FINAL REPORT

INTERIOR CAR NOISE CREATED BY TEXTURED PAVEMENT SURFACES

by

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Materials Research Analyst

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

Charlottesville, Virginia

October 1975

VHTRC 76-R17

SUMMARY

Because of widespread concern about the effect of textured pavement surfaces on interior car noise, sound pressure levels (SPL) were measured inside a test vehicle as it traversed 21 pavements with various textures.

A linear regression analysis run on the dBA values and the predicted stopping distance numbers (PSDN) for the same pavements showed no correlation between them.

It was concluded that noise is directly proportional to the degree of protuberance and to the angularity of the protruding particles, and inversely proportional to the spacing of longitudinal grooves. From the aspect of annoyance, most of the textures studied did not generate such different intensities of noise as to be perceivable to the occupants of the vehicle. Based on limited data, it appears that transverse grooves tend to created some pure tones in the high frequency range most easily sensed by humans.

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INTRODUCTION

The variety of subjects which must be considered by a highway department as it plans the construction of a road is very broad, and includes subjects such as safety, environment, engineering, and cost. These subjects are interrelated in that some of the factors that affect one of them also affect one or more of the others. Thus it seems inevitable that a design aimed at benefiting one subject area might have a deleterious effect in one of the other areas. Skid resistance (safety) and noise (environment) seem to be two such areas. A harsh pavement texture used to increase skid resistance (beneficial effect) might also be expected to increase the tire noise (deleterious effect).

A pavement in Virginia may have any one of many different textures. These textures are imparted both in new construction and through the alteration of in-service surfaces. Examples of textures built into new construction are: for bituminous materials — I-2, S-5, S-8, surface treatment, and sand mix; for concrete — burlap drag, brooming, grooving, and sprinkling on aggregate. The textures based on alteration are: bush hammering to remove paste, sawing grooves, and acid etching.

PURPOSE

This study was undertaken in response to a widespread concern that some textures may produce a noise of such frequency and level as to be annoying and distractive to the occupants of a vehicle. The purpose was to determine whether one texture or another causes a significant increase in the level of noise generated.

TEST SITES

Test sites, see Table 1, were chosen so as to include many of the textures used on both bituminous concrete and portland cement concrete pavements. The length of the test sites varied from as much as 1.5 miles (2.4 km) to as little as 250 feet (82.0 m), because many of the sites were on experimental pavements of prescribed lengths.

When possible, the test sites were the same as those used for skid resistance testing done in conjunction with other research studies so that the data from the noise measurements could be correlated with the skid resistance data.

Table 1

Test Sites
(1 mile = 1.6 km)

Site	Route	County, Lane, Pavement, General Location	Graphic Log Mile
1	I-81	Augusta, SBL — Pass, S-8 Bituminous, North of Greenville Exit	6.9-7.4
2	340	Augusta, SBL, Sand Mix Bituminous, South of Grottoes	1.0-2.5
3	I-64	Louisa EBL — Traffic, P.C. Concrete, West of Zion Cross Roads Exit	3.76-4.26
4	I-64	Louisa, EBL — Traffic, S-5 Bituminous Start West of Zion Cross Rds. Exit, Ends East of Exit.	5.26-6.76
5	I-64	Henrico, EBL — Pass, P.C. Concrete sawed grooves, East of Parham Rd. Entr.	6.38-6.78
6	1	Caroline, SBL — Pass, Surface Treatment Bituminous, 750 Feet North of Long Creek	14.02-14.52
7	I-64	New Kent, EBL — Traffic, P.C. Concrete tined grooves 3/4" centers, East of Bottoms Bridge Area.	2.7-3.7
8	I-64	New Kent, EBL — Traffic, P.C. Concrete tined grooves 1/2" centers, East of Bottoms Bridge Area.	3.8-4.9
9	I-64	New Kent, WBL — Traffic, P.C. Concrete tined grooves 3/8" centers, East of Bottoms Bridge Area	6.34-5.34
10	I-64	New Kent, WBL — Traffic, P.C. Concrete tined grooves 1/4" centers, East of Bottoms Bridge Area	5.33-4.33
11	I-64	New Kent, WBL — Pass, P.C. Concrete tined grooves 1/4" centers, East of Bottoms Bridge Area	3.71-2.71
12	Inter. Terminal Blvd.	Norfolk, EBL and WBL — Traffic, P.C. Concrete tined grooves (various patterns) paste washed off, aggregate sprinkled on, and dimpled, along the south side of the U.S. Naval Air Station	

PROCEDURES

Equipment

Only one type vehicle — a standard, medium-size, American automobile -- was used in the tests. It was operated with the windows closed and with the air circulation fan on low speed. All tests were run at 55 mph (88.5 km/hr), and testing was limited to a standard rib tread at a pressure of 30 psi (20.7×10^4 Pa).

Instrumentation

A B&K Model 2204 precision sound level meter with a one-inch (2.54 cm) B&K Model 4145 free-field condenser type microphone mounted on a flexible goose neck extension, a B&K Model 4230 calibrator, a portable two-channel, Nagra Model SD tape recorder, and 3M No. 206 magnetic tape were used to record sound pressure levels.

Measurement Methodology

The potential test sites were field checked before testing to determine the condition of the road so as to avoid as many extraneous sources of noise as possible, such as pot holes and areas with asphalt bleeding. When possible, a 0.5 mile (0.8 km) measurement zone was established and delineated. At 55 mph (88.5 km/hr) a sound record of at least 30 seconds in duration was assured. This 30-second time length proved ample for analysis.

The sound level meter was mounted on a tripod behind the front seat of the test vehicle so that the microphone extended over the front seat at approximately the ear level of a driver or passenger and midway between the left and right front doors. A technician operated the instrumentation from the back seat.

The sound level meter was calibrated and three 30-second calibrator recordings were made with the attenuators on the sound level meter set at 90, 100, and 110 dB in sequence before and after each day's group of measurements.

Identifying and supportive information was recorded before each run. The record of this information on the graphic log chart paper and the turning of the tape recorder on and off delineated the recording of the interior car noise. For the initial test runs, a visual signal was used to turn the recorder on and off so as to not interfere with the recordings. When some of the short test sections were measured, it was found that the test section was delineated better on tape by turning the tape recorder on before reaching the test section and delineating the record of the test with verbal signals of "start" and "stop". These verbal signals gave a sharp peak at both ends of the recorded test as displayed on the graphic level recorder strip chart.

By making the tests during gaps in the normal flow of traffic, it was possible for only a driver and technician to make all but the Norfolk runs. Therefore, it was helpful to mark the test sections with traffic cones.

Data Reduction and Analysis

The tape recordings of the test runs were taken to the laboratory and the data were processed on a graphic level recorder in both the linear (dB) and A-weighted* (dBA) modes. There was considerable fluctuation of the signal picked up by the microphone. However, the fluctuations occurred rapidly and their relative amplitudes were limited. Therefore, the mean sound pressure level for each run was determined graphically by using a transparent straightedge on the graphic level strip chart record. This method of determining the mean sound pressure level precludes any statistical analysis of the data.

It was planned to have one-third octave band frequency analyses made of some of the data, because some of the grooved patterns varied in a regular fashion and were expected to create different frequency spectra. If the sound heard by the driver or passenger were considerably different from one site to another, the frequency analyses might have helped explain the differences. However, no funds were available for such analyses and they were not made.

Predicted stopping distance numbers (PSDN's) for the sections of road tested were obtained from the Virginia Highway and Transportation Research Council's Maintenance Section. Later in this report the PSDN's are correlated with the dBA levels.

RESULTS AND DISCUSSION

The principal subject addressed in this section of the report are the differences between the sound pressure levels recorded as the test vehicle traversed the differently textured pavements. Thus, it is appropriate that the difference in sound pressure level that a person can sense should be referenced here by the following statements:

1. The smallest change in noise level perceptible to the ear is approximately 2 dB[1].

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* The A-weighting network is designed to match the frequency response of the instrument with that of the average human ear at a given level.

2. When real-life sounds or noises are heard, it is barely possible to detect level changes of 2 to 3 dB. A 5 dB change is readily noticeable. A 10 dB change is judged by most people as a doubling or a halving of the loudness of the sound[2].

Inasmuch as the method of data analysis precluded statistical analysis of the data, the differences between the various sound pressure levels are discussed based on their perceivability.

The data in Table 2 are grouped according to type pavement and texture (degree of protuberance and mosaic aspect). The PSDN's are included in Table 2 to facilitate the attempt, to be made later, to correlate them with the noise levels.

Aside from the parameters used to group the data in Table 2, the only distinction to be made is the pavement's degree of wear. The parameters of average daily traffic and time in service greatly affect the pavement's degree of wear. Allowing for considerable variability in the average daily traffic and the time the pavements at test sites 1 through 11 were in service, all of these pavements must be considered well-worn. The pavements at sites 12 through 21 had heavy traffic for only two months prior to testing and did not show signs of wear.

Within the categories A through E and including the subgroups under category D, which are arranged according to degree of wear and groove orientation and spacing, there are no perceivable differences between the sound pressure levels in dBA. Thus, it appears that the rationale used to form the categories and groups takes sufficient consideration of the parameters (degree of protuberance, degree of wear, and orientation and spacing of grooves) controlling tire-road noise. However, within category F there is a perceivable difference between the sound pressure level (SPL) for pavement 16 and the levels for both pavements 14 and 15. This difference is explained by the coarse size and angularity of the aggregate sprinkled on pavement 16, as compared to the size, roundness, and lesser degree of protuberance of the gravel aggregate exposed by the washed removal of paste in pavement 14 and the size of the aggregate on pavement 15. This difference illustrates the influence of the degree of protuberance and angularity on the tire-road noise.

Comparison of the dBA values for the worn grooved portland cement concrete (pcc) pavements (5, 7, and 8) with the dBA values for the unworn similarly grooved pavement (12) shows that for these types of pavements, wear (a decrease in the microasperities) makes for a quieter pavement.

Six worn grooved pcc pavements were measured on I-64, and a comparison of the dBA values for pavements 5, 7, and 8 with the dBA values for pavements 9, 10, and 11 shows that the pavements with the more closely spaced grooves are noisier. It is suggested that the closer spacing of the grooves increases the harshness of the pavement because the tines displace more paste into less intergroove space.

Table 2

Sound Pressure Levels and PSDN's
(1 inch = 2.54 cm)

Category Site	Mosaic Aspect	Pavement	dB	dBA	PSDN
A. Bituminous Nonprotruding Agg.					
2	random-medium	S-5	85.0	62.0	55
3	random-medium	S-8	85.6	61.6	54
4	random-fine	sand mix	86.2	60.6	60
B. Bituminous Protruding Agg.					
6	random-medium	surface treatment	87.2	61.6	57
C. Concrete Normal Burlap Drag					
1	random-fine	P.C.C.	83.6	61.6	54
D. Concrete Saw and Tine Grooved					
5	3/4" longitudinal (L)-fine	P.C.C.	85.7	59.2	55
7	3/4" L-fine	P.C.C.	84.6	59.8	63
8	1/2" L-fine	P.C.C.	84.8	59.4	--
9	3/8" L-fine	P.C.C.	85.7	62.4	--
10	1/4" L-fine	P.C.C.	85.3	61.6	--
11	1/4" L-fine	P.C.C.	85.3	61.6	67
12	3/4" L-fine	P.C.C.	84.4	61.0	57
18	3/4" Transverse (T)-fine	P.C.C.	84.8	60.8	58
20	1 1/2" T-fine	P.C.C.	85.0	61.9	58
13	3" T-fine	P.C.C.	85.1	61.0	56
21	3/4" L + 1 1/2" T-fine	P.C.C.	85.2	62.2	59
19	3/4" L + 3" T-fine	P.C.C.	85.3	62.3	59
E. Concrete Dimple					
17	Dimpled-fine	P.C.C.	84.3	60.3	53
F. Concrete Protruding Agg.					
14	Washed paste-medium	P.C.C.	83.6	60.0	55
15	Sprinkled-medium	P.C.C.	86.6	61.6	54
16	Sprinkled-coarse	P.C.C.	86.6	63.6	51

If the individual SPL values are compared, Table 3, it is apparent that there is no perceivable difference in the intensities of noise measured for most of the pavement textures. In fact, 15 of the 21 levels measured fall in the range from 60.6 through 62.4 dBA, and the difference between those two values is barely perceivable. Perhaps the most important observation to be made is that practically all the types of textures are included in that group of pavements. Only the dimpled, the worn longitudinally grooved, and the gravel and coarse sprinkled protruding types are not included.

The lack of perceivable difference in intensity should not be construed to mean that the noises are the same; they are not. As a person drives from one pavement texture to another, the difference in the noises is often very apparent. However, the difference that is noticed may be one of frequency content rather than intensity, and frequency analyses of the recordings were not made.

The differences in dBA intensities have been looked at based on their perceivability. Such an approach to the consideration of the data is principally concerned with the annoyance of the vehicle's occupants. Another approach would be to consider the health of the vehicle's occupants. Certainly the rationale that "the noiser an environment the less healthy it is" seems reasonable. Unlike outside noise, the principal source of the noise the occupant is exposed to is the occupant's vehicle. Thus, the range of dBA values from 59.2 through 63.6 dBA, and the range of PSDN's from 51 through 67 provide the design engineer considerable alternatives to be used to design a pavement such that the contribution of the tire-road noise to the interior car noise is as little as possible for any set of circumstances.

In an earlier study by Noble[3], the exterior car-road noise was recorded for some of the same pavements used in the investigation reported here, and a frequency analysis was run on ten of the recordings. Among those textures so analyzed were the 3/4 inch (19 mm) L and the 3/4 inch (19 mm) T. Their sound pressure levels in the linear mode were within 0.4 dB of each other. The 0.4 dB value is not a significant difference in intensity, yet the occupants of the vehicle could tell that the noises were different. The frequency analyses showed that there were no well delineated pure tone peaks in the data for the longitudinal grooves, but there were pure tones at 160 hertz (Hz) and 1,250 Hz in the data for the transverse grooves. Tones of 1,250 Hz are very noticeable to humans, which accounts for the difference sensed by the occupants of the vehicle.

CORRELATION -- dBA AND PSDN

Perusal of the data in Tables 2 and 3, taking the parameters of degree of protuberance, degree of wear, and the orientation and spacing of grooves into consideration, indicated that there was no correlation between the sound pressure levels in dBA and the predicted stopping distance numbers. The plot of the data in Figure 1 supports that conclusion. A linear regression analysis was run to compare the dBA values with the PSDN's. With a percent of the variance explained of 2.65, the linear regression analysis also supports the conclusion that there is essentially no correlation between the two groups of data.

Table 3

dBA Levels, Surface Textures, and PSDN
(1 inch = 2.54 cm)

dBA	Surface Textures	PSDN
59.2	3/4" L, worn	55
59.4	1/2" L, worn	--
59.8	3/4" L, worn	63
60.0	Gravel, not worn	55
60.3	Dimpled, not worn	53
60.6	Sand mix, worn	60
60.8	3/4" T, not worn	58
61.0	3/4" L, not worn	57
61.0	3" T, not worn	56
61.6	S-8, worn	54
61.6	Surface treatment, worn	57
61.6	Burlap drag, worn	54
61.6	1/4" L, worn	67
61.6	1/4" L, worn	--
61.6	Sprinkle medium, not worn	54
61.9	1 1/2" T, not worn	58
62.0	S-5, worn	55
62.2	3/4" L + 1 1/2" T, not worn	59
62.3	3/4" L + 3" T, not worn	59
62.4	3/8" L, worn	--
63.6	Sprinkle coarse, not worn	51

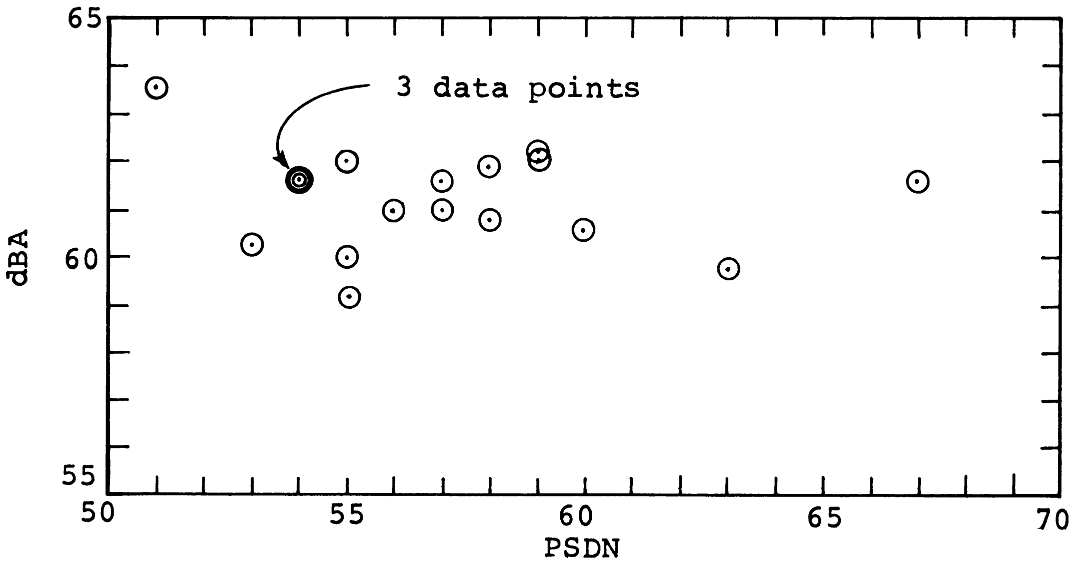

Figure 1. Correlation of dBA with PSDN.

CONCLUSIONS

As related to pavements and tire-road noise, it is concluded that:

1. Noise is directly proportional to the degree of protuberance.
2. Noise is directly proportional to the angularity of the protruding particles.
3. As a pavement wears from a harsh state to a smooth state, the noise is inversely proportional to the degree of wear (decrease of micro-asperities) during the early stages of wear.
4. Noise is inversely proportional to the spacing of longitudinal grooves, i.e., the less intergroove space, the more noise.
5. There is no apparent correlation between SPL's and PSDN's.
6. From the aspect of annoyance, most of the textures that were studied did not generate such different intensities of noise as to be perceivable to the vehicle's occupants.
7. Based on limited data, it appears that transverse grooves tend to create some pure tones in the high frequency range most easily sensed by humans.

RECOMMENDATIONS

To help control highway noise, it is recommended that:

1. When the design engineer specifies the spacing of longitudinal grooves in portland cement concrete, he should consider that the grooves on 1/4 and 3/8 inch (6.4 mm and 9.5 mm) centers were 2 and 3 dBA noisier, respectively than the grooves on 1/2 and 3/4 inch (12.5 mm and 19 mm) centers.
2. When possible, the design engineer should consider possibilities other than creating protuberances to enhance the drainage properties of a pavement.
3. Where noise is an acute problem, consideration should be given to the economic feasibility of a plan whereby the pavement surface would be designed for good durability and noise qualities and adequate skid resistance. Then as skid resistance decreases a secondary texture could be applied to the pavement.
4. Data such as those in Table 3 should be used by the design engineer to weigh his options in terms of texture for the sake of skid resistance and texture as it affects interior car noise.

5. Should a procedure as suggested in No. 4 above be adopted, many additional noise measurements on all types of pavements should be made to provide an adequate data base.

6. More information concerning the pure tones generated on the transverse grooves should be acquired from either the literature, contact with other researchers, or by making additional recordings in the field and having them analyzed for their frequency content.

ACKNOWLEDGEMENTS

The cooperation of G. T. Gilbert of the Council's technical staff in the collection and processing of the data was very helpful in the conduct of this study.

D. C. Mahone, D. W. Hill and C. W. Payne were most considerate in locating test sites and providing skid data.

This work was supported by state funds at the Virginia Highway and Transportation Research Council, Jack H. Dillard, Head.

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