COMMONWEALTH OF KENTUCKY
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS
JOHN C. ROBERTS
COMMISSIONER

JOHN C. ROBERTS
SECRETARY

JULIAN M. CARROLL
GOVERNOR

Division of Research
533 South Limestone
Lexington, KY 40508

March 3, 1975

H-3-24

MEMO TO: J. R. Harbison
State Highway Engineer
Chairman, Research Committee

SUBJECT: Research Report No. 417; "Effect of Pavement Texture on Traffic Noise;" KYP-72-24; HPR-PL-1(10), Part III.

Except for any necessary monitoring of highway noises as may be required of us under the environmental action plan, the report submitted herewith completes the work planned under KYP-72-24. The study, however, is not being terminated at this time. Three previous reports have issued from this study: No. 322, "Noise Abatement; A Review of Literature," February 1972; No. 375, "Vehicle Noise Survey in Kentucky," September 1973; and No. 379, "Evaluation of the Traffic Noise Prediction Procedure," November 1973.

The results from the current study clearly show sand-asphalt surfaces -- and, we believe porous sand-asphalts more so than dense ones -- to be significantly and persistently quieter than most other surfaces. The coarse, open-graded seal on US 31W has begun to ravel in the wheel tracks and is noisier than it was when it was newer. The adjustment factors provided should be applied to the noise prediction procedure in the same way as the correction factors from the nomograph (Fig. B1, in the report) are applied -- both apply and are added algebraically to the standard prediction.

Broomed concrete was not included in the designations of surface types. All remaining, available sites are on bridge decks or approaches; and noise measurements cannot be made outside in the normal way. The only broomed surface surveyed was the northbound approach to the US 25 bridge at Covington; readings made inside the car at 45 mph were comparable to those obtained on normal concrete.

Readings were taken inside the car on the open-grid, steel decks of the Roebling Suspension Bridge and the Central Bridge at Cincinnati; the Suspension Bridge read 82 dBA at 30 mph and 75 dBA at 45 mph. Central Bridge read 78.4 dBA at 30 mph and 75.2 at 45 mph. It is interesting to note, here, that noise levels subsided as the speeds increased; this may be due to some resonating element or panel in the car body; this inverse, noise-speed relationship may not persist outside the car.

Respectfully submitted,

Jas. H. Havens
Director of Research

sh
Enclosure

cc's: Research Committee

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Effect of Pavement Texture on Traffic Noise		5. Report Date February 1975 6. Performing Organization Code
7. Author(s) K. R. Agent and C. V. Zegeer		8. Performing Organization Report No. 417
9. Performing Organization Name and Address Division of Research Bureau of Highways Kentucky Department of Transportation 533 South Limestone Lexington, Kentucky 40508		10. Work Unit No. 11. Contract or Grant No. KYP-72-24
12. Sponsoring Agency Name and Address		13. Type of Report and Period Covered Interim 14. Sponsoring Agency Code

15. Supplementary Notes

Study Title: Noise Abatement

16. Abstract

Tire noise is one of the primary sources of highway noise, particularly at high speeds. Different types of road surfaces generate different noise levels. Noise data were collected on eight different surface types found in Kentucky. Noise measurements were made using a reference car, and noise recordings were obtained from the traffic stream. A reference truck was used for one test. It was found that portland cement concrete; Class I, Type A and A(Modified) bituminous concrete; chip seals; and open-graded, plant-mix seals were more or less "normal" surfaces in regard to generated noise. Sand-asphalt and Kentucky rock asphalt surfaces were about 3 dBA quieter (cars) than "normal" surfaces. Grooved portland cement concrete surfaces were approximately 4 dBA louder (cars) than "normal" surfaces. The surface type did not affect the noise emitted by trucks.

17. Key Words		18. Distribution Statement
Pavement Texture Traffic Noise Surface Type Test Car Noise Recordings	Speed Adjustment Factor	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-69)

Research Report
417

EFFECT OF PAVEMENT TEXTURE ON TRAFFIC NOISE

KYP-72-24; HPR-PL-1(10), Part III

by

Kenneth R. Agent
Research Engineer

and

Charles V. Zegeer
Research Engineer

Division of Research
Bureau of Highways
DEPARTMENT OF TRANSPORTATION
Commonwealth of Kentucky

February 1975

SUMMARY

To determine the effect of pavement texture on traffic noise levels, noise measurements were made on eight different surface types in Kentucky. Measurements were obtained of a reference car, and recordings were obtained from the traffic stream. A reference truck was used for one test. The findings were:

1. Portland Cement Concrete; Class I, Type A and A(Modified), bituminous concrete; chip seals; and open-graded, plant-mix seals were considered "normal" surfaces. A reference car on these surfaces produced noise levels within 1 dBA of one another. Noise recordings were within ±1 dBA of predicted noise levels.
2. Sand-asphalt and Kentucky rock asphalt surfaces were about 3 dBA quieter (cars) than "normal" surfaces. Noise recordings were within 1 dBA of predicted noise levels.
3. Grooved portland cement concrete surfaces were approximately 4 dBA louder (cars) than "normal" surfaces. There was no difference in the noise emitted from a reference truck on the grooved surface compared with a "normal" concrete surface (burlap finish).
4. The following adjustments are recommended for the noise prediction procedure:

SURFACE DESCRIPTION	CAR ADJUSTMENT	TRUCK ADJUSTMENT
Grooved Portland Cement Concrete	+4 dBA	0 dBA
Normal Surfaces: Class I, Type A, Bituminous Class I, Type A (Modified), Bituminous Portland Cement Concrete Open-Graded, Plant-Mix Seal Chip Seals	0 dBA	0 dBA
Smooth Surfaces: Kentucky Rock Asphalt and Sand Asphalts	-3 dBA	0 dBA

INTRODUCTION

Noise emitted from highway vehicles emanates primarily from engine exhausts, tire-pavement interaction, gears, and rattles. Studies have shown that at high speeds tires become the dominant generators of noise. Measurements on different road surfaces have produced different noise-versus-speed relationships *(1)*. This led to the road surface adjustment used in the noise prediction procedure developed in NCHRP Report 117 *(2)* as follows:

SURFACE TYPE	DESCRIPTION	ADJUSTMENT
Smooth	Very smooth, seal-coated asphalt pavement	-5dBA
Normal	Moderately rough asphalt and concrete surface	0dBA
Rough	Rough asphalt pavement with large voids 1/2 in. (12 mm) or larger in diameter, grooved concrete	+5dBA

As can be seen, the surface descriptions are vague, and it is left to the discretion of the user to apply adjustments where applicable. Consideration was given initially in this report to "rough" surfaces, but the term was abandoned because it seemed vague and maybe misleading. Also, various degrees of roughness gave a wide range of noise levels. In fact, it appears that the terms "smooth", "normal", and "rough" address only that portion of tire noise generated by drumming or percussion of the tire against knobs in the pavement surface. "Smooth" does not distinguish "smooth and dense" from "smooth and porous". It has been argued that the -5 dBA adjustment should not be used since some truck tires become excessively noisy on very smooth surfaces and inasmuch as such surfaces are presumed to be ready for renewal because of their inherent low friction characteristics *(3)*. Noises attributable to "tractive squeal" and "clapping of air" between worn tires and polished or glassy, dense surfaces suggest that a term indicating the degree of porosity should always be associated with smoothness. Minimum noise is believed to be associated with smoothness and an optimum porosity. In this report, surfaces are identified according to Kentucky specifications.

Noise data were taken on all major types of surfaces presently used in Kentucky. A reference automobile was used to determine any difference in noise. Strip-chart records were made to evaluate the effect road surface type had on the noise of the entire traffic stream.

PROCEDURE

Noise data were taken on the following surface types:

Class I, Type-A, Bituminous Concrete,
Class I, Type A(Modified), Bituminous Concrete,
Portland Cement Concrete,
Sand Asphalt,
Kentucky Rock Asphalt,
Open-Graded, Plant-Mix Seals,
Chip Seals, and
Grooved Portland Cement Concrete.

A detailed description of each type of surface is given in APPENDIX A.

All data were taken at locations having zero grade, with the observer level with the roadway, and without any shielding. The distance from the center of the lane tested to the noise level meter was 50 feet (15 meters). The locations were selected to give as great a range in traffic exposure as possible. A Bruel and Kjaer precision sound-level meter, Type 2203, was used for all measurements. The strip-chart recorder was Type 2305.

Two reference cars were used for single vehicle tests (Figure 1). Care was taken to insure no error was introduced in using two different cars. Data were taken at 30, 45, and 60 mph (13, 20, and 27 m/s) at each location, when possible. The data taken at 45 mph (20 m/s) were used for direct comparisons since it was not possible to obtain 30- and 60-mph (13- and 27-m/s) tests at all locations. The meter readings were noted by the operator as the reference vehicle passed. Measurements were taken only when the noise from the reference cars could be clearly isolated from the traffic stream. Test runs were made at each speed and until representative measurements were obtained. In all cases, the ground cover between the roadway and observer was short grass. Noise levels were also taken inside the cars at 45 mph (20 m/s). A reference truck was used at one location.

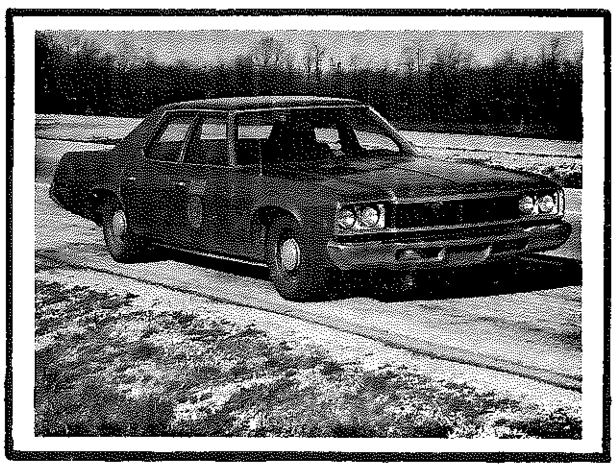


Figure 1. Reference Car.

To evaluate the effect of surface type on the noise of the traffic stream, strip-chart records were compared with predicted values. The measured L_{10} noise level (level exceeded 10 percent of the time) was determined from a 10-minute chart record. Noise levels on the chart were read at slightly greater than one second intervals in the laboratory utilizing a digitizing data reduction system and computer cards. The L_{10} noise level was computed. The predicted noise level was determined by the method developed in NCHRP 117 *(2)* but then corrected according to the nomograph developed for Kentucky data (APPENDIX B) *(4)*. No adjustment for surface type was used in the noise prediction. The measured L_{10} noise level was then compared with the predicted level.

RESULTS

Reference Car Noise Measurements

After preliminary testing of several locations involving each type of pavement, a relationship was found between noise level and cumulative traffic. A plot of noise level versus cumulative traffic volume was made for each pavement type using the noise level found at 45 mph (20 m/s) (APPENDIX C). The noise level versus cumulative traffic for all pavement surface types (except chip seals) is summarized in Figure 2.

Class I, Type A, Bituminous Concrete Surfaces: The noise measurements taken at five locations (eight tests) showed an average of 69.6 dBA. No further increase in noise level was found as the cumulative traffic approached 30 million vehicles (Figure C1).

Class I, Type A(Modified), Bituminous Concrete Surfaces: This surface type has been used for much of the resurfacing in Kentucky in the past several years. It is a smooth, dense surface when placed, but it becomes noticeably polished after the cumulative traffic reaches about one million vehicle passes. Results of 24 tests showed an increase from an average of 64.5 dBA on surfaces with cumulative traffic of less than one million vehicle passes to an average of 70.0 dBA on surfaces which had accumulated more than one million vehicle passes (Figure C2).

Portland Cement Concrete Surfaces: Concrete surfaces showed very little variation in noise level as the cumulative traffic increased. The average noise level was 69.2 dBA for seven locations (nine tests) (Figure C3).

Grooved Portland Cement Concrete Surfaces: An average noise reading of 73.0 dBA was obtained on three sections (five tests) of transversely, plastically grooved concrete (Figure C4). Readings on two sections of very new, unopened pavement gave noise levels of 69.8 dBA and 74.2 dBA. This large difference was the result of the work being done by different contractors. The section with the higher noise level had deeper grooves.

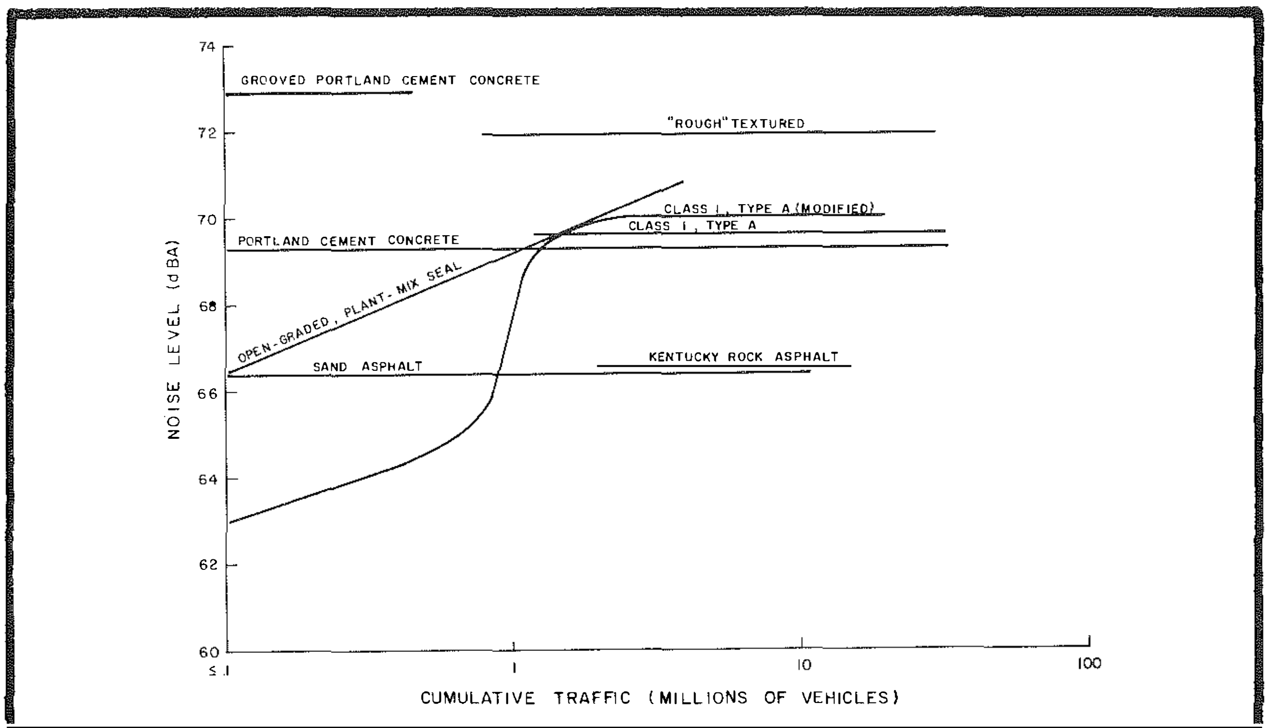


Figure 2. Effects of Cumulative Traffic on Noise Levels of Various Pavement Surfaces.

Sand-Asphalt Surfaces: The locations tested included various types of sand-asphalt pavements, but the noise levels were very similar for all types. The average noise level was 66.4 dBA for the 13 locations (17 tests) and remained constant as the cumulative traffic increased to about 10 million vehicle passes (Figure C5).

Kentucky Rock Asphalt Surfaces: These surfaces showed a constant noise level up to a cumulative traffic volume of 15 million vehicle passes. The average noise level was 66.5 dBA (five tests) (Figure C6).

Open-Graded, Plant-Mix Surfaces: This is a new surface type which was first used in Kentucky in 1973 to improve skid resistance of pavements. The tests on this surface showed a large increase in noise level over time. Tests on new surfaces resulted in noise levels of around 66 dBA, but as the surface became worn, noise levels increased to over 70 dBA (Figure C7).

Chip Seals: These surfaces are placed only on low volume roads and are expected to endure for a limited period of time. For this reason, it was not included with the other surface types in Figure 2. A new chip seal (limestone aggregate) is extremely rough textured. The surfaces may become smoother with exposure to traffic. With continued traffic, the surface often tends to crack, bleed, and break up. Thus, the noise level from a chip-seal surface may change significantly. The average noise level for the ten chip seals tested was 66.8 dBA. A wide variation in noise level existed at various locations, but there appears to be a relation between the noise level and cumulative traffic. On a new surface, the exposed aggregate produces a noise level of about 69 dBA. As the aggregate is worn and the surface bleeds, the noise level drops to 64 dBA. Finally, the older surfaces begin to crack and break up, and the noise level again rises (Figure C8).

Summary of Noise Measurements Involving the Reference Car

Sand-asphalt and Kentucky rock asphalt surfaces are the only surfaces which maintained a low noise level (about 66 dBA) with increased cumulative traffic. Class I, Type A(Modified), chip seals, and open-graded, plant-mix surfaces were all relatively quiet sometime during their service life, but the noise level of each increased to between 69 to 70 dBA as the cumulative traffic increased. Portland cement concrete and Class I, Type A, bituminous surfaces maintained a relatively constant noise level (69.5 dBA). Tests on transversely grooved portland cement concrete surfaces yielded a noise level around 73 dBA. Test locations are cited in APPENDIX D.

A few readings were obtained for surfaces which were unusually cracked and bumpy. These surfaces might be classified as "rough" and were not included in any of the preceding surface types. These "rough" surfaces had an average noise level of about 72 dBA.

To assure that the reference car noise data were representative of the "average" car, results from a previous vehicle noise survey *(5)* were compared to the reference car data. The survey was conducted on Class I, Type A and portland cement concrete surfaces for various speed limit locations. The data at 45-mph (20-m/s) and 60-mph (27-m/s) speed limit locations were compared to the reference car data for the corresponding speeds. Admittedly, the survey vehicles were not traveling at exactly the speed limit, but the large number of vehicles in the survey should make the comparisons valid. The median automobile noise level was 68 and 74 dBA for 45- and 60-mph (20- and 27-m/s) speed limit locations, respectively. This compares to reference car noise levels of 69.5 and 74 dBA at the corresponding speeds (Table 1). From this comparison, it can be seen that the reference car was representative of the "average" car.

Relationship between Speed and Noise Level

The relationhsip between car speed and noise level for each surface type was investigated (Figure 3). Noise levels at each speed for each pavement type were averaged. Only locations which were tested at all three speeds were counted in these averages. Because of the large variation in noise levels for Class I, Type A(Modified), bituminous surfaces, these surfaces were classified as either new (less than one million vehicle passes) or worn (greater than one million vehicle passes).

The change in noise level with speed was similar for all surfaces. The average increase in noise level from 30 to 45 mph (13 to 20 m/s) was 5.2 dBA while the average increase from 45 to 60 mph (20 to 27 m/s) was 4.6 dBA. This yields a 9.8 dBA increase with doubling of speed (30 to 60 mph) (13 to 27 m/s)). A 10-dBA increase constitutes a doubling of the loudness of sound *(3)*. Table 1 summarizes the data used in Figure 3.

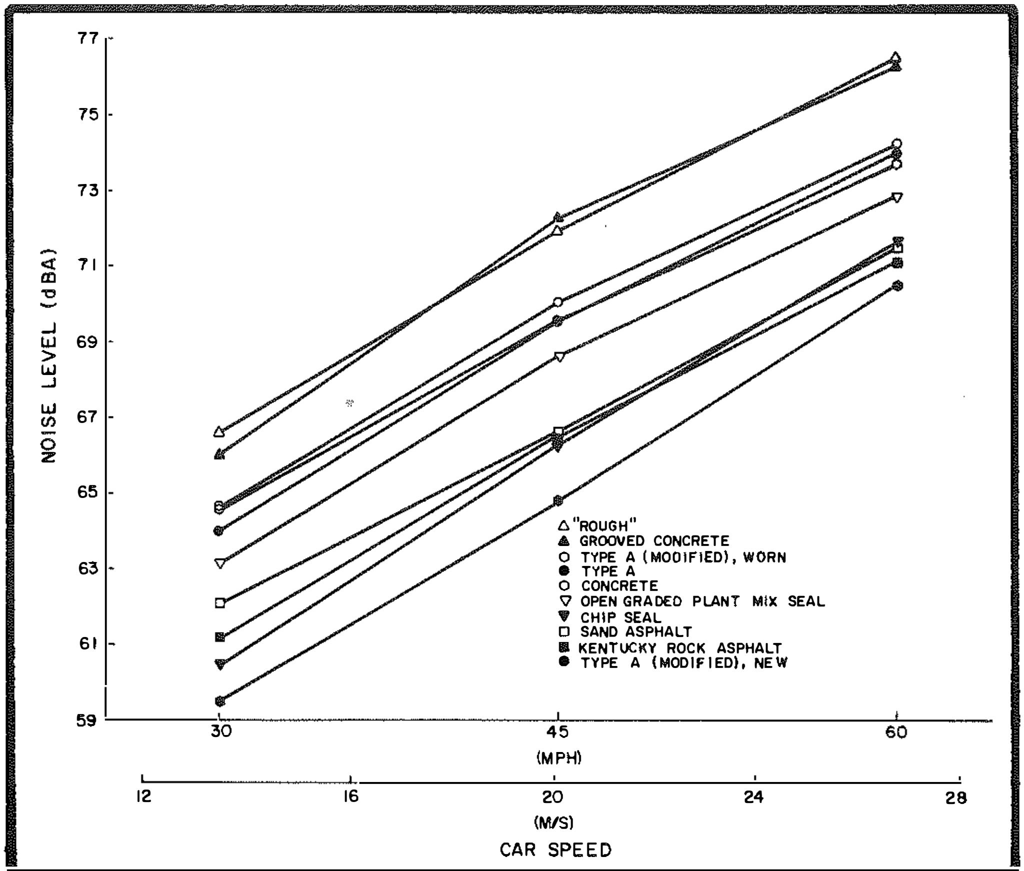


Figure 3. Effect of Car Speed on Noise Levels of Various Surface Types.

Noise Measurements inside the Reference Car

To determine the differences in noise levels for occupants of vehicles driving on various surfaces, measurements were taken inside the reference car. In all cases, the vehicle speed was 45 mph (20 m/s). The sound level meter was held about 6 inches (152 mm) above the back rest of the front seat -- closely corresponding to ear level. The slow response of the sound level meter was used so variations in the noise could be minimized. The average noise level over a uniform stretch of highway was tabulated for each pavement type. From three to fourteen locations were tested for each surface type. The readings were averaged. The results are presented in Figure 4. The sand-asphalt and Kentucky rock asphalt surfaces gave the lowest noise levels (65.3 dBA). The other surface types ordered in the same way as the data obtained from outside the reference car (Figure 2).

Noise measurements were also made inside the car on some bridge decks. Two bridge decks which had been grooved were compared to one ordinary deck. The average readings for the grooved decks were identical to the average of grooved concrete pavements (Figure 4). The grooved decks gave readings approximately 3 dBA higher than the ordinary decks.

Noise Recordings

A total of 260 noise recordings taken on various surface types were compared to predicted values. A comparison of the predicted L_{10}-noise levels (NCHRP 117 with Kentucky correction nomograph) with measured values are summarized in Table 2. The actual and predicted L_{10}-values for Class I, Type A; worn Class I, Type A(Modified); portland cement concrete; sand-asphalt; open-graded, plant-mix seal, and Kentucky rock asphalt surfaces were within ± 1 dBA. New Class I, Type A(Modified), surfaces were nearly 5 dBA under the predicted levels. This, however, is not indicative of the long-term noise level. Also, at these locations, there was a large number of smaller, quieter trucks which resulted in actual noise levels below the predicted levels. It was not possible to obtain reliable noise recordings for the grooved concrete surface because the only section which had been opened to traffic was on only two lanes of a four-lane highway. The very low traffic volumes on the chip-seal surfaces made noise recordings unreliable. Some recordings were also taken on some surfaces which were very cracked and bumpy and may be classified as "rough". These "rough" surfaces had actual L_{10}-noise levels which were approximately 5 dBA above the predicted values.

Figure 4. Noise Levels Inside Car (45 mph (20 m/s)) on Various Surfaces.

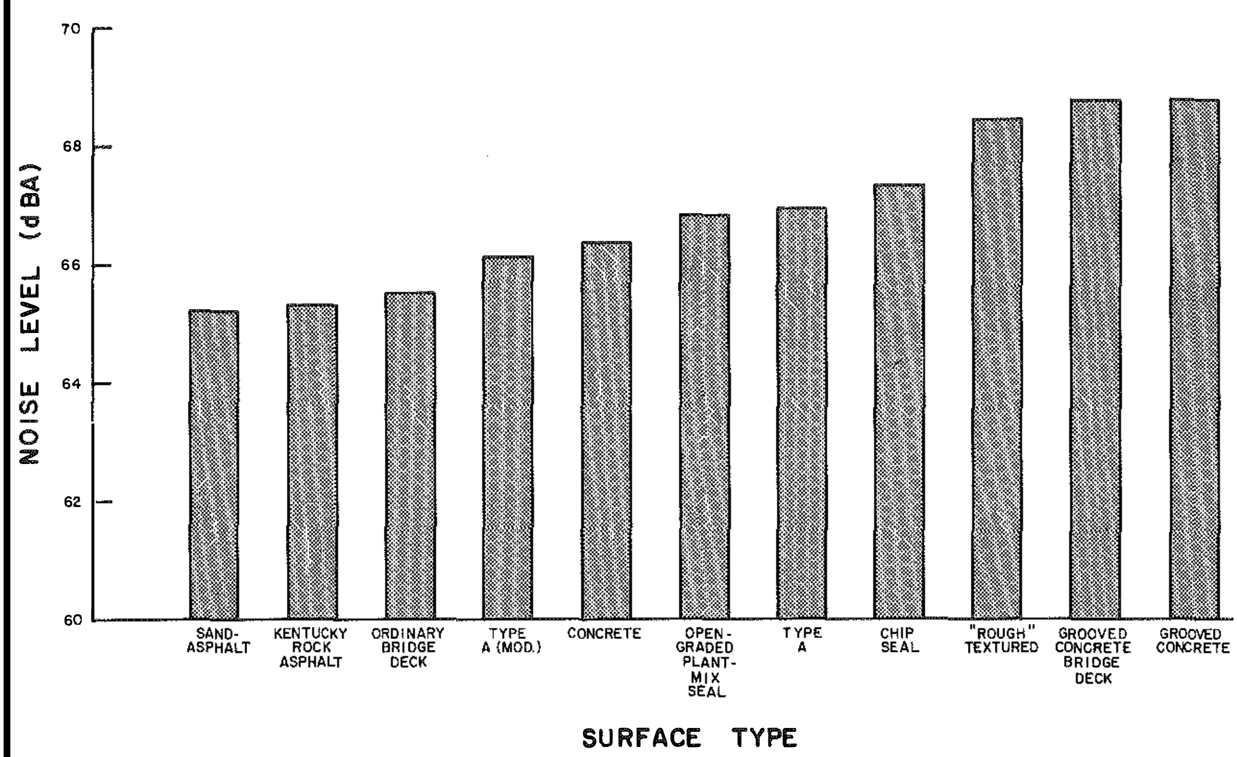


TABLE 1

RELATIONSHIP BETWEEN SPEED AND NOISE LEVEL FOR VARIOUS SURFACE TYPES

SURFACE TYPE	NOISE LEVEL (dBA) 30 mph (13 m/s)	45 mph (20 m/s)	60 mph (27 m/s)
Class I, Type A, Bituminous	64.6	69.5	74.0
Class I, Type A (Modified), Bituminous — New	59.5	64.8	69.5
Class I, Type A (Modified), Bituminous — Worn	64.6	70.0	74.2
Portland Cement Concrete	64.0	69.5	73.7
Grooved Portland Cement Concrete	66.0	72.2	76.3
Sand Asphalt	62.1	66.6	71.3
Kentucky Rock Asphalt	61.2	66.5	71.1
Open-Graded, Plant-Mix Seal	63.2	68.6	72.8
Chip Seals	60.5	66.3	71.6
"Rough"	66.6	71.9	76.5
All Tests	62.2	67.4	72.0

Reference Truck Noise Measurements

The truck used was single-unit, two-axle, six-tire truck (Figure 5). It was loaded to approximately 18,000 pounds (8165 kg) on the rear axle. Measurements were taken on a new, unopened section of interstate. There were two sections of grooved concrete and one section of ordinary concrete. The data was taken 50 feet (15 meters) from the center of the lane tested. At 45 mph (20 m/s), the truck gave readings of 80.7 dBA, 81.9 dBA, and 81.2 dBA on the two sections of grooved and one section of ordinary concrete, respectively. It can be seen that the grooved concrete did not cause additional noise to be emitted by the truck.

DEVELOPMENT OF ADJUSTMENT FACTORS

To develop adjustment factors for noise levels on various pavement types, the individual vehicle readings and the traffic stream recordings were considered. The individual vehicle noise readings showed that after a traffic exposure of ten million vehicle passes, only Kentucky rock asphalt and sand-asphalt surfaces give consistently low values (about 66 dBA). Grooved concrete exhibits noise levels of about 73 dBA. All other surfaces show "normal" noise levels of 69 to 70 dBA. Thus, the car adjustment was considered to be +4 dBA for the grooved concrete surfaces. An adjustment of -3 dBA was considered appropriate for cars on Kentucky rock asphalt and sand-asphalt surfaces.

The truck adjustments were determined from noise recordings on the different surface types as well as the reference truck data on grooved concrete. By comparing predicted with measured noise recordings, several conclusions were reached. Actual values on new Class I, Type A(Modified), surfaces were quieter than predicted; but worn Class I, Type A(Modified), surfaces showed noise levels similar to those predicted. The other surface types showed very little differences between predicted and measured levels. Thus, no adjustment was considered necessary for trucks on the surfaces for which noise recordings were taken. The reference truck data indicated that no adjustment for trucks was necessary for grooved concrete surfaces.

There is a definite advantage in considering adjustments separately for cars and trucks. In most cases, the L_{10}-noise level for trucks predominates in the traffic stream. However, in cases where car noise predominates, a separate adjustment for cars would make predicted levels more accurate. The recommended adjustments for car and truck noise levels are given in Table 3.

IMPLEMENTATION

The adjustment factors derived in this study should be used to adjust predicted noise levels with respect to various surface types. An adjustment of +4 dBA for cars and 0 dBA for trucks is recommended for grooved concrete surfaces. Zero adjustment is recommended for the specified "normal" surface types. Smooth surfaces (Kentucky rock asphalt and sand asphalt) should have a -3 dBA adjustment for cars and 0 dBA adjustment for trucks.

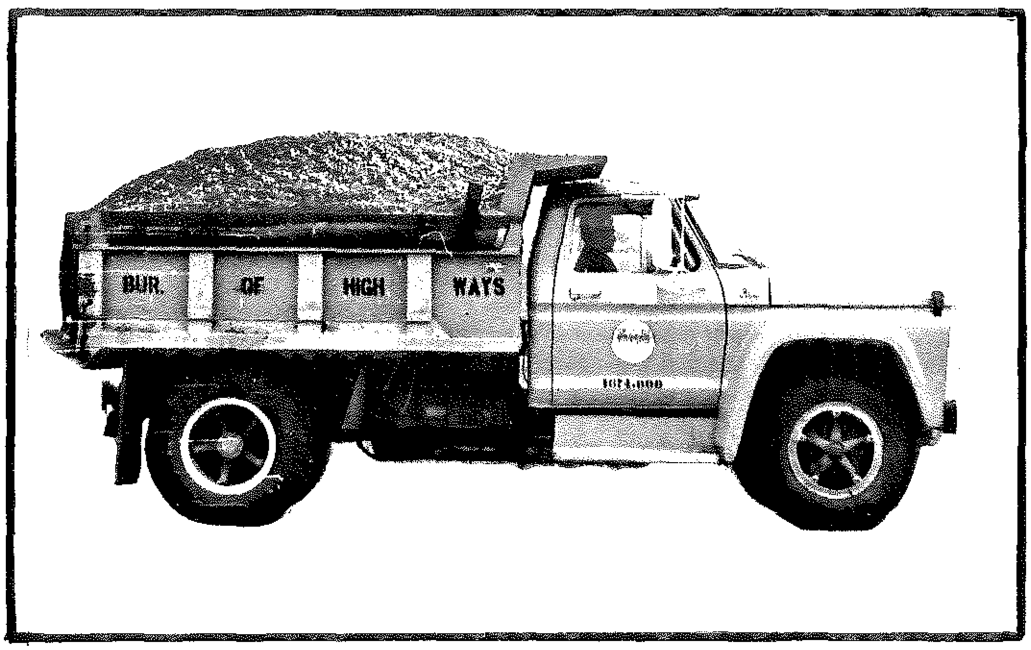


Figure 5. Reference Truck.

TABLE 2

COMPARISON OF PREDICTED AND MEASURED NOISE LEVELS FOR VARIOUS SURFACE TYPES

SURFACE TYPE		NUMBER OF RECORDINGS	PREDICTED L_{10} MINUS MEASURED L_{10} (AVERAGE)
Class I, Type A, Bituminous		122	+0.8
Class I, Type A (Modified), Bituminous	New	8	+4.7
	Worn	15	+1.0
Portland Cement Concrete		51	+1.0
Sand Asphalt		34	-0.7
Kentucky Rock Asphalt		10	-0.9
Open-Graded, Plant-Mix Seal		5	-0.5
"Rough"		15	-5.2

TABLE 3

RECOMMENDED SURFACE TYPE NOISE LEVEL ADJUSTMENTS

SURFACE DESCRIPTION	CAR ADJUSTMENT	TRUCK ADJUSTMENT
Grooved Portland Cement Concrete	+4 dBA	0 dBA
Normal Surfaces: Class I, Type A, Bituminous; Class I, Type A (Modified), Bituminous; Portland Cement Concrete; Open-Graded, Plant-Mix Seal; Chip Seals	0 dBA	0 dBA
Smooth Surfaces: Kentucky Rock Asphalt and Sand Asphalts	-3 dBA	0 dBA

REFERENCES

1. Galloway, W. J.; Clark, W. F.; and Kerrick, J. S.; *Highway Noise -- Measurement, Simulation, and Mixed Reactions,* **National Cooperative Highway Research Program Report No. 78**, Highway Research Board, 1969.
2. Gordon, C. G.; Galloway, W. J.; Kugler, B. A.; and Nelson, D. L.; *Highway Noise – A Design Guide for Highway Engineers,* **National Cooperative Highway Research Program Report No. 117**, Highway Research Board, 1971.
3. *Fundamentals and Abatement of Highway Traffic Noise,* **Report No. FHWA-HN1, HEV- 73-7976-1**, U. S. Department of Transportation, June 1973.
4. Agent, K. R. and Zegeer, C. V.; *Evaluation of the Traffic Noise Prediction Procedure,* Division of Research, Kentucky Bureau of Highways, November 1973.
5. Agent, K. R. and Rizenbergs, R. L.; *Vehicle Noise Survey in Kentucky,* Division of Research, Kentucky Bureau of Highways, September 1973.
6. **Standard Specifications for Road and Bridge Construction,** Kentucky Bureau of Highways, 1965.
7. **Bituminous Plant Inspector's Guide,** Division of Materials, Kentucky Bureau of Highways, 1974.
8. Florence, R. L. and Southgate, H. F.; *Experimental Sand-Asphalt Surface,* Division of Research, Kentucky Bureau of Highways, October 1970.

APPENDIX A

DESCRIPTION OF PAVEMENT TYPES

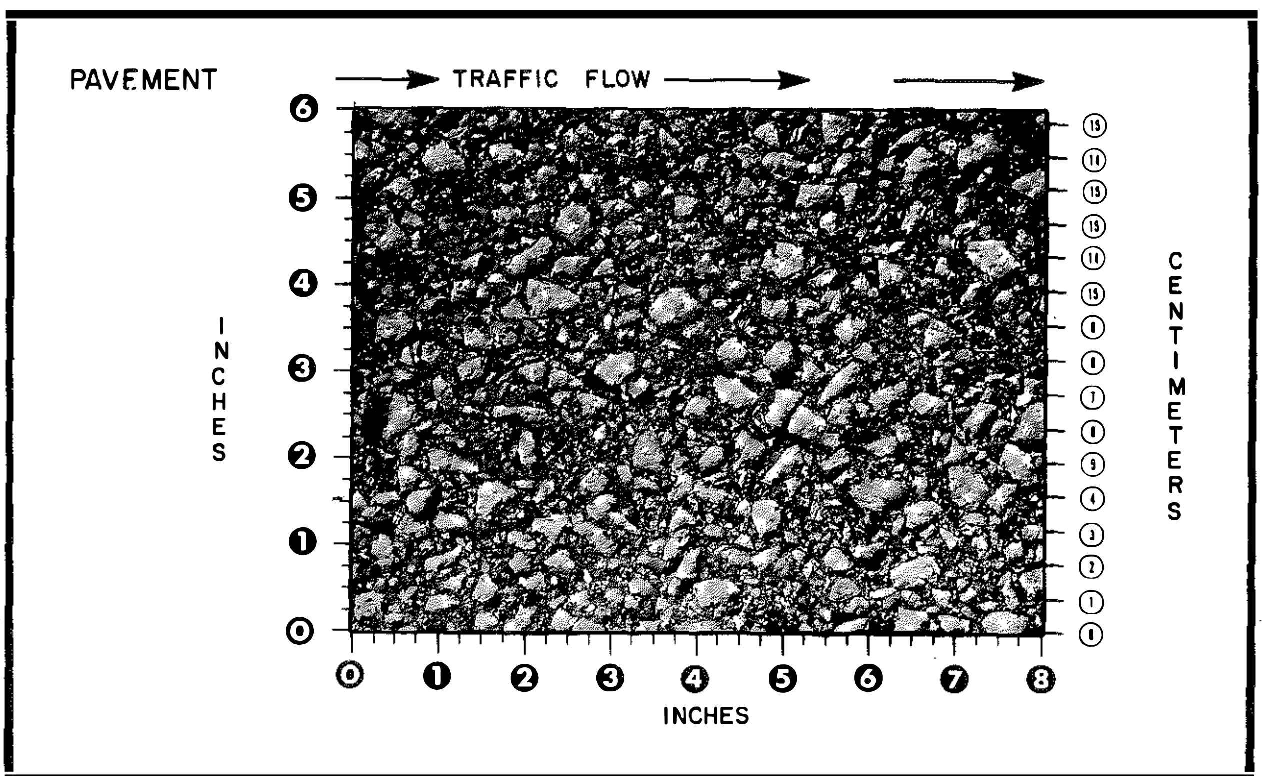
CLASS I, TYPE A, BITUMINOUS

More detailed information can be obtained from the **Kentucky Standard Specifications for Road and Bridge Construction** *(6)*.

Composition Limits

Sieve Size	Percent Passing by Weight
1/2 in.	100
3 in.	80-100
No. 4	55-75
No. 8	35-60
No. 16	25-50
No. 50	9-21
No. 100	5-14
No. 200	3-7
Bitumen	4-8

Figure A1. Class I, Type A, Bituminous Surface.



CLASS I, TYPE A(MODIFIED), BITUMINOUS

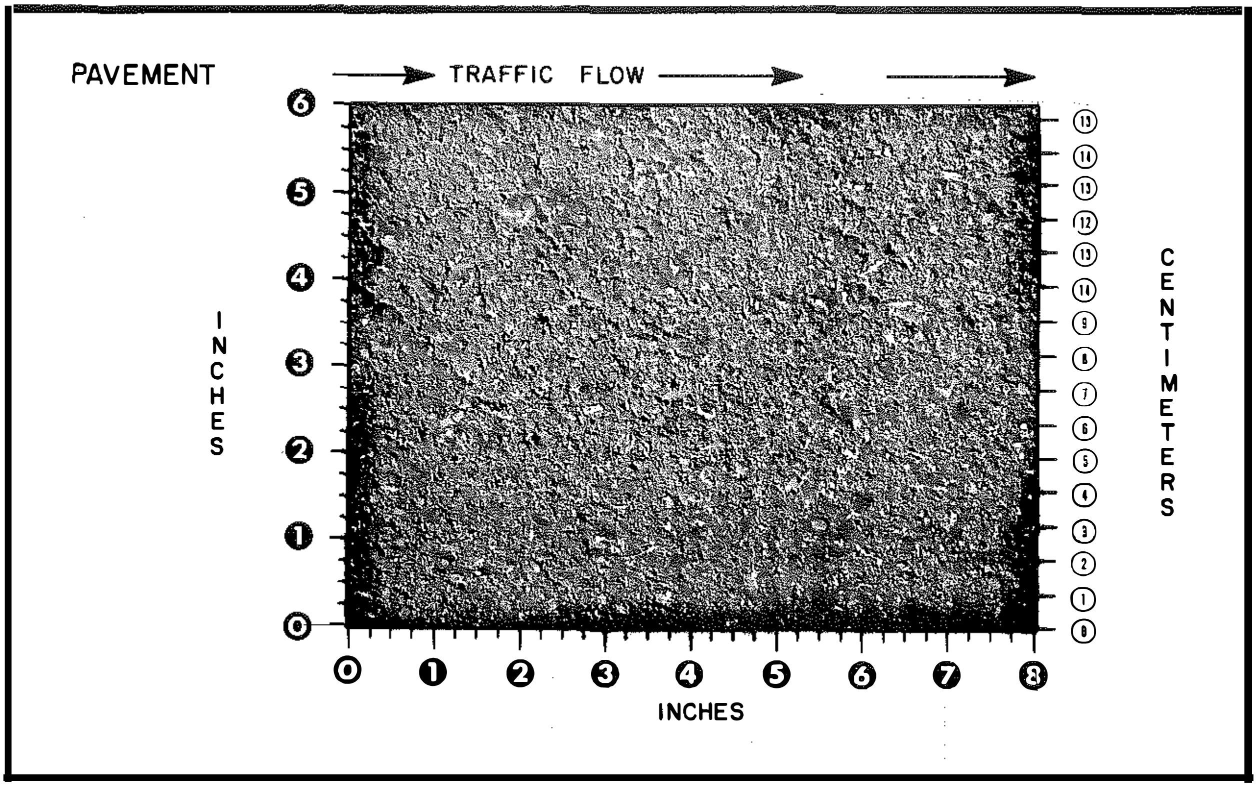
More detailed information can be obtained from the **Bituminous Plant Inspector's Guide** *(7)*.

Composition Limits

Sieve Size	Percent Passing by Weight
1/2 in.	100
3/8 in.	85-100
No. 4	60-80
No. 8	40-60
No. 16	25-50
No. 50	5-20
No. 100	3-12
No. 200	2-6

Bitumen = 4.0 to 8.0 percent

Figure A2. New Class I, Type A(Modified), Bituminous Surface.



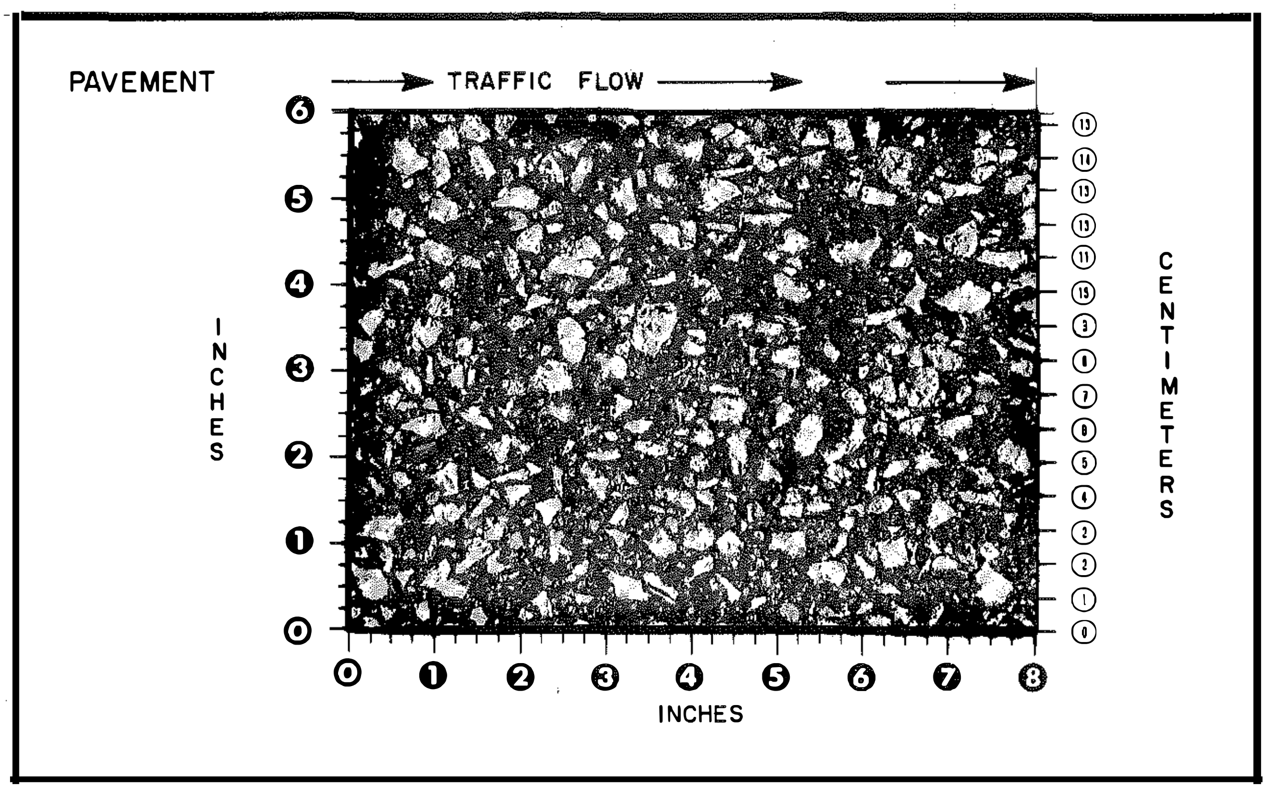


Figure A3. Worn Class I, Type A(Modified), Surface.

PORTLAND CEMENT CONCRETE

The following specifications can be found in the **Kentucky Standard Specifications for Road and Bridge Construction** *(6)*:

1. **Portland Cement**

Portland cement shall conform to the requirements for Type I of the Standard Specifications for Portland Cement, ASTM Designation: C 150.

2. **Admixtures**

All air-entraining admixtures shall conform to the requirements of the Specifications for Air-Entraining Admixtures for Concrete, AASHTO Designation: M 154, currently in force, for compressive and flexural strengths and resistance to freezing and thawing, except as hereinafter provided for vinsol resin solution. Tests for bleeding, bond strength, and volume change will not be required, except at the option of the Department.

3. **Water**

Water, shall meet the approval of the engineer and may be tested at any time it is of questionable quality, either prior to or during its usage.

Potable water supplied by public distribution systems will ordinarily be accepted without being tested. Water from other sources shall be fresh, clean, clear, and free from oil and shall not contain acid or alkali (calculated in terms of calcium carbonate), or organic or inorganic solids in excess of 0.05 percent when tested in accordance with the applicable methods of AASHTO T 26.

4. **Five Aggregates (natural sand)**

A. Sand Equivalent Values. The sand equivalent value for sand covered herein shall be not less than 80.

B. Deleterious Substances. Deleterious substances shall not exceed the following percentages by weight of the total sample.

Clay Lumps	None
Coal and Lignite	0.25
Other deleterious substances such as, but not limited to, shale, alkali, mica, coated grains, and soft and flaky particles	1.0

C. Organic Impurities. The sand shall be free from injurious amounts of organic impurities. When subjected to the colorimetric test for organic impurities and producing a color darker than the standard, the sand shall be rejected unless it passes the mortar strength test.

D. Mortar Strength. Sand which does not pass the test for organic impurities may be used provided that, when tested for the effect of organic impurities on strength of mortar in accordance with AASHTO T 71, the relative strength at 7 and 28 days is not less than 95 percent.

E. Gradation. The sand shall be graded from coarse to fine and, when tested by standard laboratory sieves, shall conform to the following requirements:

Sieve Size	Percent Passing
3/8 in.	100
No. 4	85-100
No. 16	40-80
No. 50	5-25
No. 100	0-5

5. **Coarse Aggregate (Limestone)**

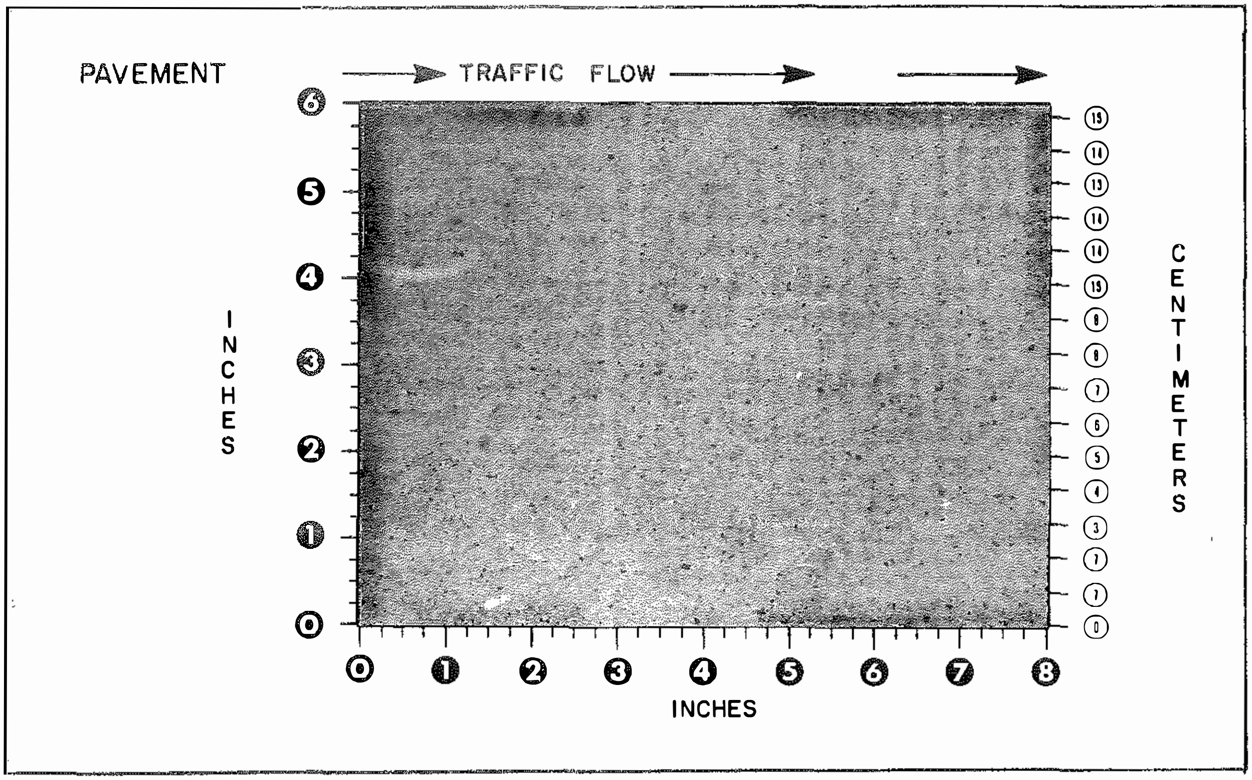
A.

	Maximum Percent by Weight
Clay lumps	0.25
Shale	2.0
Finer than No. 200 seive	2.0
Chert, specific gravity of 2.35 or less	0.25
Other deleterious substances	0.25
Flat or elongated pieces	15.0
Wear, Los Angeles	40.0

B. Gradation

Sieve Size	Percent Passing by Weight
1 1/2"	100
1"	95-100
1/2"	25-60
No. 4	0-10
No. 8	0-5

Figure A4. **Portland Cement Concrete Surface.**



SPECIAL NOTES FOR TRANSVERSE GROOVING OF PLASTIC CEMENT CONCRETE PAVEMENT

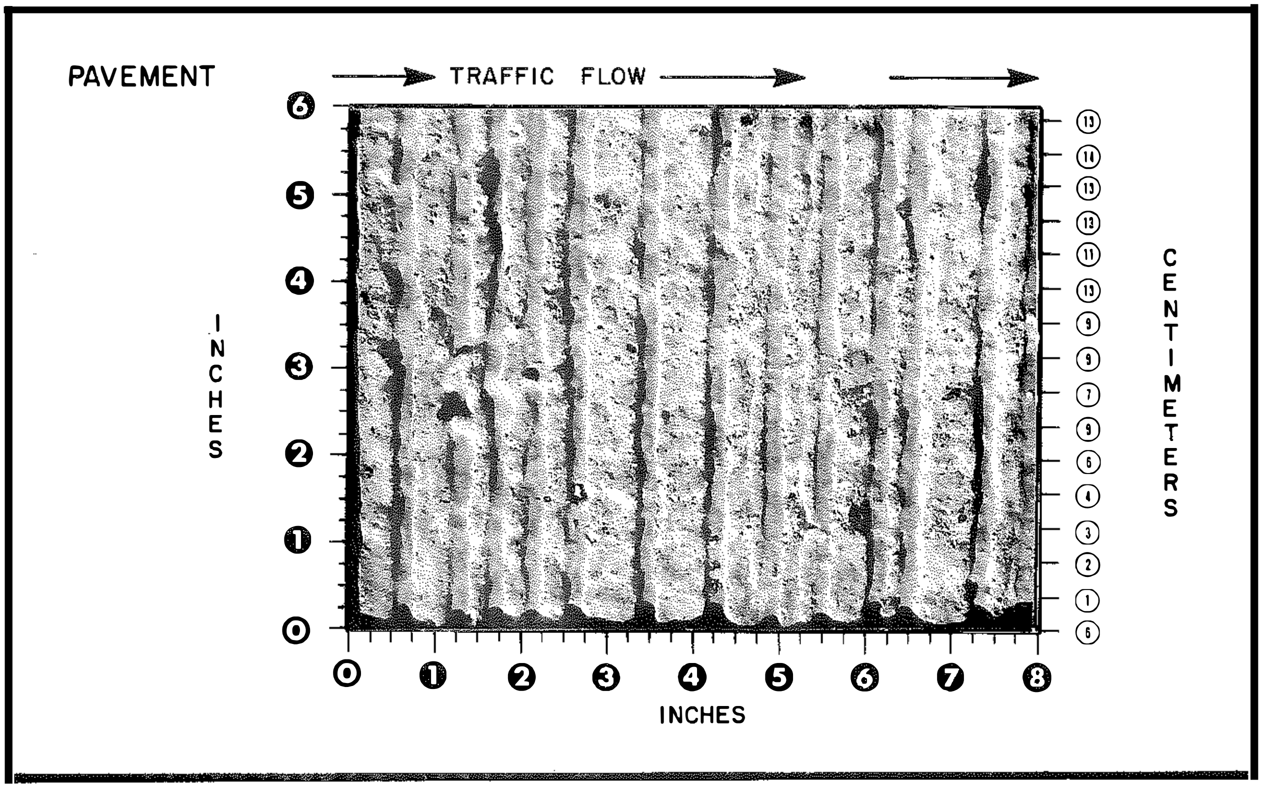
The final finish for the cement concrete pavement shall be a transverse grooved finish which is accomplished by mechanized equipment using either a vibrating beam roller of a comb made with steel tines, or other approved device. The grooves shall be formed in the plastic concrete at an appropriate time during the stiffening of the concrete, so that in the hardened concrete, the grooves will be between 0.09 to 0.13 inch in width, between 0.12 to 0.19 inch in depth, and be spaced at intervals between 0.5 and 1.0 inch. The grooves shall be relatively smooth and uniform in all aspects, and shall be formed without tearing the surface and without bringing pieces of the coarse aggregate to the top of the surface.

The transverse grooves shall be formed within the above specified size limits so that a minimum average texture depth of 0.030 inch is provided when determined by the Bureau's current Sand Patch Method. Any area of pavement which exhibits a value of less than 0.025 inch shall be check tested as necessary to determine the extent of the area. If check tests confirm that the size of the area with the low reading is 200 square yards or larger, then the area will be considered deficient and require corrective work as hereinafter specified.

Manual tools such as fluted floats or rakes with spring steel tines may be used for forming the transverse grooves in areas such as ramps, connections, and other miscellaneous sites where the mechanized grooving equipment cannot be utilized. Careful attention shall be given to the manual workmanship in order to achieve grooves which conform to the same requirements as those specified for the grooves formed by the mechanized equipment.

Areas of the hardened grooved pavement which do not conform to these requirements, either because of a deficiency in the grooving or because of a rough or open texture of the surface, shall be corrected by the cutting of acceptable grooves in the hardened pavement with an approved mechanical grinder or cutting machine.

Figure A5. **Grooved Portland Cement Concrete Surface.**



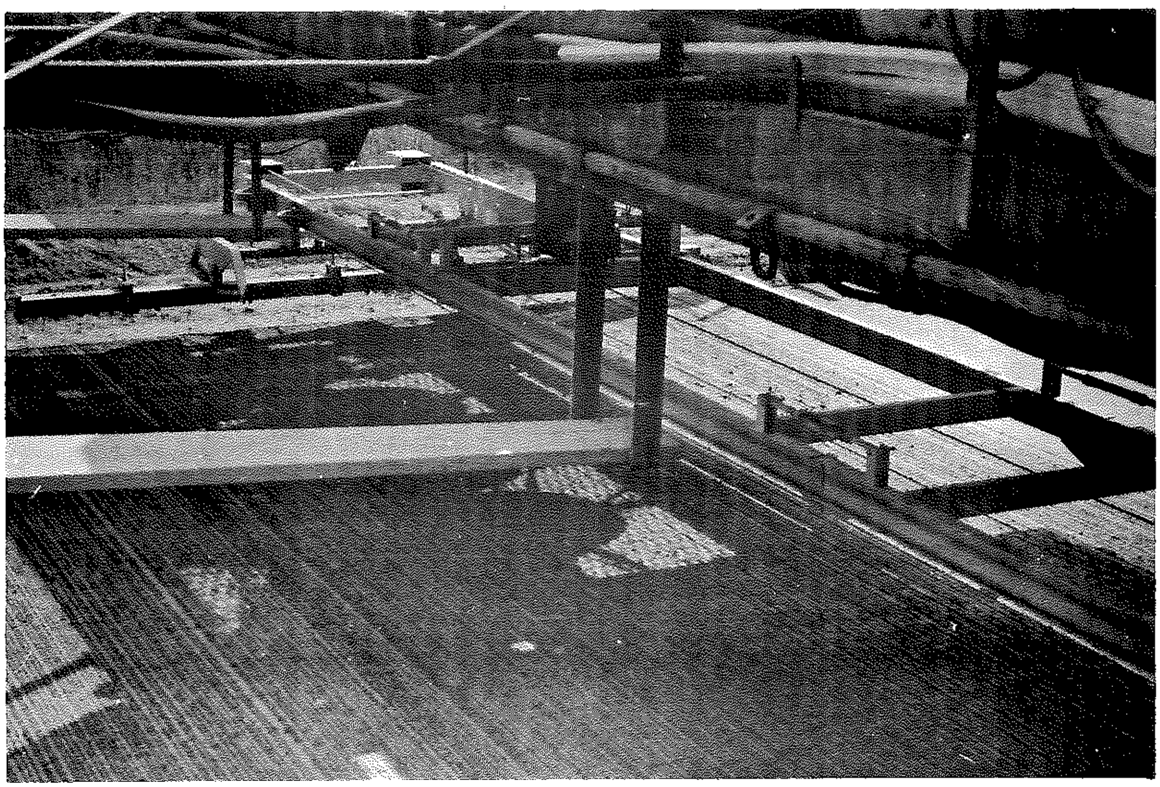


Figure A6. **Equipment Used To Groove Portland Cement Concrete; I 24-3(19)76 and I 24-3(18)65 (this photo taken on I 24-3(18)65).**

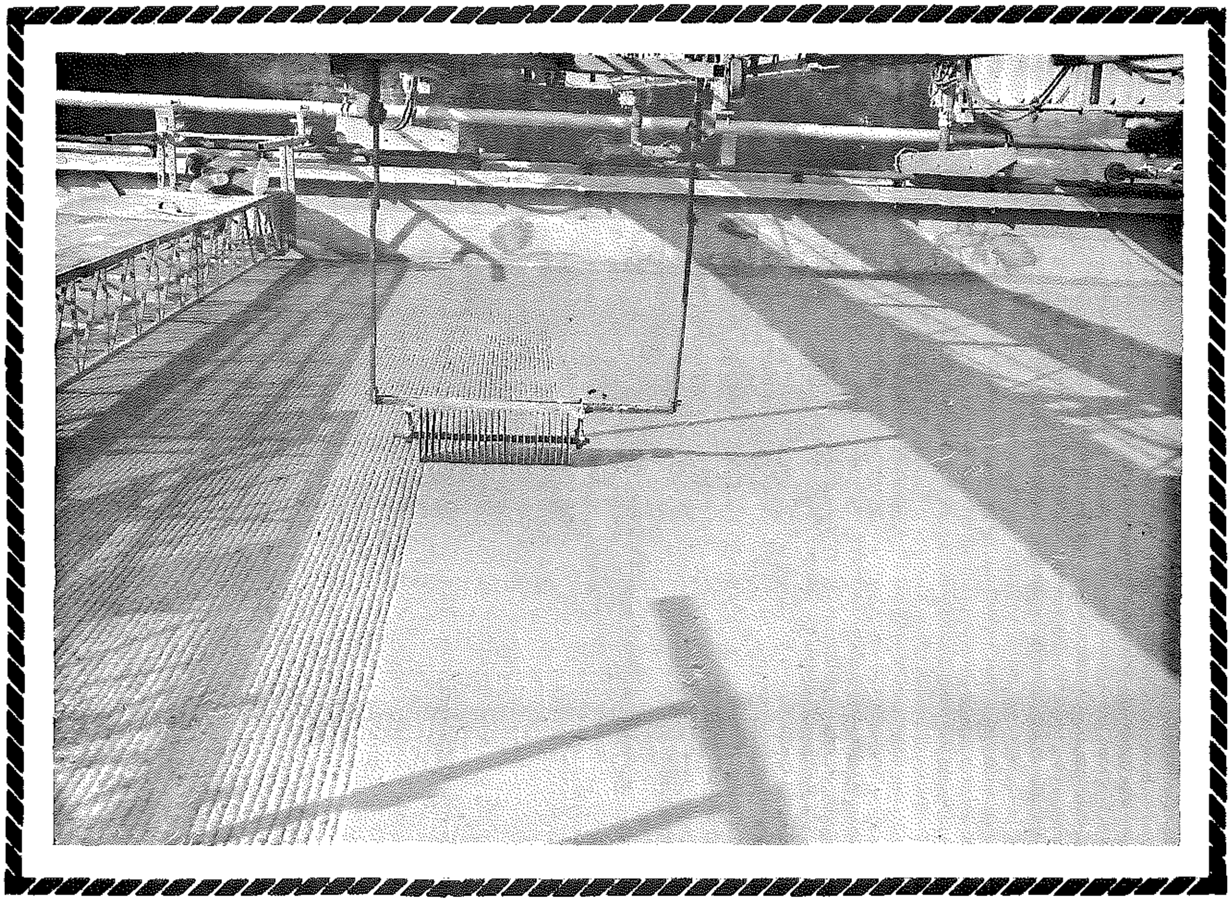


Figure A7. Equipment Used To Groove Bridge Decks; Camp Nelson, US 27.

SAND ASPHALT (SPECIAL PROVISION NO. 22-A)

The specifications were obtained from a report entitled *Experimental Sand-Asphalt Surface (8)* and more detailed information on this and other special provisions may be found there.

1. Materials

A. Bituminous Materials. The asphalt cement to be mixed with the sand shall be of the grade specified on plans or proposals and shall meet the particular requirements of Section 621 of Kentucky Standard Specifications for road and bridge construction. The quantity of asphalt cement used shall be as directed by the Engineer.

Bituminous material for the tack coat shall meet the requirements of Section 621 for the particular type and grade specified on the plans or proposals.

B. Aggregate. The aggregate shall consist, by weight, of not less than 50 percent quartz (SiO_2). Quartz, to fulfill this requirement, shall be obtained from crushed sandstone, conglomeratic sand, bank sand, river sand or combinations thereof. The remaining portion of aggregate shall consist of quartz sand, limestone sand, slag sand, or blends thereof. Unless otherwise provided, mineral filler meeting the requirements of Article 611.5.0 for quality may comprise not more than 5 percent of the aggregate combination. Each aggregate, except mineral filler, shall have a minimum sand-equivalent value of 10 as determined by AASHTO T 176, and the total combined aggregate, including mineral filler, shall have a minimum Sand-Equivalent value of 35. Deleterious substances retained on the No. 200 sieve shall not exceed the following percentages by weight of the total combined aggregate.

	Percent by Weight
Clay lumps	None
Other deleterious substances such as, but not limited to, alkali, mica, shale, coated granes, soft and flaky particles	1.0

C. Admixture. A moisture controlling admixture such as silicone fluid (dimethyl siloxane polymer) shall be furnished by the Contractor to be blended with the mix when and as directed by the Engineer.

2. Approval of Materials.

Silicone shall be of a type approved by the Department and shall be from a source approved by the Department.

At least one week prior to commencing production, the Contractor shall notify the Engineer that the aggregates, including blended natural sand if used, have been stocked at the job site. Prior to notification, at least 500 tons or one-half the anticipated project requirement, whichever is least, of each aggregate shall be stocked.

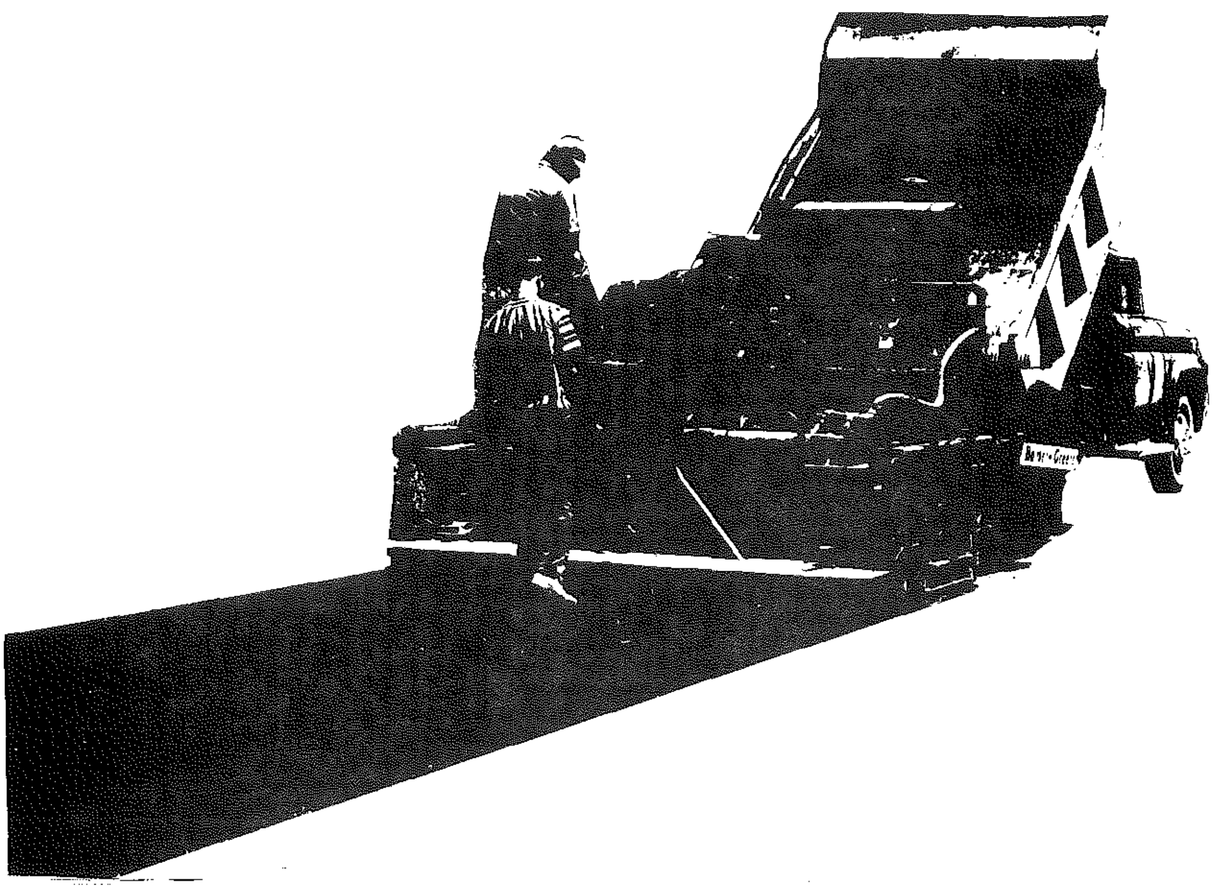
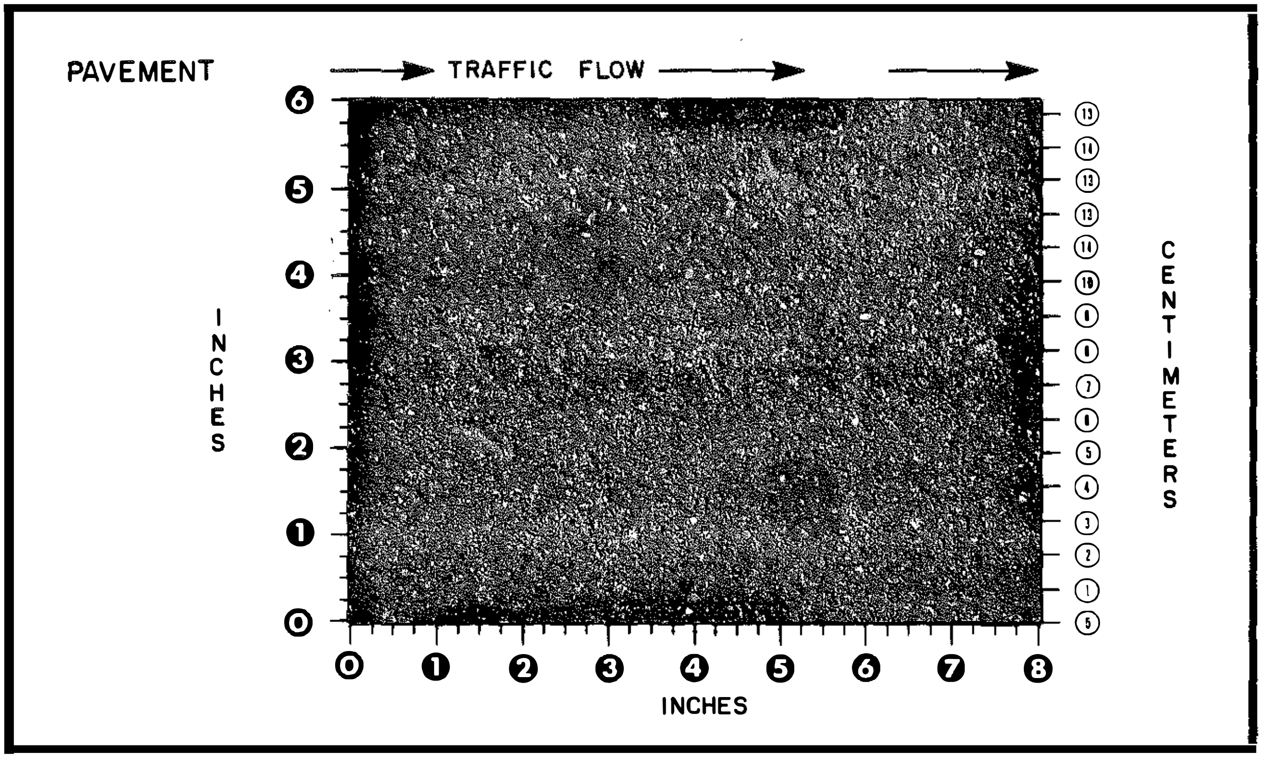


Figure A8. Sand Asphalt Surface.



KENTUCKY ROCK ASPHALT
(SPECIAL PROVISION NO. 24-B)

These specifications were obtained from a report entitled *Experimental Sand-Asphalt Surface (8)* and more detailed information on this and other special provisions may be found there.

1. Aggregate.

The aggregate shall consist of crushed, bituminous, quartzy sandstone having uniform quality and hardness. It shall be free of dirt and debris and shall meet the following requirements:

A. *Bitumen Content:* The raw aggregate shall contain not less than 3.5 percent of natural bitumen by weight. Bitumen content shall be determined on the aggregate as produced (without additional crushing or fracturing) by extraction with trichloroethylene used as the solvent.

B. *Gradation.* The size-gradation of the extracted aggregate shall comply with the following requirements:

Sieve Size	Percent Passing
1/2 in.	100
No. 4	40-50
No. 100	0-15

C. *Silica.* The extracted aggregate shall contain not less than 90 percent Silica (SiO_2) as determined by chemical analysis.

2. Asphalt Binder

Asphalt cement enrichment shall consist of PAC-5 (Article 621.4.0) as specified on the plans or in the proposal.

3. Bituminous Tack Coat

Tack coats shall be of the type and in the quantities designated on the plans or in the proposal for the work and shall be applied in the manner described in Section 301 and as prescribed by the Engineer.

4. **Admixture**

A moisture controlling admixture such as silicone fluid (dimethyl siloxane polymer) shall be furnished by the Contractor to be blended with the mix when and as directed by the Engineer. The silicone shall be of a type approved by the Department and shall be from a source approved by the Department.

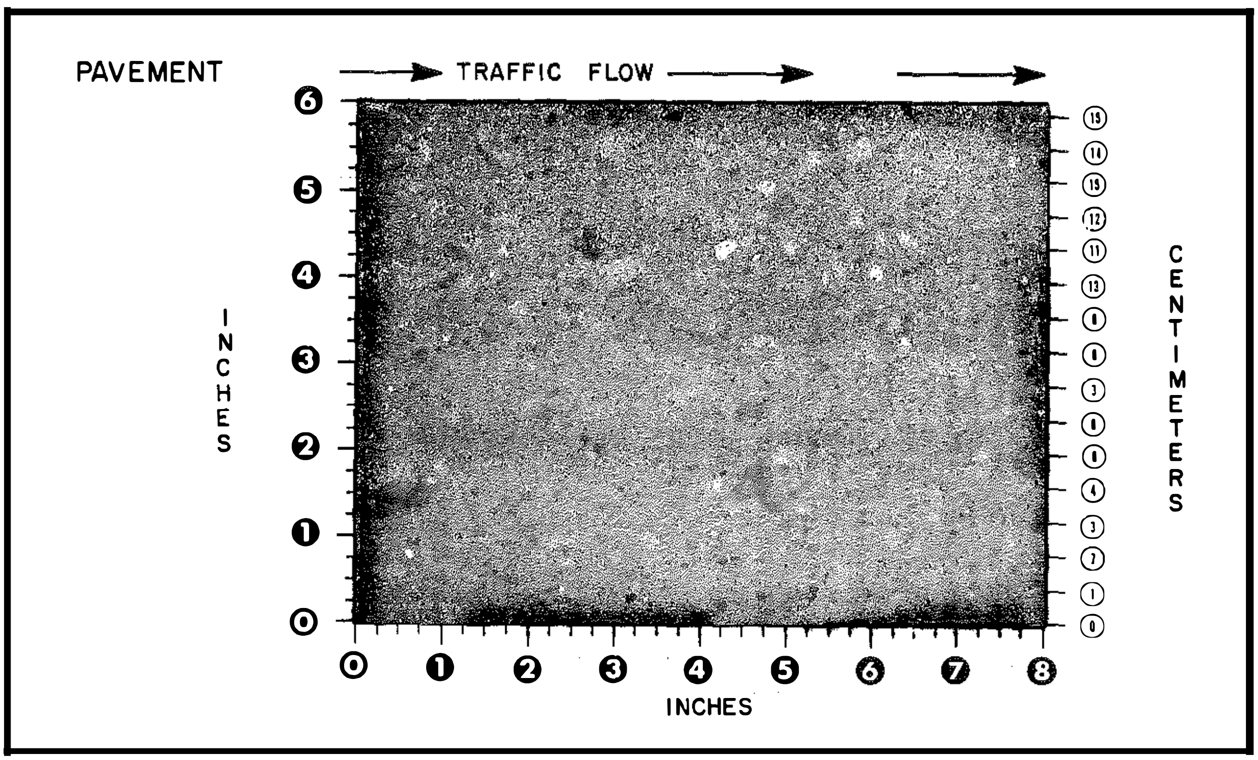
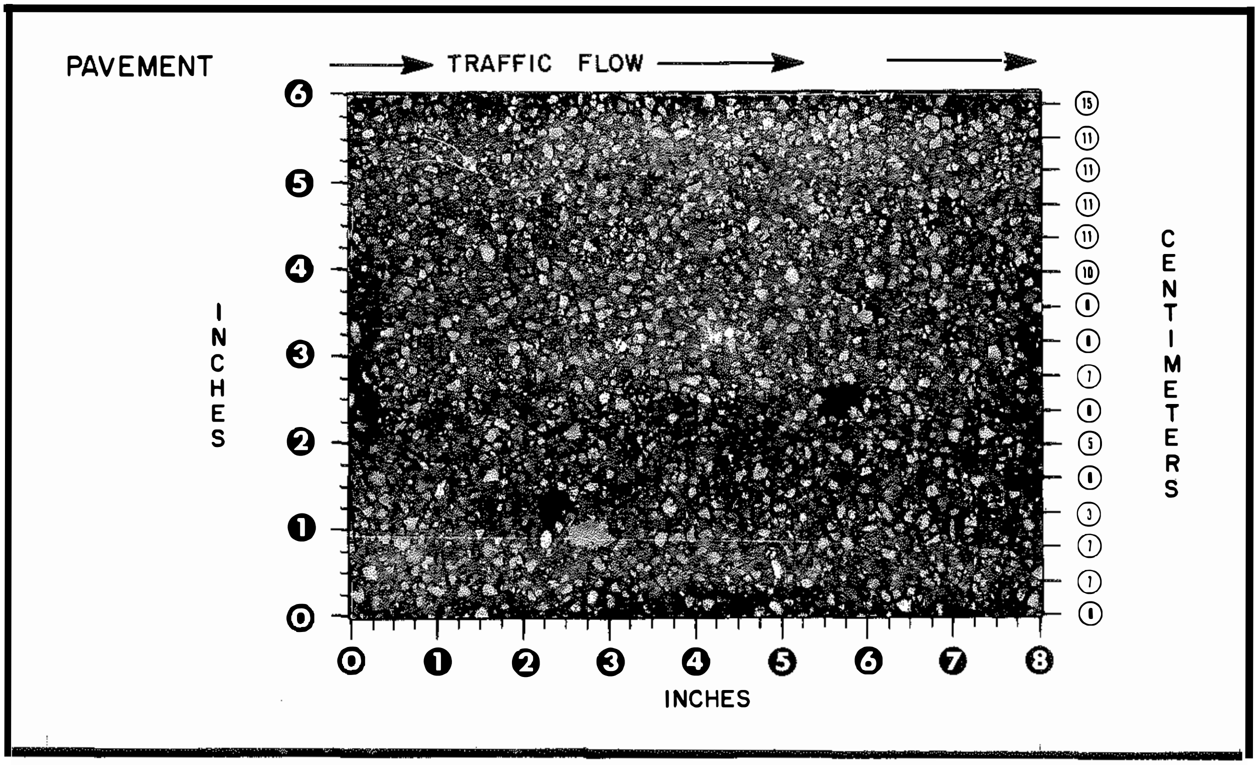


Figure A9. Kentucky Rock Asphalt.

Figure A10. Open-Graded, Plant-Mix Surface.



OPEN-GRADED, PLANT-MIX SEALS

The following specifications are for a silica aggregate surface. A slag aggregate material is also used and is the same except for the substitution of slag aggregate for the silica material.

1. **Bituminous Material**
   A. *For mixture.* Viscosity graded asphalt cement AC-20 in the range of 5.5 - 8.5% by weight of total mix.
   B. *For Tack Coat.* SS-lh.

2. **Aggregates**
   Aggregate for this mixture shall be crushed gravel meeting the quality requirements of Special Provision No. 102 except that the material is intended to be 100 percent crushed product with at least 95% having one or more crushed faces and at least 75 percent shall have two or more crushed faces when tested by Kentucky Method 64-403. This material shall have minimum silica (SiO_2) content of 90 percent.

3. **Weather Limitations**
   The mixture shall be placed only when the pavement surface is dry and is at least 50°F. The air temperature shall be at least 60°F. No seasonal limitations shall apply.

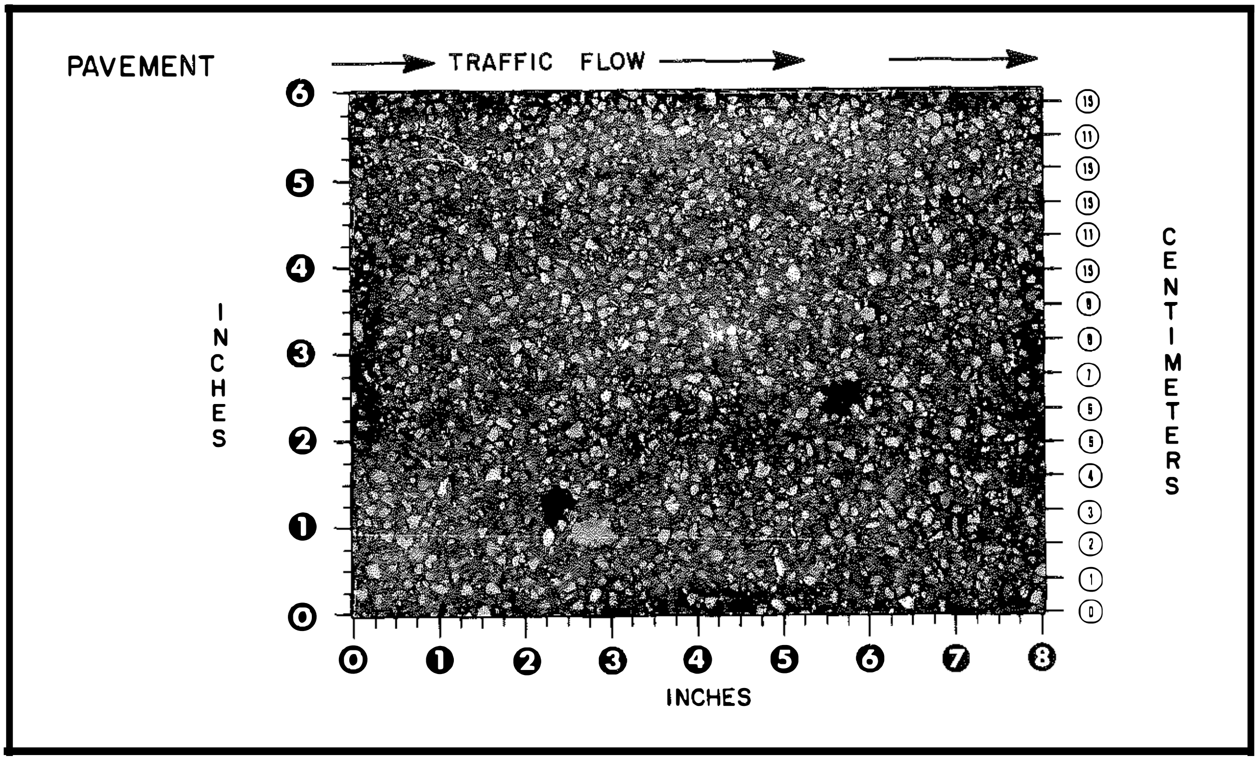
4. Temperature Requirements
   A. *Aggregate.* 200-260°F
   B. *Asphalt Cement.* 250-325°F
   C. *Mixture*
      1) Immediately after mixing: 200-260°F
      2) Laying: 180°F Minimum

5. **Gradation of Mixture**

Sieve Size	Percent Passing
1/2"	100
3/8"	90-100
No. 4	25-50
No. 8	0-12
No. 200	0-3

Normal equipment for placing and compaction will apply except that rolling may be accomplished by means of a 8-10 ton steel wheel tandem roller only. Rolling shall be held to a minimum. Excessive rolling shall be avoided. The rate of application shall be 75 pounds per sq yd.

Figure A10. Open-Graded, Plant-Mix Surface.



OPEN-GRADED, PLANT-MIX SEALS

The following specifications are for a silica aggregate surface. A slag aggregate material is also used and is the same except for the substitution of slag aggregate for the silica material.

1. **Bituminous Material**
   A. For mixture. Viscosity graded asphalt cement AC-20 in the range of 5.5 - 8.5% by weight of total mix.
   B. For Tack Coat. SS-1h.

2. **Aggregates**
   Aggregate for this mixture shall be crushed gravel meeting the quality requirements of Special Provision No. 102 except that the material is intended to be 100 percent crushed product with at least 95% having one or more crushed faces and at least 75 percent shall have two or more crushed faces when tested by Kentucky Method 64-403. This material shall have minimum silica (SiO_2) content of 90 percent.

3. **Weather Limitations**
   The mixture shall be placed only when the pavement surface is dry and is at least 50°F. The air temperature shall be at least 60°F. No seasonal limitations shall apply.

4. Temperature Requirements
   A. Aggregate. 200-260°F
   B. Asphalt Cement. 250-325°F
   C. Mixture
   1) Immediately after mixing: 200-260°F
   2) Laying: 180°F Minimum

5. **Gradation of Mixture**

Sieve Size	Percent Passing
1/2"	100
3/8"	90-100
No. 4	25-50
No. 8	0-12
No. 200	0-3

Normal equipment for placing and compaction will apply except that rolling may be accomplished by means of a 8-10 ton steel wheel tandem roller only. Rolling shall be held to a minimum. Excessive rolling shall be avoided. The rate of application shall be 75 pounds per sq yd.

CHIP SEALS

More detailed information can be obtained from the **Kentucky Standard Specifications for Road and Bridge Construction** *(6)*.

1. **Aggregate**

Sieve Size	Percent Passing by Weight
1/2"	100
3/8"	85-100
No. 4	10-30
No. 8	0-10
No. 16	0-5

2. **Bituminous Material**

The bituminous material shall be the type and grade specified on the plans in the proposals and shall meet the requirements of Section 621 for that type and grade.

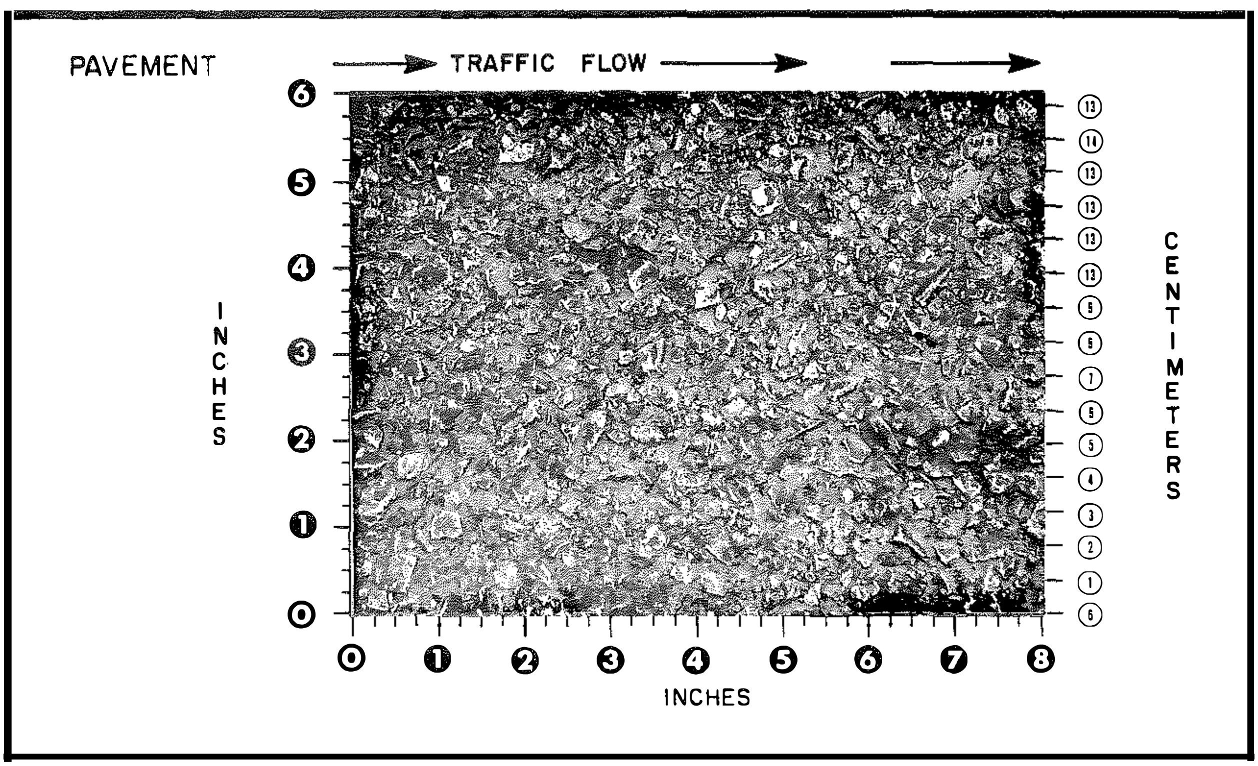


Figure A11. Chip Seals.

APPENDIX B

PREDICTION PROCEDURE CORRECTION NOMOGRAPH

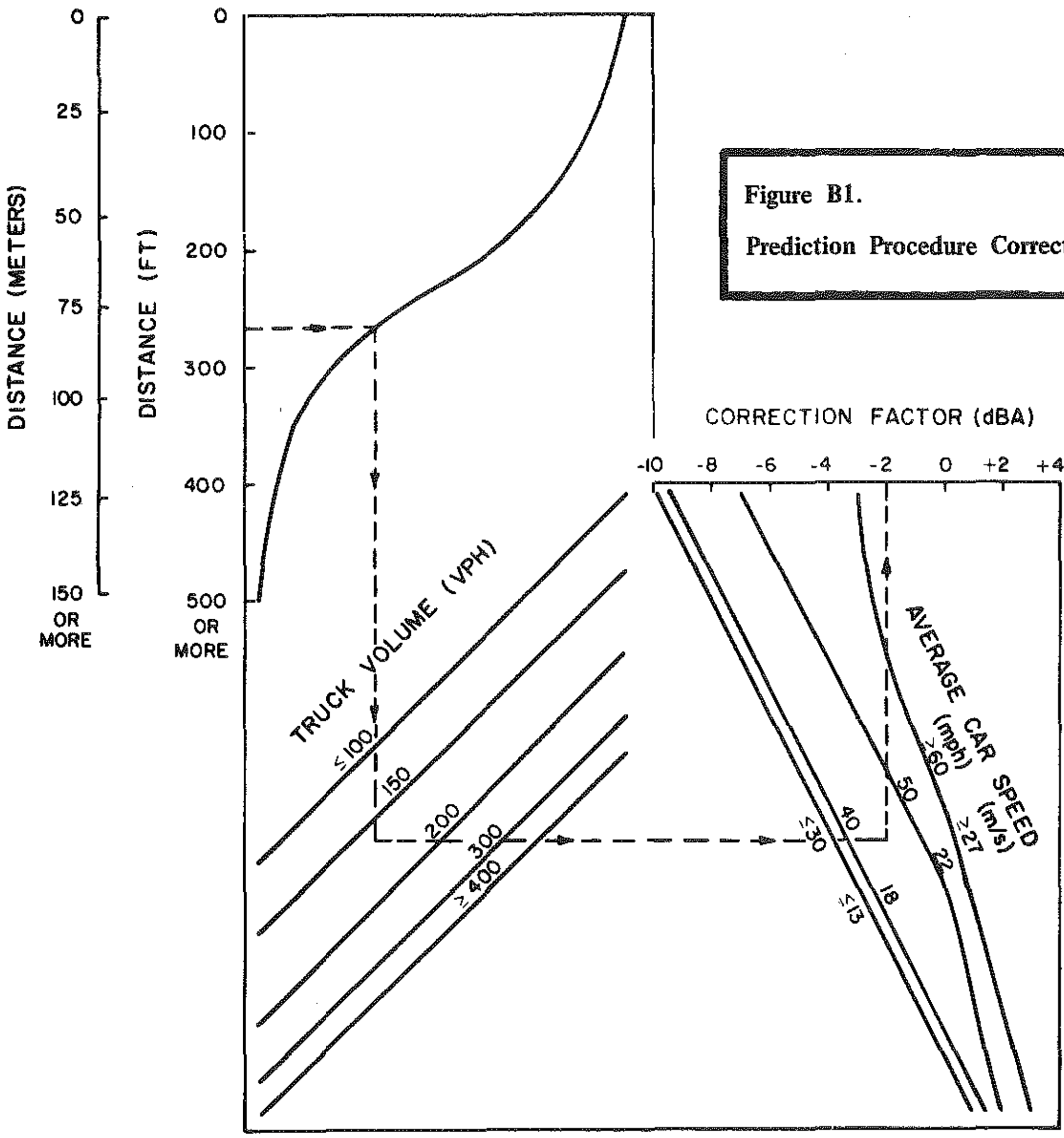


Figure B1.

Prediction Procedure Correction Factor.

APPENDIX C

PLOTS OF TEST CAR NOISE MEASUREMENTS VERSUS CUMULATIVE TRAFFIC VOLUME FOR VARIOUS PAVEMENT TYPES

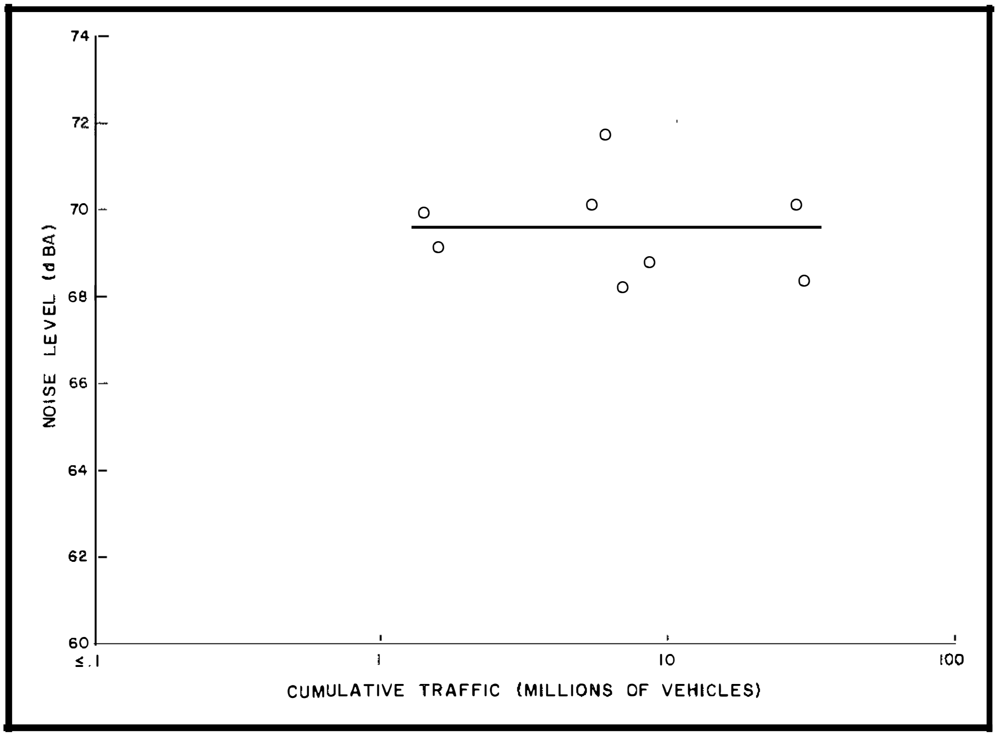


Figure C1. **Effect of Cumulative Traffic on Noise Levels of Class I, Type A, Bituminous Surfaces.**

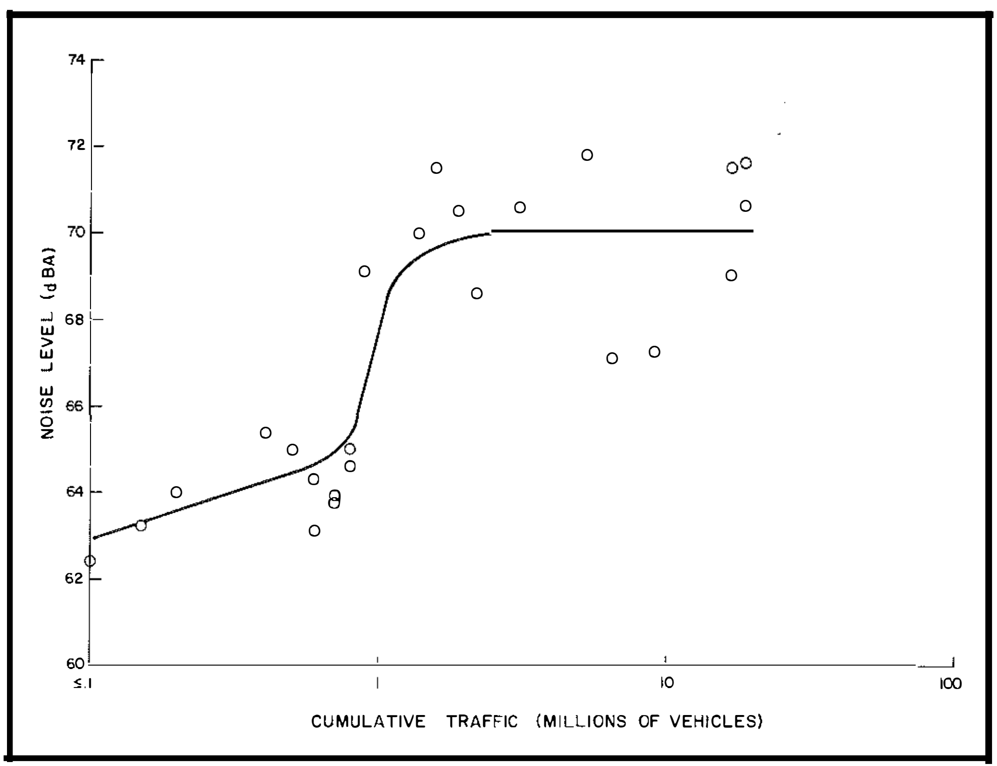
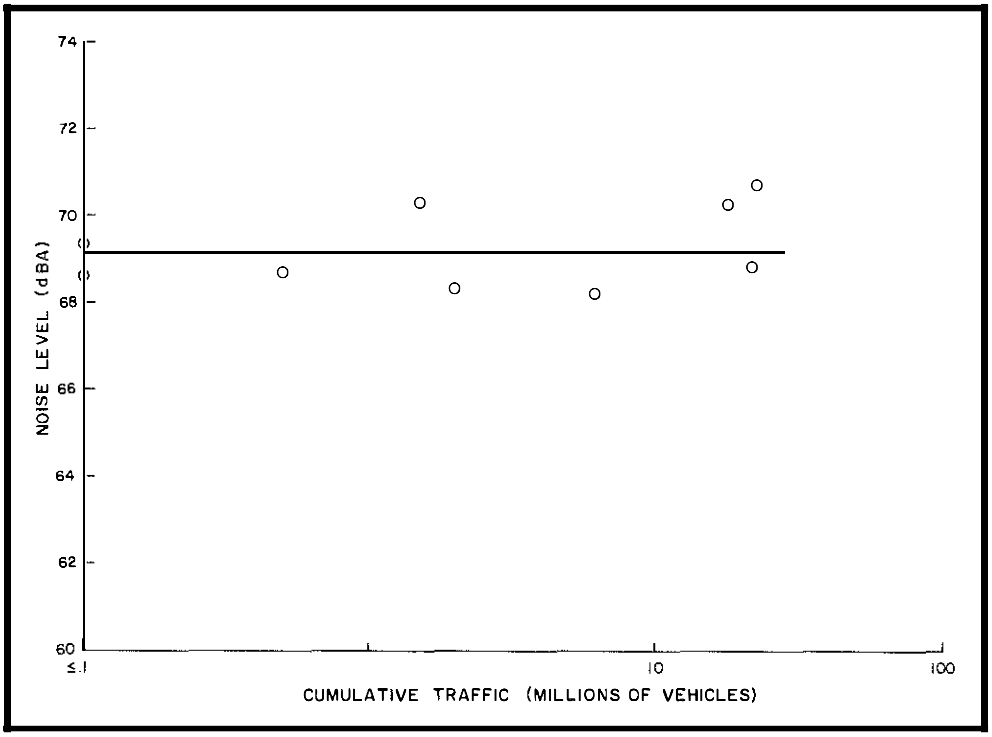


Figure C2. **Effect of Cumulative Traffic on Noise Levels of Class I, Type A(Modified), Bituminous Surfaces.**

Figure C3. Effect of Cumulative Traffic on Noise Levels of Concrete Surfaces.



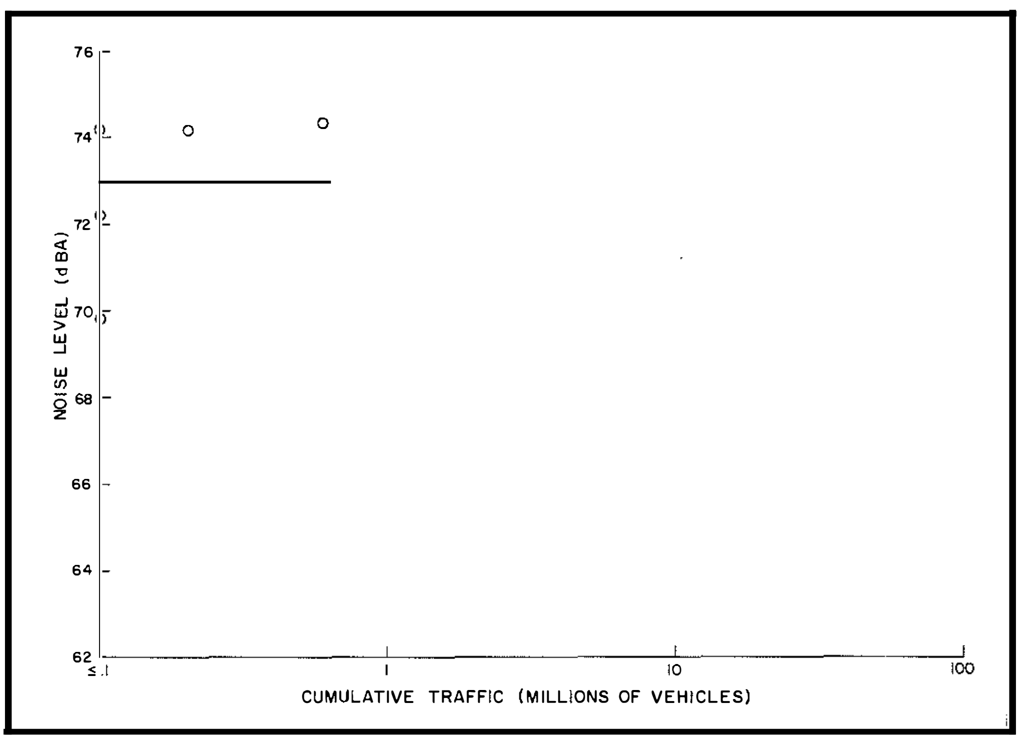


Figure C4. Effect of Cumulative Traffic on Noise Levels of Grooved Surfaces.

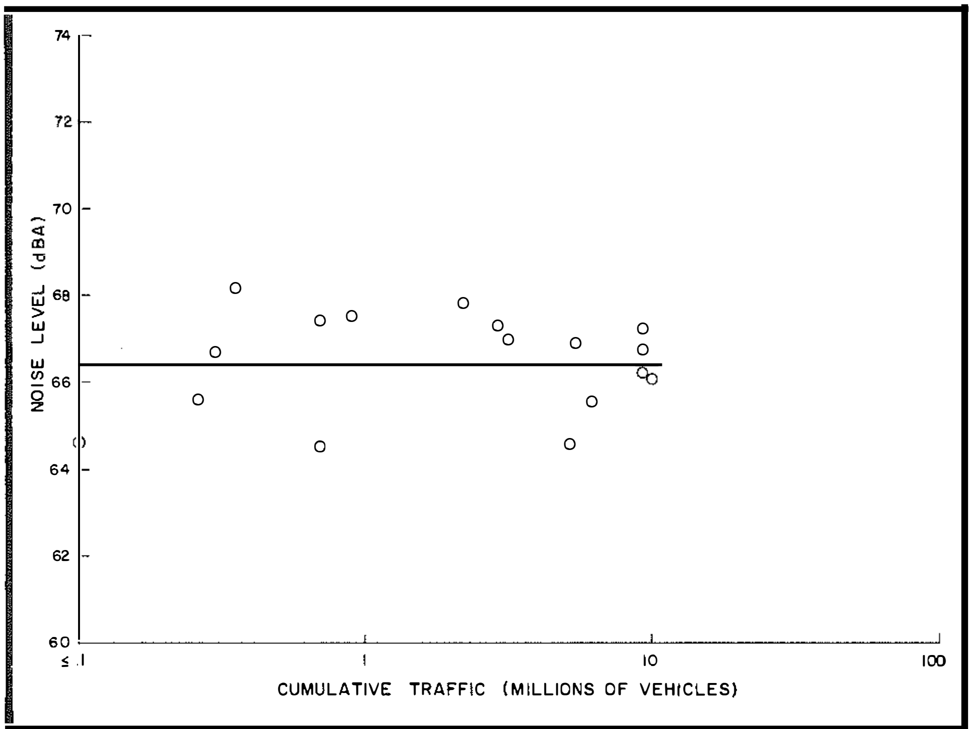


Figure C5. Effect of Cumulative Traffic on Noise Levels of Sand-Type Surfaces.

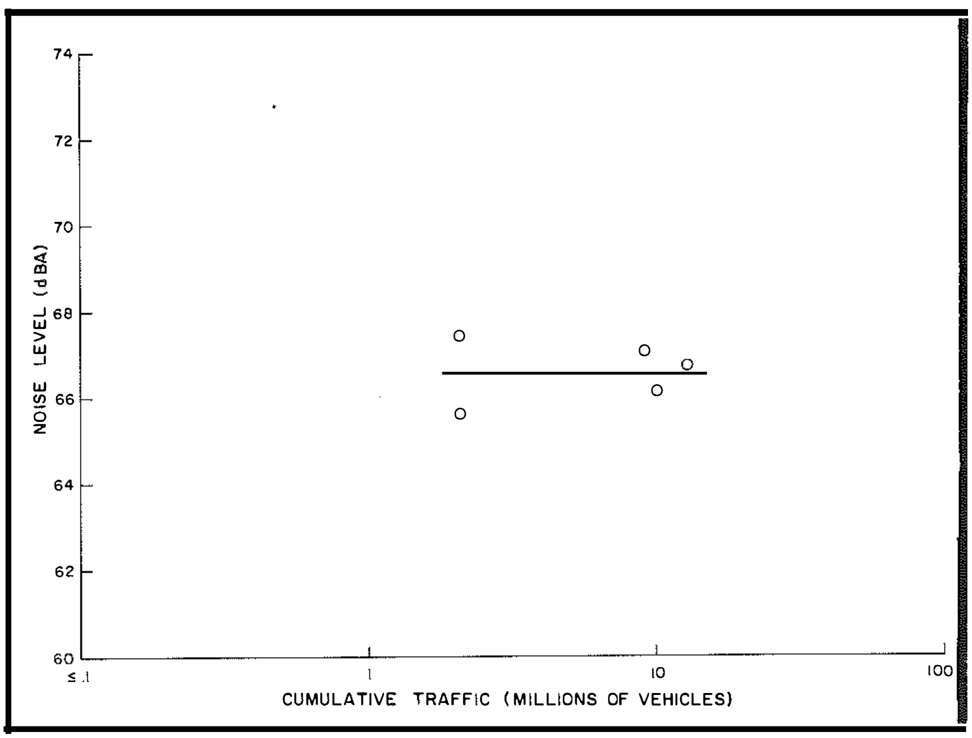
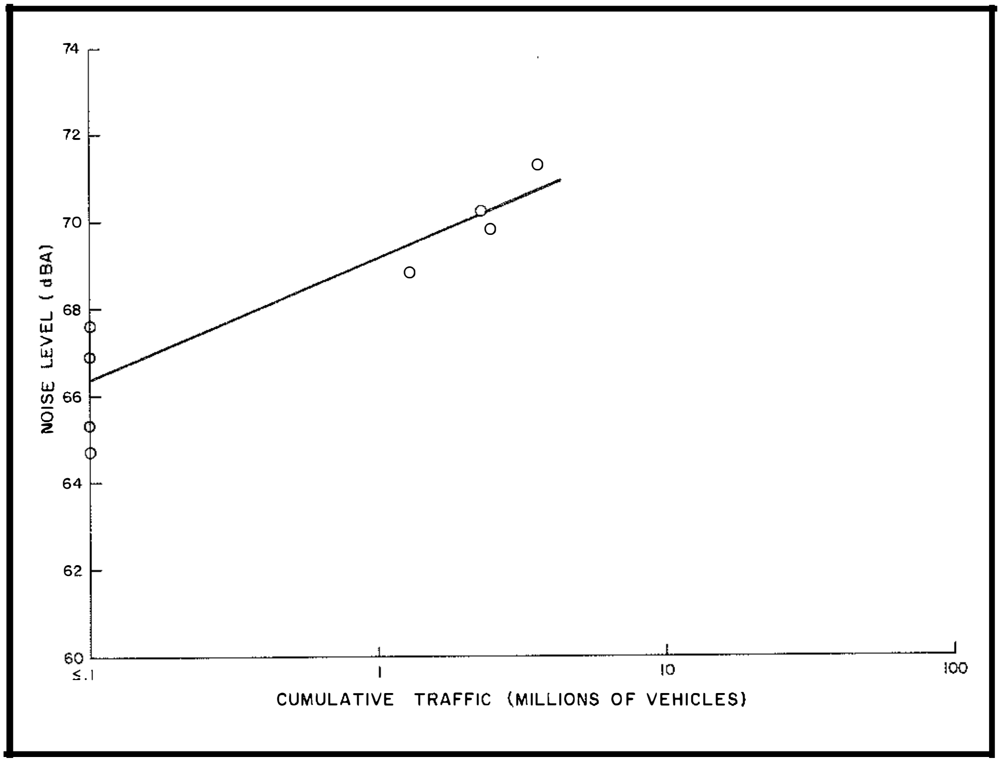


Figure C6. Effect of Cumulative Traffic on Noise Levels of Kentucky Rock Asphalt Surfaces.

Figure C7. Effect of Cumulative Traffic on Noise Levels of Open-Graded, Plant-Mix Surfaces.



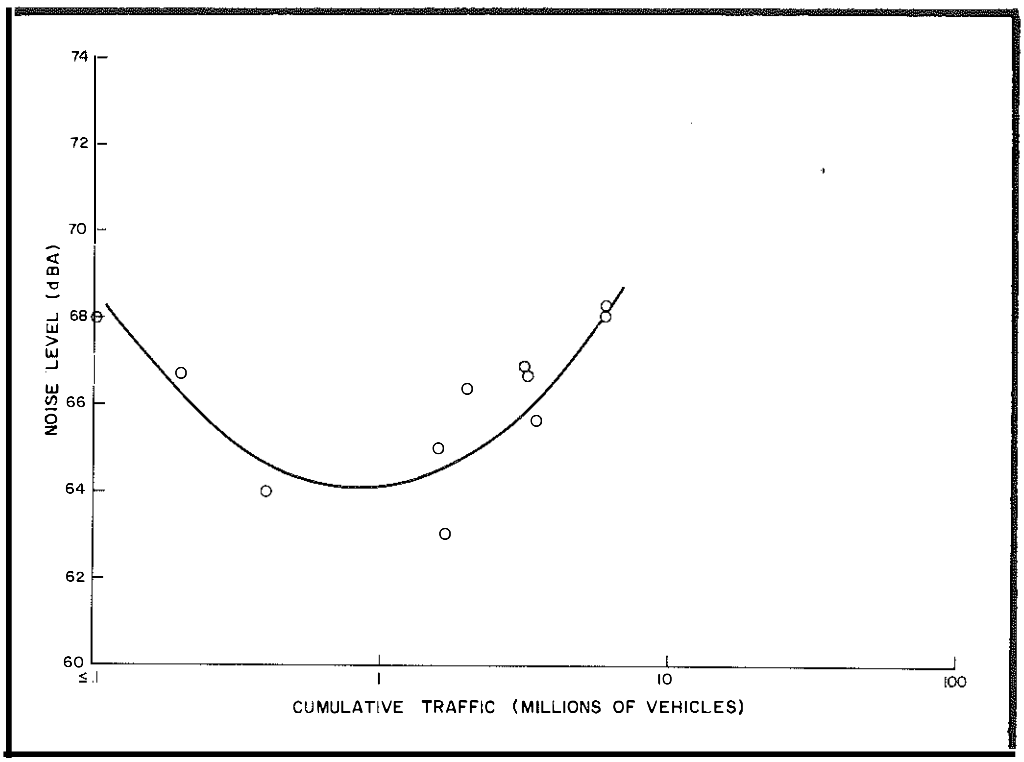


Figure C8. Effect of Cumulative Traffic on Noise Levels of Chip Seals.

APPENDIX D

REFERENCE CAR NOISE MEASUREMENTS FOR VARIOUS PAVEMENT TYPES

					NOISE LEVEL (dBA)		
COUNTY	ROUTE	LOCATION	DATE PAVED	CUMULATIVE TRAFFIC (MILLIONS OF VEHICLES)	30 mph (13 m/s)	45 mph (20 m/s)	60 mph (27 m/s)
		CLASS I, TYPE A, BITUMINOUS					
Bourbon	US 68	East of Paris	1964	7.0	63.5	68.1	72.5
Fayette	US 27	South of Lexington	1970	8.7	63.8	68.8	73.2
Woodford	BGP	1 mile (1.6 km) West of Exit 33, Shoulder Lane	1965	5.4 6.0	64.4	70.1 71.7	74.6
		1 mile (1.6 km) West of Exit 33, Median Lane	1965	1.4 1.6	65.2	69.9 69.1	73.7
	US 60	Between Lexington and Versailles at Parkway Golf Course	1965	27.7 30.2	66.0	70.5 68.4	76.0
		CLASS I, TYPE A(MODIFIED), BITUMINOUS					
Scott	US 460	West of Georgetown	1970	2.2		68.6	
Mercer	US 68	Near Harrodsburg	1972	0.6	57.0	63.1	67.5
Woodford	US 62	Between US 60 and KY 1681	1974	0.1		62.4	
Clark	US 60	4 miles (6.4 km) West of Winchester	1973	0.7	58.7	63.8	70.5
Mercer	US 68	West of Harrodsburg	1972	0.5	58.3	65.0	68.9
Fayette	KY 4	Near IBM	1972	6.6 9.2	63.2	67.1 67.2	72.9
Fayette	US 60	East of Lexington	1973	0.6 0.8	57.6	64.3 65.0	69.7
Clark	I 64	East of Fayette County Line	1973	1.6 1.9 3.1	64.2 64.7	71.5 70.5 70.6	74.3 74.3
Fayette	KY 4	Near US 27	1970	17	63.0	69.0	72.1
		Near Versailles Road	1970	19		71.6	
Madison	I 75	Near White Hall Exit	1972	5.3	65.8	71.8	74.8
Fayette	KY 4	Near Nicholasville Road	1970	17 19	66.8	71.5 70.6	76.7
Jessamine	US 27	Camp Nelson	1974	0.4	60.7	65.4	68.8
Fayette	KY 922	5 miles (8.0 km) North of KY 4	1974	0.2	60.7	64.0	69.3
Woodford	US 421	Near Midway	1973	0.9 1.4	64.5	69.1 70.0	74.4
Clark	US 60	2 miles (3.2 km) East of Winchester	1972	0.7	58.7	63.9	69.5
Fayette	US 60	5 miles (8.0 km) East of I 64		0.8		64.6	
	US 421	3 miles (4.8 km) North of Lexington	1974	0.15		63.2	

NOISE LEVELS FOR VARIOUS SURFACE TYPES

COUNTY	ROUTE	LOCATION	DATE PAVED	CUMULATIVE TRAFFIC (MILLIONS OF VEHICLES)	NOISE LEVEL (dBA) 30 mph (13 m/s)	45 mph (20 m/s)	60 mph (27 m/s)
		PORTLAND CEMENT CONCRETE					
Woodford	I 64	3 miles (4.8 km) West of US 62	1973	0.5	64.0	68.7	72.8
		Between Lexington	1973	2.0		68.3	
		and Frankfort		1.5	64.5	70.3	73.6
Franklin	I 64	0.5 mile (0.8 km) West of US 60 Between Frankfort and Louisville	1962	18.0	64.5	70.3	74.4
Fayette	I 75	1 mile (1.6 km) North of Richmond Road near Lexington	1964	21.7	64.3	68.8	74.1
Franklin	US 421	East of Frankfort	1974	0.1	62.8	69.3	73.5
Fayette	US 68	1 mile (1.6 km) West of Lexington	1968	6.1		68.2	
Woodford	US 60	Between Frankfort and Versailles	1960	22.5		70.7	
Christian	I 24	South of Hopkinsville	1975	0	63.8	68.6	
		GROOVED PORTLAND CEMENT CONCRETE					
Franklin	US 421	Frankfort	1974	0.1	66.0	72.2	76.3
				0.2		74.2	
				0.6		74.4	
Christian	I 24	South of Hopkinsville	1975	0	64.7	69.8	
				0	66.5	74.2	

COUNTY	ROUTE	LOCATION	DATE PAVED	CUMULATIVE TRAFFIC (MILLIONS OF VEHICLES)	NOISE LEVEL (dBA) 30 mph (13 m/s)	45 mph (20 m/s)	60 mph (27 m/s)
		SAND ASPHALT					
Jessamine	KY 33	1 mile (1.6 km) North of US 68	1971	0.3	62.1	66.7	71.7
Pulaski	US 27	Somerset	1968	9.3	62.4	66.2	71.2
				9.3	61.0	67.2	72.5
				9.3	62.4	66.7	71.3
				10.1	62.0	66.0	71.0
Hardin	US 62	Elizabethtown near I 65	1970	3.3	62.5	67.0	71.9
	US 31W	Elizabethtown	1972	2.6	61.8	65.6	71.0
Meade	US 31W	Between US 60 and KY 1638	1972	5.2	60.6	64.5	69.4
	US 60	0.3 mile (0.5 km) West of KY 144	1969	3.5	63.6	68.2	72.4
Hardin	KY 61	Elizabethtown Country Club	1970	5.5	62.3	66.9	72.0
Warren	KY 1484	Bowling Green	1970	2.2	62.2	67.8	71.2
	US 231	1 mile (1.6 km) South of I 65	1966	2.9	60.7	67.3	72.1
Allen	KY 100	2 miles (3.2 km) East of Scottsville	1970	0.7	61.6	64.5	70.1
Meade	US 31W	Muldraugh	1972	6.1	62.0	65.5	69.7
Franklin	US 60	Frankfort	1974	0.1		64.6	
Warren	GRP	West of Bowling Green	1972	0.7	63.3	67.4	70.6
				0.9	62.5	67.5	72.0
		KENTUCKY ROCK ASPHALT					
Pulaski	US 27	Somerset	1968	9.3	62.2	67.0	71.7
				10.1	61.1	65.9	70.8
Barren	KY 70	West of Cave City	1967	2.1	60.5	65.6	70.3
Warren	US 31W	3 miles (4.8 km) East of Bowling Green	1966	13.6	61.0	66.7	71.0
	KY 101	North of I 65	1967	2.1	61.0	67.4	71.8

COUNTY	ROUTE	LOCATION	DATE PAVED	CUMULATIVE TRAFFIC (MILLIONS OF VEHICLES)	NOISE LEVEL (dBA) 30 mph (13 m/s)	45 mph (20 m/s)	60 mph (27 m/s)
		OPEN-GRADED, PLANT-MIX SEALS					
Hardin	US 31W	Elizabethtown	1973	0.1	62.6	67.6	72.0
				0.1	62.2	66.9	71.4
				2.3	63.4	70.2	74.0
				2.5	64.7	69.8	73.8
				3.6		71.3	
	US 62	15 miles (24 km) West of Elizabethtown	1974	0.1	60.1	64.7	
Greenup	KY 7	North of Carter County Line	1974	0.1	60.7	65.3	70.0
Boyd	US 23	4 miles (6.4 km) South of I 64	1973	1.3	62.9	68.8	72.6
		CHIP SEALS					
Bourbon	US 460	Near Paris	1972	0.4	58.9	64.0	69.1
	KY 57	2 miles (3.2 km) West of US 460	1966	0.2	61.0	66.7	71.4
Fayette	KY 1681	Between Lexington and US 62	1966	1.6	58.5	65.0	71.5
				2.0		66.4	
Woodford	US 62	Between US 60 and KY 1681	1953	6.1	62.6	68.1	72.6
		Between KY 1681 and Midway	1953	6.1	62.0	68.2	74.0
Fayette		Entrance to Horse Farm Park	1973	0.1	62.0	68.0	
	KY 1681	Between Lexington and US 62	1966	1.7	58.4	63.0	
Woodford	KY 33	0.5 mile (0.8 km) North of KY 169	1963	3.1		66.7	
		0.5 mile (0.8 km) North of Troy	1963	3.1	60.2	66.8	71.9
		2 miles (3.2 km) North of US 68	1963	3.0	60.3	65.6	70.4
		"ROUGH" SURFACES					
Bourbon	KY 1678	2 miles (3.2 km) East of US 27	1965	1.3	67.5	71.8	75.7
Fayette	KY 1683	Lexington	1959	11.9	67.6	72.9	77.5
	US 25	Lexington at Idle Hour	1968	22.2	65.8	70.6	75.4
	US 60	East of Lexington	1965	9.8	66.3	71.6	77.6
Woodford	US 62	Between US 60 and Old Frankfort Pike	1966	0.9	65.6	72.8	76.4