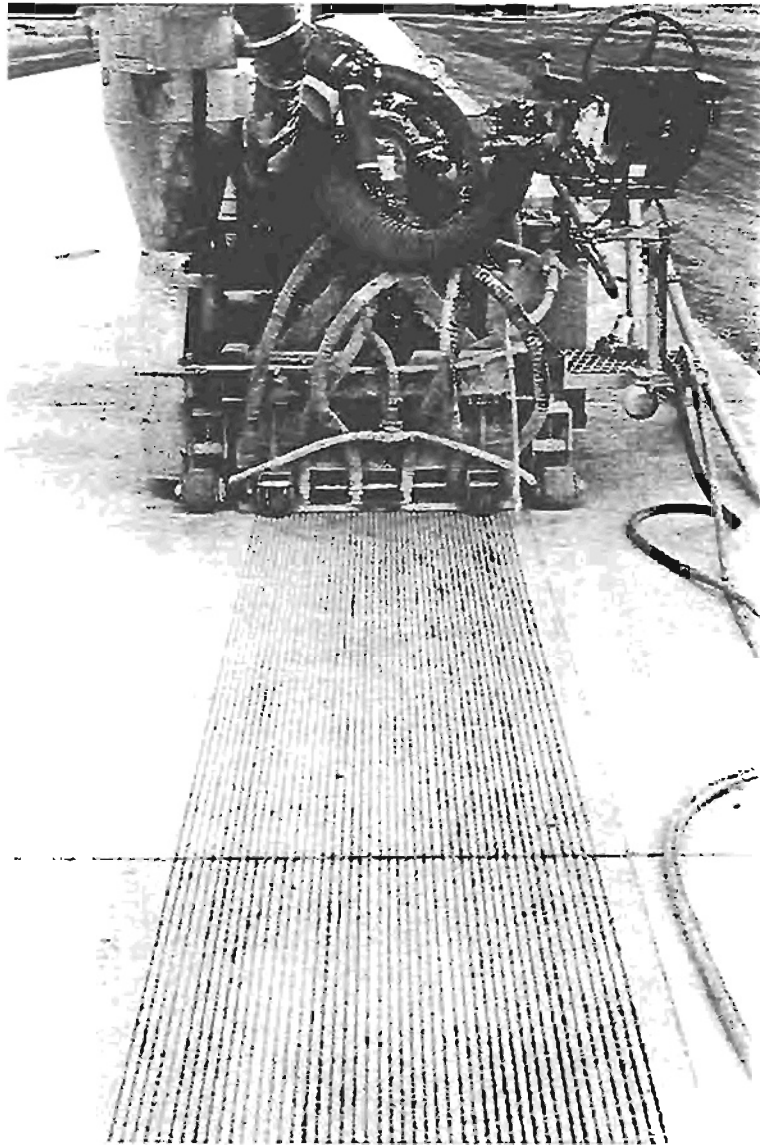


Photo 13: Installation of longitudinal grooves

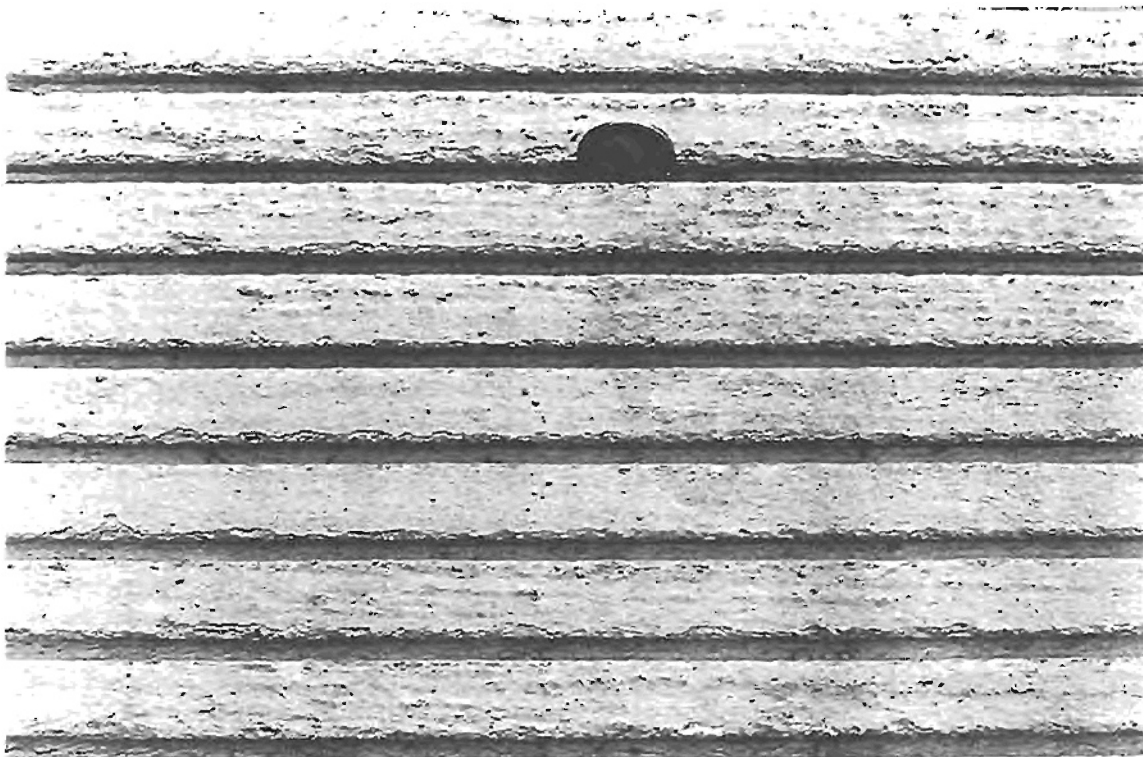


Photo 14: Close-up view of longitudinal grooves



Photo 15: Grooved rumble strip in the right shoulder

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 17.

In general, the transverse and the longitudinal grooving appeared orderly and aesthetically more pleasing than 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 texture may offset their extra initial costs.

V. Data Acquisition and Analysis

A. 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 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

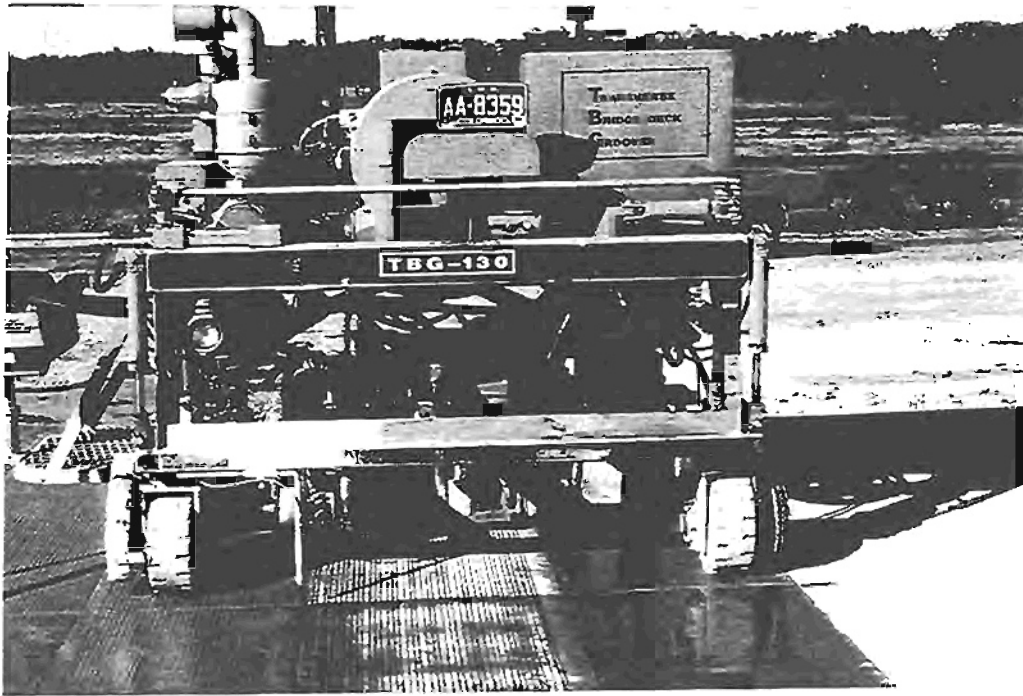


Photo 16: Installation of transverse grooves

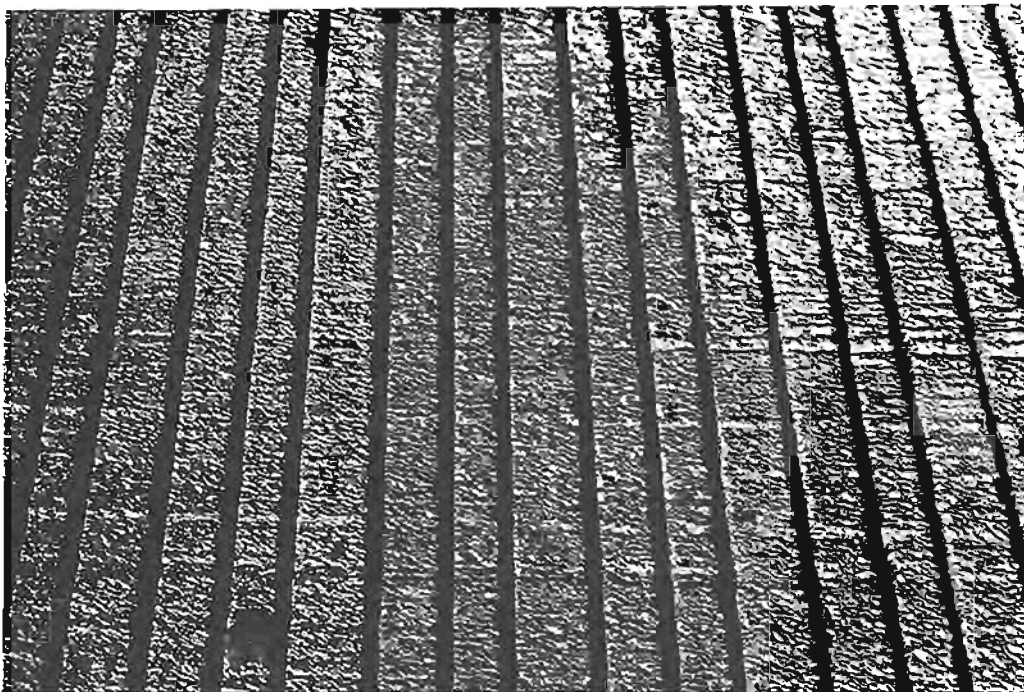


Photo 17: Close up view of random transverse grooves with $5/8"$, $7/8"$, and $3/4"$ spacing

test sections. A minimum of 5 skid resistance tests were conducted for each test section as required by the standard ASTM procedure E 274. The arithmetic average 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, 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 only received 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

RIBBED TIRE SKID NUMBERS

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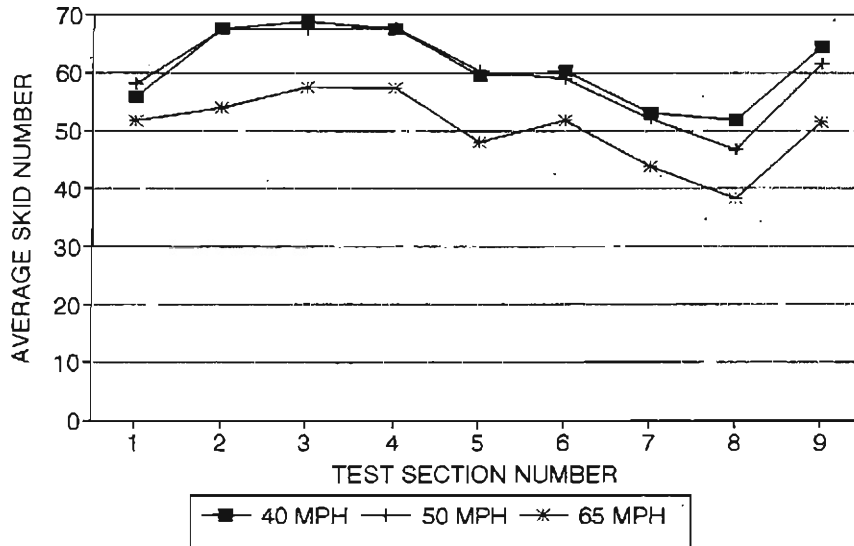


Figure 3

SMOOTH TIRE SKID NUMBERS

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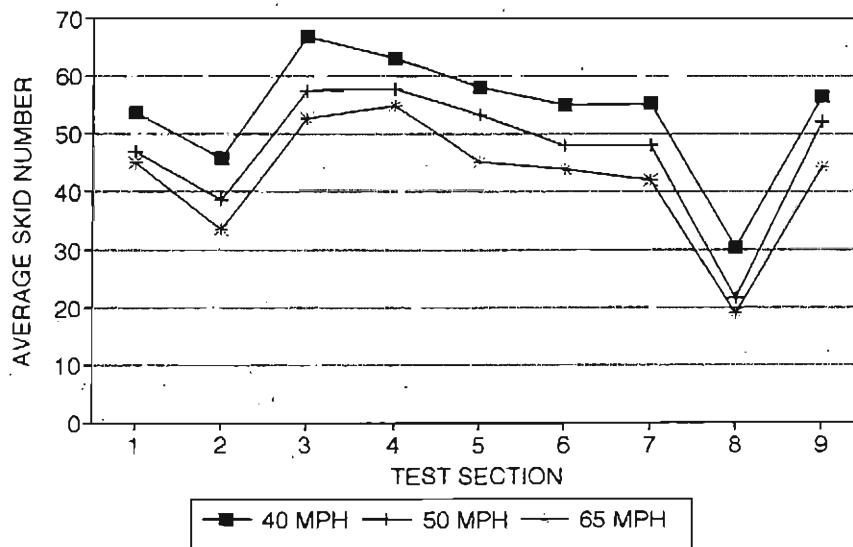


Figure 4

macrotexture. 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.

The smooth-tire and the ribbed-tire speed gradient for the individual test sections are shown in Figure 5. As shown in Figure 5, 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 B.

B. Texture Measurement

Several different types of texture measuring devices were used 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 description were provided by the FHWA, Pavement Division (9).

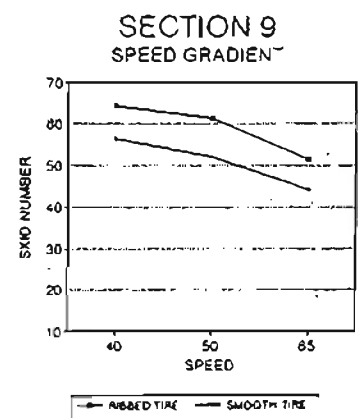
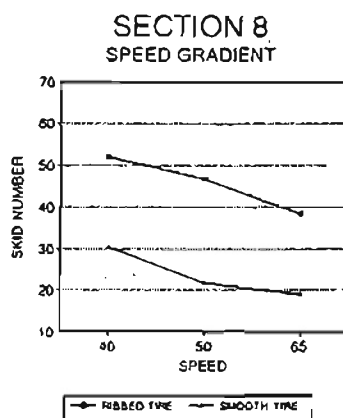
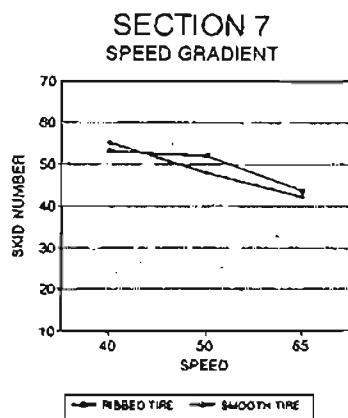
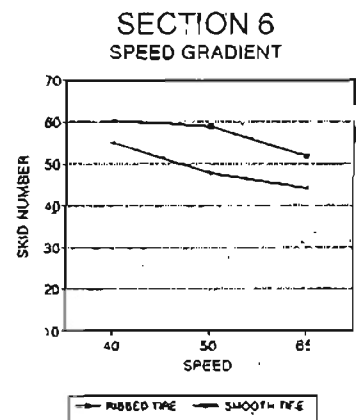
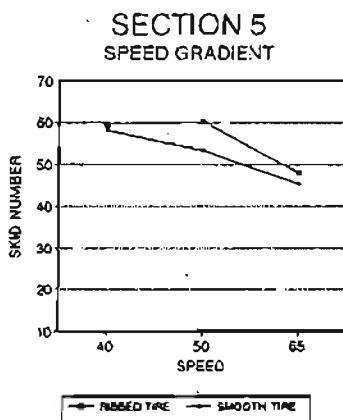
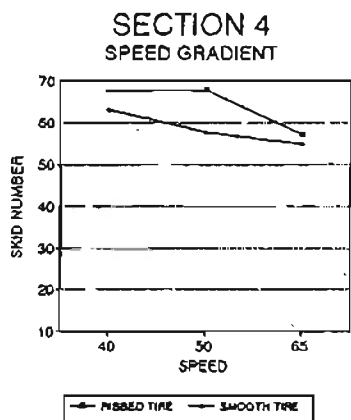
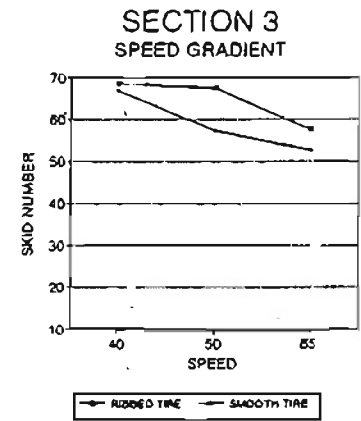
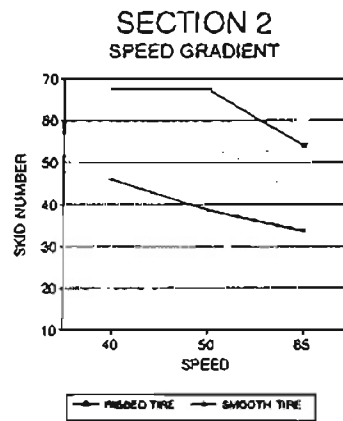
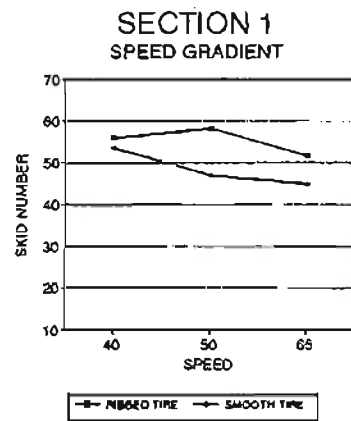


Figure 5

Texture Van (Laser Van)

This equipment (Photograph 18), 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 will take 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 strobelight, and an infrared sensor assures that the field of view is in focus. The images are formed by a slit mask 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 6 compares the average rms values for the 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 longitudinal tining (test section 9). This may indicate that the laser van is more sensitive to transverse texture than 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.



Photo 18: Inside of a texture van.

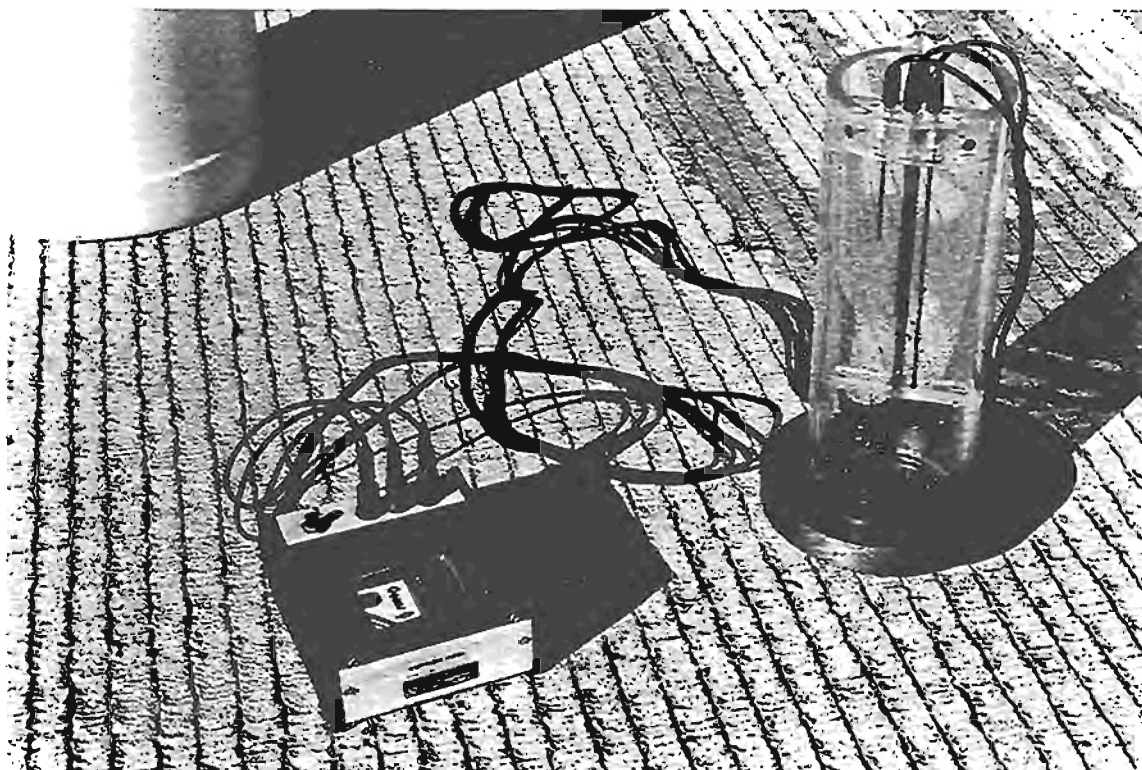


Photo 19: View of an outflow meter.

Outflow Meter

This is an indirect measure of texture (Photograph 19). 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 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. Coarse textured surfaces will allow fast escape, that is the outflow time will be shorter than on smooth pavements.

Figure 7 shows the rate of the dissipation of water in seconds for all the test sections. Section 8 with longitudinal astroturf (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). nevertheless, the time of water dissipation was less than 2 seconds for most of the test sections.

Texture Beam

This equipment (photograph 20), 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

TEXTURE MEASUREMENT LASER VAN

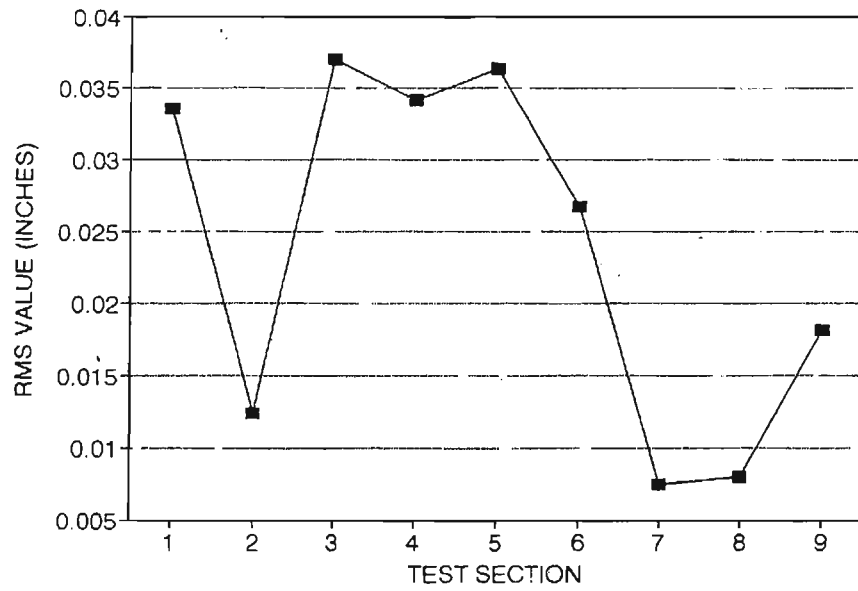


Figure 6

INDIRECT TEXTURE MEASUREMENT WATER FLOW METER

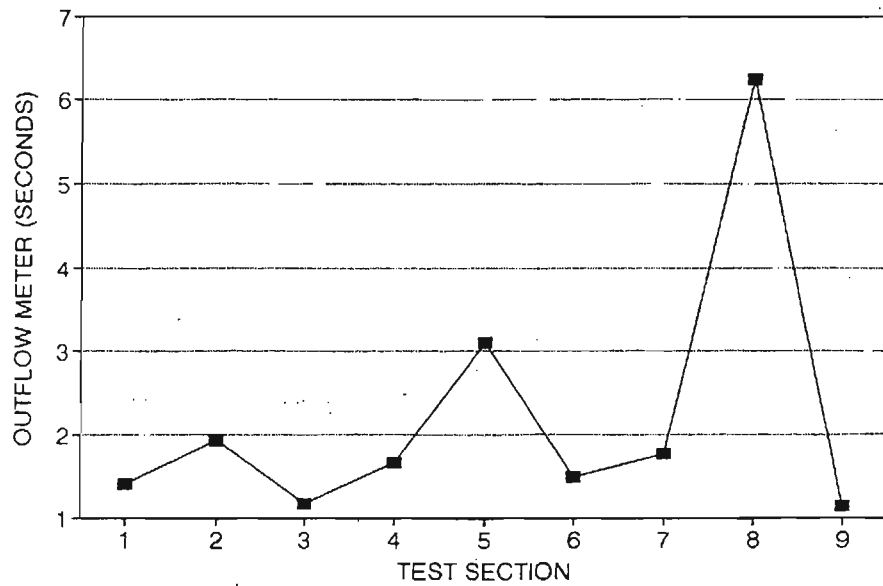


Figure 7

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. Figure 8 and 9 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), which measured to be lower than the rms values of test section 2 and 8 with microtexture.

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 21 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

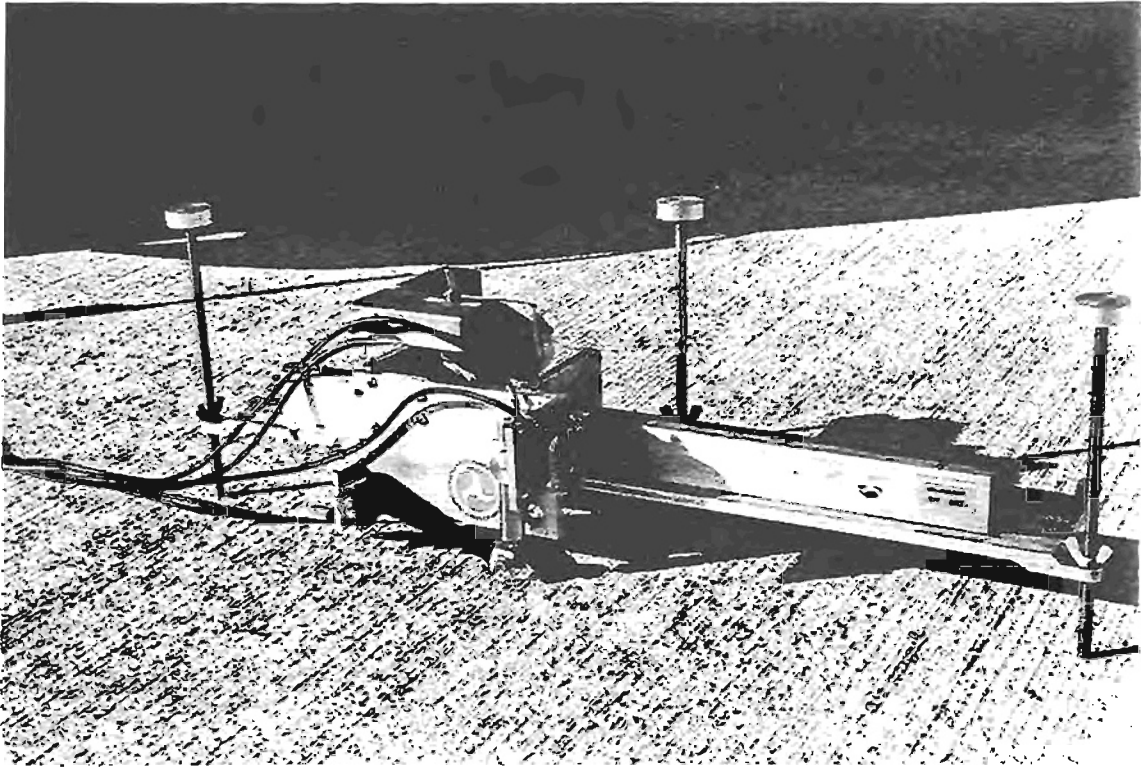


Photo 20: Texture Beam, equipped with an LVTD, and a laser stylus.

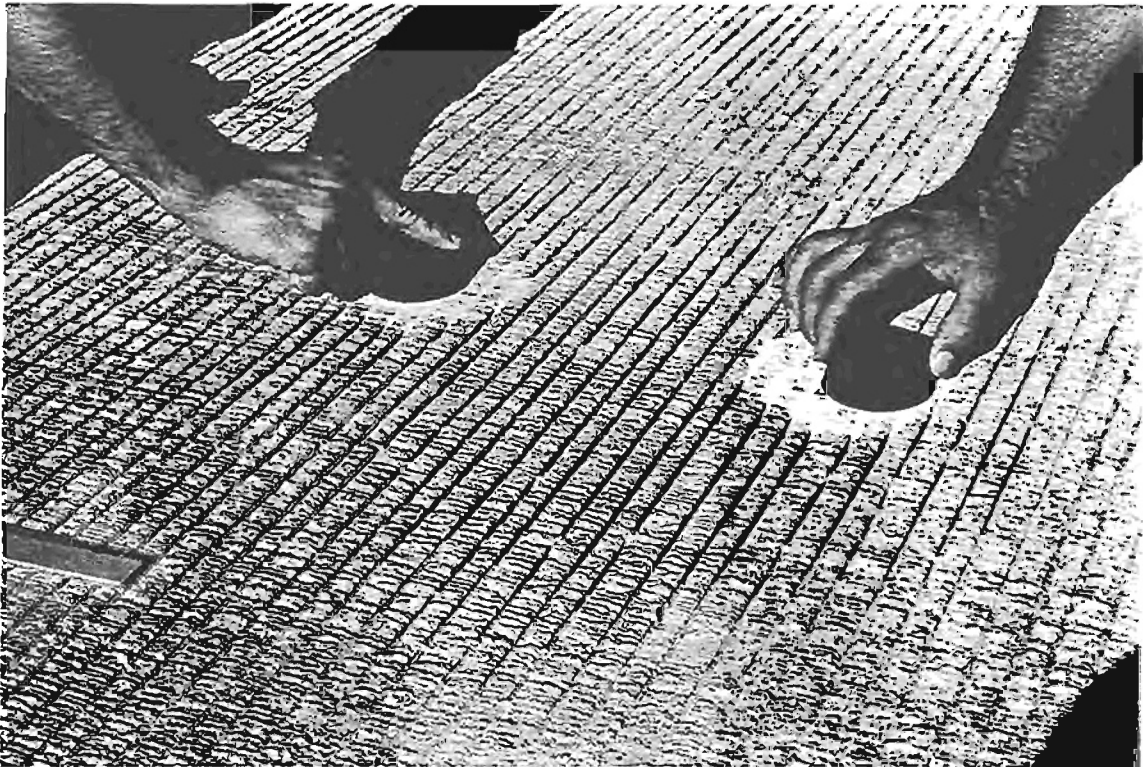


Photo 21: Sand patch method for measuring texture depth.

TEXTURE MEASUREMENT LVDT BEAM

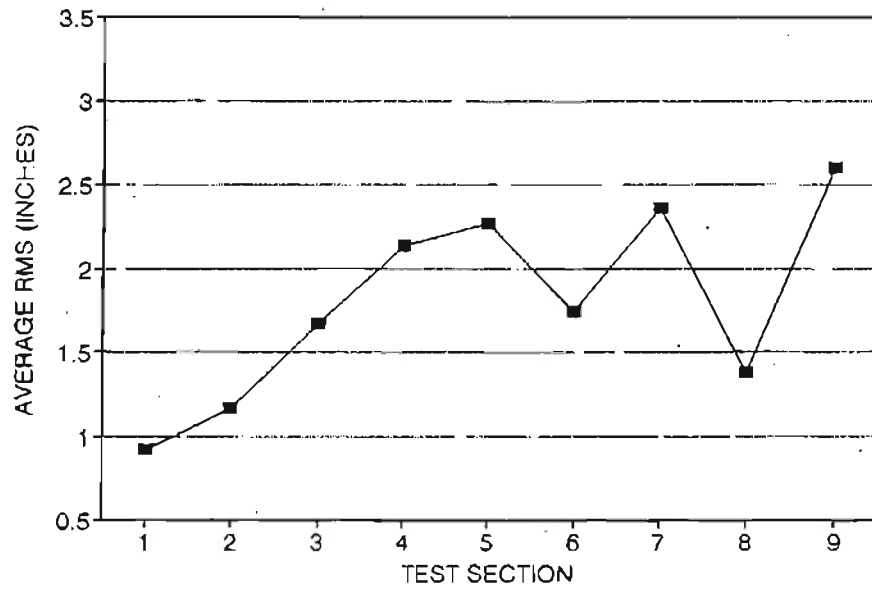


Figure 8

TEXTURE MEASUREMENT LASER BEAM

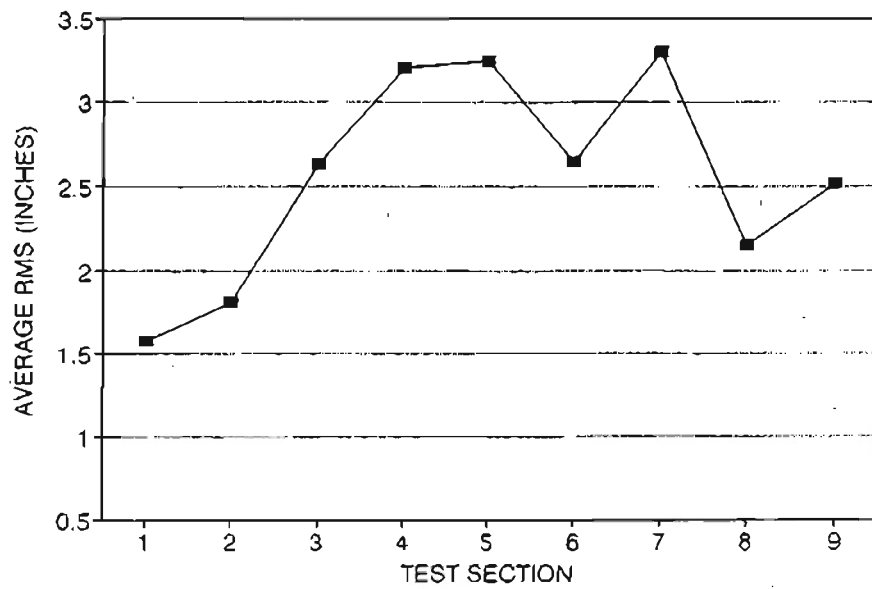


Figure 9

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 10, 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 10 further illustrates a good correlation between these two methods.

Tire Gauge

A tire tread depth gauge with an accuracy of 1/32 of an inch was also used to measure texture depth (Photograph 22). 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 11. These measurements appeared

TEXTURE MEASUREMENT SAND PATCH METHOD

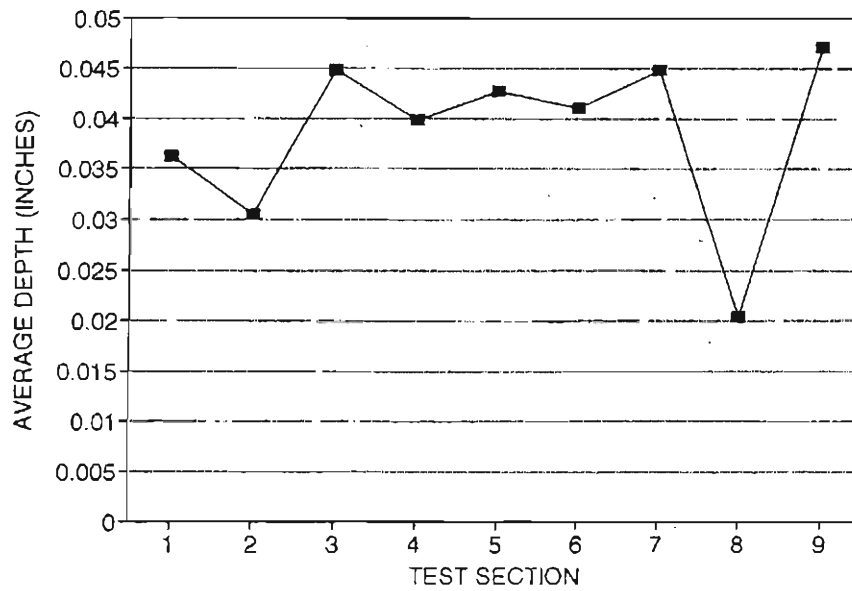


Figure 10

TEXTURE MEASUREMENT TIRE GAUGE

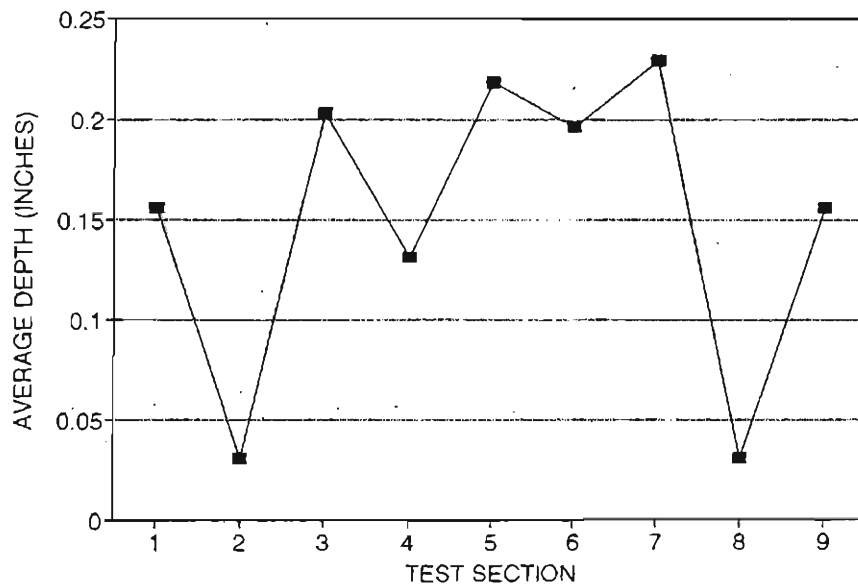


Figure 11

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 relationship between various variables refer to scatter charts in Appendix A.

C. 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 these measurements were to acoustically assess the impact of various surface texture 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 were as follows:

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



Photo 22: Texture depth measurement using a tire gauge.



Photo 23: SPL measurement at the roadside.

Noise data were acquired in the following three conditions:

1. SPL measurements were acquired at 25 feet from the center line 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 23). 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 the engine off produced the same SPL, indicating that the tire noise was predominately louder than the engine noise.

Figure 12 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.

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

2. SPL measurements were acquired inside of 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 13 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.

SPL AT THE SHOULDER COMPARED TO STATE STANDARD SECTION

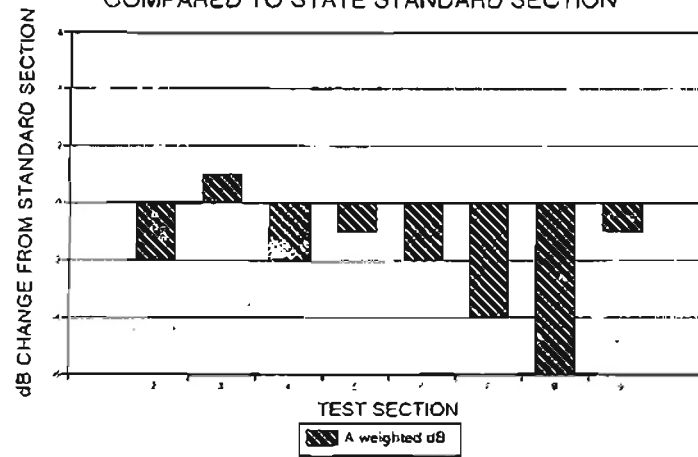


Figure 12

SPL INSIDE TEST VEHICLE COMPARED TO STATE STANDARD SECTION

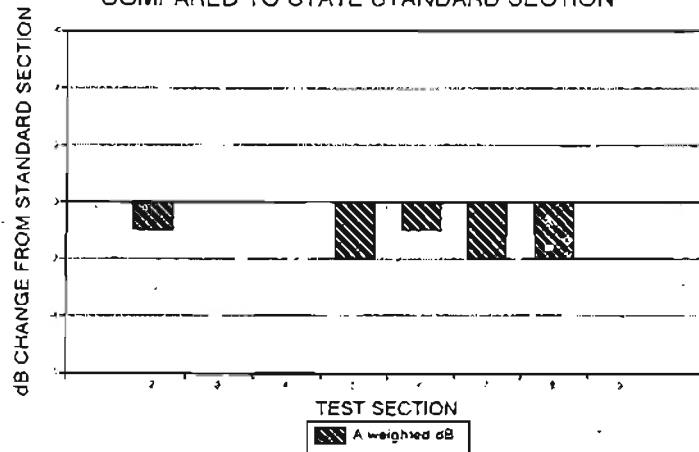


Figure 13

SPL AT REAR TIRE COMPARED TO STATE STANDARD SECTION

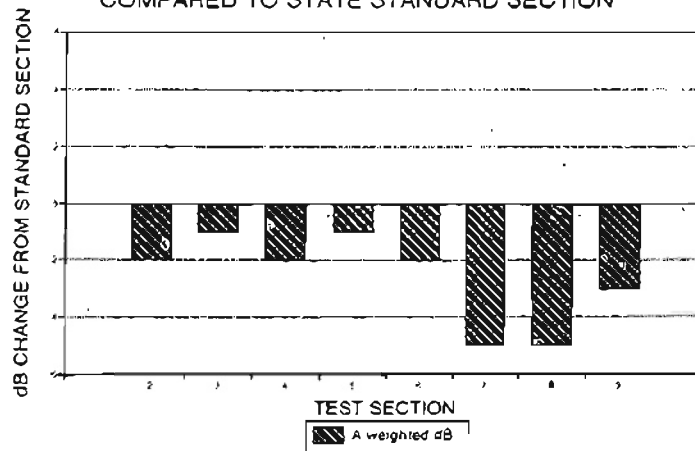


Figure 14

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 24). Figure 14 compares the change in SPL measurements of 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 14. 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 15 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 of 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

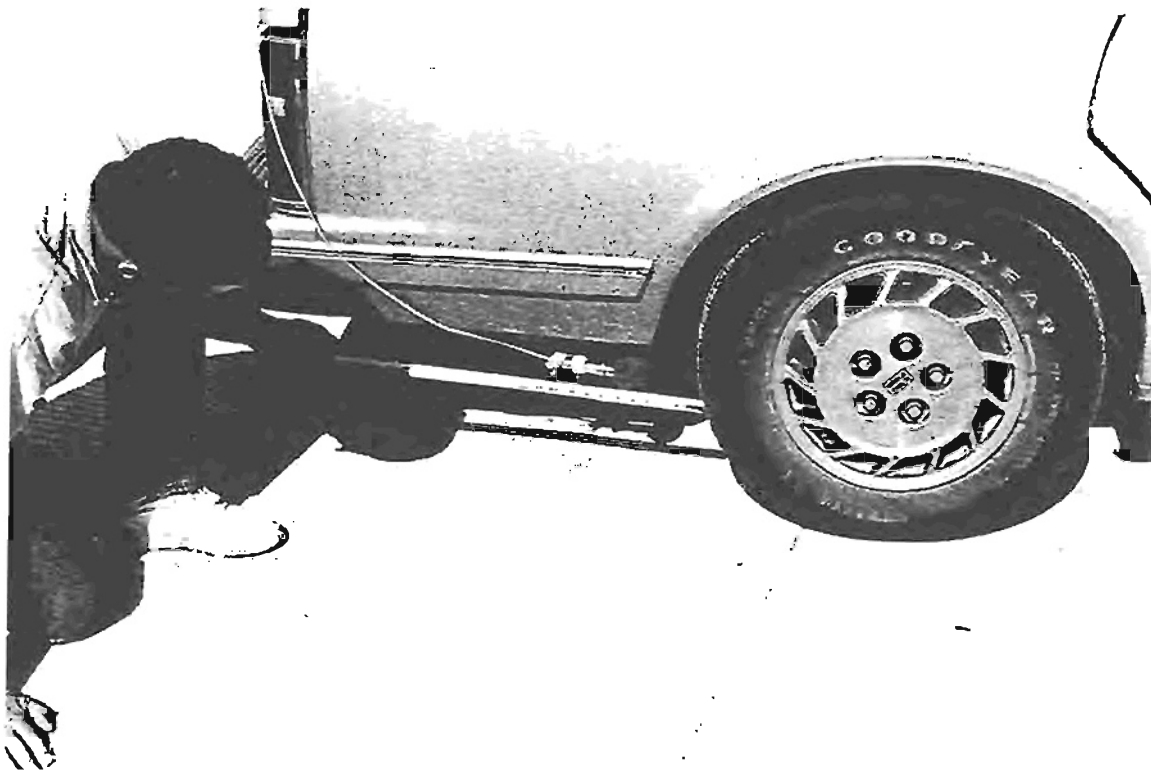


Photo 24: View of the microphone behind the rear tire



Photo 25: Acquiring truck noise levels at the roadside

(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 16 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 seen in this figure the SPL for both the truck and the test vehicle peaked at 1000 Hz. However, the figure shows that the noise from the truck (Photograph 25) to be at the higher annoyance range (by about 8 dB) than the test vehicle. The A-weighted dB for the truck was also 7 dB higher than the A-weighted dB of the test vehicle.

D. Roughness Data

Figure 17 compares the average right- and left-wheel-path roughness data for all the test sections. Test section 6, which was textured using 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 system and generate vibration inside vehicles are primarily due to megatextue or small scale roughness (explained below). The influence of surface texture on ride quality, with the exception of noise level, is minimal.

A-WEIGHTED SOUND LEVELS

OCTOBER 1994

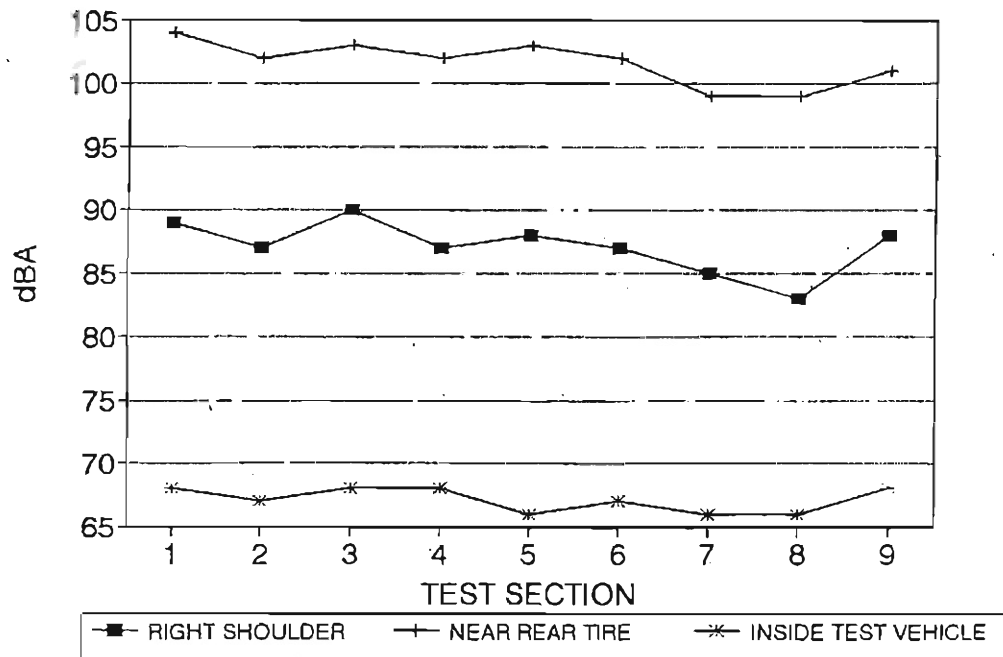


Figure 15

SPL COMPARISONS CAR vs. TRUCK (SHOULDER SECT 1)

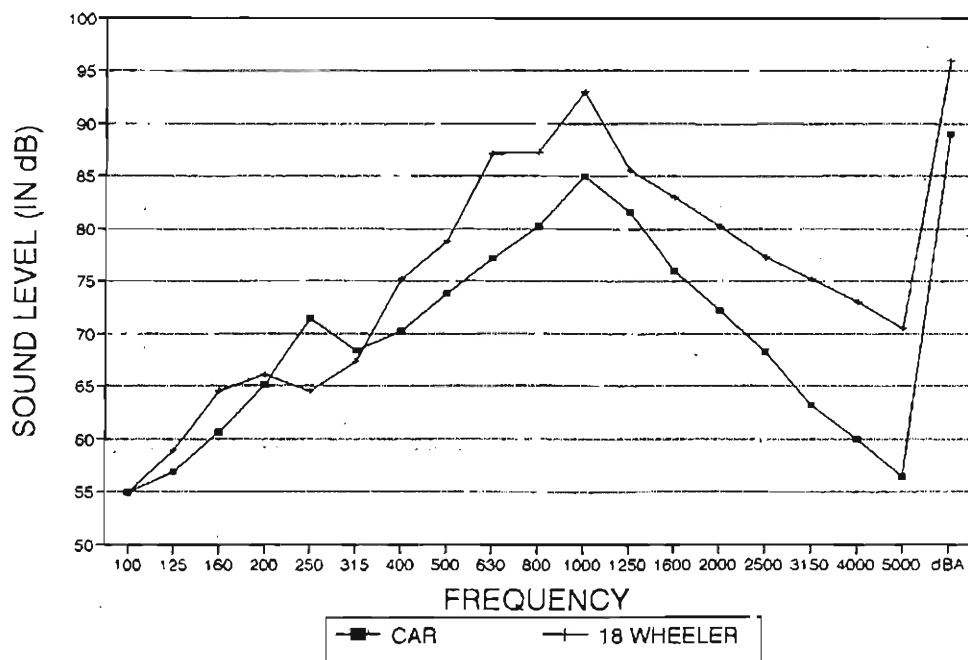


Figure 16

PROFILOGRAPH

OCTOBER 1994

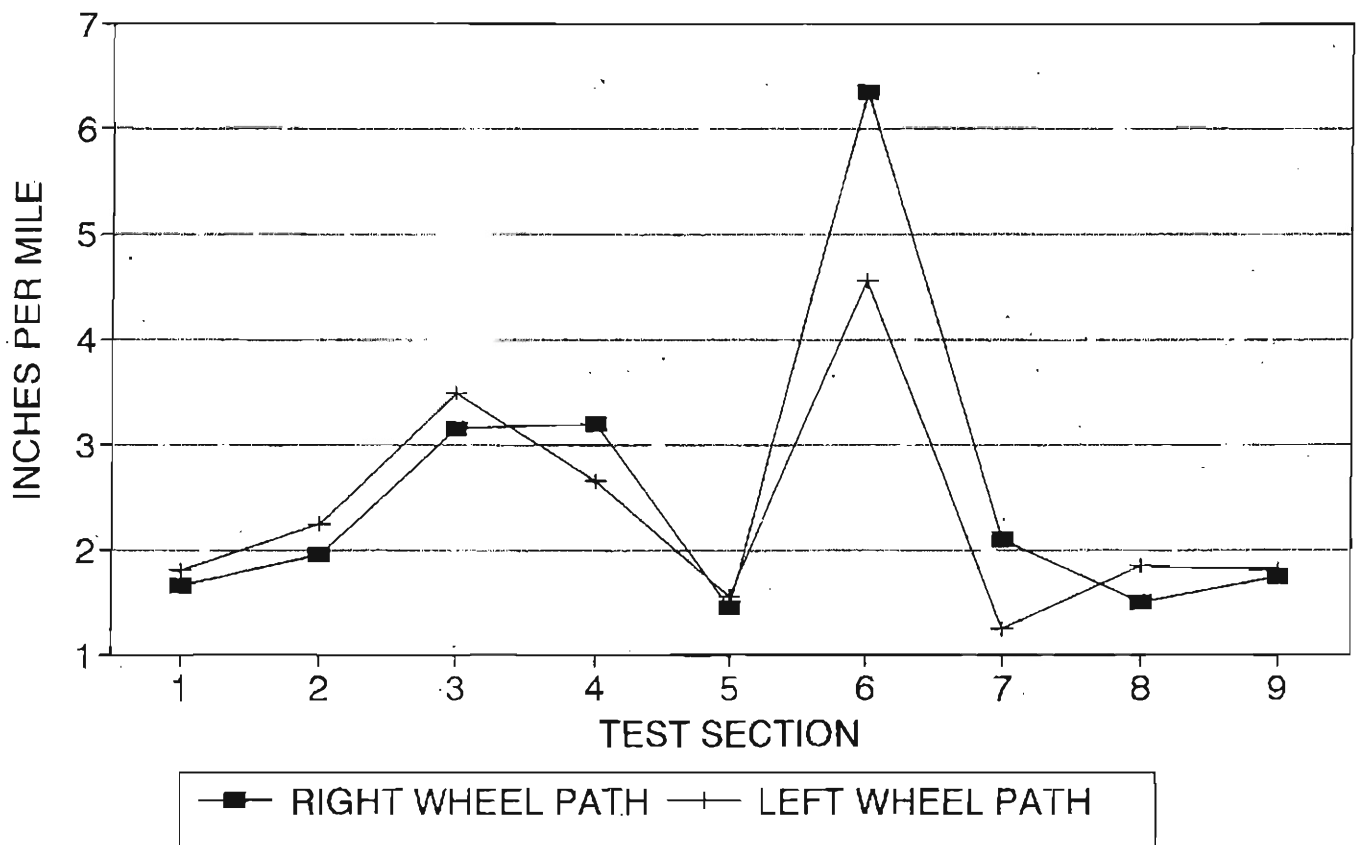


figure 17

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 only irregularities with wavelength 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, only have beneficial effects (14).

VI. Conclusions and Recommendations

The conclusions are based on the first round of data, which were acquired prior to opening to traffic, therefore, they are considered preliminary. Nevertheless, data collection will continue over the next 4 years on an annual basis, and the results will be distributed as they become available. The preliminary results are as follows:

- 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 their 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.

- 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 favorable with the ribbed-tire skid numbers. For a thorough view of the scatter diagrams (relationship between various variables) refer to Appendix A.
- The use of 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).
- 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 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 macro- 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 that A-weighted dB of a semi-truck to be approximately 7 dB higher than the A-weighted dB of the test vehicle.

VII. References

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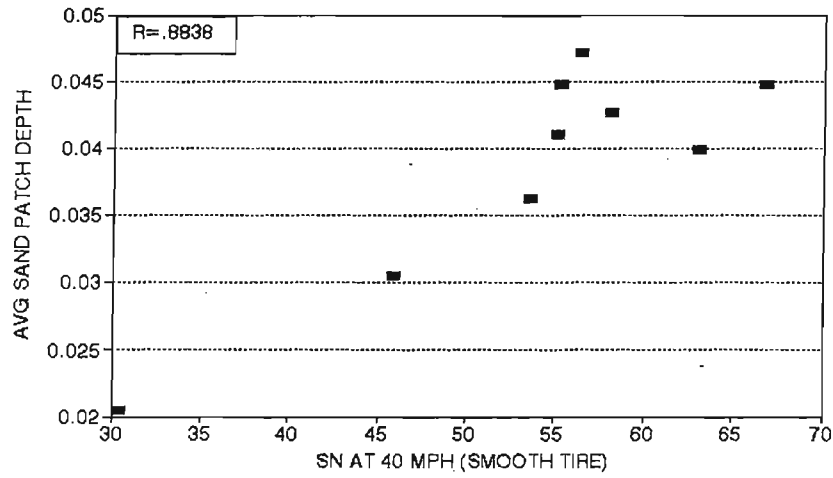
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Appendix A

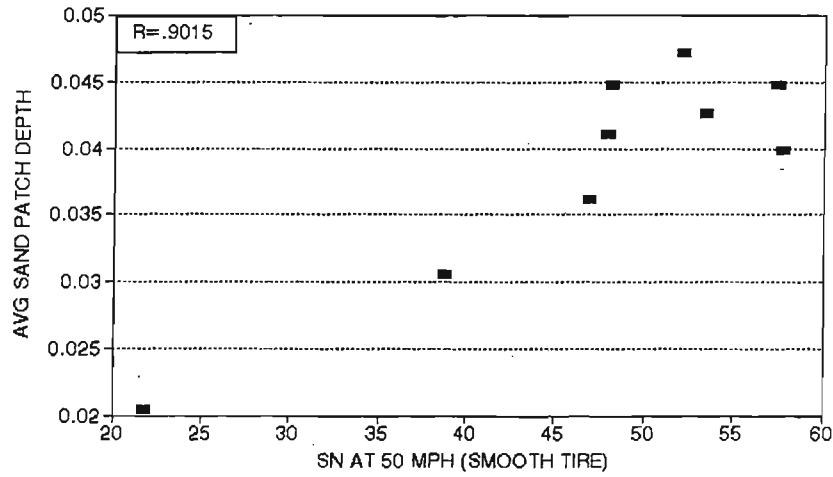
SKID MEASUREMENT AVERAGES						
SITE	SN40R	SN50R	SN65R	SN40S	SN50S	SN65S
1	55.8	58.1	51.7	53.6	46.9	45
2	67.5	67.4	54	45.9	38.7	33.6
3	68.7	67.3	57.6	66.8	57.4	52.6
4	67.5	67.7	57.3	63	57.7	54.8
5	59.5	60.3	48.1	58.1	53.3	45.3
6	60.3	59	51.9	55.1	47.9	44.1
7	53.1	52	43.8	55.2	48.1	42.2
8	52	46.7	38.4	30.4	21.8	19
9	64.4	61.4	51.5	56.4	52.1	44.4

TEXTURE MEASUREMENT AVERAGES							
SITE	LASER VAN (RMS INCHES)	SAND PATCH (DIA. IN INCHES)	SAND PATCH (DEPTH INCHES)	FLOW METER (SECONDS)	BEAM LASER (RMS INCHES)	BEAM LVDT (RMS INCHES)	TIRE TREAD GAUGE (INCHES)
1	0.03363	7.26	0.036	1.403	1.575	0.919	.156
2	0.01236	7.91	0.031	1.923	1.806	1.170	.031
3	0.037	6.53	0.045	1.158	2.639	1.673	.203
4	0.03416	6.92	0.040	1.662	3.209	2.139	.131
5	0.0364	6.69	0.043	3.093	3.252	2.267	.219
6	0.0268	6.82	0.041	1.491	2.648	1.742	.196
7	0.00747	6.53	0.045	1.763	3.303	2.360	.229
8	0.00797	9.67	0.020	6.247	2.148	1.377	.031
9	0.0181	6.36	0.047	1.133	2.519	2.603	.156

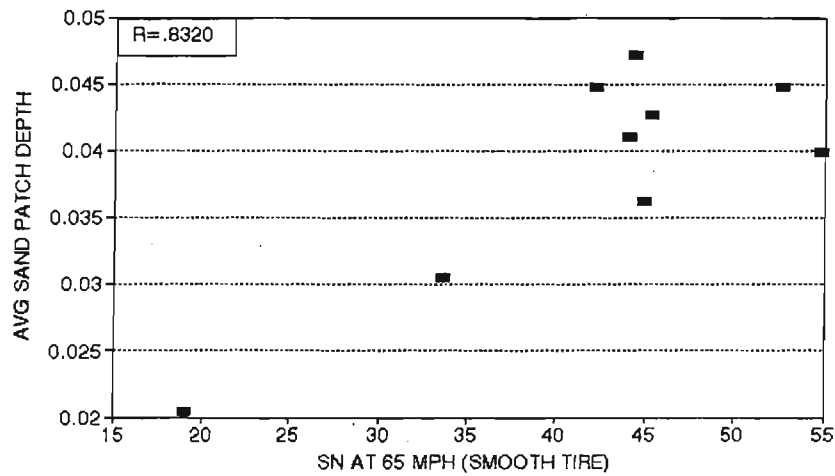
SN40S vs SAND PATCH DEPTH



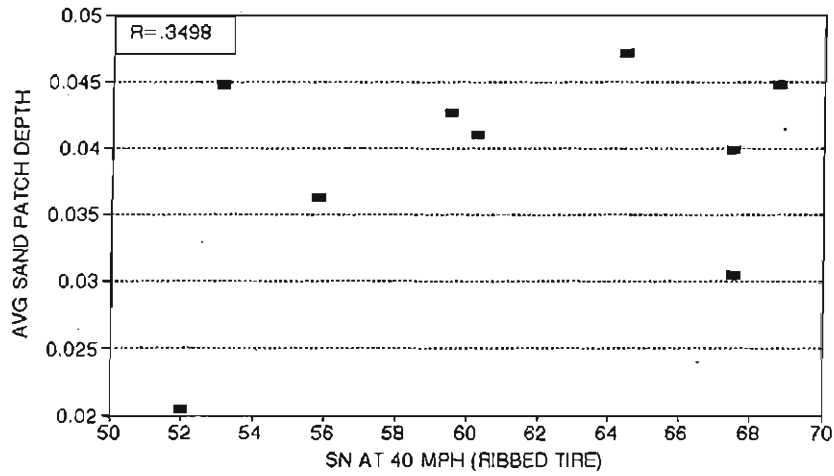
SN50S vs SAND PATCH DEPTH



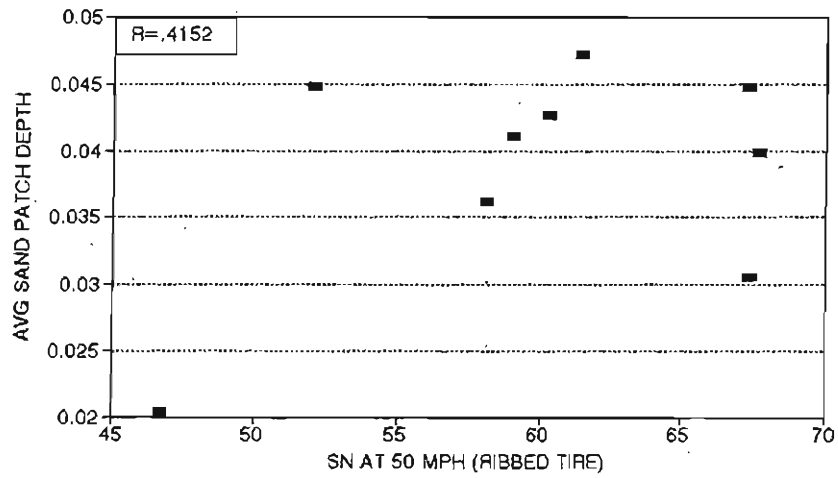
SN65S vs SAND PATCH DEPTH



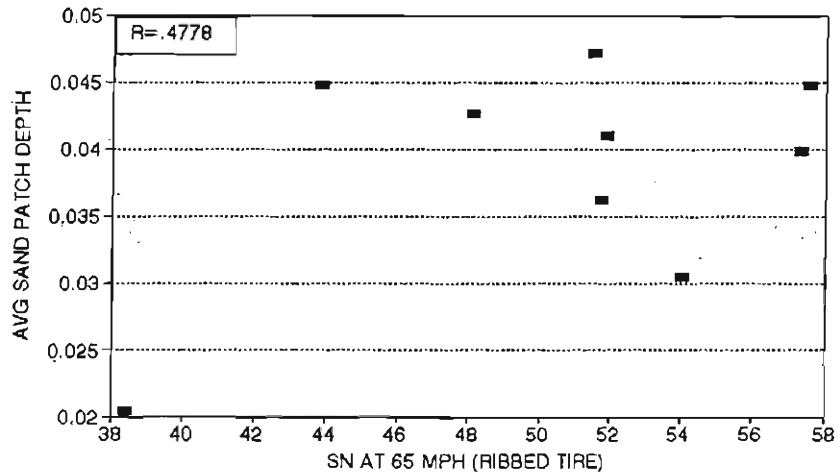
SN40R vs SAND PATCH DEPTH



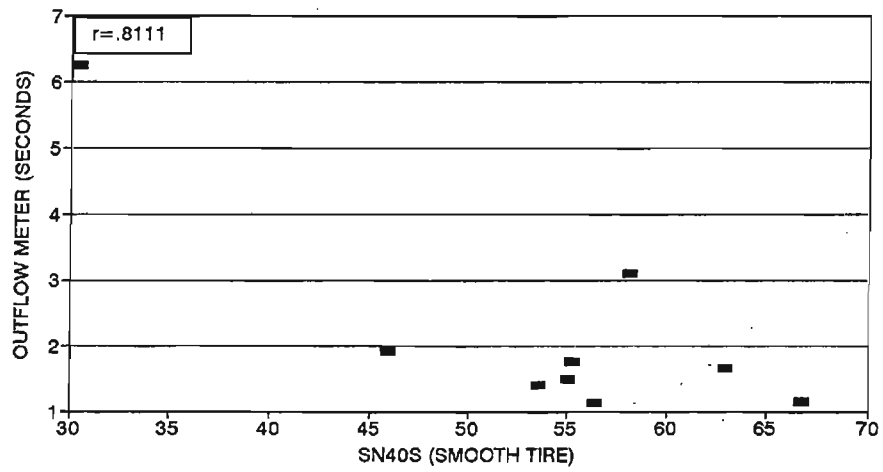
SN50R vs SAND PATCH DEPTH



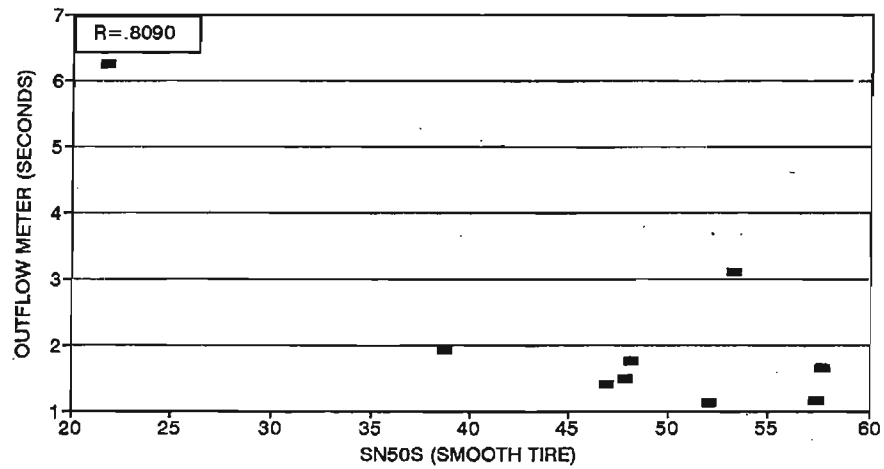
SN65R vs SAND PATCH DEPTH



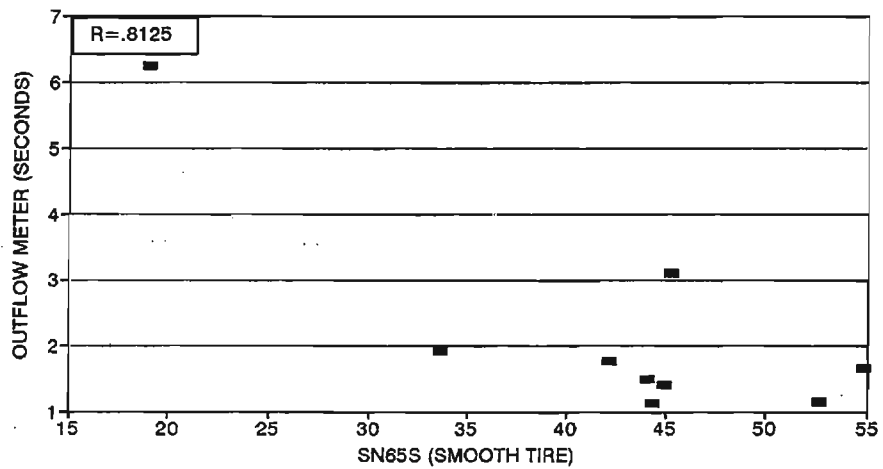
SN40S vs. OUTFLOW METER



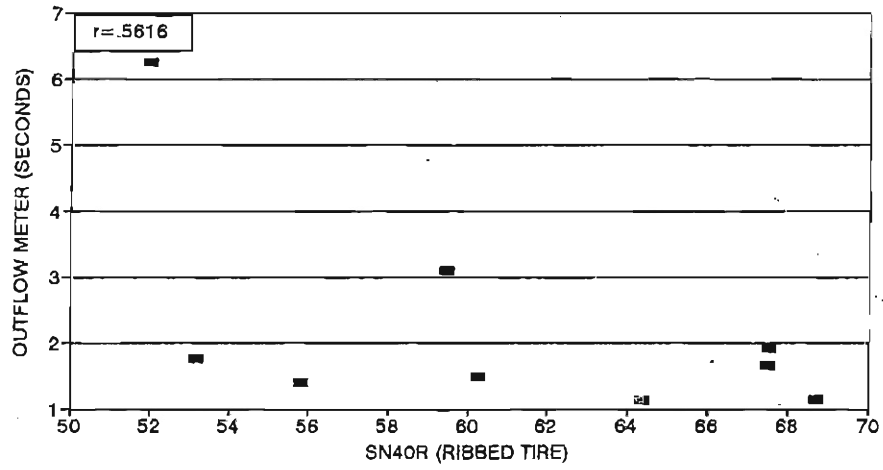
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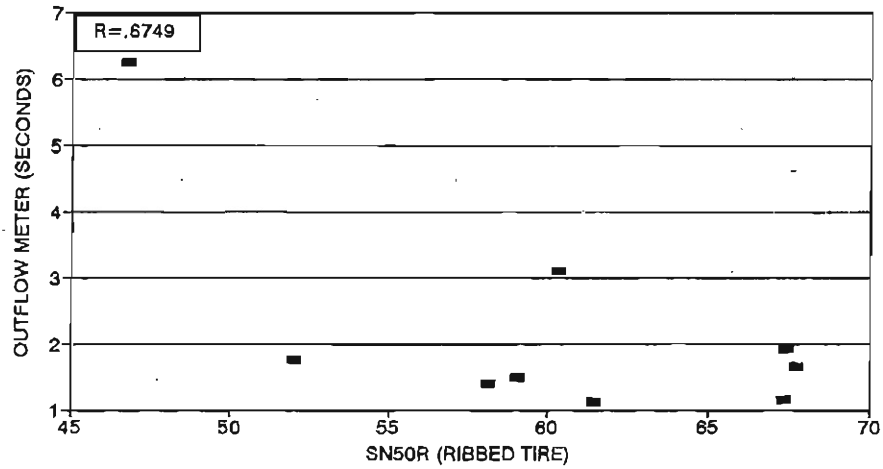
SN65S vs. OUTFLOW METER



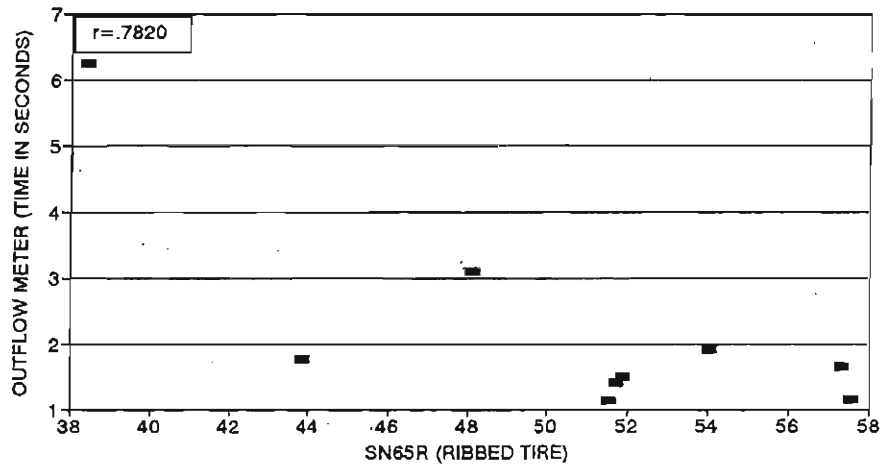
SN40R vs. OUTFLOW METER



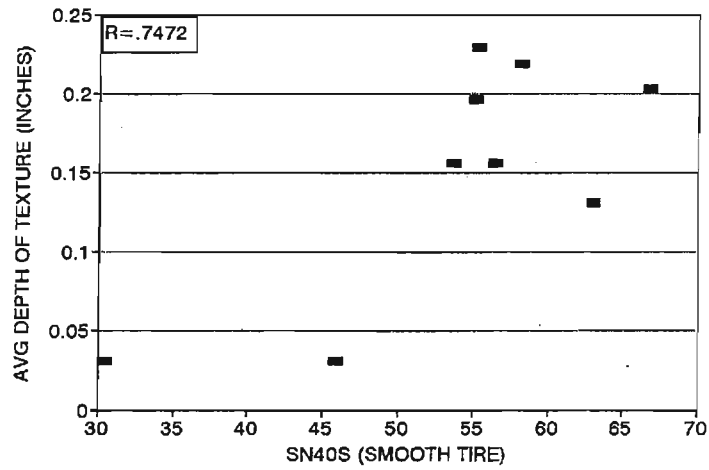
SN50R vs. OUTFLOW METER



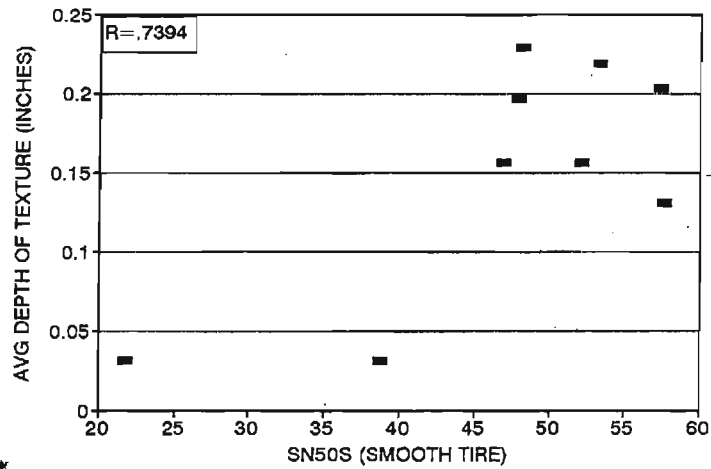
SN65R vs. OUTFLOW METER



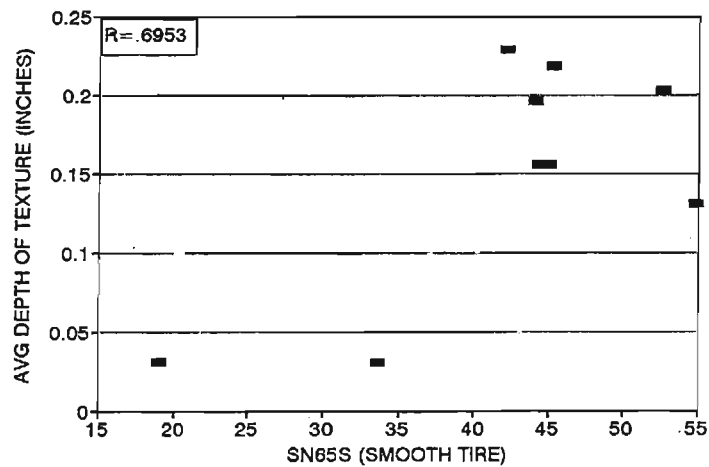
SN40S vs. TIRE TREAD GAUGE



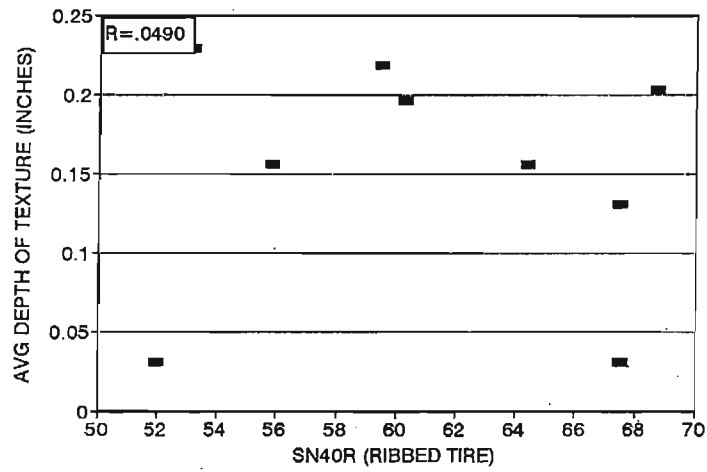
SN50S vs. TIRE TREAD GAUGE



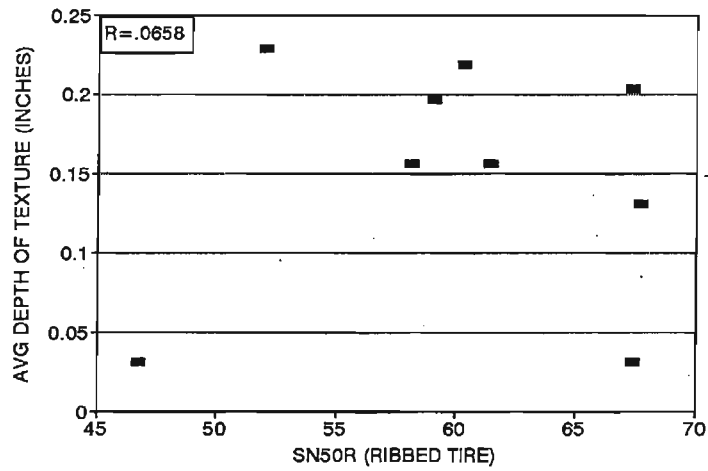
SN65S vs. TIRE TREAD GAUGE



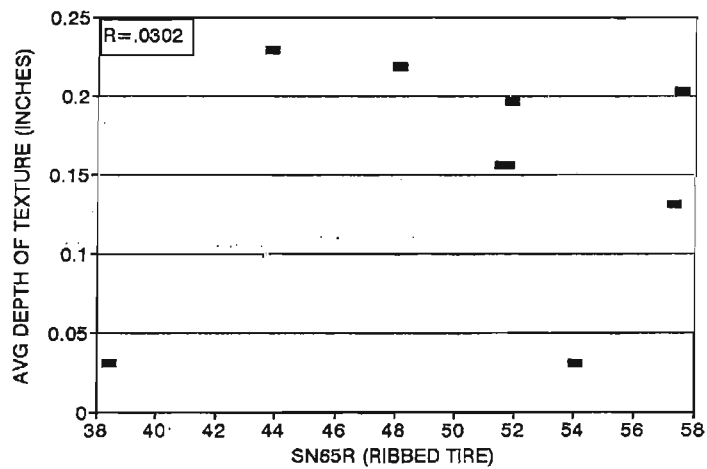
SN40R vs. TIRE TREAD GAUGE



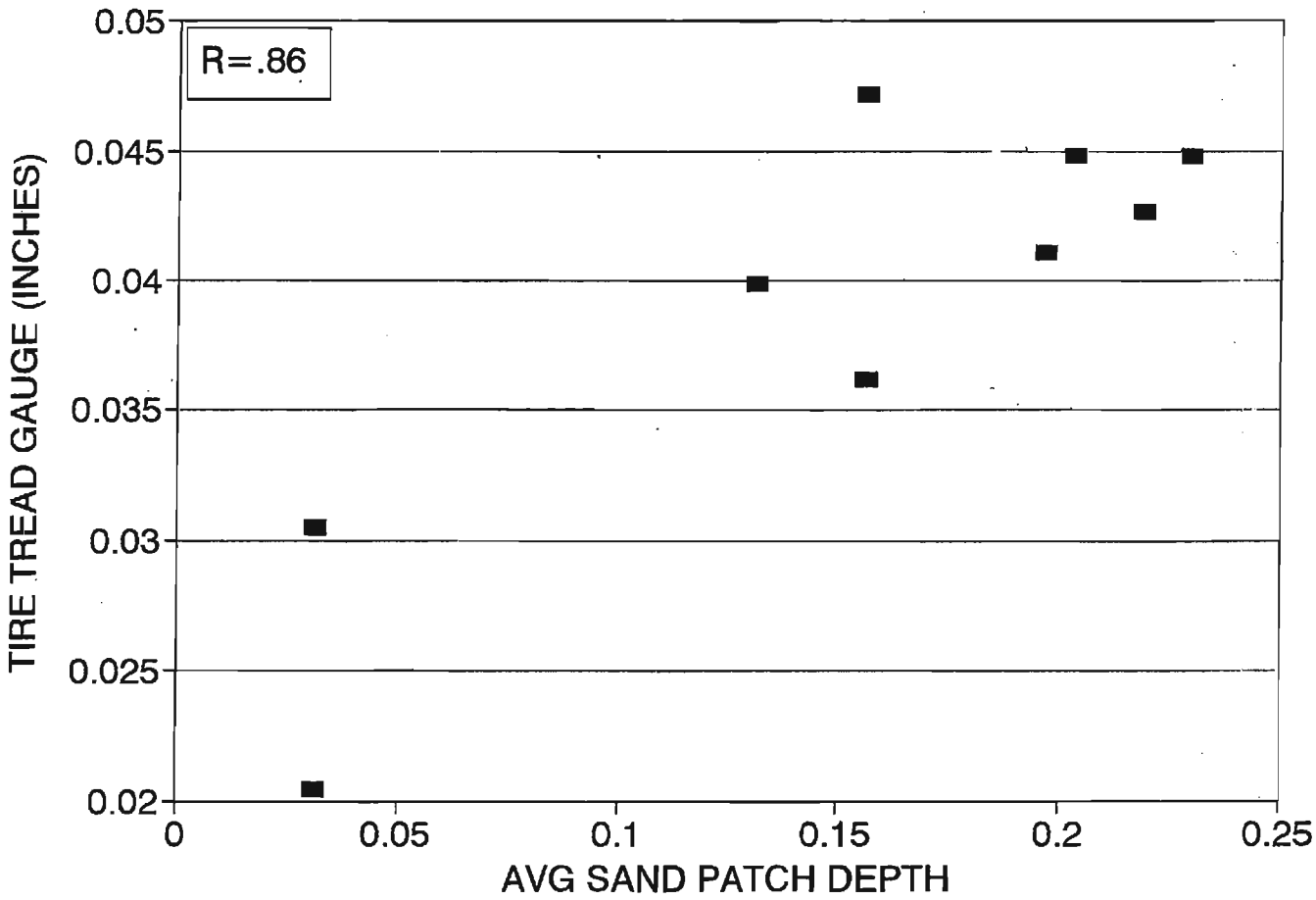
SN50R vs. TIRE TREAD GAUGE



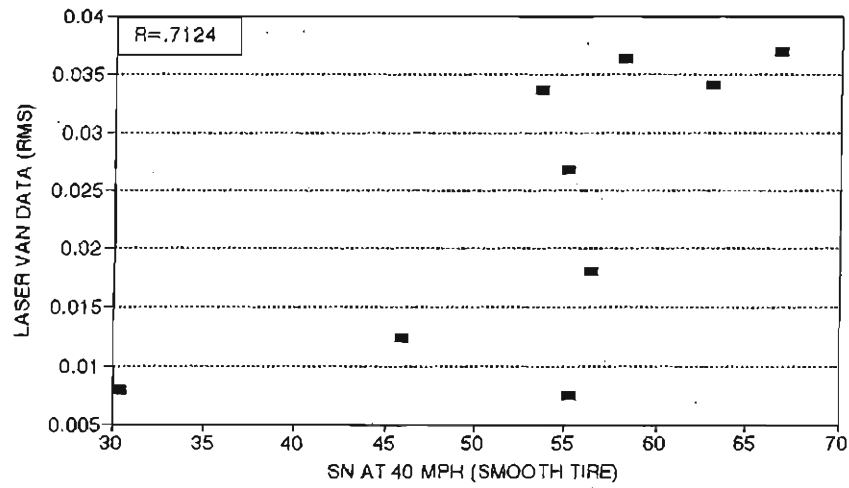
SN65R vs. TIRE TREAD GAUGE



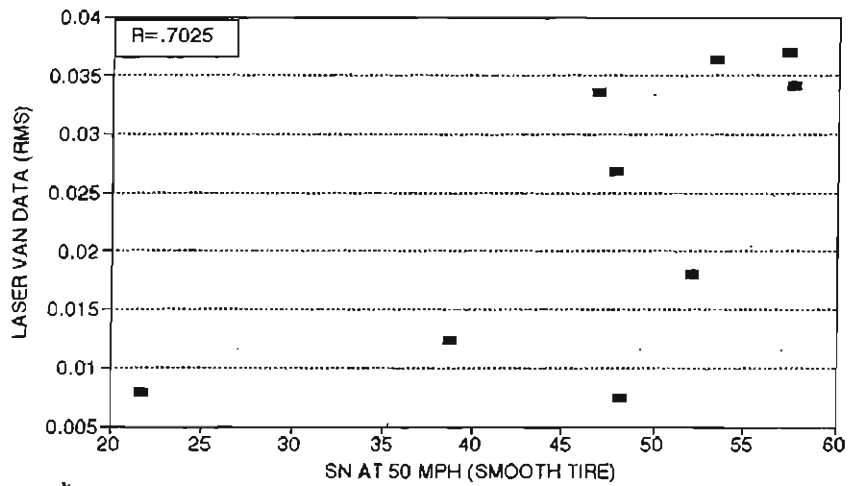
SAND PATCH DEPTH VS TIRE TREAD GAUGE



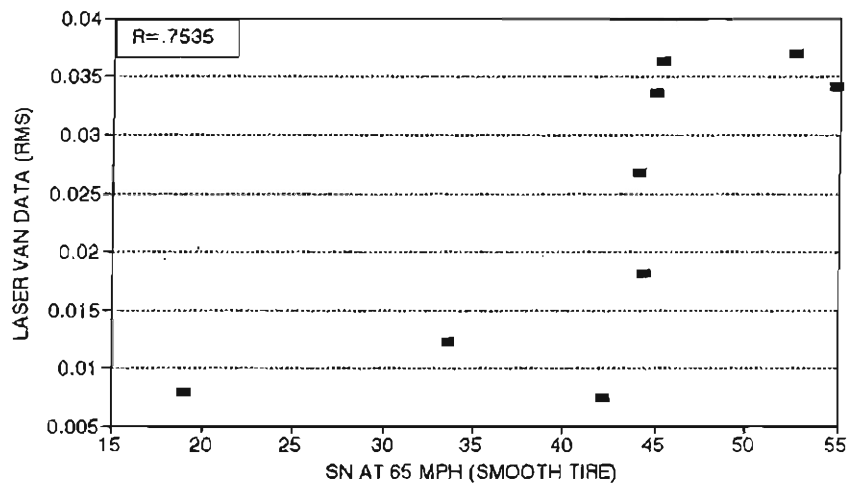
SN40S vs LASER VAN DATA



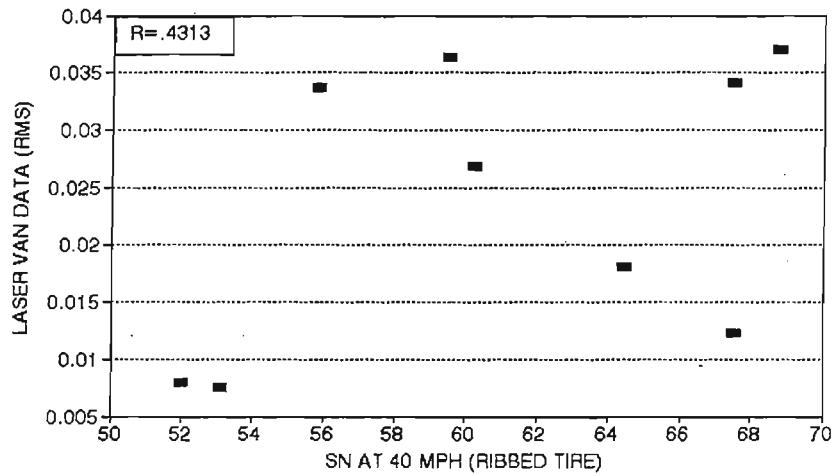
SN50S vs LASER VAN DATA



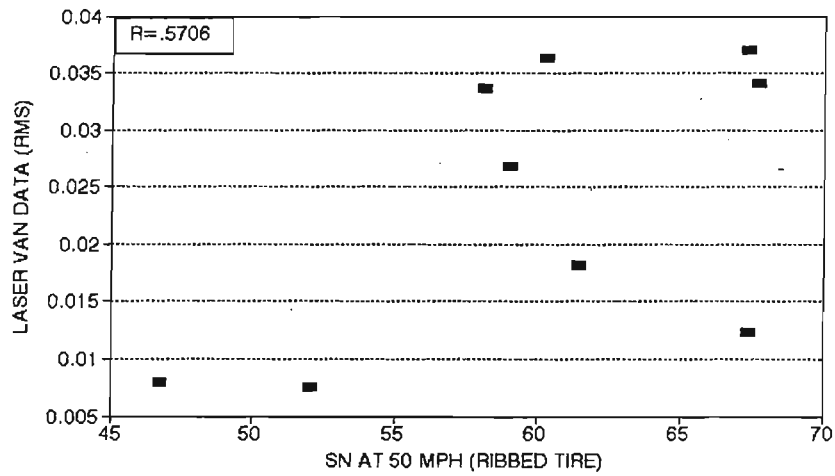
SN65S vs LASER VAN DATA



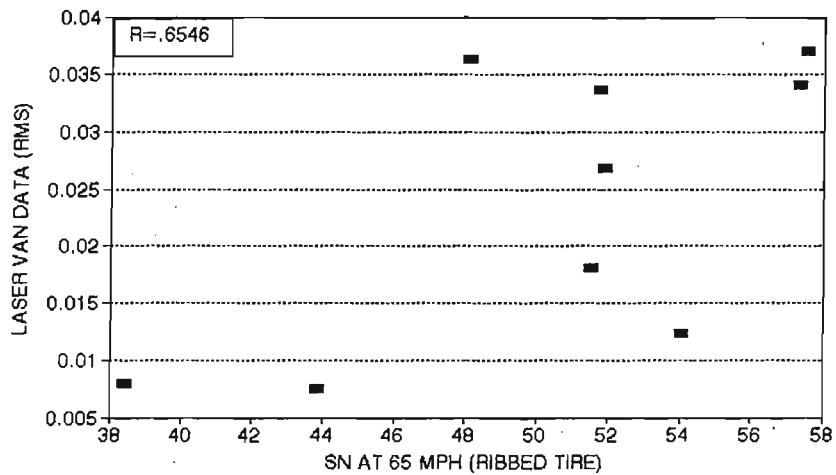
SN40R vs LASER VAN DATA



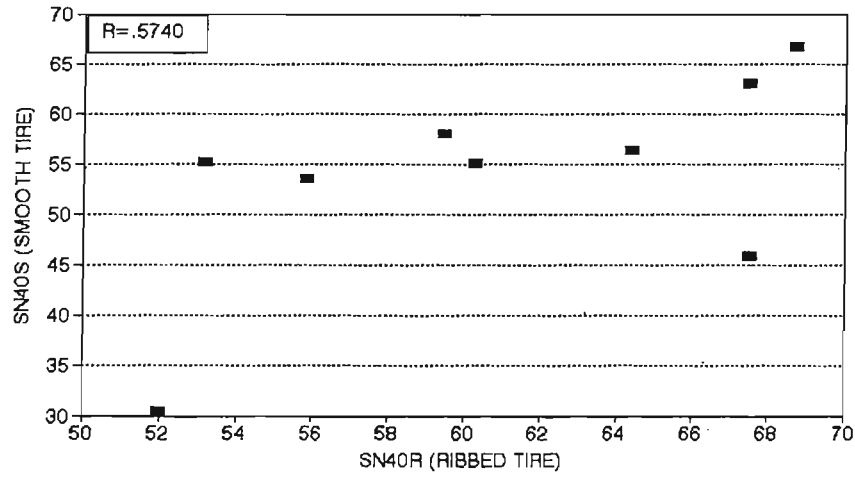
SN50R vs LASER VAN DATA



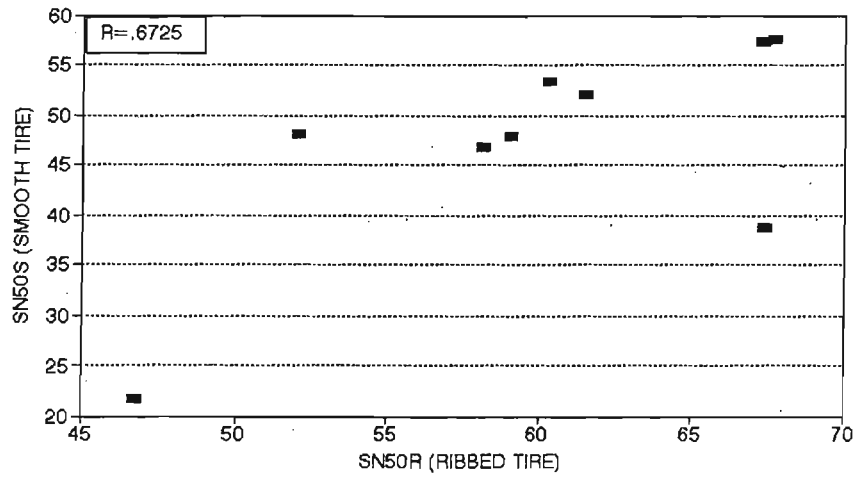
SN65R vs LASER VAN DATA



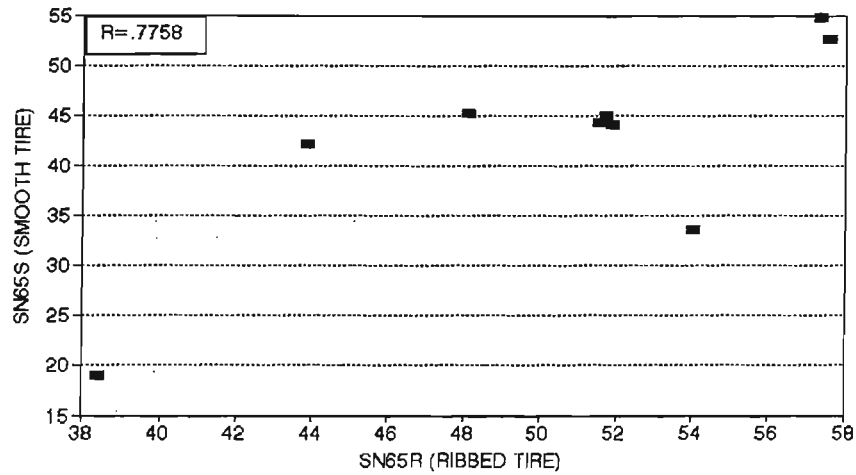
SN40R vs. SN40S



SN50R vs. SN50S

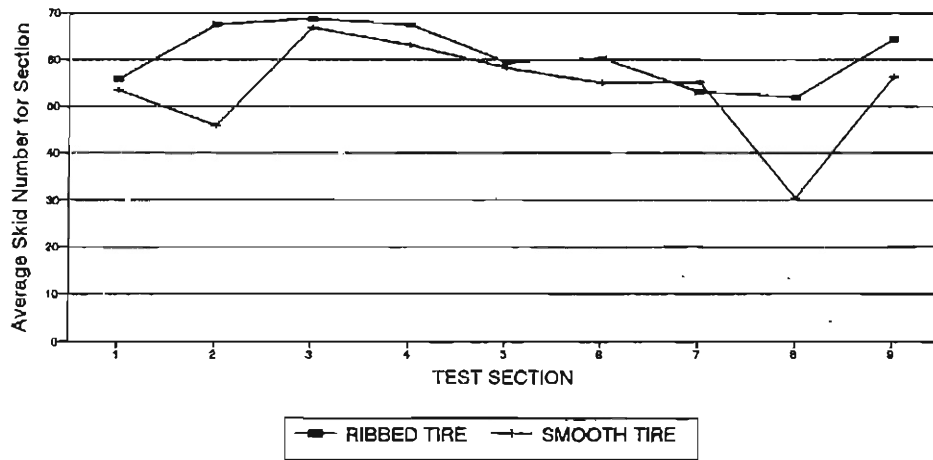


SN65R vs. SN65S



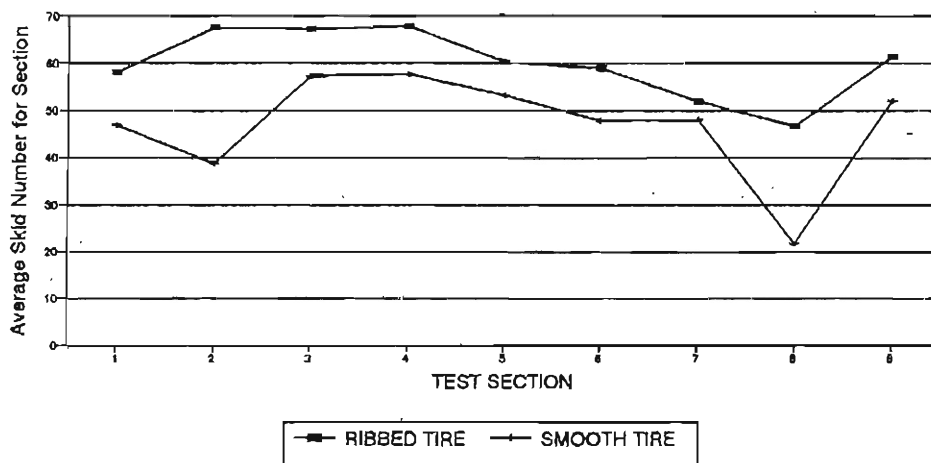
SKID NUMBERS - 40 MPH

SMOOTH vs RIBBED TIRE



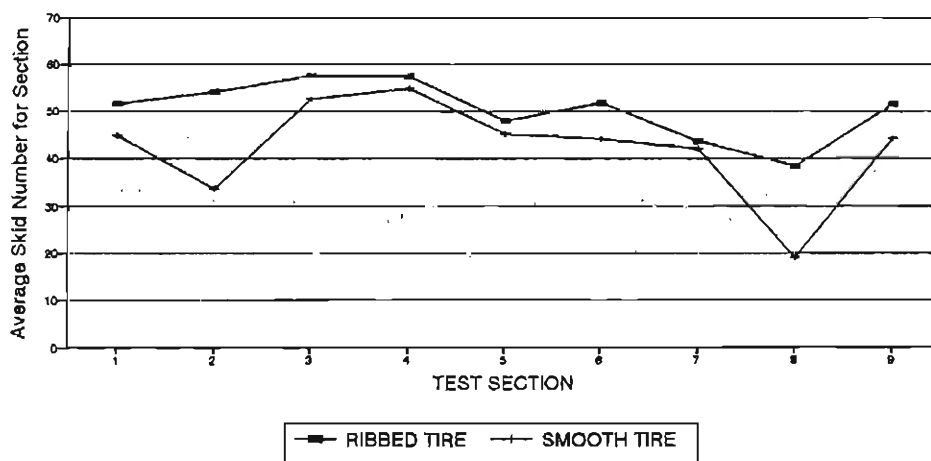
SKID NUMBERS - 50 MPH

SMOOTH vs RIBBED TIRE



SKID NUMBERS - 65 MPH

SMOOTH vs RIBBED TIRE



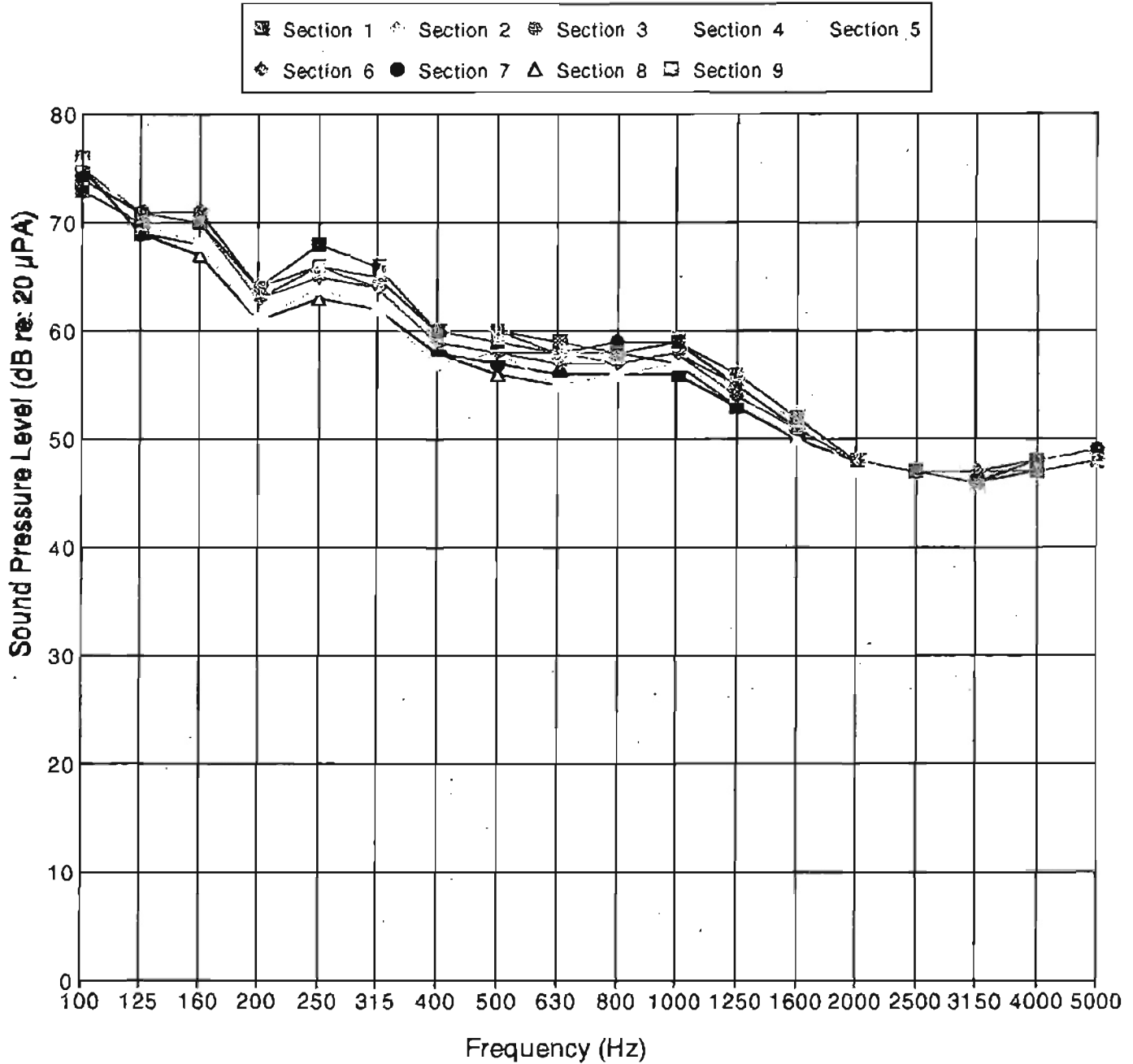
Appendix B

TABLE 1: Sound Measurement Results

Location	1/3 Octave Band SPL (dB)																		dBA
	Frequency (Hz.)																		
Roadside	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	dBA
Section 1	74	73	74	76	80	75	75	77	79	81	85	81	75	71	67	62	59	56	89
Section 2	75	75	74	75	78	74	75	77	79	81	82	78	75	71	67	62	58	56	87
Section 3	74	75	74	76	79	79	79	81	83	83	85	79	74	69	66	61	58	55	90
Section 4	75	73	74	74	76	75	76	78	79	81	82	79	73	69	65	60	57	55	87
Section 5	76	73	73	75	77	75	74	74	75	80	83	80	80	72	67	62	59	56	88
Section 6	75	72	74	75	76	74	74	75	77	81	83	80	74	71	66	61	57	55	87
Section 7	72	70	72	71	74	71	72	74	74	79	81	75	72	66	64	59	55	52	85
Section 8	71	69	70	72	71	71	69	72	71	74	79	74	72	69	65	60	57	53	83
Section 9	73	72	75	74	79	76	76	77	78	83	84	77	71	68	65	60	57	55	88
Tire	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	dBA
Section 1	96	93	92	92	90	88	85	88	92	94	98	98	96	90	85	82	78	73	104
Section 2	97	93	92	93	90	87	83	88	90	94	95	96	94	89	85	83	78	74	102
Section 3	95	92	93	92	91	89	87	94	93	96	98	96	93	88	84	81	77	73	103
Section 4	94	91	92	92	90	88	86	91	93	95	97	95	93	87	84	81	77	73	102
Section 5	94	90	90	90	87	85	81	87	87	90	95	95	98	88	85	82	77	73	103
Section 6	96	93	92	91	89	87	84	88	90	93	97	96	93	88	84	81	77	73	102
Section 7	94	91	90	88	86	83	79	84	86	92	94	91	88	85	82	79	75	71	99
Section 8	95	90	89	88	86	83	79	83	86	90	92	91	91	87	84	82	77	73	99
Section 9	94	91	91	91	90	83	86	91	92	95	96	92	90	86	82	79	75	73	101
Front Seat	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	dBA
Section 1	73	70	70	64	66	65	60	59	58	58	59	56	52	48	47	46	47	48	68
Section 2	73	70	70	63	65	64	59	58	57	57	58	54	51	48	47	47	47	48	67
Section 3	74	71	71	64	68	66	60	60	58	59	59	55	51	48	47	46	48	49	68
Section 4	76	70	70	64	67	65	59	59	58	58	58	54	50	47	47	46	48	49	68
Section 5	73	70	68	61	64	62	57	58	55	56	57	54	52	47	47	47	47	49	66
Section 6	75	71	70	63	66	64	59	58	58	57	58	55	51	48	47	47	48	49	67
Section 7	75	69	68	61	64	62	58	57	56	56	56	53	50	47	47	47	48	49	66
Section 8	75	69	67	61	63	62	58	56	55	56	56	53	50	48	47	47	48	49	66
Section 9	76	70	70	64	68	66	60	60	59	58	57	53	50	48	47	47	48	49	68
Typical Semi-*	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	dBA
	74	75	78	77	73	74	80	82	89	88	93	85	82	79	76	74	72	70	96

* Sound measurements taken of a typical semitractor-trailer travelling west-bound. Microphone located 25 feet from centerline of the two lanes Truck in nearest lane.

Front Seat SPL Measurements

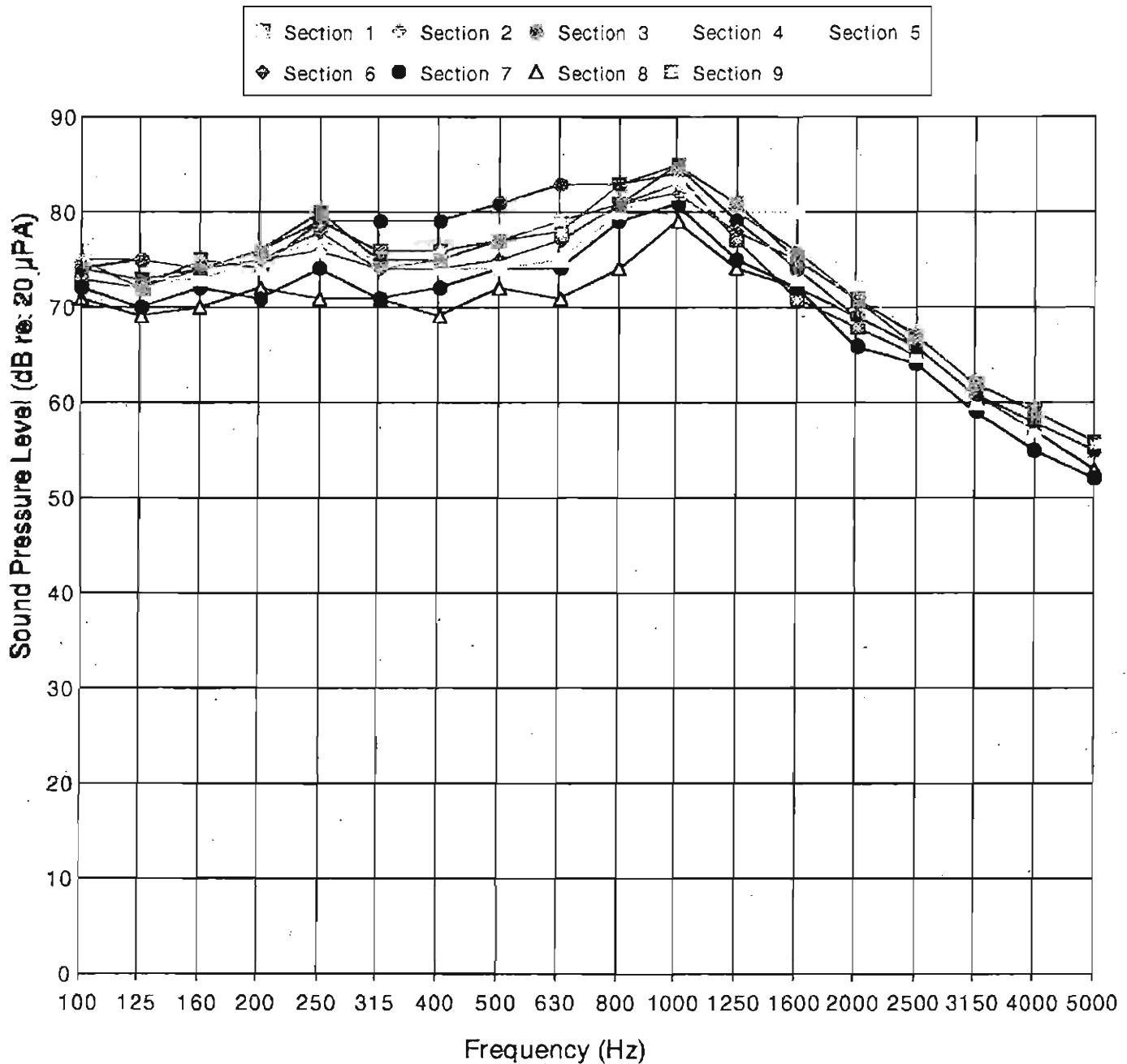


Graph No. 2: 1/3-Octave Band Sound Pressure Level Measurements

Location: Front Seat

Nov. 9, 1994 CDOT Pavement Noise Measurements DLAA Project No. 5017

Roadside SPL Measurements

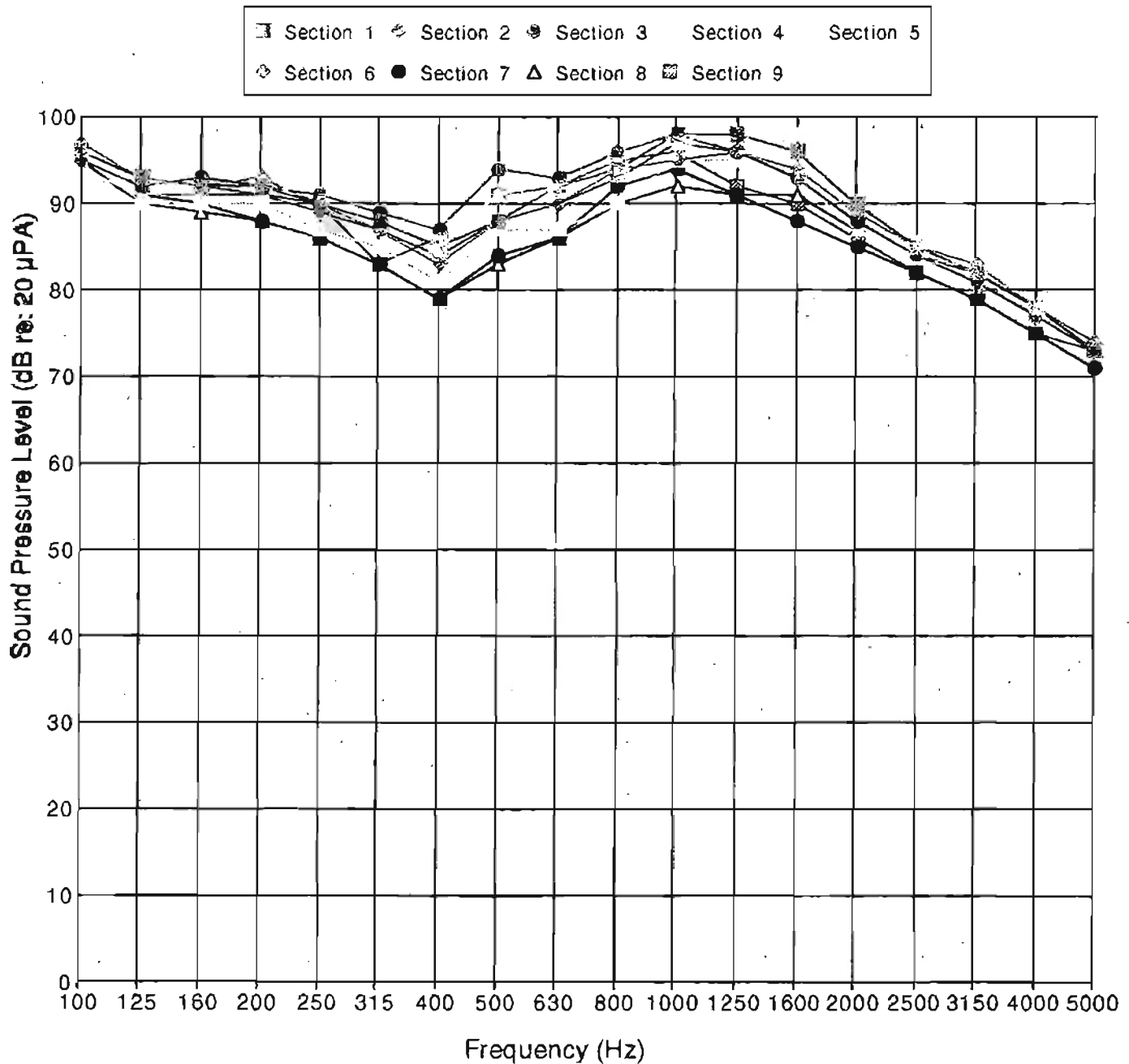


Graph No. 1: 1/3-Octave Band Sound Pressure Level Measurements

Location: Roadside

Nov. 9, 1994 CDOT Pavement Noise Measurements DLAA Project No. 5017

Tire SPL Measurements

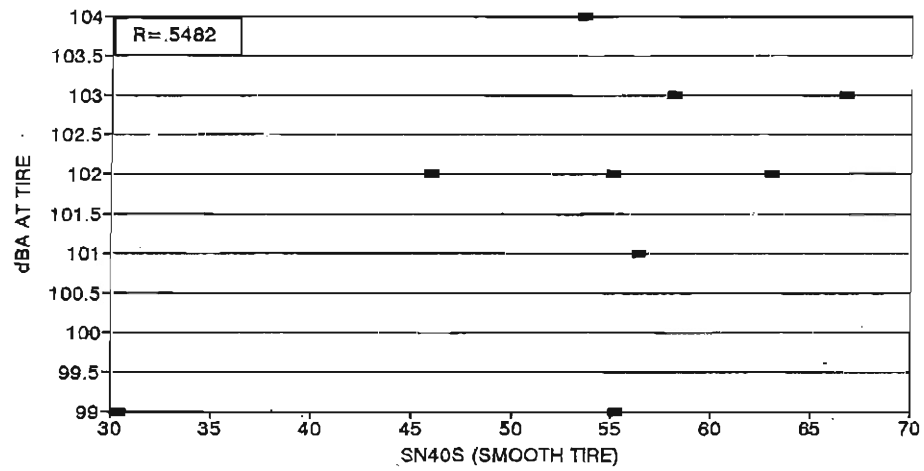


Graph No. 3: 1/3-Octave Band Sound Pressure Level Measurements

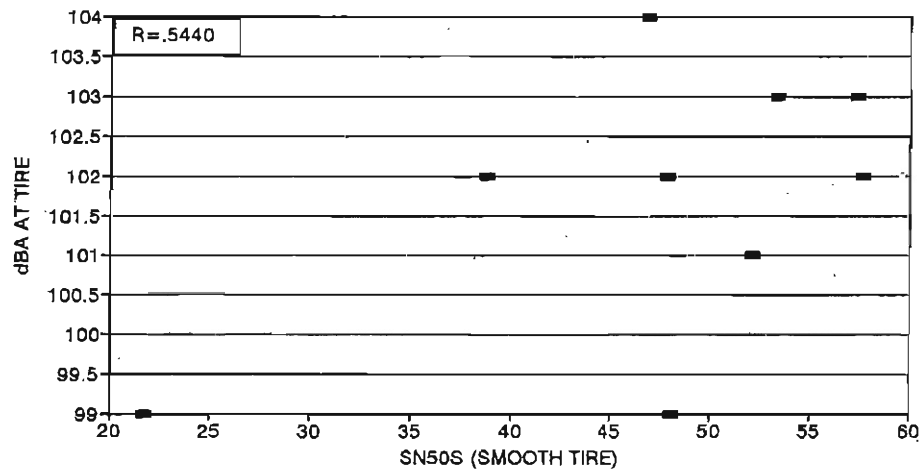
Location: Near Tire

Nov. 9, 1994 CDOT Pavement Noise Measurements DLAA Project No. 5017

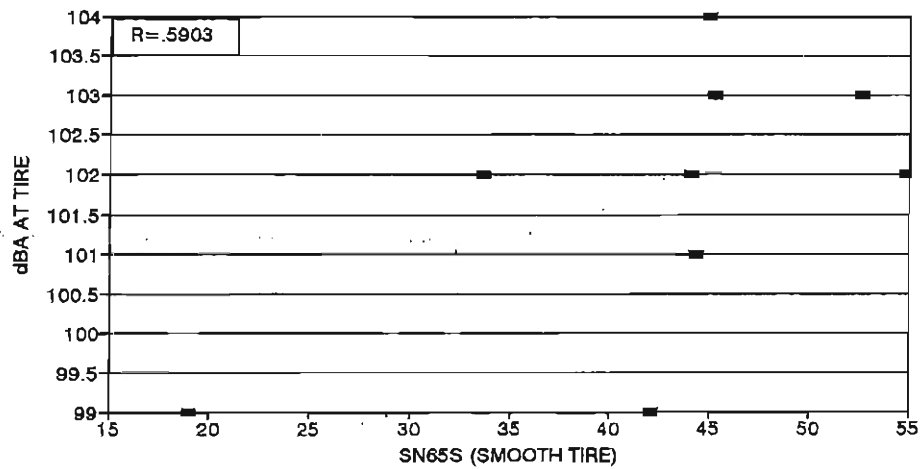
SOUND vs. SN40S



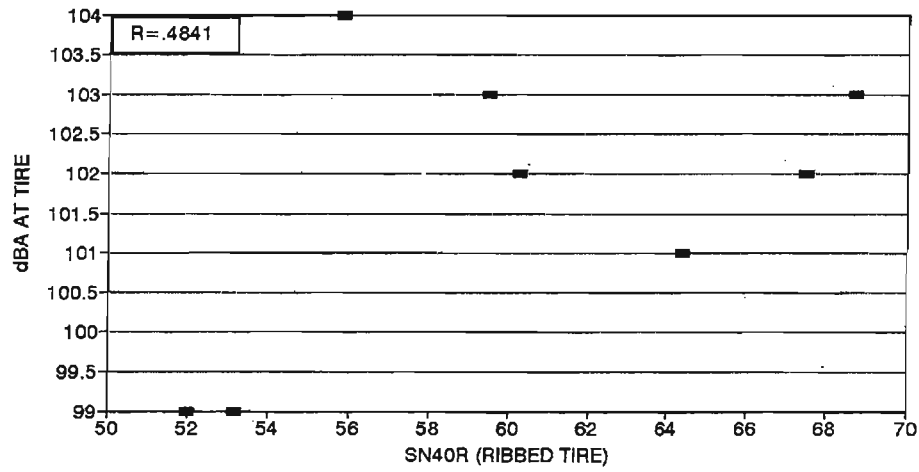
SOUND vs. SN50S



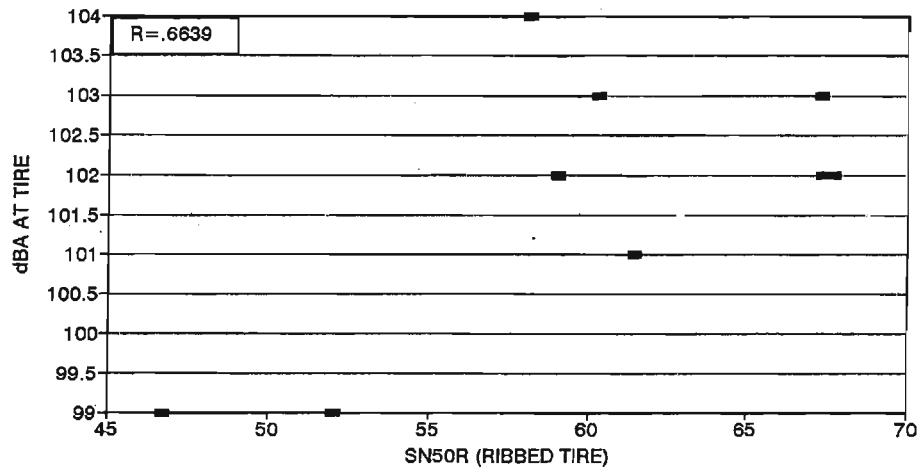
SOUND vs. SN65S



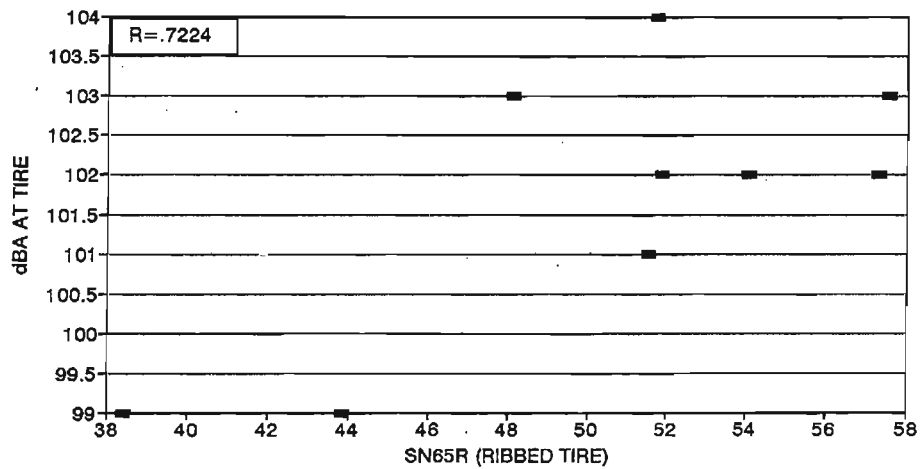
SOUND vs. SN40R



SOUND vs. SN50R



SOUND vs. SN65R



Appendix C

CHEMICAL AND PHYSICAL ANALYSES OF FLY ASH

TICKET NUMBER: 7717-17993 Job Number: 7717 REPORT DATE: 11/22/93

REPORT TO: Pozzolanic International
7525 SE 24th St.
Suite 630
Mercer Island , WA 98040

AGENT OF ORIGIN : Jim Bridger

SAMPLE ID : 18-93

TICKETS : T.R. 8420-8557

R.R. 5760-5999

DATE SAMPLED : 09/30/93 -

ASTM: C 618-92A

DATE RECEIVED : 10/12/93

SPECIFICATIONS

CHEMICAL COMPOSITION(%):

CLASS F

CLASS C

Silicon Dioxide 62.22

Aluminum Oxide 18.62

Iron Oxide 4.71

* * * Total

85.55

70.0 Min

50.0 Min

Sulfur Trioxide

0.25

5.0 Max

5.0 Max

Calcium Oxide

5.73

Moisture Content

0.05

3.0 Max

3.0 Max

Loss on Ignition

0.25

6.0 Max

6.0 Max

PHYSICAL TEST RESULTS:

Fineness

Retained on #325 sieve, (%)

27.29

34 Max

34 Max

Strength Activity Index

With Portland Cement (%)

Ratio to Control @ 7 days

82.1

Ratio to Control @ 28 days

96.6

75 Min

75 Min

Pozzolanic Activity Index

With Lime @ 7 days (psi)

1040.0

Water Requirement, % of Control

99.6

105 Max

105 Max

Soundness

Autoclave Expansion (%)

-0.016

0.8 Max

0.8 Max

Specific Gravity

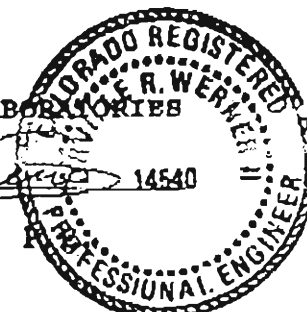
2.32

COMMENTS:

COMMERCIAL TESTING LABORATORIES

By

Orville R. Werner II,



14540



Ground
Engineering
Consultants, Inc.

March 17, 1994

Subject: Laboratory Test Results, Concrete
Mix Designs, Deer Trail Project

Job No. 94-150

Interstate Highway Construction
7135 South Tucson Way
P.O. Box 4356
Englewood, CO 80155
Airport Field Office

Attention: Mr. Cal Thomas

Gentlemen:

We have summarized results of laboratory tests performed to date on aggregates delivered to our laboratory for the Deertrail concrete mix designs.

Coarse Aggregate:

Gradation:

Sieve Size or No.	Percent Passing
1-1/2"	100
1"	100
3/4"	81
1/2"	38
3/8"	17
No. 4	1.6
No. 8	1.2

Moisture content of pile (delivered) - 5.0%

Specific Gravity (SSD basis) - 2.630

Absorption - 0.89%

Los Angeles Abrasion - 41.3% loss

Fine Aggregate:

Gradation:

Sieve Size or No.	Percent Passing
3/8"	100
No. 4	100
No. 8	95
No. 16	78
No. 30	47
No. 50	14
No. 100	3.2
No. 200	1.6

Moisture content of pile (delivered) - 7.0%

Specific Gravity (SSD basis) - 2.608

Absorption - 2.31%

Fineness Modulus - 2.63

Sand Equivalent Value - 85

We have also attached mix data for Mix Designs 1, 2 and 3. Compressive and flexural strength test results will be updated as additional values are determined. The tests were completed in accordance with accepted ASTM and AASHTO test procedures. If you have any questions, please do not hesitate to contact our office.

Sincerely,
GROUND ENGINEERING CONSULTANTS, INC.

James B. Kowalsky
James B. Kowalsky, P.E. 27680 1/17/98



Mix No. 1

BATCH MIXTURE

<u>Item</u>	<u>Description</u>	<u>Weight</u> <u>lbs / Cubic Yard</u>
Cement	Holnam J/II, L.A.	565
Fly Ash	Bridges Pozzolonic, F	113
Coarse Aggregate	Cooley No. 57, Brighton	1586
Fine Aggregate	T&W, Byers	1215
Air Entraining Admixture	Masterbuilders Paveair	10.3 oz
Water	-	287

94035

Physical Properties

Slump	1.5 inches
Air Content	5.9 %
Temperature	62 deg F
Unit Weight	139.9 pcf
Relative Yield	0.9972

Compressive Strength

(psi)

3 days	7 Days	14 Days	28 Days
3220	4810	5840	
3090	5040	6080	

Average Strength	3155	4925	5960
(psi)			

Flexural Strength

(psi)

3 days	7 Days	14 Days	28 Days
480	600	675	
520	580	660	

Average Strength	500	590	670
(psi)			

HOLNAM INC**Silo Test Certificate**
Average of Test Results

18-106-1-8

Consignee: I.H.C.
Deer Trail
East I 70

Car or Truck No. _____

Date Shipped _____

Quantity _____

PORTLAND CEMENT — Type I-II LA FEDERAL SPECIFICATION _____A.S.T.M. DESIGNATION C-150

1. Chemical Composition:

	Percent
Silicon Dioxide (SiO ₂)	21.2
Aluminum Oxide (Al ₂ O ₃)	4.7
Ferric Oxide (Fe ₂ O ₃)	3.2
Calcium Oxide (CaO)	64.7
Magnesium Oxide (MgO)	1.3
Sulfur Trioxide (SO ₃)	2.6
Loss on Ignition	1.4
Insoluble Residue	0.2
Tricalcium Silicate (C ₃ S)	58
Dicalcium Silicate (C ₂ S)	17
Tricalcium Aluminate (C ₃ A)	7.0
Tetracalcium Aluminoferrite (C ₄ AF)	10
Alkalies (Na ₂ O Equivalent)	0.29

2. Specific Surface:

Blaine, Sq. M. PER Kg	400
Wagner, Sq. M. PER Kg	

3. Soundness:

Autoclave Expansion	0.00 %
---------------------	--------

4. Time of Setting:

Vicat, Initial Set	1	Hrs.	30	Mins.
Vicat, Final Set	4	Hrs.	05	Mins.

5. Compressive Strength Tests:

1 Day		Lbs. per Sq. In.
3 Days	3810	Lbs. per Sq. In.
7 Days	4780	Lbs. per Sq. In.

6. Air Entrainment

% by Volume 5.8

HOLNAM INC is warranted to conform at the time of shipment with the specification designated above. No other warranty is made or to be implied. Having no control over the use of its cements, HOLNAM does not guarantee finished work.

HOLNAM INC

Portland, Colorado Plant

By W. W. Gordon
Quality Control Supervisor

.: November 18, 1994

J: A.G. Peterson

FROM: Jay Goldbaum

SUBJECT: Carbonate sand in PCCP

In order to determine the susceptibility of the sand to polish in project number IR(CX) 070-4(153), Deertrail - East, ASTM test number D 3042 was performed. The test uses a hydrochloric acid solution to dissolve the carbonates in a sample.

According to some research performed, a higher amount of carbonic materials found represents a higher possibility of polishing and/or a loss in friction of the pavement surfaces. The maximum amount of carbonates allowed in PCCP is 25 percent.

After performing ASTM test D 3042 on the sand used in the PCCP at Deertrail, it was found to have 0.42 percent carbonates.

Test#	3 Day			7 Day			14 Day			28 Day			28Day			28 DAY											
	Compressive Strength	Average		Compressive Strength	Average		Compressive Strength	Average		Compressive Strength	Average		Tensile Strength	Average		Flexural Strength	Average										
EBL																											
81	3030	3040	3035	4660	4630	4645	4980	5230	5105	5510	5570	5240	5440														
82	3860	4020	3940	4340	4580	4450	4750	4730	4740	5490	5860	5480	5610														
83	3310	3350	3330	4320	3970	4145	4120	4610	4365	5430	5280	5330	5347														
84	3310	3370	3340	3760	3990	3875	4070	4510	4290	5250	5150	5030	5143														
85	2960	2850	2905	3680	3550	3615	3980	3930	3955	4800	4680	4490	4857														
86				3590	3570	3580				4680	4830	4440	4650	420	442	431	610 550 580										
IAT-86										4680	4270		4465														
67				3750	3680	3705				4870	4620	4612	4634														
68	3410	3350	3380							4820	4720	4900	4813														
69	3310	3210	3260							5220	5050	5530	5267														
70	3500	3570	3535	3520	4340	3930				4880	5110	5210	5067														
71	3410	3330	3370	4200	4290	4245				5390	5010	4800	5067														
IAT-71										5490	5520		5505														
72	3290	3310	3300	4060	4120	4090				5050	5450	5130	5210														
73	2950	2880	2915	3230	3250	3240				4760	4850	4410	4673														
74	2680	2540	2615	3520	3130	3325				4770	4310	4470	4517														
75	3230	3810	3420	4540	4550	4545				8240	6210	5250	5900														
76										5800	6210	5840	5983														
77										4890	5280	4940	5040														
78				3460	3680	3570				4880	5080	4420	4797														
79										5720	5700	5520	5647														
80										5300	5310	5850	5420														
81										5430	5450	5190	5357														
82				4220	4180	4190				5210	5650	5620	5493														
83										5720	5850	5730	5767														
84										4720	5210	5030	4987														
85										4930	4980	4860	4917														
86				4520	4290	4405				5850	5110	5640	5467														
87										5380	5300	5140	5267	354	359	357	605 645 625										
IAT-87										5430	5220		5325														
88										5310	5370	5620	5433														
89										5120	4740	4880	4913														
90				4180	4260	4225				5290	5680	5370	5447														
91										5420	5240	5060	5240														
92										4800	4700	4690	4730														
93										5410	5380	5650	5480														
94				4480	4500	4490				5290	5350	5310	5317														
95										5310	5380	5300	5330														
96										4700	4830	5080	4870														
97				3330	3360	3345				4020	4230	4040	4067														
98				4340	3930	4135				5000	4990	4840	4943														
99										4360	4550	4610	4507														
100				3730	3700	3715				4260	4200	4580	4347														
101										4536	4960	4770	4755	440	425	433	615 605 610										
102										4400	4270	4250	4307														
103				4200	4340	4270				5180	5230	5110	5167														
104										4140	4540	4890	4457														
105				3340	3700	3520				4340	4220	4340	4300														
106										4570	4590	4200	4453	430	450	440	595 520 558										
107										5470	5240	4800	5103														
108										5090	5380	5180	5217														
109				3520	3630	3575				4160	4470	4510	4380														
110										4630	4530	4840	4667														
111				4580	4810	4585				5180	5580	4830	5233														
IAT-111										5750	5800		5775														
112										5580	5530	5390	5500														
113										5380	5040	5070	5187														
114										4890	4880	4640	4803														
115				4490	4530	4510				5720	5840	5440	5600														
116										4690	4480	4540	4563														
117										5420	5360	5870	5483														
118										4740	4420	4810	4590														
119				4480	4530	4505				5200	5170	5270	5213														
120										5220	5350	5040	5203	465	440	453	620 615 618										
IAT-120										5260	5230		5245														
121										4790	4680	4700	4717														
122										4350	4380	4300	4347														
123				4590	4620	4605				5170	5540	4890	5233														
124										4440	5440	5200	5027														
125										5180	5040	5370	5180														
126										3650	3940	3910	3900	395	370	363	510 575 543										
Average (EB & WB)																		3257		4039		4491		4989		613	
Std. Dev. (EB & WB)																		325.2		520		426		564.1		69.9	
Max. Value (EB & WB)																		4020		6270		5230		6370		725	
Min. Value (EB & WB)																		2540		2800		3930		2360		510	
Number of tests (EB & WB)																		26		70		10		402		24	
Average (WB)																								4942			
Std. Dev. (WB)																								640.6			
Max. Value (WB)																								6370			
Min. Value (WB)																								2356			
Number of tests (WB)																								194			
Average (EB)																								5032			
Std. Dev. (EB)																								477.7			
Max. Value (EB)																								6240			
Min. Value (EB)																								3850			
Number of tests (EB)																								208			

11-Oct-84

IR(CX) 70-4(153)

Deertrail - EAST

Class P Results

Test#	3 Day		7 Day		14 Day		28 Day		28 Day		28 DAY	
	Compressive Strength	Average	Compressive Strength	Average	Compressive Strength	Average	Compressive Strength	Average	Tensile Strength	Average	Flexural Strength	Average
WBL												
1			4120	4210	4165		4990	5270	5340	5200		
2			3990	4130	4060		5090	5480	5170	5247		
3			3870	4130	4000		4760	4960	5060	4927		
4							3580	2990	3610	3393		
5			6270	2800	4535		4100	4010	4420	4177		
6			3470	3630	3550		4350	4350		4350		
7			4230	3510	3870		5300	5240		5270		
IAT-7							5300	5240		5270		
8			4000	4250	4125		2520	2360	2560	2480		
9							5220	4860	5260	5113		
10							5480	5240	5600	5440		
10a							5243	5480	5598	5440		
11							5336	5251	4928	5172		
11a							5020	4940	4630	4863		
12							6008	5936	6061	6002		
12a							6010	5940	6060	6003		
13							5100	4870	5210	5060		
14							5640	5530	5440	5537		
15							5780	5830	5110	5573		
16							4830	4720	4600	4717		
17							5140	5180	5250	5190		
18							4890	5270	4940	5033		
19							5060	4780	5080	4973		
20							5230	5510	5010	5250		
21							5240	3320	5370	4643		
22							5900	5950	6370	6073	498	400
IAT-22							6250	5830		6040	449	725
23							5170	5110	3890	4723	690	708
24							5170	5330	5250	5250		
25							5320	5370	5330	5340		
26							4930	4700	5020	4883		
27							5060	5620	5380	5353		
28							4880	4660	4410	4583		
29							3800	3960	3660	3807		
30							5630	5620	5970	5740		
IAT-31							4860	5130		4995		
31							5120	5150	5280	5183		
32							5110	5230	5320	5220		
33							5200	5220	5060	5160		
34							5080	5160	5680	5300	497	478
35							5010	4760	4290	4687	488	715
36							5220	4740	5210	5057	690	703
37							5250	5230	5080	5187		
38							5100	4990	5360	5157		
39							5110	5340	5080	5177		
IAT-40							4730	4730		4730		
40							4770	4740	4950	4820		
41							5260	5670	5660	5530	460	444
42							5480	5190	4850	5173	452	680
43							4730	4740	4970	4813	685	683
44							4890	5020	4740	4883		
45							4230	4170	4200	4200	339	335
46							4510	4240	4710	4487	337	565
47							5080	5370	5175	5208	540	553
48							4900	5100	4970	4990		
49							3870	3870	3860	3867		
50							4990	4840		4915		
51							4800	4610	4520	4643		
52							4080	4020	4060	4053	335	340
53							5340	4630	5370	5113	338	575
54							5090	4890	5240	5073	560	568
55							4450	4770	4790	4670		
56							4780	4730	4630	4713		
57							5050	5450	5270	5257		
58							3960	3930	4010	3967		
59							5030	5010	4790	4943	439	436
60							4170	4000	4310	4160	438	650