

EFFECT OF PAVEMENT TEXTURE ON TIRE-ROAD NOISE

by

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

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SUMMARY

Because of the potentially conflicting considerations for cost, durability, environment, and safety, the design engineer must have information on each such subject on which to base his decisions. The great variety of pavement textures for affecting the noise levels generated by traffic on the highway, made the need for information on the effect of pavement texture on tire-road noise obvious.

Noise measurements were made at 19 sites, including both bituminous (I-2, S-5, S-8, surface treatment) and portland cement concrete (aggregate exposed and grooved) pavements that had a wide variety of textures. A 1971 Plymouth 4-door sedan was used as the test vehicle. Both rib treads and snow treads were used in the tests. The data were analyzed in the linear (dB) and A-weighted (dBA) modes. Frequency analyses were made on ten recordings that were representative of most of the data.

It was determined that pavement parameters such as density, type of aggregate, and the flat-mosaic aspect had very little effect on the intensity of the noise generated. The parameter that had the greatest effect was the degree of protuberance.

From the analyses of the frequency content of the noise it was determined that the 3/4 inch (1.9 cm) transverse grooved and the dimpled textures generated relatively pure tones in the high frequency range most easily sensed by humans.

Recommendations are made concerning the use of the various pavement surfaces tested.

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INTRODUCTION

Because of concern for the environment, highway departments have to consider the effect of their proposed facilities on many environmental factors, one of which is noise. Highway noise is created primarily by cars and heavy trucks,⁽¹⁾ and under moderate to high speed cruise conditions the tire-road noise is the principal source of car noise⁽¹⁾ and one of the three main sources of heavy truck noise, along with motor and exhaust noises.⁽¹⁾ The parameters having the greatest effect on tire-road noise are the type of tread, the degree of wear of the tread, the pavement texture (fine, medium, coarse), and the speed of the vehicle, because these parameters affect the magnitude of the tread vibration (repetitive, oscillatory deformation of the tread), and the potential for trapping air between the tire and the pavement.⁽²⁾

In addition to environmental factors, items such as cost, safety, and maintenance must be considered in the construction and upkeep of a highway. Consideration of these other items gives rise to the use of different materials and different construction and maintenance techniques. Frequently the most obvious differences in the roadway that result from consideration of these items are the differences in the texture of the pavement surfaces. Inasmuch as the surfaces of today's highways have many different textures and inasmuch as many of these textures are designed to enhance the skid resistant properties of the pavements, it seemed prudent to investigate the effect of pavement texture on highway noise.

PURPOSE

The purpose of this investigation was to determine the effect of pavement texture on tire-road noise. The aspect of tire-road noise of greatest concern was the intensity. It was thought that if some textures were found to produce significantly more intense noise than others, they might not be recommended for use except where dictated by a concern for safety.

An aspect of tire-road noise that was of secondary concern, and that was considered in the study, was the frequency of the noise generated by traffic on different textures. Human hearing is most sensitive to frequencies in the range of 500 to 6,000 hertz (Hz).⁽³⁾ It is possible that, of two different sounds, the one with the lower intensity might seem louder to a person if most of its energy were concentrated within the 500 to 6,000 Hz range and the energy of the higher intensity sound was spread over the entire spectrum of wavelengths.

The effect of different tire treads was not a consideration in the study, and only two tread designs were used.

TYPES OF SURFACE TEXTURES

The investigation was not meant to be an exhaustive survey of all the pavement textures that might be found in Virginia. It was hoped, however, that several different pavement types representing distinctly different textures could be found at locations satisfactory for test sites.

Because the discussion in this section of the report attempts to impart an understanding of the parameters that control the texture of a pavement, as well as describe the textures, and the terms may not be used in the same sense that a civil engineer would use them, the terms used here to describe macro texture are defined below.

1. Density
 - a. Open or open-graded — Many voids are apparent. Example: S-8 or I-2 bituminous mixture, and, considering grooves to be voids, a grooved portland cement concrete pavement.
 - b. Dense or dense-graded — Very few voids are apparent. Example: S-5 bituminous mixture or an ungrooved portland cement concrete pavement.
2. Protuberance
 - a. Non-protuberant — Very few, if any, protuberances are apparent. Example: S-5 bituminous mixture, lightly finished portland cement concrete.

- b. Rough — Many protuberances are apparent and may be sharp-angular or rounded-knobby. Example: bituminous surface treatment or portland cement concrete with the aggregate exposed by removal of the surficial paste.

3. Flat-mosaic (two-dimensional aspect)

- a. Coarse — Typified by an I-2 bituminous mixture which may have as much as 5% of plus 3/4 inch (1.9 cm) to minus 1 inch (2.5 cm) rock as its maximum size aggregate.
- b. Medium — Typified by an S-5 bituminous mixture which may have as much as 17% of plus 3/8 inch (0.94 cm) to minus 1/2 inch (1.25 cm) rock as its maximum size aggregate.
- c. Fine — Typified by a bituminous sand deslicking mix or a concrete pavement with the cement paste covering the coarse aggregate.

The pavement types that were surveyed and their characteristics are listed in Table 1.

The original texture of the surface of a bituminous pavement is an intrinsic property of the materials used and their proportioning. It is determined primarily by the shape, size, and grading of the aggregates. Table 2 lists the design range for the aggregate used in the type pavements tested.

On the other hand, the original texture of a portland cement concrete pavement is determined by the finishing method used. Historically, burlap drags or bristle brooms have been used to impart the desired finishes, but recently, to increase skid resistance, metal tines have been used to form grooves in the plastic concrete. With this technique a variety of depths, widths, orientations and spacings of the grooves can be obtained. The grooves in the pavement tested in this study were 1/8 inch (3.2 mm) deep and 1/8 inch (3.2 mm) wide. They were oriented both longitudinally (L) and transversely (T) to the roadway and were at various spacings. The following patterns were included: L at 3/4 inch (19 mm) spacings, T at 3/4 inch (19 mm), T at 1 1/2 inches (38 mm), T at 3 inches (76.2 mm), L at 3/4 inch (19 mm) plus T at 1 1/2 inches (38 mm), and L at 3/4 inch (19 mm) plus T at 3 inches (76.2 mm). Additional patterns tested were produced by (1) passing a roller with oblong protrusions over the paste to create a dimpled effect, (2) sprinkling aggregate on the paste, (3) washing the paste off the concrete such that the aggregate was exposed, and (4) beating the paste off worn concrete with pneumatic hammers.

Table 1
Pavement Surface Textures

Bituminous			
Virginia Designation	Density	Protuberance	Flat Mosaic Aspect
I-2	open	non-protuberant	coarse
S-5	dense	non-protuberant	medium
S-8	very open	non-protuberant	medium
surface treatment	dense	rough	medium
Concrete			
Grooved with tines	open	non-protuberant	fine
Agg. exposed (Colonial Parkway)	dense	very rough	very coarse
Agg. exposed washed-sprinkled	dense	rough	medium-coarse
Agg. exposed paste chipped off	dense	rough	medium-coarse

Table 2 (4)
Design Range

Material	Type	Percentage by Weight Passing Square Mesh Sieves													
		1 1/2	1	3/4	1/2	3/8	0.187	0.0937	0.0469	0.0234	0.0117	0.0029			
Bituminous Concrete	I-2		100	95-100		60-80	40-60	31-39							1-7
Bituminous Concrete	S-5				100	83-97	50-70	41-49						15-30	2-10
Bituminous Concrete	S-8				100	84-100	10-40	0-10							0-2
Surface Treatment	#8 Agg.				100	92 ± 8	25 ± 15	Max. 8			Max. 3				
Portland Cement Concrete	A-3 Paving	Min. 100	95 ± 5		43 ± 17		Max. 10	Max. 5							

TEST SITES

Factors Considered in Selection

The principal consideration in selecting test sites was to include typical examples of the various pavement types in Virginia. A straight stretch of road was considered desirable so that the geometry of the site would be as simple as possible and the driver of the test car would have as much sight distance as possible. To minimize noise other than that related to the normal texture of the road, roadway surfaces without imperfections (potholes, cracks, bumps, etc.) were sought. Areas containing sources of cultural noise such as service stations, country stores, and factories were avoided.

Site Location

Nineteen test sites, including both bituminous and concrete pavements, were included in the investigation. The locations and description of the test sites follow.

1. & 2. Route 460 east of Lynchburg in Campbell County, approximately 0.2 mile (0.32 km) east of Beaver Creek. Straight section of 4-lane divided highway with 0.0% grade. The eastbound lanes (EBL) site 1, had an S-8 surface course, Figure 1, with less than 10% aggregate exposed. The surface was very open and non-protuberant, with a medium mosaic aspect. The westbound lanes (WBL), site 2, had an S-5 surface, Figure 2, with the aggregate (Arch Marble) 100% exposed. The surface was dense and non-protuberant, with a medium mosaic aspect. The traffic lane in each site was used for the test runs. The microphone was placed in the median.
3. & 4. Route 60 east of Bent Creek at the James River in Appomatox County, approximately 0.3 mile (0.48 km) east of Routes 26 & 605. Straight section of 2-lane highway with a 4.6% downgrade to the west. Both lanes had S-8 surfaces with 80-100% of the aggregate exposed. The surface was very open and non-protuberant, with a medium mosaic aspect. The Arch Marble, Figure 3, and a lightweight (fired) stone, Figure 4, were the aggregates

in the EBL (site 3) and WBL (site 4), respectively. The test runs were made downgrade in both lanes. The microphone was on the opposite side of the road to the test lane.

5. Route 250 west of Charlottesville in Albemarle County. Straight section, 2-lane highway, approximately 150 feet (45.7 m) west of the entrance to West Leigh, the roadway was approximately 6.5% downgrade to the east and 3% downgrade at 150 feet (45.7 m) east of the microphone site. Both lanes had an S-5 surface, Figure 5, with the Catoctin greenstone aggregate exposed. The surface was dense, and non-protuberant, with a medium mosaic aspect. The test runs were made downgrade in the EBL. The microphone was placed on the north side of the road.
6. Route 250 west of Charlottesville in Albemarle County, approximately 0.6 mile (1.0 km) east of Mechum River and 0.2 mile (0.32 km) west of entrance to Route 738. Straight section of 2-lane highway with approximately 8% downgrade to the west. Both lanes had a young I-2 surface, Figure 6, with no aggregate exposed. The surface was open and non-protuberant with a coarse mosaic aspect. The test runs were made downgrade in the EBL. The microphone was placed on the north side of the road.
7. Route 250 west of Charlottesville in Albemarle County, approximately 0.75 mile (1.2 km) west of Mechum River and Routes 240 and 680. Straight 2-lane section, approximately 5% downgrade to the east. Both lanes had a new I-2 surface, Figure 7, with no aggregate exposed. The surface was open and non-protuberant, with a coarse mosaic aspect. The test runs were made downgrade in the EBL. The microphone was placed on the north side of the road.
8. Route 1 just north of Hanover County in Caroline County, approximately 750 feet (228.6 m) north of Long Creek. Straight 4-lane section of undivided highway with approximately 6.3% downgrade to the south. All lanes had a surface seal, Figure 8, with the granitic gneiss aggregate exposed. The

surface was dense and rough, with a medium mosaic aspect. The test runs were made down-grade in the southbound passing lane. The microphone was placed on the west side of the road.

(The International Terminal Boulevard in Norfolk connects the Norfolk International Terminal's containerized shipping facility with I-64. It runs from Hampton Boulevard at the west end to I-64 at the east end. The Council's Maintenance Section chose this roadway as the test site for experimenting with various surface textures. Several patterns of metal tine plastic grooving were used in addition to two methods of exposing the aggregate.

Measurements were taken at eight sites on the boulevard. Inasmuch as many of the aspects of the site descriptions are the same, these aspects are described for site 9 and only the differences in the succeeding seven sites are enumerated.)

9. International Terminal Boulevard in Norfolk, approximately 0.25 mile (0.4 km) east of Hampton Boulevard. Straight 4-lane divided highway with 0.0% grade had not been opened to traffic. All lanes had a concrete pavement with longitudinal grooves on 3/4 inch (19 mm) centers, Figure 9. The surface was open and non-protuberant, with a fine mosaic aspect. The test runs were made in the eastbound traffic lane. The microphone was placed in the median.
10. International Terminal Boulevard in Norfolk, approximately 0.15 mile (0.24 km) east of Ruthven Road. The EBL's had transverse grooves on 3/4 inch (19 mm) centers, Figure 10. The roadway curves to the north near the east end of the measurement zone on an upgrade approach to a bridge. Nevertheless, the measurement zone had essentially 0.0% grade and was straight. The test runs were made in the eastbound traffic lane. The microphone was placed in the median.
11. International Terminal Boulevard in Norfolk, approximately 100 feet (30.5 m) east of Diven. The WBL's had transverse grooves on 1½ inch (38 mm) centers, Figure 11. The test runs were made in the westbound passing lane. The microphone was placed on the north side of the road.

12. International Terminal Boulevard in Norfolk, approximately 200 feet (61.0 m) west of Diven. The EBL's had transverse grooves on 3 inch (76.2 mm) centers, Figure 12. The test runs were made in the eastbound passing lane. The microphone was placed on the south side of the road.
13. International Terminal Boulevard in Norfolk, approximately 125 feet (38.1 m) east of the entrance to the Supreme Allied Commander Atlantic and 0.3 mile (0.48 km) west of Diven. The WBL's had longitudinal grooves on 3/4 inch (19 mm) centers and transverse grooves on 1½ inch (38 mm) centers, Figure 13. The test runs were made in the westbound passing lane. The microphone was placed on the north side of the road.
14. International Terminal Boulevard in Norfolk, approximately 250 feet (76.2 m) east of Ruthven Road. The WBL's had longitudinal grooves on 3/4 inch (19 mm) centers and transverse grooves on 3 inch (76.2 mm) centers, Figure 14. The measurement zone had 0.0% grade and was straight in that the curve and grade aspects mentioned for site 11 were beyond the east end of the measurement zone. The test runs were made in the westbound traffic lane. The microphone was placed in the median.
15. International Terminal Boulevard in Norfolk, approximately 0.2 mile (0.32 km) west of Ruthven Road. The EBL's had aggregate exposed west and east of the microphone position (a) by removal of paste by washing and (b) by sprinkling on aggregate, Figures 15 and 16, respectively. The surface was dense and rough, with a medium mosaic aspect. The test runs were made in the eastbound traffic lane. The microphone was placed in the median.
16. International Terminal Boulevard in Norfolk, approximately 275 feet (83.8 m) west of Ruthven Road. The EBL's had dimples staggered in longitudinal rows on 3/4 inch (19 mm) centers, Figure 17. The test runs were made in the eastbound passing lane. The microphone was placed on the south side of the road.
17. Colonial National Historical Parkway in York County, approximately 1.2 miles (1.93 km) east of the near end of the bridge over Felgates

Creek. Straight section of 3-lane highway with 0.0% grade. All the lanes were concrete with the rounded gravel aggregate exposed, the paste had been washed away at construction, Figure 18. The surface was dense and very rough, with a very coarse mosaic aspect. The test runs were made in the middle lane headed west. The microphone was placed on the north side of the road.

18. Colonial National Historical Parkway in James City County, approximately 1.5 miles (2.86 km) west of the near end of the bridge over College Creek and opposite an overlook. Straight 3-lane highway with 0.0% grade. All the lanes were concrete with the rounded gravel aggregate exposed, the paste had been washed away at construction, Figure 19. The surface was dense and very rough, with a very coarse mosaic aspect. The test runs were made in the eastbound lane. The microphone was placed on the north side of the road.
19. Route I-95 south of Emporia in Greenville County, approximately 0.8 mile (1.61 km) south of Route 58. Straight 4-lane divided highway with 0.0% grade. The surface of the SBL was dense and rough, and with a medium mosaic aspect. It had been impacted by pneumatic hammers to chip the cement paste away and expose the aggregate, Figure 20. The noise generated by the traffic passing over the hammered and unhammered areas was recorded. The microphone was placed on the west side of the road. The record from this site was worthless because the attenuator settings on the sound level meters were set too low to handle the noise level that was generated. This site will not be discussed further, but is mentioned here because it is illustrative of a particular type of pavement texture.

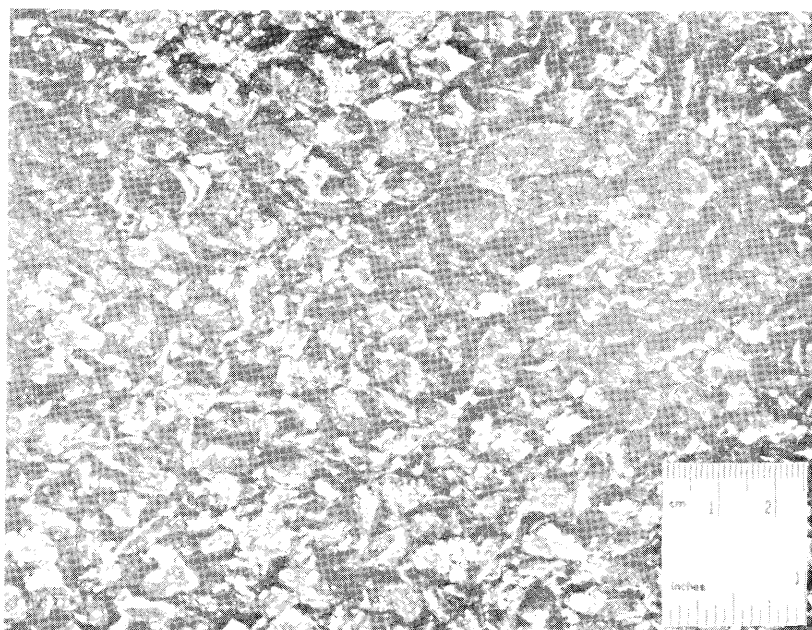


Figure 1. Route 460, EBL, S-8 surface.

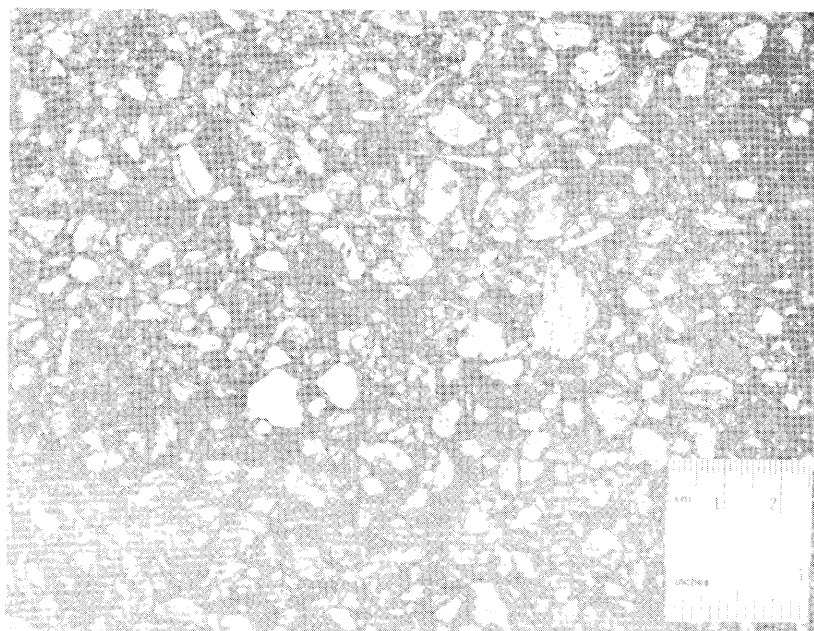


Figure 2. Route 460, WBL, S-5 surface.

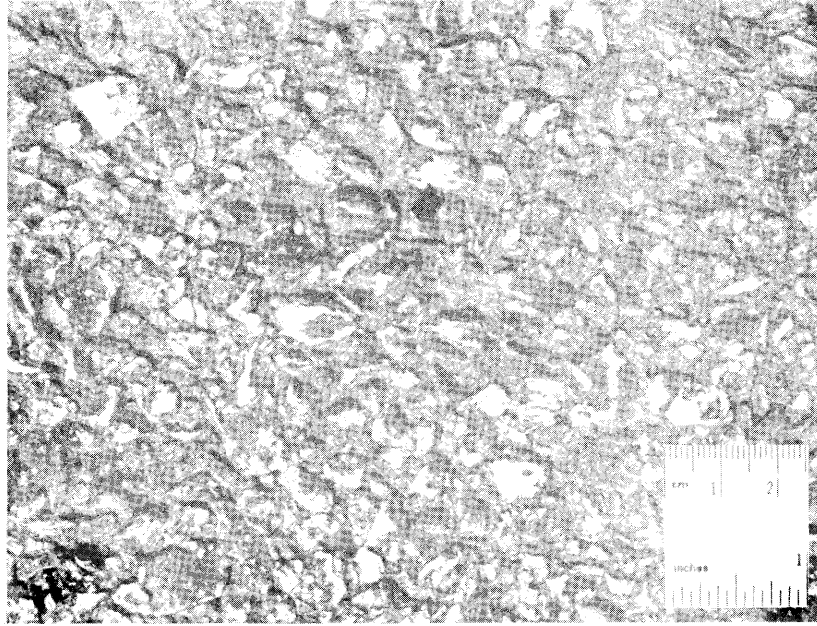


Figure 3. Route 60, EBL, S-8 surface.

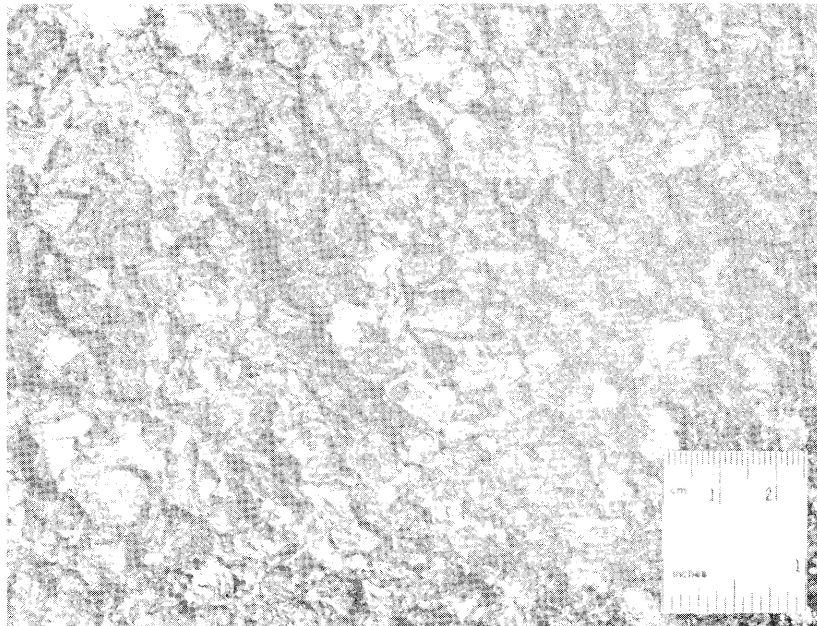


Figure 4. Route 60, WBL, S-8 surface.

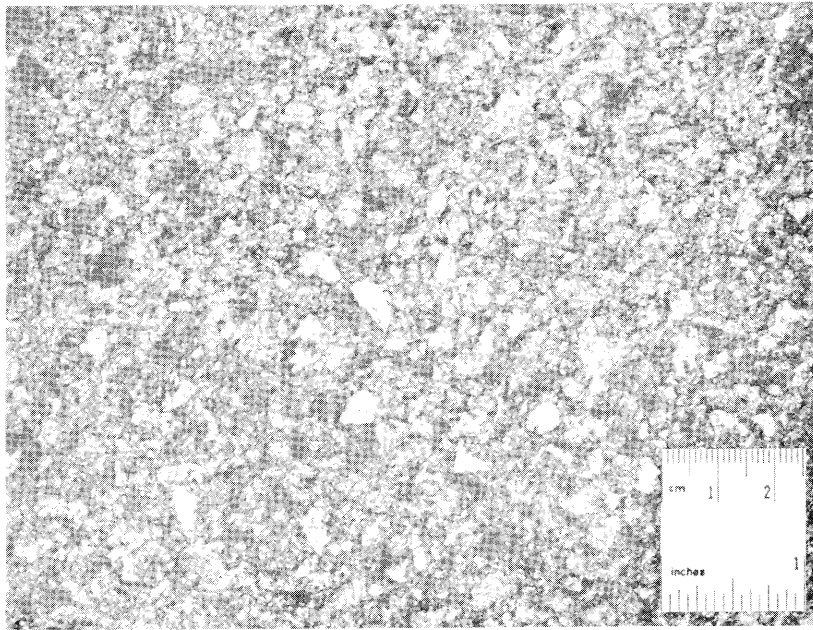


Figure 5. Route 250, EBL, S-5 surface.



Figure 6. Route 250, EBL, I-2 surface.

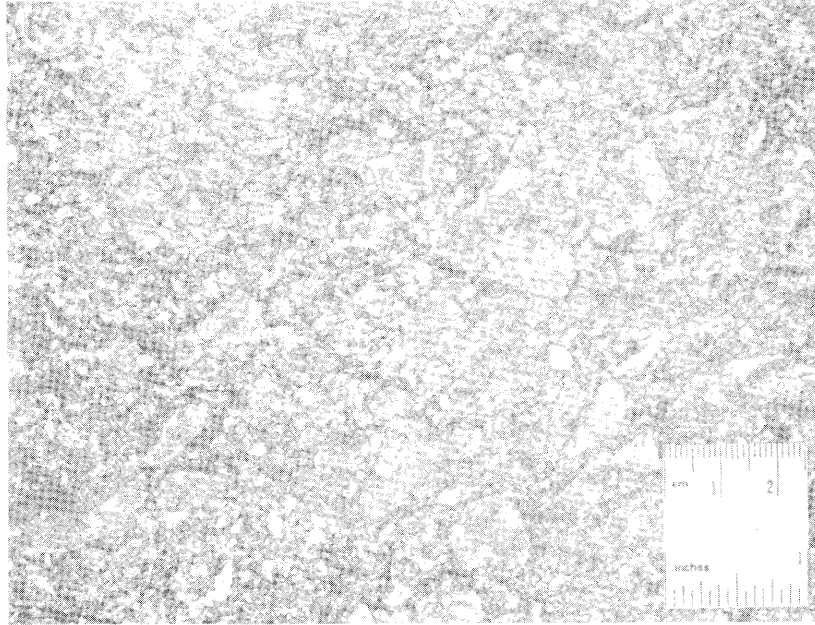


Figure 7. Route 250, EBL, I-2 surface.

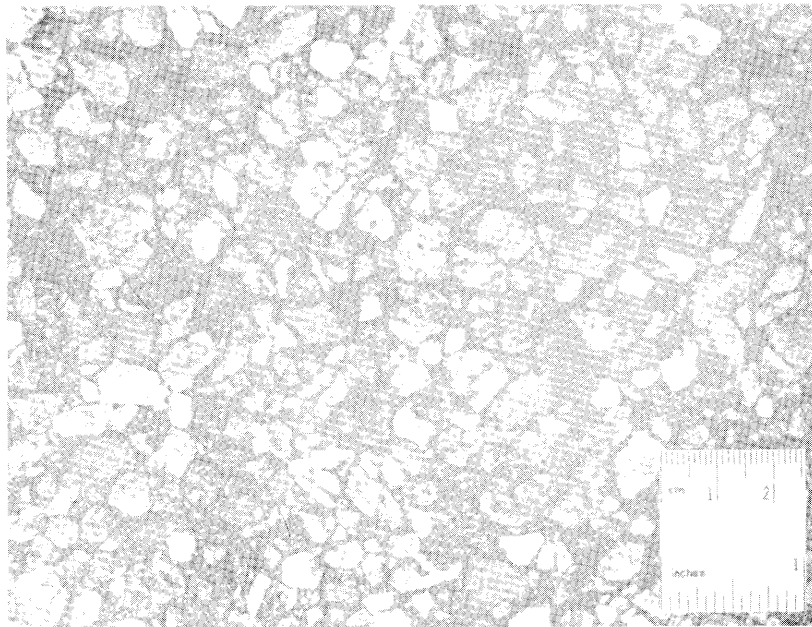


Figure 8. Route 1, SBPL, surface treatment.

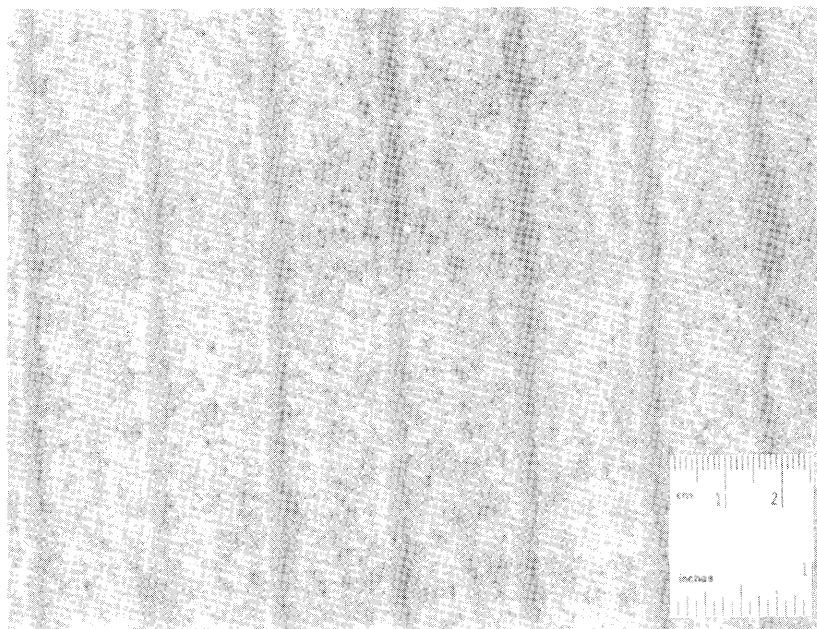


Figure 9. Norfolk International Terminal Boulevard, EBTL, 3/4 inch L.

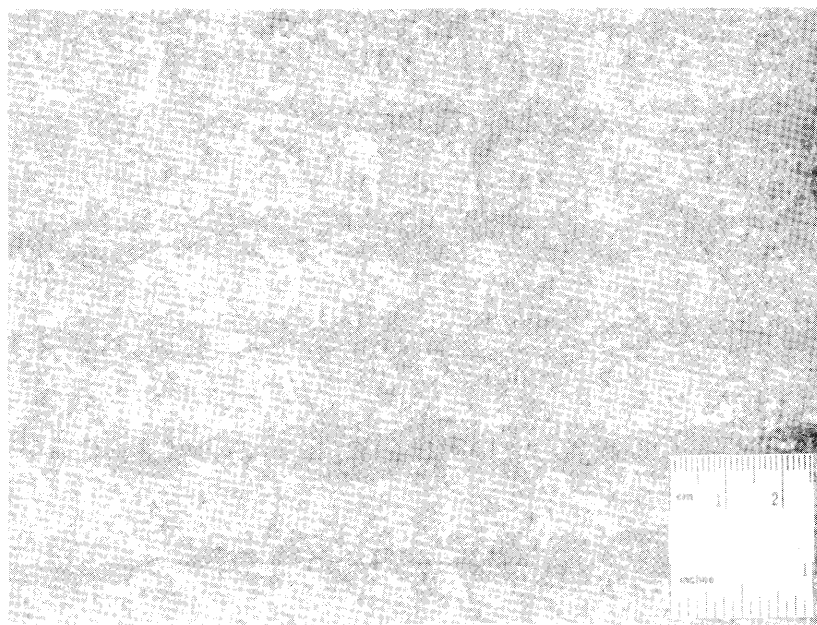


Figure 10. Norfolk International Terminal Boulevard, EBTL, 3/4 inch T.

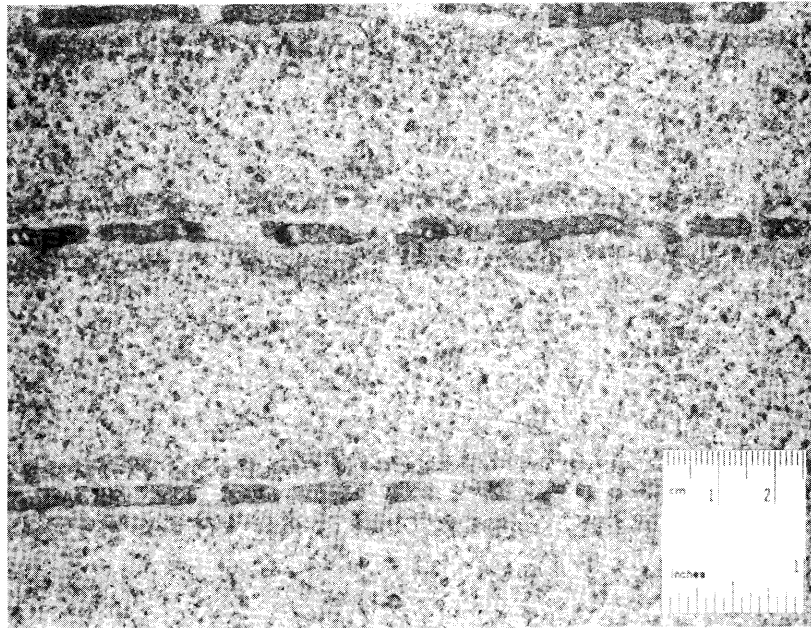


Figure 11. Norfolk International Terminal Boulevard, WBPL, 1½ inch T.

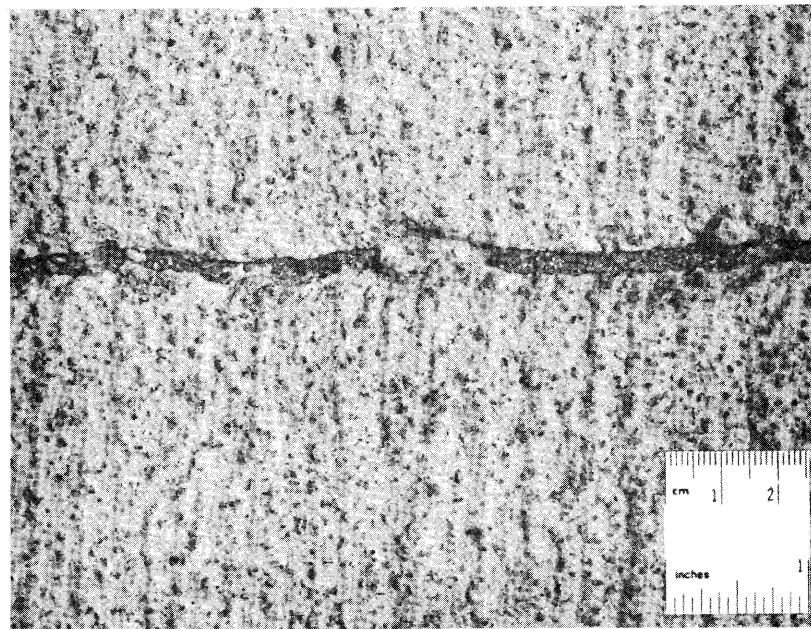


Figure 12. Norfolk International Terminal Boulevard, EBPL, 3 inch T.

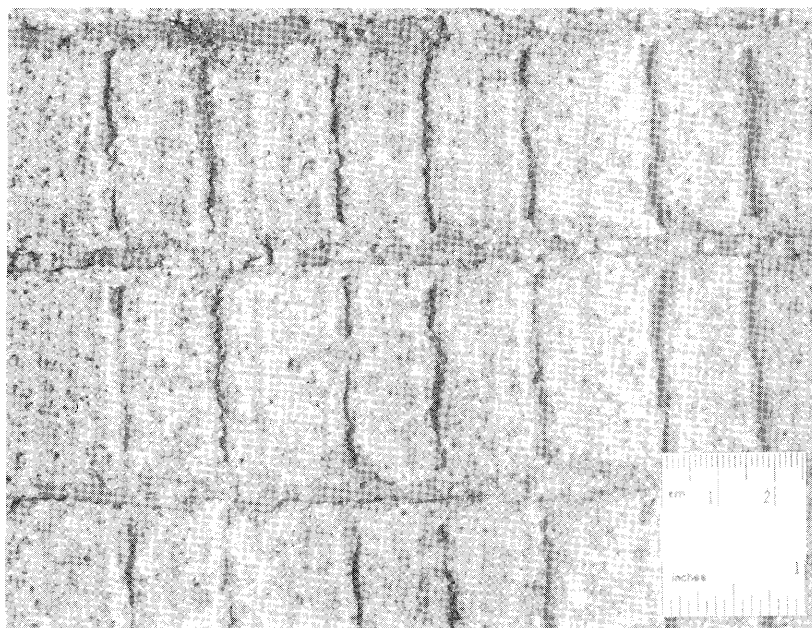


Figure 13. Norfolk International Terminal Boulevard, WBPL,
3/4 inch L + 1½ inch T.

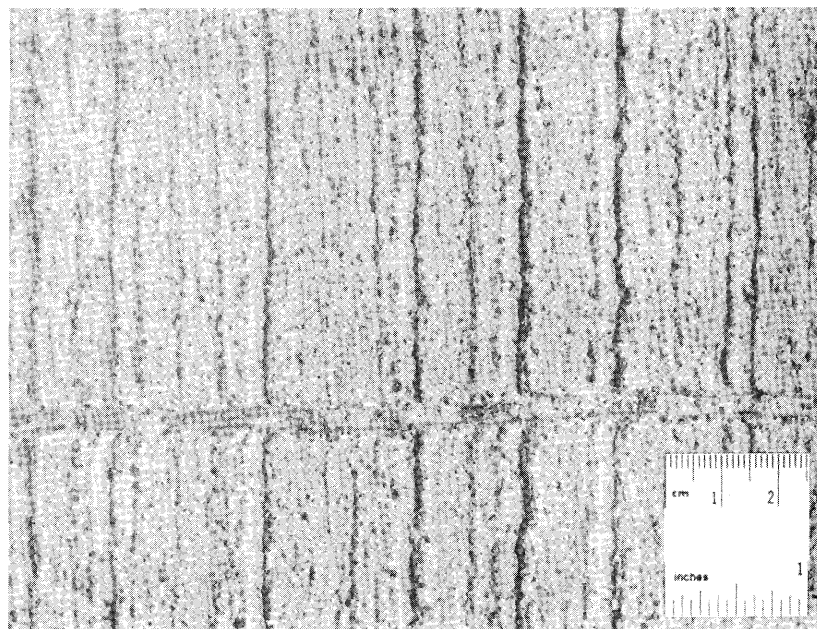


Figure 14. Norfolk International Terminal Boulevard, WBTL,
3/4 inch L + 3 inch T.

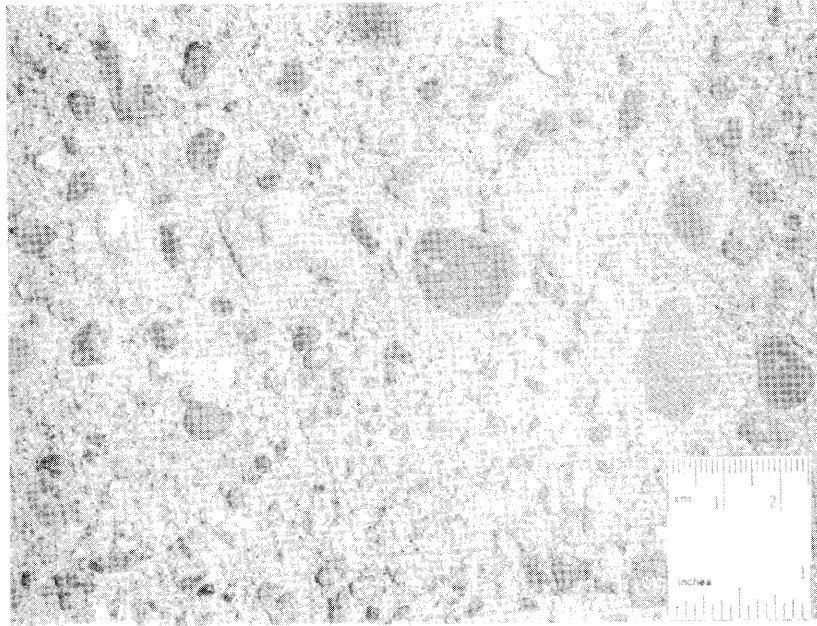


Figure 15. Norfolk International Terminal Boulevard, EBTL, washed.

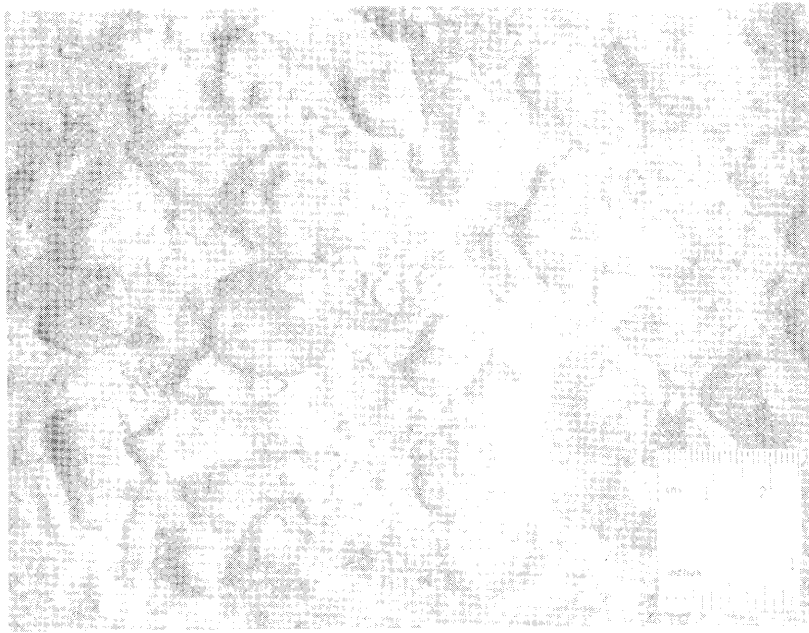


Figure 16. Norfolk International Terminal Boulevard, EBTL, sprinkled.

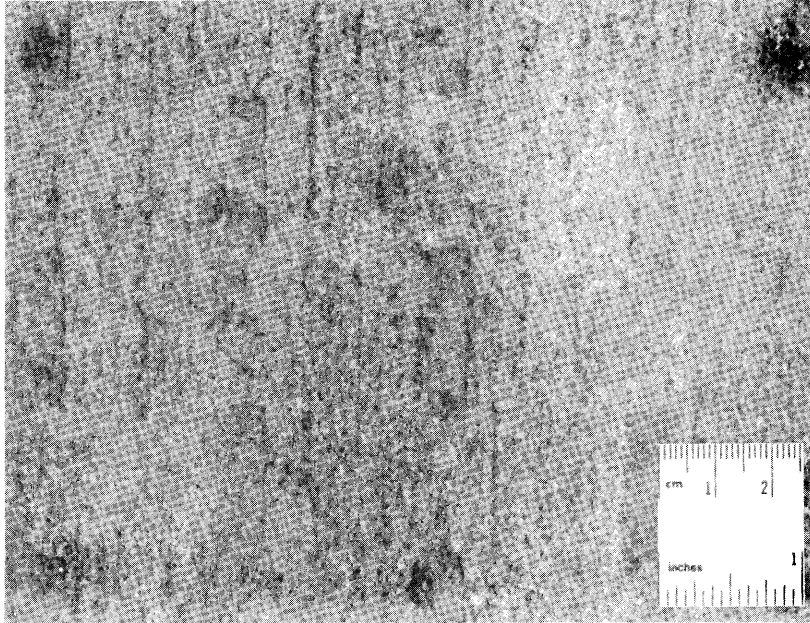


Figure 17. Norfolk International Terminal Boulevard, EBPL, dimpled.

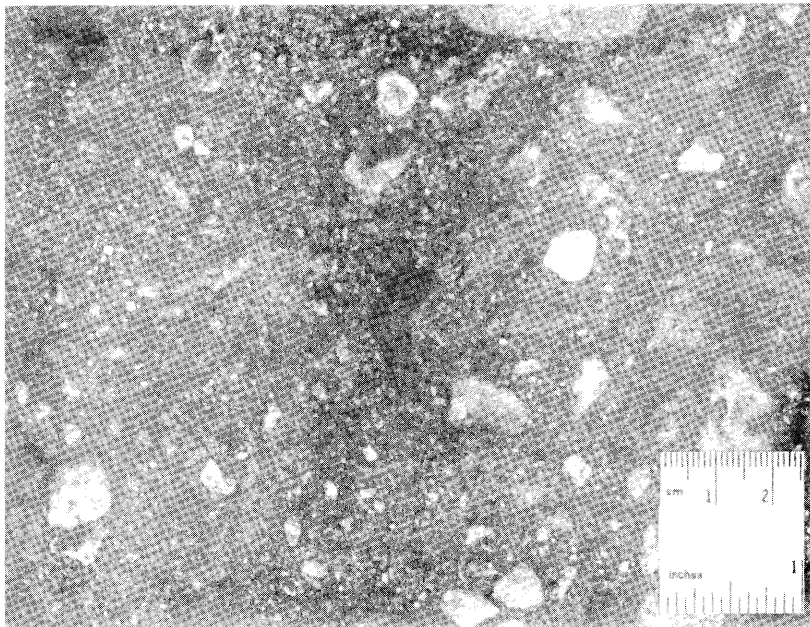


Figure 18. Colonial National Historical Parkway, middle lane, washed.

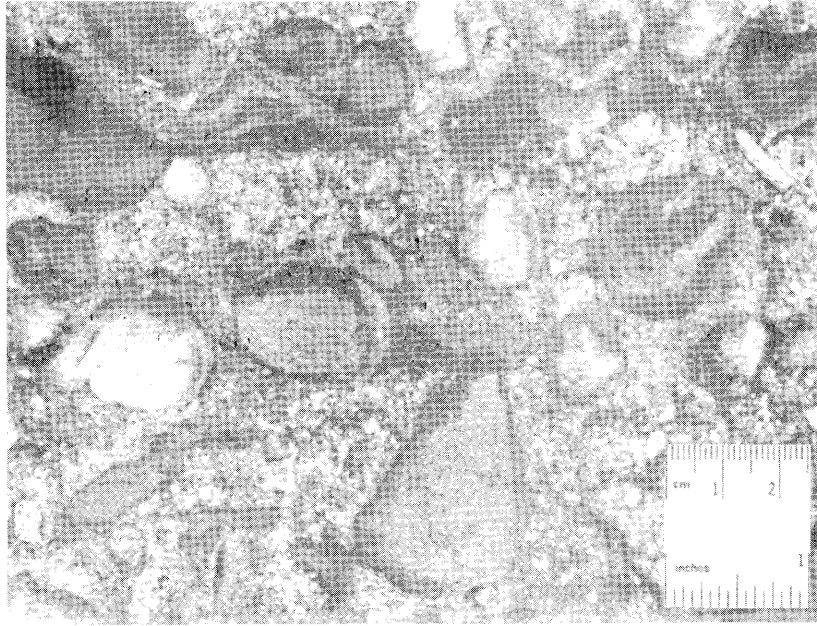


Figure 19. Colonial National Historical Parkway, EBL, washed.

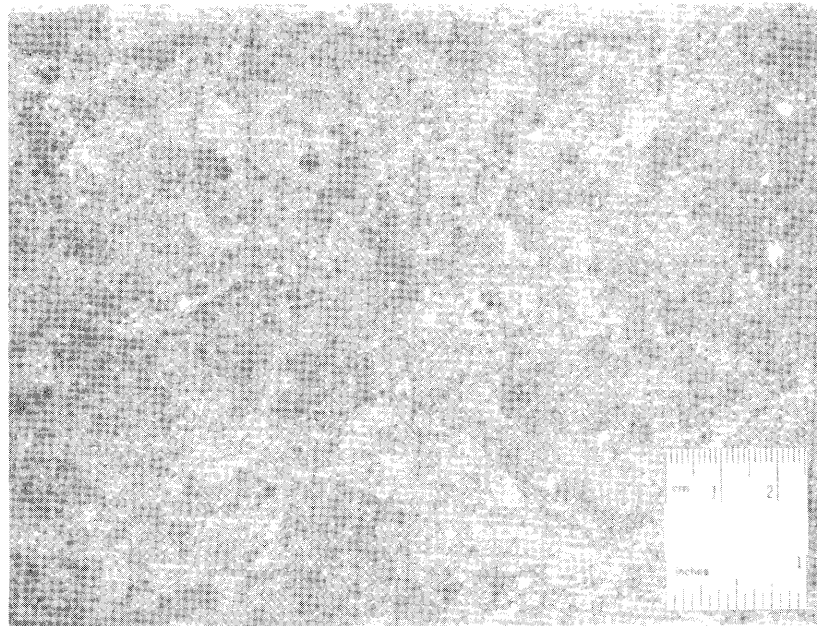


Figure 20. Route I-95, SBL, hammered.

MEASUREMENT AND RECORDING INSTRUMENTATION

The instrumentation for measuring and recording the noise levels consisted of a B & K Model 2204 precision sound level meter with a one-inch (2.54 cm) B & K Model 4145 condenser type microphone, a B & K Model 4230 calibrator, 100 feet (30.5 m) of coaxial cable, a portable two-channel, Nagra Model SD tape recorder, and 3M No. 206 magnetic tape. A vehicular detection radar unit was used to monitor the speed of the vehicle. The speed was also monitored by observation of the speedometer.

TEST VEHICLE AND TIRES

The test vehicle was a 1971, 4-door, Plymouth. Four tires, F78-15, with a standard rib tread, Figure 21, were used for one set of measurements; then two tires, G78-15, with snow and mud treads, Figure 22, were placed on the rear wheels and a second group of measurements were taken. Inasmuch as tests with 14-inch (35.6 cm) and 15-inch (38.1 cm) tires in load ratings F, G, and H and with the same tread pattern produce no significant or systematic difference in sound levels,⁽⁵⁾ it was considered that comparing the difference in noise levels caused by different tread types, the one on an F rated and the other on a G rated tire, would be a valid comparison. The test runs were made with a tire inflation pressure between 28 and 30 psi (20.7×10^4 and 19.3×10^4 Pa). The tread depth changed from 10/32-inch (7.9 mm) at the start of testing to 8/32-inch (6.4 mm) at the end of testing. It is considered that neither of these parameters had a significant effect on the results.

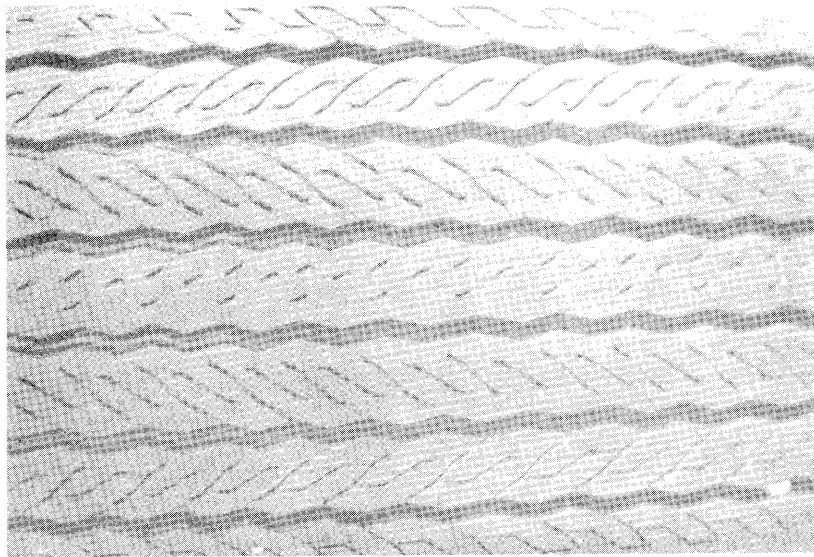


Figure 21. Rib tread.

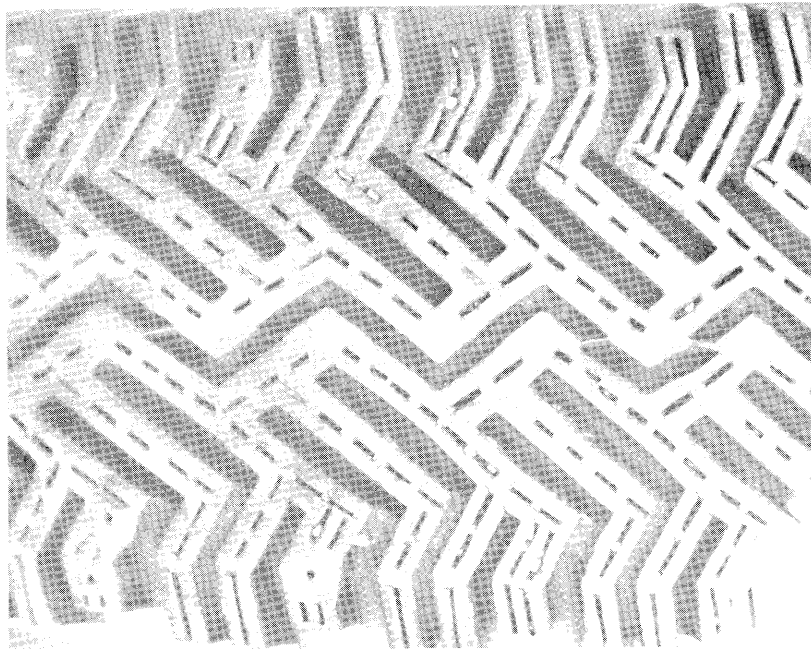


Figure 22. Snow and mud tread.

METHODOLOGY

There are two principal methods that might be used to measure the noise created by the interaction of the tire and the road. Each method has its technical drawbacks. One requires the suspension of the microphone outside the automobile near the tire-road contact. The advantage of this method is that it permits the acquisition of a relatively long, steady record which is easier to analyze than a short record when no sophisticated instrumentation such as a real time analyzer is available. The disadvantage is the difficulty of shielding the microphone from the wind as the automobile moves over the roadway. The second method, which was used in this study, locates the microphone at the midpoint of the measurement zone and off the roadway. It measures and records the sound as the automobile passes. The advantage of this method is that the microphone is in a less rigorous, less dynamic environment and can provide a relatively undistorted record. The disadvantage is that the record is very short.

It has become common practice to measure traffic noise 50 feet (15.2 m) from the center of the near lane.⁽⁵⁾ However when dealing with tire-road noise which may be low relative to ambient levels, as with this study, the microphone can be placed 25 feet (7.6 m) from the center of the test lane. For all but one test site, there were one and one-half paved lanes between the center of the test lane and the microphone. The microphone was mounted on a tripod approximately four feet (1.2 m) above the level of the road. The sound level meter, tape recorder, and personnel were located approximately 25 feet (7.6 m) from the microphone.

Starting well up the road from the microphone, the driver of the test vehicle accelerated to attain the desired speed by the time he reached the measurement zone, and then passed through the measurement zone using only enough power to maintain the desired speed. The technicians on the site noticed little if any exhaust or engine noise.

The speed of the vehicle influences the intensity of the noise generated by the tire-road interaction. Sound levels increase on the order of 8-10 dB from 40 to 70 miles per hour (64.4-112.6 kph), thus varying approximately as the fourth power of speed in this range.⁽⁵⁾ Maximum speed limits had been reduced to 55 mph (88.5 kph) in Virginia, and it was decided to make the measurement runs as close to 50 mph (80.5 kph) as possible. The test vehicle's speedometer was checked for accuracy and was found to indicate a speed 2 mph (3.2 kph) greater than the

actual speed in the range from 25 mph (40.2 kph) to 45 mph (72.4 kph), and 3 mph (4.8 kph) greater than the actual speed in the range from 45 mph (72.4 kph) to 65 mph (104.6 kph).

The tests on sites other than those on the International Terminal Boulevard in Norfolk were run at an average speed of 51 mph (82.1 kph), which corrects to 48 mph (77.2 kph). The tests on the Boulevard were started at approximately 50 mph (80.5 kph), but it was obvious that the ambient noise level was too high to permit a good measurement of the tire-road noise at 50 mph (80.5 kph). Thus these tests were run at approximately 62 mph (99.8 kph), which corrects to 59 mph (94.9 kph).

The potential for variation in this procedure is considerable. The speed of the vehicle, the position of the wheel path in the lane, the distance from the microphone, the speed and direction of the wind, and other parameters may vary despite the effort to keep them constant. Therefore, repeated runs were made until approximately ten recordings as free from extraneous noise as possible were obtained.

ANALYSIS

The tape recordings of the test runs were returned to the laboratory and the data were processed on a graphic level recorder in both the linear (dB) and dBA modes. Both the dB and dBA values were normalized for a speed of 48 mph (77.2 kph). In Tables 3 and 4, presented later, the data are organized in four categories — dB-Rib, dB-Snow, dBA-Rib, and dBA-Snow. The mean and standard deviation of the maximum levels were computed for each group of data collected at each test site, see Table A-1 of Appendix A. The means listed in each category were analyzed statistically using the pooled estimate of the standard deviation as described in "Experimental Statistics"⁽⁶⁾ pages 3-40 through 3-42 to determine what magnitude of difference between any two means was significant. The differences between means found to be significant are 1.60, 1.26, 2.00 and 2.50, respectively, see page A-1 of Appendix A for computation.

Ten recordings considered to be representative of most of the data were submitted to a consultant for frequency analysis. The analyses of the data in the linear mode were presented on a computer printout sheet for the one-third octave bands for each half a second over a time span of 10 to 17 seconds. The dBA levels were also presented on a computer printout sheet for the same time spans. Graphic presentations were made of

the maximum linear sound pressure level (db vs. 1/3 octave bands), the variation of the linear sound pressure level with time, and the variation of the dBA levels with time.

RESULTS AND DISCUSSION

The principal subjects addressed in this section of the report are the differences between the sound pressure levels recorded as the test vehicle traversed the test sites, and the nature of the sounds produced. 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. (3)
2. When real life sounds or noises are heard, it is just 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. (1)

If the maximum significant difference for the four categories of means, which coincides with the difference in dBA that humans can just perceive, 2.50 is stipulated as the frame of reference for this discussion of the data, the discussion will be meaningful both statistically and in terms of the human's ability to perceive differences in dBA levels.

Bituminous Pavements

Inasmuch as most data on highway noise are presented in dBA, most of the discussion of the data of Tables 3 and 4 will be on the dBA values. The sound pressure levels in Table 3 were measured at eight sites on four bituminous pavement types and textures.

dBA-Rib

The range in dBA means for the rib tread is from 77.4 dBA on a non-protuberant S-8 pavement through 84.3 dBA on a rough surface treatment pavement. This difference in intensity of 6.8 dB is easily perceived.

Table 3

dB and dBA Means of Sound Pressure Levels Measured on Bituminous Pavements

Site	Route	Lane	Pavement			dB		dBA	
			Aggregate Condition and Type	Mix	Rib	Snow	Rib	Snow	
1	460	EBTL	Not Exposed	S-8	81.3*	82.1	77.5	78.8	
2	460	WBTL	Exposed Arch Marble	S-5	81.0	84.2	78.2	82.4	
3	60	EBL	Exposed Arch Marble	S-8	86.2	86.1	78.6	82.1	
4	60	WBL	Exposed Lt. Wt. Synthetic	S-8	84.7	86.0	79.0	80.3	
5	250	EBL	Exposed Greenstone	S-5	84.4	85.1	79.7	79.4	
6	250	EBL	Not Exposed	I-2	86.0	86.6	80.4	84.8	
7	250	EBL	Not Exposed	I-2	85.6	85.3	77.7	78.4	
8	1	SBPL	Exposed Granite Gneiss	Surface Treatment	88.5	89.6	84.3	84.7	

*A correction of minus 5 dB⁽²⁾ can be applied to bring the values to the level that would be expected if the microphone had been 50 feet (15.2 m) from the centerline of travel rather than 25 feet (7.6 m).

0-15

The next to the highest dBA mean of 80.4 for an I-2 pavement is within 3.9 dB of the mean for the surface treatment pavement and this difference is perceivable, though much less so than the 6.8 dB difference. A comparison of values for pavements with only one of the parameters considered here varying, such as the density of the S-8 and S-5 pavements on Route 460, the aggregate in the S-8 pavements on Route 60, and the mosaic aspect of the S-5 and I-2 pavements on Route 250, indicates that these parameters have very little effect on the intensity of the sound pressure level generated with rib treads. Based on these rather limited data, it appears that differences in the degree of protuberance have the greatest effect on the tire-road noise.

dBA-Snow

The data in the dBA mode for the snow tread did not fit a well delineated rationale as well as did the dBA levels for the rib tread. The extremes of the range in the dBA levels were measured on the same type pavement, I-2, at two locations on Route 250. There is no information in the support data that tends to explain such an anomaly. Certain parameters did vary, but these differences do not adequately explain the anomaly. The higher level measurements were taken on a relatively cool (24° C) pavement with the test vehicle traveling in the direction opposite to the normal traffic flow; the low level measurements were taken on a relatively hot (46° C) pavement with the car traveling in the same direction as the normal traffic flow.

Disregarding the anomaly of the I-2 pavements, the range for the levels measured for the other pavements is from 78.8 dBA on a non-protuberant S-8 pavement through 84.7 dBA on a rough surface treatment pavement. This 5.9 dB difference is easily perceived. The differences between the surface treatment and the two S-5 and three S-8 pavements are, respectively, 2.3 to 5.3 dB and 2.6 to 5.9 dB. These differences are just perceivable to easily perceived. Comparison of the mean dBA level of the two S-5 pavements with that of the three S-8 pavements, 80.9 dBA and 80.4 dBA, respectively, shows that there is no distinguishable difference in the dBA level measured for these types of pavements.

With the exception of the data for the I-2 pavement, these data for the snow tread indicate, as did the data for the rib tread, that the degree of protuberance is the pavement parameter that has the greatest effect on tire-road noise.

Concrete Pavements

The sound pressure levels in Table 4 were measured at ten sites on eight portland cement concrete pavement textures.

Table 4

dB and dBA Means of Sound Pressure Levels Measured
on Portland Cement Concrete Pavements

Site	Route	Lane	Pavement		dB		dBA	
			Aggregate Condition and Type	Pattern	Rib	Snow	Rib	Snow
9	Int'l. Term. Boulevard	EBTL	Not Exposed	3/4" L	84.6*	85.4	82.5	81.1
10	Int'l. Term. Boulevard	EBTL	Not Exposed	3/4" T	--	85.4	--	82.3
11	Int'l. Term. Boulevard	WBPL	Not Exposed	1 1/2" T	--	--	--	--
12	Int'l. Term. Boulevard	EBPL	Not Exposed	3" T	83.6	87.8	79.6	86.3
13	Int'l. Term. Boulevard	WBPL	Not Exposed	3/4" L + 1 1/2" T	85.1	85.5	80.7	83.7
14	Int'l. Term. Boulevard	WBTL	Not Exposed	3/4" L + 3" T	81.1	86.1	79.6	84.4
15	Int'l. Term. Boulevard	EBTL	Exposed rounded gravel crushed rock	washed and sprinkled-random	88.9	86.8	85.8	84.5
16	Int'l. Term. Boulevard	EBPL	Not Exposed	dimpled	90.5	89.0	86.9	85.1
17	Colonial Park-York	Mid. L.	Exposed rounded gravel	washed-random	87.6	88.5	82.1	83.1
18	Colonial Park-James	EBL	Exposed rounded gravel	washed-random	89.0	89.3	83.7	84.7

*A correction of minus 5 dB(2) can be applied to bring the values to the level that would be expected if the microphone had been 50 feet (15.2 m) from the centerline of travel rather than 25 feet (7.6 m).

dBa-Rib

The range in dBA values for the rib tread is from 79.6 dBA on the 3-inch T and 3/4-inch L + 3-inch T grooves through 86.9 dBA on the dimpled texture. This difference of 7.3 dB is easily perceived. The high noise level from the dimpled texture was expected because the dimples are closed, ellipsoidal depressions in which air can successively be trapped, compressed, and explosively released by the rib tread. The dBA levels for the four patterns of grooving have a range of 2.9 dBA, a difference that is just perceivable. The various patterns of grooving do not change the amplitude of the asperities, they simply change the frequency of occurrence and orientation to the direction of travel of the grooves. Therefore, there is little change in the degree of protuberance and, as might be expected, not much difference in the noise levels. The dBA levels for the three pavements with aggregate exposed have a range of 3.7 dBA. This rather limited range in relatively high dBA values may be caused by the similarity in the parameter that most greatly affects the tire-road noise, and with these three pavements that parameter appears to be the degree of protuberance. An additional parameter that appears to affect the noise generated is the angularity of the particles that cause the degree of protuberance. The very rough, very coarse surfaces on the Colonial Parkway pavement generated noise levels somewhat lower than those of the rough, medium surface of the washed and sprinkled section of the International Terminal Boulevard in Norfolk. This apparently anomalous situation is explained by the round shape of the exposed gravel on the Colonial Parkway and the angular shape of the crushed aggregate that was sprinkled on the International Terminal Boulevard. If tire noise is caused by vibrations set up in the tire tread, as Richards⁽²⁾ said, the sharp edges of the crushed aggregate should grab at the tire more than do the smooth, rounded surfaces of the gravel and thus cause tire tread vibrations of greater amplitude.

Even when the mean dBA values of the grooved and aggregate protruding surfaces are compared, 80.6 and 83.9 respectively, there is a significant and perceivable difference, with the protruding aggregate surface being noisier.

dBa-Snow

There are two somewhat anomalous aspects of the dBA-Snow means for concrete pavements that, at first glance, are not readily explained. One is that the greatest noise was generated on the 3-inch transverse grooves, the texture that had been the least noisy with rib treads. The other is that the range of the means for three of the grooved pavements and those with protruding aggregate is, at 3.2 dBA, rather limited for pavements of such different textures.

Richards⁽²⁾ states that both the road texture and tread pattern contribute to tire noise but not necessarily in an additive manner. He presents the following few generalizations that cover most of the combinations;

1. Smooth tire-smooth road. A relatively quiet condition.
2. Smooth tire-rougher surface. Noise levels generally increase with surface roughness.
3. Aggressive tire-smooth road. Louder than smooth tire and generally tonal (depending greatly on the tread pattern).
4. Aggressive tire-rough surface. Noise levels are nearly independent of the surface to the point at which the road roughness overshadows tread amplitudes. From this point on, the noise levels again increase with road roughness. The fact that some aggressive tires (such as cross-lug truck tires) may become quieter on a coarse surface is explained by the tire vibration theory of noise, because the random texture of the road serves to disrupt the regular impacting of the tread blocks on the road, thus decreasing the amplitude of the tire vibrations.

The basis for the explanation of the two anomalies lies in the fourth generalization. Tread amplitudes are an important factor in the level of noise generated, and any road characteristic that affects the tread amplitudes directly affects the noise generated. Addressing the first anomaly, if the random texture of a road can disrupt the repetitive impacting of the tread blocks on the road and cause less noise than when regular impacting occurs, then a road texture such as 3-inch transverse grooves coupled with a regularly varying tread block spacing of 2 through 3¼ inches might act in phase to increase tread amplitudes and conjunctively increase the level of noise generated.

The explanation of the rather limited range in dBA levels for six pavements is based on the statement that when an aggressive tire and rough surfaces are involved, noise levels are nearly independent of the surface until the point at which the road roughness overshadows tread amplitudes. Also, a random road texture disrupts the regular impacting of the tread blocks on the road. Thus, a

random surface such as protruding aggregate that tends to diminish tread amplitude and an aggressive snow and mud tread that is less sensitive than a rib tread to relatively minor changes in surface texture, as with grooving, tend to create dBA levels of similar magnitudes.

The level for the snow tread on the dimpled pavement is 1.8 dBA lower than the level for the rib tread on this pavement. A lower level was not expected, but is easily explained in terms of the snow tread configuration and dimensions. The tread blocks are at angles to the long axis of the dimple (1/4 inch [6.4 mm] by 1 inch [25.4 mm]) of 30°, 45°, and 65°, and are only 3/8 (9.6 mm) to 5/8 inch (16.0 mm) wide, thus there was less opportunity for trapping air in the dimples.

dBA Means and Degree of Protuberance

The dBA means for each test site and tread type have been examined and discussed. The principal conclusion is that the degree of protuberance is the pavement parameter that has the greatest effect on tire noise. The variability of measurements within a mix type or particular type of protuberance may tend to obscure that observation. Therefore, the data in Table 5 have been organized in terms of bituminous mix and method of finishing portland cement concrete pavements, which control the degree of protuberance of pavements. The individual dBA values, grouped by mix and type of finish were normalized for a speed of 48 mph (77.2 kph), and their means were computed.

There is no significant difference between the values for the S-8, S-5, or I-2 pavements for either the rib or snow treads. With the rib tread there is a just perceivable difference between the S-8 and the grooved portland cement pavements, but it is hardly worthy of note. Again for the rib tread, there is a significant difference between the non-protuberant S-8, S-5, I-2 and grooved portland cement pavements and the rough protruding aggregate surfaces (both bituminous and portland cement concrete). The dimpled surface, which had the highest dBA level, is significantly noisier than all the other surfaces.

Looking at the levels generated with the snow tread, it is obvious that, as mentioned earlier, there is no significant difference in the values for the S-8, S-5, and I-2 pavements. However, the difference between the grooved portland cement concrete pavements and the S-8 pavements is significant, and that between the grooved pavements and the S-5 pavements is only perceivable. There is no significant difference between the values for the grooved portland cement concrete, the protruding aggregate, and the dimpled

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pavements. There is a significant difference between the values for the non-protuberant S-8, S-5, and I-2 pavements and the rough protruding aggregate and dimpled pavements.

The comparisons just made amply document that, within the scope of this study, the degree of protuberance is the most important parameter affecting tire-road noise. It is also apparent that snow treads are perceivably noisier than rib treads only on non-protuberant pavements.

Table 5

dBA Means According to Bituminous Mix and Type of Concrete Finish

Type	Rib	Snow
Bituminous —		
S-8	78.5	80.5
S-5	79.2	81.2
I-2	79.2	81.8
Protruding Aggregate-Surface Treatment	84.3	84.7
Concrete —		
Grooves	80.7	83.6
Protruding Aggregate in P. C. Concrete	83.9	84.2
Dimples	86.9	85.1

Frequency Analysis of the Data

One-third octave band frequency analyses were made of ten recordings considered representative of the rib tread data. The curves, with the 1/3 octave bands on the abscissa and dB on the ordinate, are given in Appendix B. Table 6 was prepared to facilitate comparison of these analyses.

Table 6
Frequency Analyses

Site	Background and Pure Tones	dB			Off Chart	
		1.6 k Hz	3 k Hz	6 k Hz	k Hz	dB
3 (Rt. 60 - Bent Crk.)	70 dB-25 through 317 Hz and 800-1250 Hz; P.T. 80 Hz-79 dB	64	50	40	6	40
4 (Rt. 60 - Bent Crk.)	63 dB-63 through 631 Hz; P.T. 31 Hz-65 dB, 100 Hz-76 dB, 500 Hz-70 dB	52	45	---	5	40
5 (Rt. 250 W.L.)	64 to 70 dB-25 Hz through 1.6 k Hz; undulating	65	56	40	6	40
6 (Rt. 250 EMR)	66 to 70 dB-125 Hz through 1.6 k Hz; P.T. 40 Hz-74 dB, 100 Hz-81 dB	68	56.5	---	5	50
9 (3/4 L)	67 to 73 dB-25 Hz through 1.6 k Hz; undulating	70	58	46.5	20	42
10 (3/4 T)	67 to 70 dB-25 Hz through 1.6 k Hz; P.T. 160 Hz-77 dB, 1250 Hz-74 dB	70	59.5	47	20	42
13 (3/4 L + 1 1/2 T)	71 to 78 dB-25 through 200 Hz, 70 to 74 dB-800 Hz through 1.6 k Hz; P.T. 40 Hz-76 dB, 160 Hz-78 dB	70.5	60	48	20	42
14 (3/4 L + 3 T)	65 to 71 dB-25 through 200 Hz, 66 dB-800 Hz through 1.6 k Hz; P.T. 125 Hz-72 dB	66	55	50	20	52
15 (Washed and Sprinkled)	73 to 70 to 77.5 dB-25 Hz through 1.6 k Hz; undulating	72	62.5	51	20	41
16 (Dimpled)	73 to 81 to 77 to 78 dB-25 Hz through 1.6 k Hz; undulating with P.T. 31.5 Hz-81 dB, 160 Hz-78 dB, 1000 Hz-77 dB	73	62	50	6	50

The fact that is most obvious from just a brief examination of the curves in Appendix B is that vehicular noise is quite similar regardless of the pavement surface traversed. That the frequency components of vehicular noise are similar is especially true in the low to mid-frequency range. The curves fluctuate around a background level with peaks at various frequencies indicative of relatively pure tones, and then drop off in intensity rather rapidly (approximately 25 dB) from the region between 800 Hz and 1,600 Hz to 6 Kilohertz (k Hz). In order to provide a sense of the high frequency content, the dB levels for 1.6 k Hz, 3 k Hz, 6 k Hz, and where the curve leaves the chart are listed in Table 6. As shown earlier by the data for the rib tread, there is no significant difference between the overall sound pressure levels (OASPL) for the non-protuberant bituminous pavements and the non-protuberant grooved portland cement concrete pavements.

The dissimilarities in the data are not large in magnitude, but can be very important in explaining the differences the ear senses as the vehicle traverses the different pavements. The principal difference, and that which is most noticeable, is that the noise generated on the portland cement concrete pavements has a more intense high frequency component than does the noise generated on the bituminous pavements. The greater intensity is just noticeable starting at 1.6 k Hz but is quite obvious at 3 k Hz and 6 k Hz, and the curves for the portland cement concrete pavements are above the 40 dB lower limit of the graph to 20 k Hz. It is probable that this high frequency noise is what is heard as the characteristic whine of the portland cement concrete pavements.

At sites 9 and 10 there are 3/4 inch (19 mm) longitudinal and transverse grooves, respectively, and the OASPL's for these sites are within 0.4 dB of each other. However, the noise caused by the transverse grooves seems louder or more pronounced than does the noise caused by the longitudinal grooves. The frequency analyses show that there are no well delineated pure tone peaks in the data for the longitudinal grooves, but there are pure tones at 160 Hz and 1,250 Hz in the data for the transverse grooves. Tones of 1,250 Hz are very noticeable to humans, thus the strong impression that the transverse grooves make is understandable.

CONCLUSIONS

The following conclusions are drawn from the discussion of the results.

1. The dimpled texture on the portland cement concrete pavement generated significantly more noise than all the other textures except the washed and sprinkled aggregate section.
2. The rough protruding aggregate surfaces on both bituminous and portland cement concrete pavements generated significantly higher intensity noise than did the non-protuberant bituminous and portland cement concrete surfaces.
3. The degree of protuberance parameter of pavements, as herein defined, has a greater effect on the intensity of the tire-road noise than do the other parameters such as aggregate type, flat mosaic aspect, density, and binder (bituminous or portland cement).
4. There was no significant difference between the intensity of the noise generated on the non-protuberant S-8, S-5, I-2 bituminous and grooved portland cement concrete pavements.
5. The noise generated on the portland cement concrete pavements measured has a greater intensity of high frequency noise than the noise on the bituminous pavements measured. The high frequency noise is more noticeable than low frequency noise and therefore, possibly more annoying than noise with a less intense high frequency component.
6. A noise with relatively pure tones of 1,000 Hz and greater, such as those generated on the 3/4-inch transverse grooved and the dimpled pavements, is more noticeable (annoying) than a noise of equal intensity that has no such pure tones.

RECOMMENDATIONS

At this stage of a report, when courses of action are to be considered based on the results and conclusions, it might be worthwhile to point out to the reader who is not familiar with sound that decibels are a logarithmic expression and are not directly additive. Thus if ten equal sound pressure levels from ten different sources are decreased by 1 dB the net effect on the total sound pressure level will not be a decrease of 10 dB but will be a decrease of only 1 dB.

In the introduction to this report it was mentioned that at moderate to high speed cruise conditions the tire-road noise is the principal source of car noise and one of the three main sources of heavy truck noise along with motor and exhaust noise. Thus, keeping the above caution in mind, it is clear that if automobile tire-road noise were decreased by 6 dB the total automobile contribution under cruise conditions would be decreased by close to 6 dB, and 5-6 dB is a very noticeable difference. While trucks were not studied, it is considered advisable to caution the reader against applying the same rationale to trucks. There are three sources of truck noise, and in the hypothetical situation where each of these sources are producing the same sound pressure level, decreasing one of the sources by 6 dB would decrease the overall noise level of the truck by only 1.2 dB.

The necessity for considering items such as cost, safety, and maintenance, in addition to environmental factors, in the construction and upkeep of a highway was also mentioned in the introduction to this report. Recommendations based only on noise should not be acted upon on the basis of their merits alone, but should be considered as they relate to or affect the above mentioned factors.

The following recommendations are made with the above thoughts in mind.

1. Do not use closed depressions in the texturing of portland cement concrete pavements because they provided the noisiest texture and they do not seem to efficiently drain water from the roadway surface so as to enhance skid resistance.
2. Be cautious about using protruding aggregate surfaces, especially in high density population centers, because they are significantly noisier than the other surfaces, with the exception of

the dimpled texture. However, it should be noted that because of the magnitude of the macro-asperities the protruding aggregate surfaces drain water freely and thus enhance skid resistance.

3. Be cautious about using transverse grooves on portland cement concrete pavements, especially in high density population centers, because they tend to create relatively pure tones in the frequency range that humans are most sensitive to. Be mindful, however, that transverse grooves are noted for channeling the water quickly from the pavement and thereby minimizing hydroplaning. (7)
4. Give preference to the use of S-8, S-5, and longitudinally grooved portland cement concrete pavements in high density population centers because they were the most quiet pavements and they also provide acceptable skid resistance.

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APPENDIX A
ANALYSIS OF THE MEANS

Table A-1
Means and Standard Deviations

Site	dB-Rib			dB-Snow			dBA-Rib			dBA-Snow		
	\bar{X}	Sx	n	\bar{X}	Sx	n	\bar{X}	Sx	n	\bar{X}	Sx	n
1	81.26	0.51	7	82.12	0.73	9	77.47	0.50	7	78.78	0.44	9
2	80.96	0.71	7	84.18	0.39	11	78.22	0.49	7	82.42	0.24	11
3	86.15	0.36	11	86.13	0.95	10	78.63	0.38	11	82.14	1.12	10
4	84.74	1.52	10	86.04	0.69	10	78.98	0.39	10	80.28	0.34	10
5	84.35	0.57	13	85.13	0.53	7	79.68	0.47	13	79.40	1.11	7
6	86.01	0.60	12	86.55	0.68	11	80.40	0.55	12	84.78	0.71	11
7	85.57	0.75	10	85.33	0.76	10	77.74	1.07	10	78.41	0.68	10
8	88.50	0.53	10	89.56	0.43	10	84.27	0.25	10	84.65	0.77	10
9	84.64	1.23	12	85.41	0.86	11	82.48	1.49	12	81.14	2.98	11
10				85.36	1.53	10				82.26	1.11	10
11												
12	83.58	2.18	11	87.80	0.64	10	79.57	3.37	11	86.32	0.94	10
13	85.12	1.40	10	85.52	0.88	9	80.70	1.24	10	83.70	0.50	9
14	81.14	1.56	10	86.14	0.79	12	79.63	2.20	10	84.43	1.69	12
15	88.90	1.56	10	86.83	1.08	11	85.76	2.02	10	84.48	0.68	11
16	90.53	0.53	10	89.02	0.52	10	86.92	0.94	10	85.13	0.95	10
17	87.63	0.57	10	88.48	0.39	6	82.06	0.43	10	83.07	0.43	6
18	89.00	0.43	10	89.33	0.50	10	83.74	0.53	10	84.67	0.66	10

The difference between means that is significant is computed as follows:

$$1. \text{ Compute } S_e^2 = (n_1 - 1) S_1^2 + (n_2 - 1) S_2^2 + \dots + (n_{16} - 1) S_{16}^2 / (n_1 + n_2 + \dots + n_{16}) - t$$

where t = number of sites.

2. Look up $q_{1-\alpha}(t, v)$, where $v = (n_1 + n_2 \dots n_{16})$ and $q_{1-\alpha}$ is given in Table A-10 on page T-21 of reference 6.

3. Then compute $w = q_{1-\alpha} S_e / n_H$ where $n_H = t / (1/n_1 + 1/n_2 \dots 1/n_{16})$.

The differences between means found to be significant are:

dB-Rib : (1) $S_e^2 = 1.17$, $S_e = 1.08$

(2) $q_{1-\alpha}(t, v) = 4.90$

(3) $n_H = 10.9$

(4) $w = 1.60$

dB-Snow: (1) $S_e^2 = 0.62$, $S_e = 0.79$

(2) $q_{1-\alpha}(t, v) = 4.95$

(3) $n_H = 9.56$

(4) $w = 1.26$

dBA-Rib: (1) $S_e^2 = 1.83$, $S_e = 1.35$

(2) $q_{1-\alpha}(t, v) = 4.90$

(3) $n_H = 10.9$

(4) $w = 2.00$

dBA-Snow: (1) $S_e^2 = 2.95$, $S_e = 1.56$

(2) $q_{1-\alpha}(t, v) = 4.95$

(3) $n_H = 9.56$

(4) $w = 2.50$

APPENDIX B

ONE-THIRD OCTAVE SPECTRA FOR TEN SITES

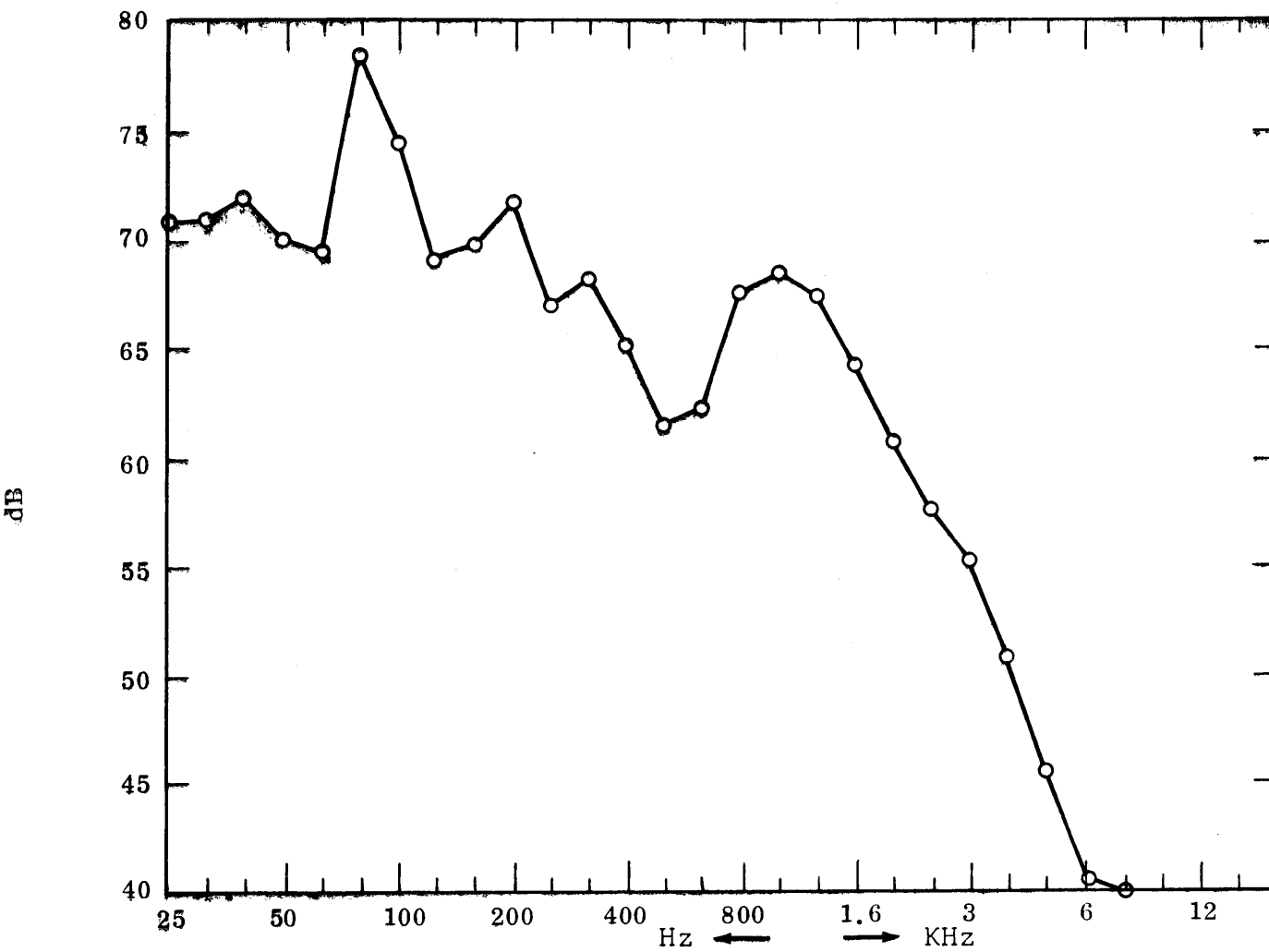


Figure B1. One-third octave spectrum of the maximum overall sound pressure level for site 3.

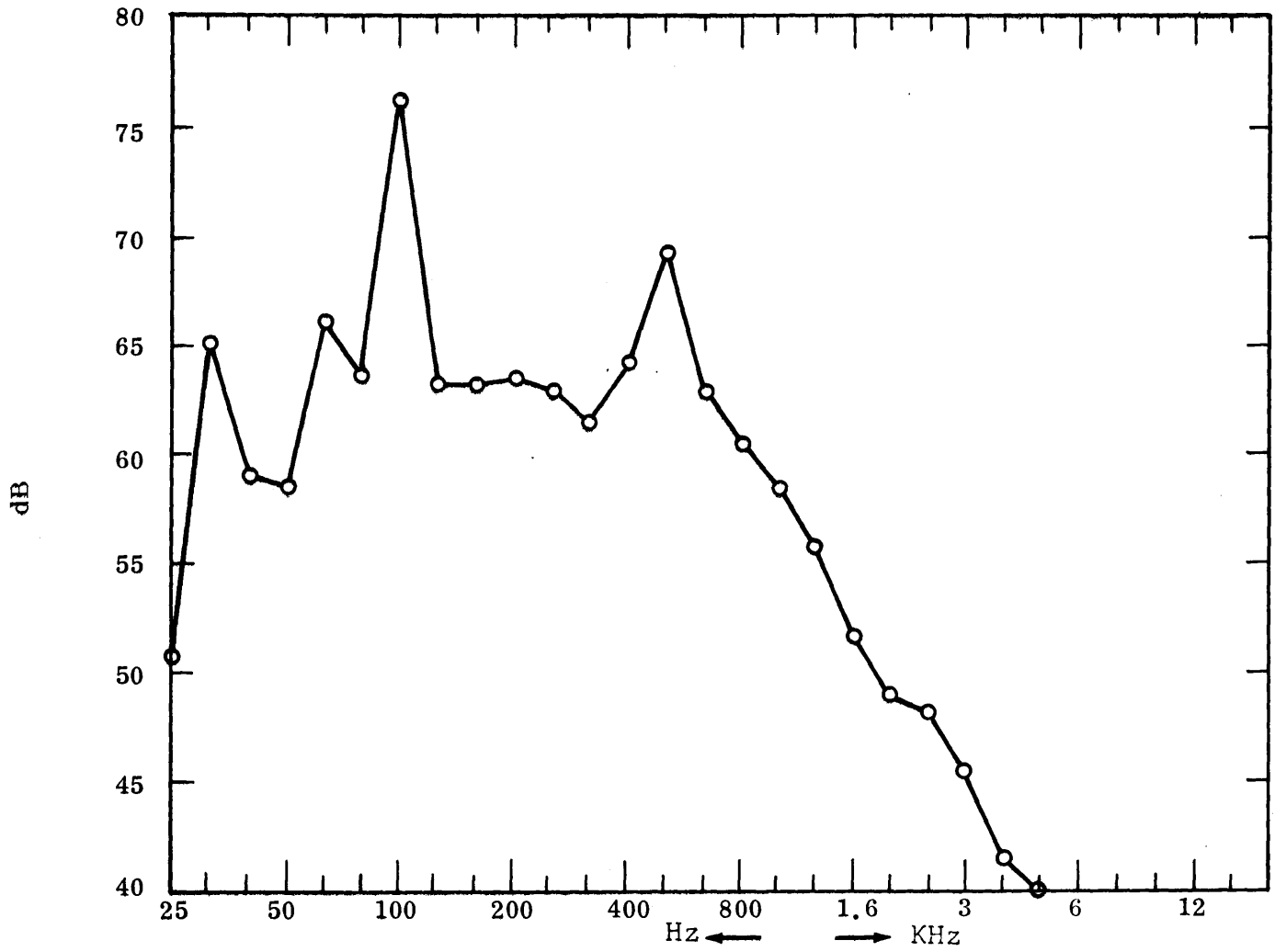


Figure B2. One-third octave spectrum of the maximum overall sound pressure level for site 4.

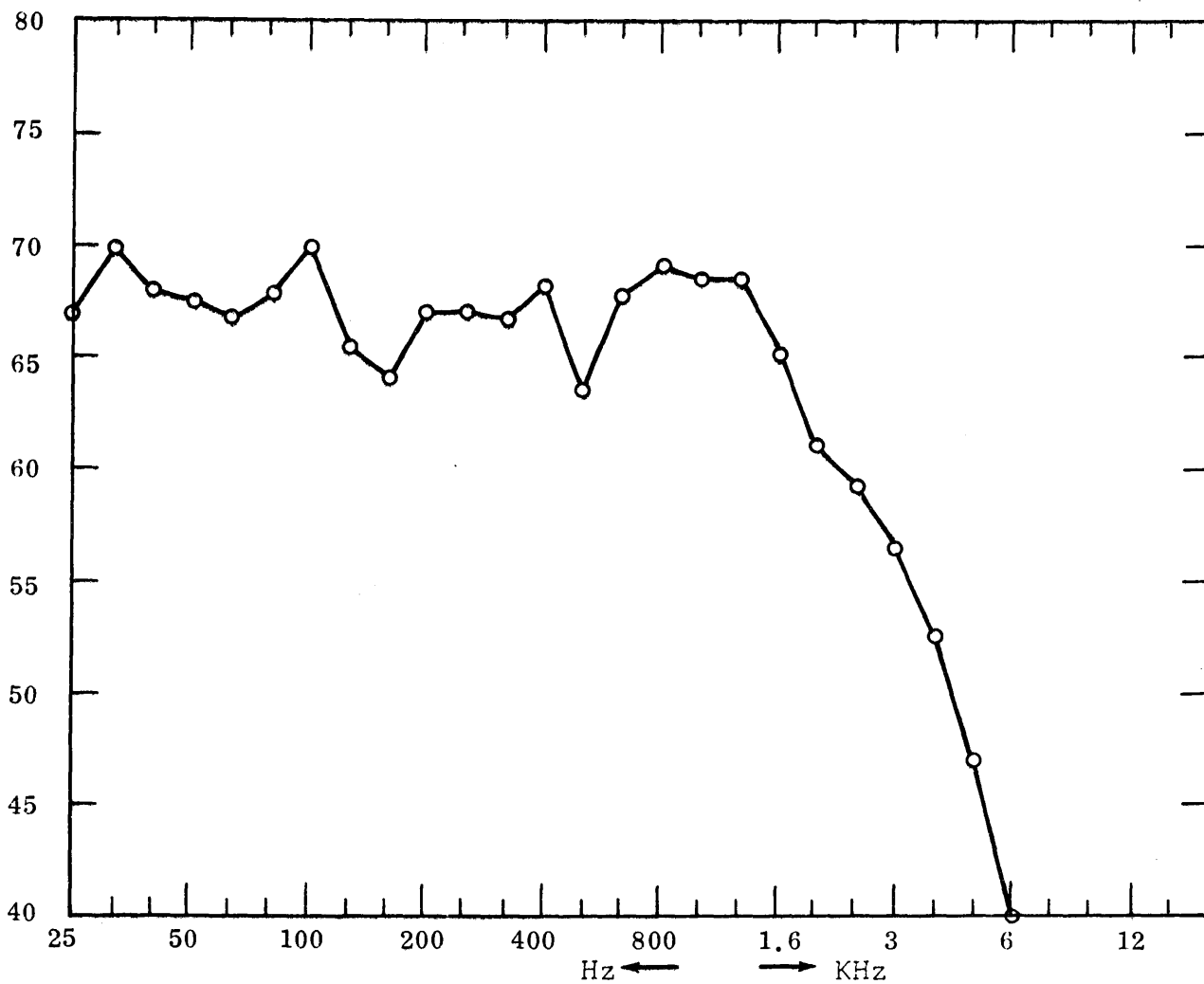


Figure B3. One-third octave spectrum of the maximum overall sound pressure level for site 5.

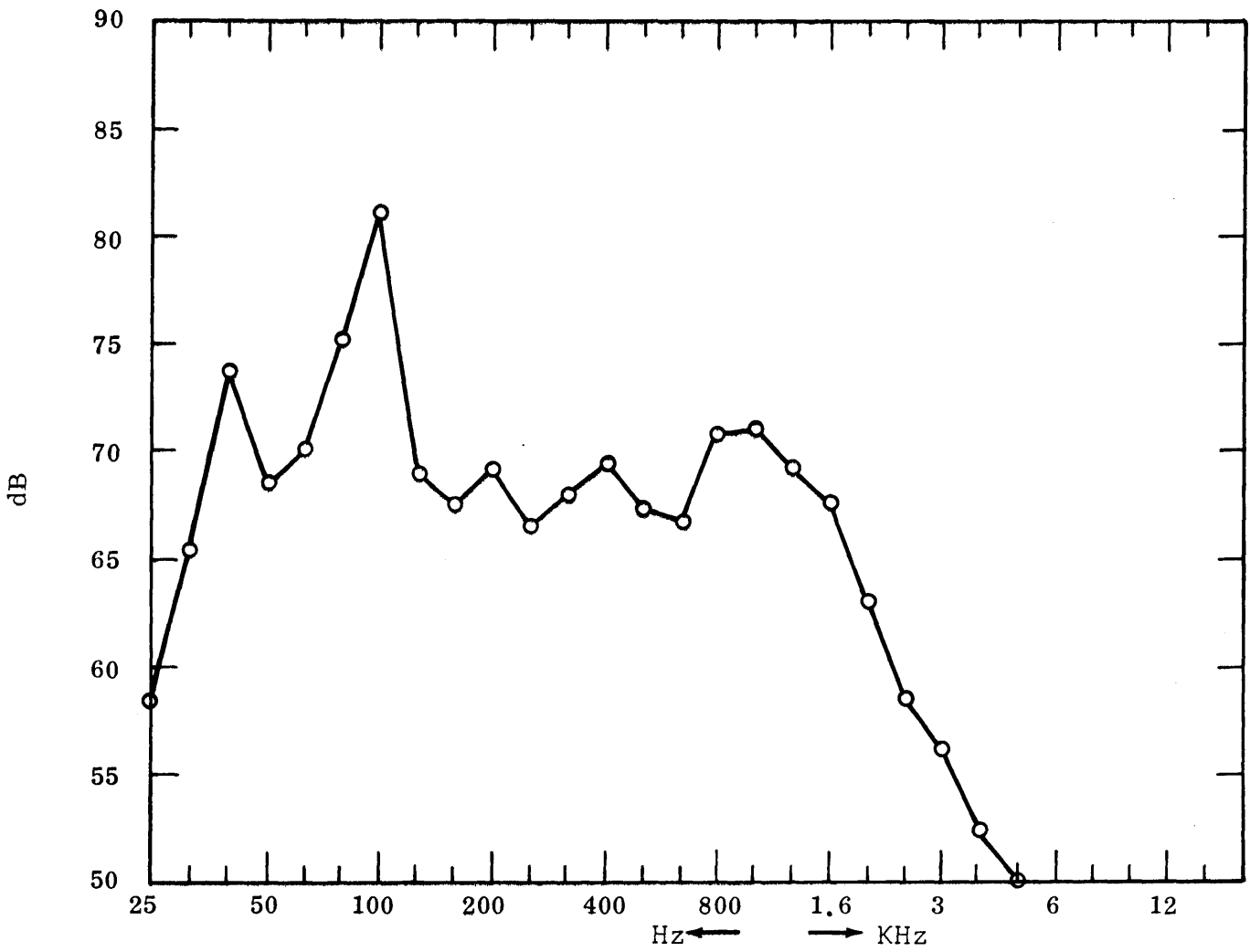


Figure B4. One-third octave spectrum of the maximum overall sound pressure level for site 6.

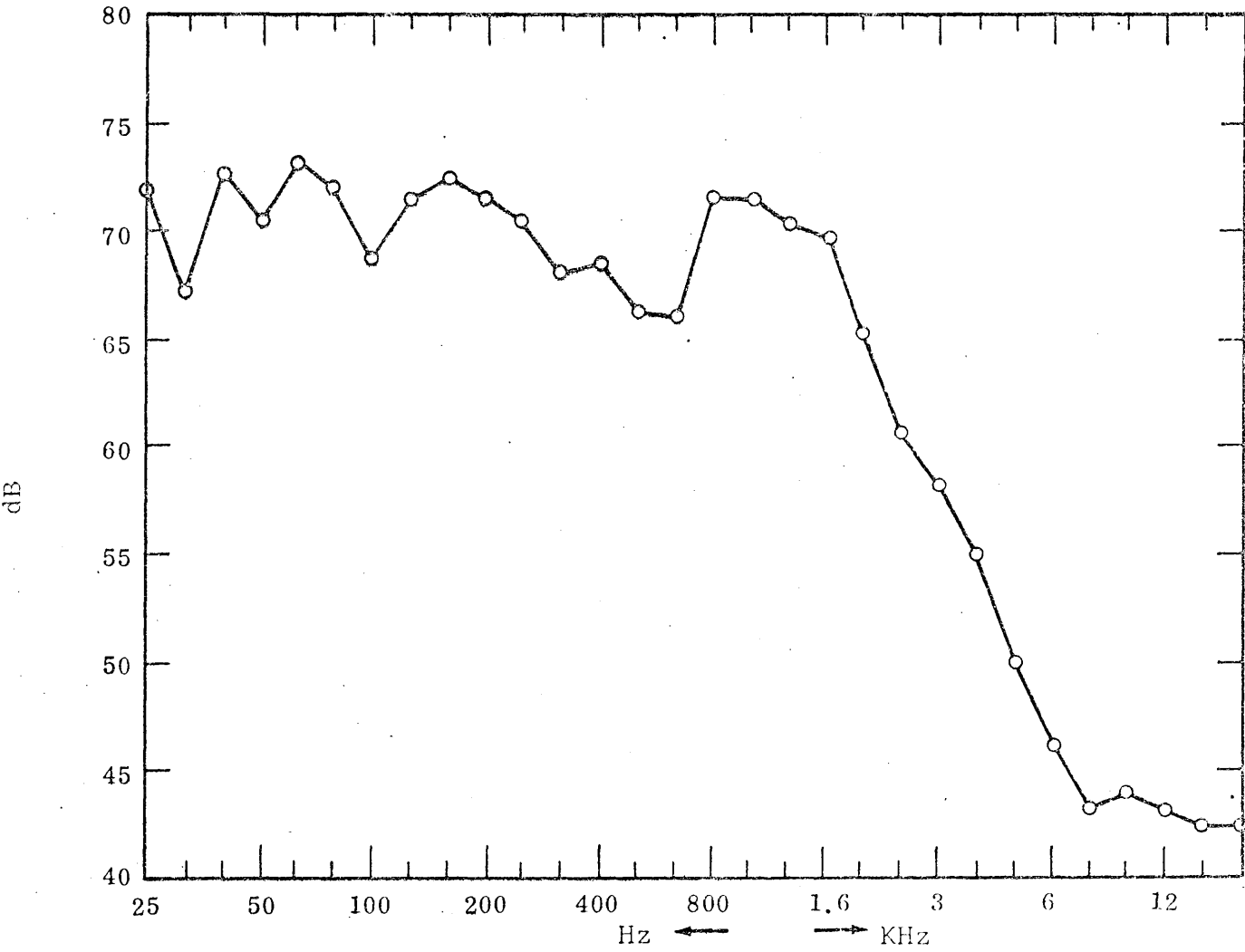


Figure B5. One-third octave spectrum of the maximum overall sound pressure level for site 9.

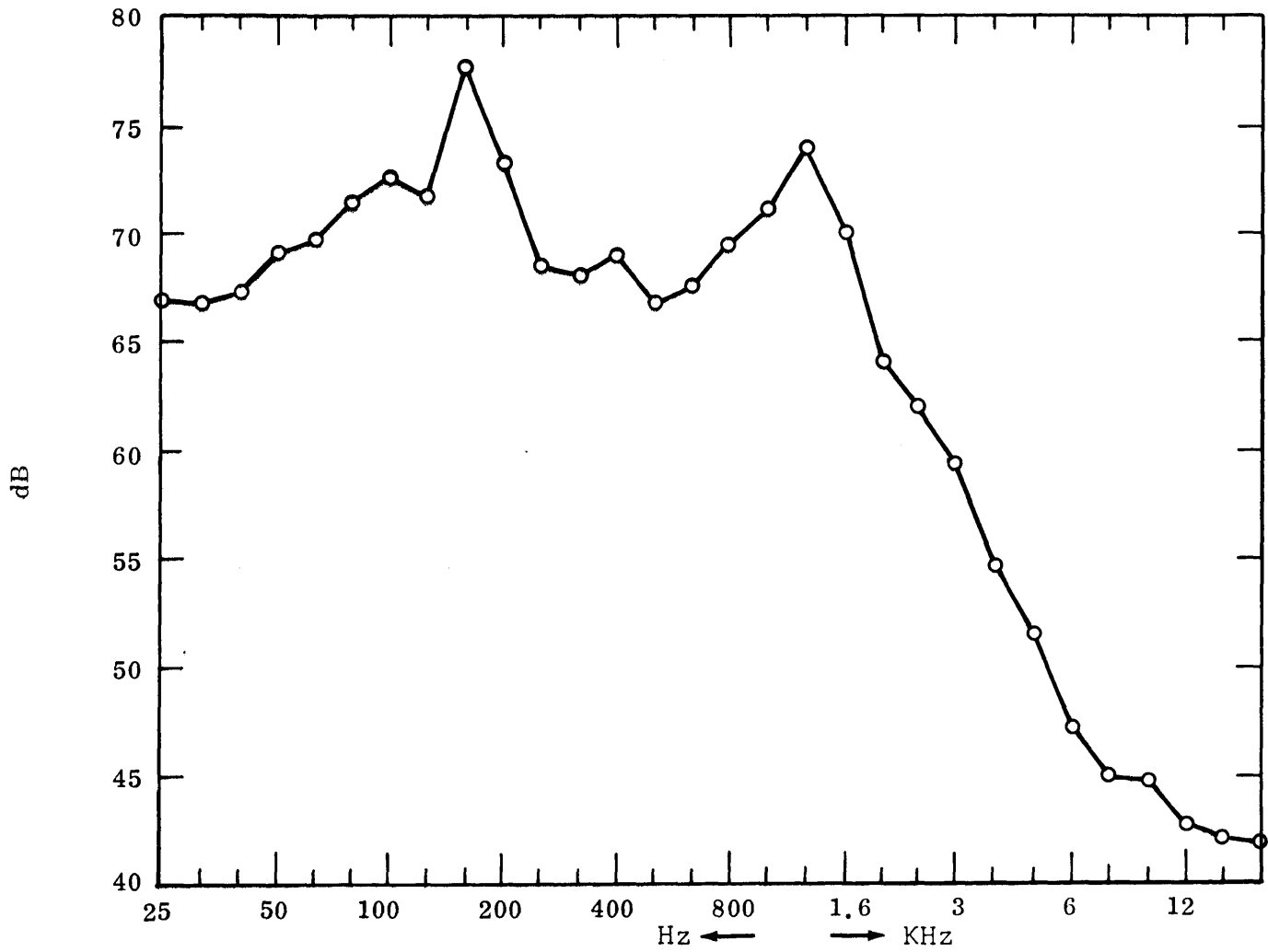


Figure B6. One-third octave spectrum of the maximum overall sound pressure level for site 10.

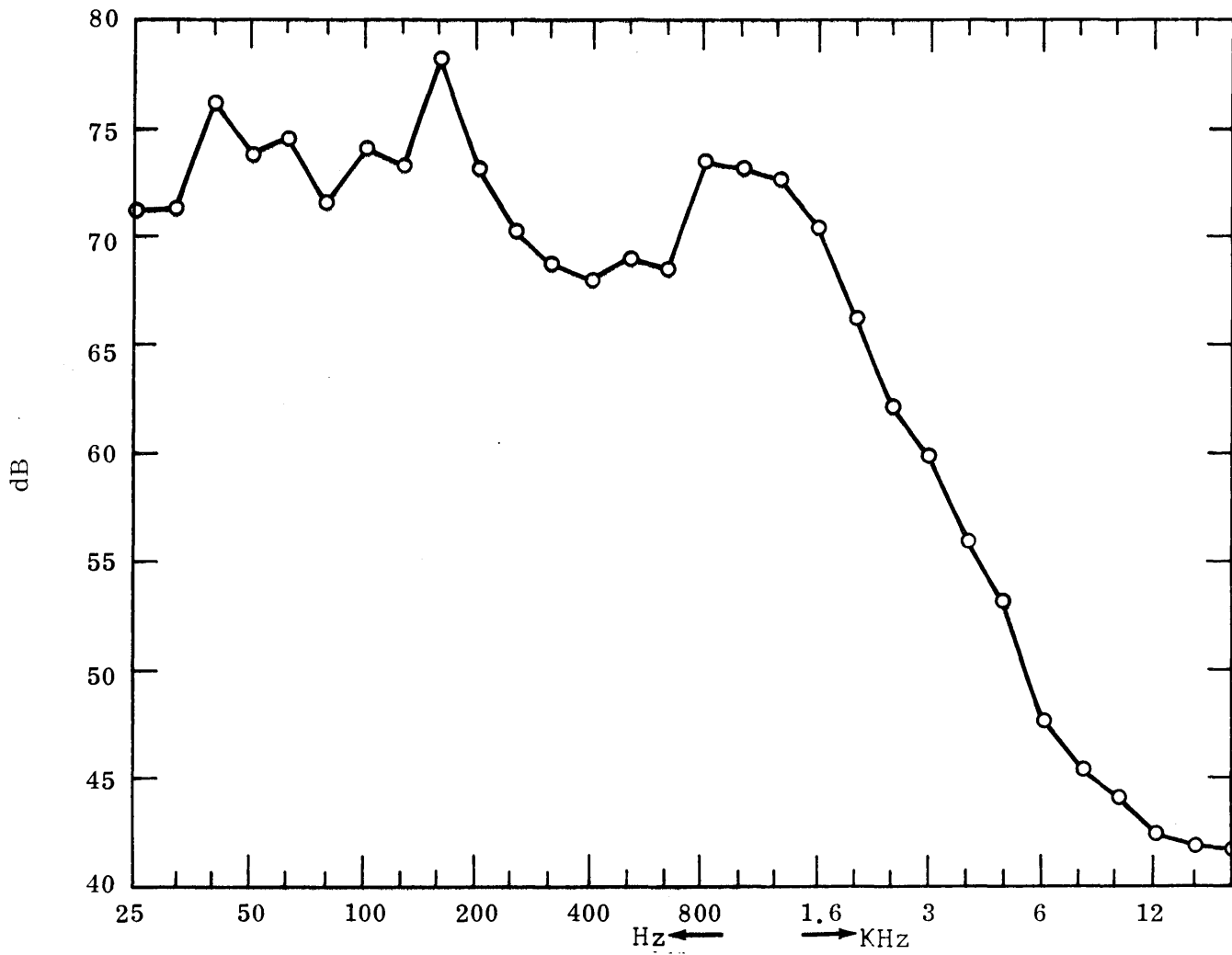


Figure B7. One-third octave spectrum of the maximum overall sound pressure level for site 13.

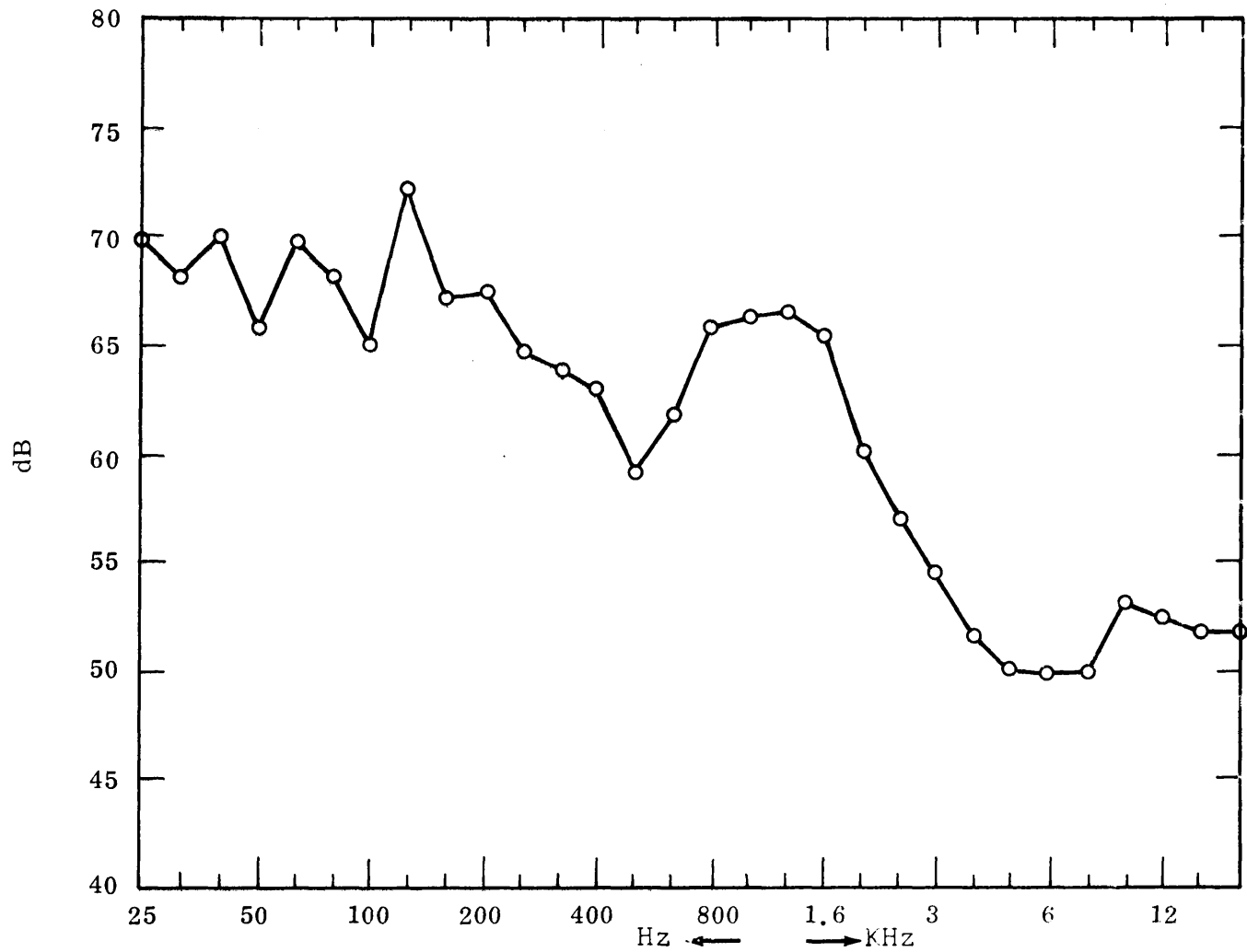


Figure B8. One-third octave spectrum of the maximum overall sound pressure level for site 14.

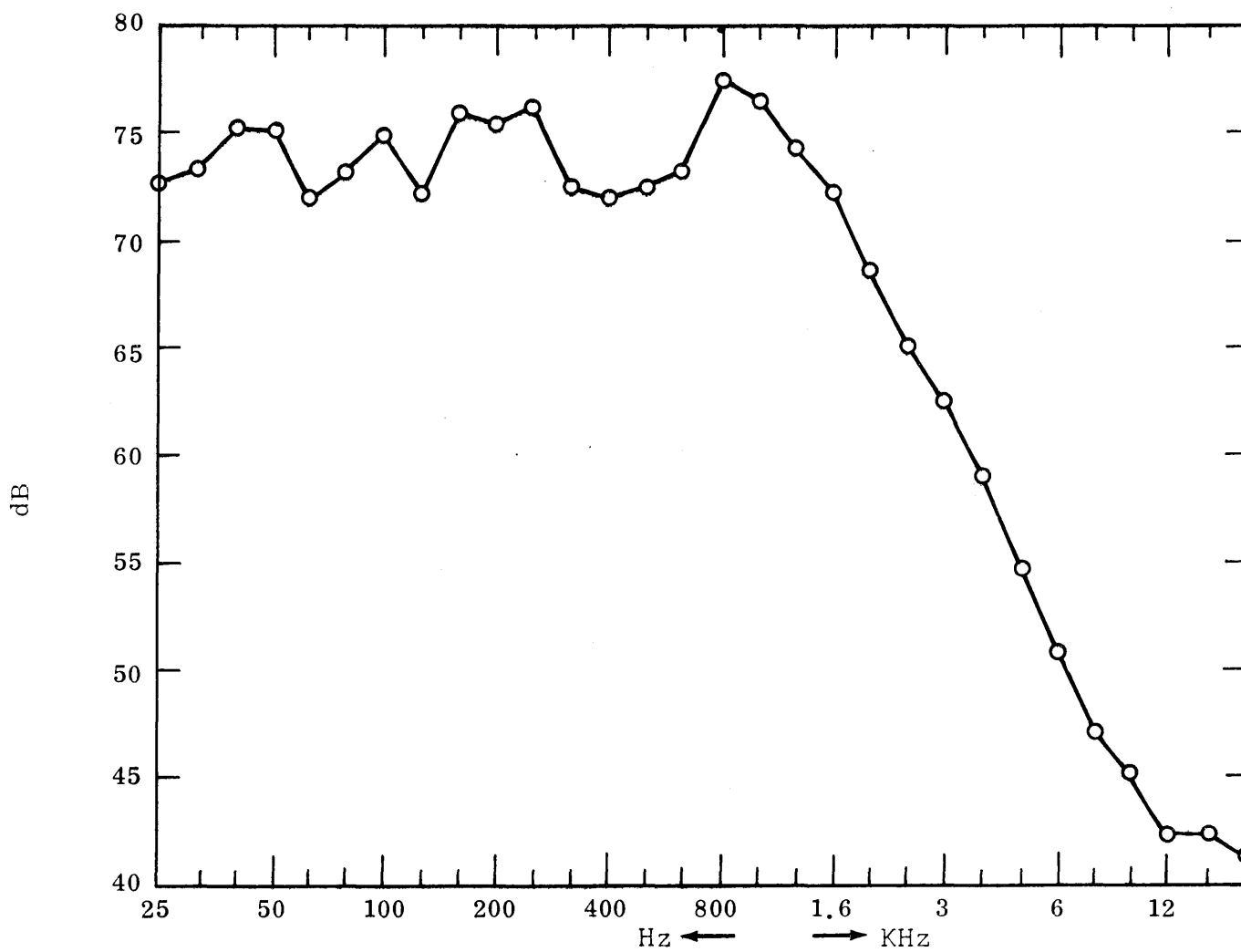


Figure B9. One-third octave spectrum of the maximum overall sound pressure level for site 15.

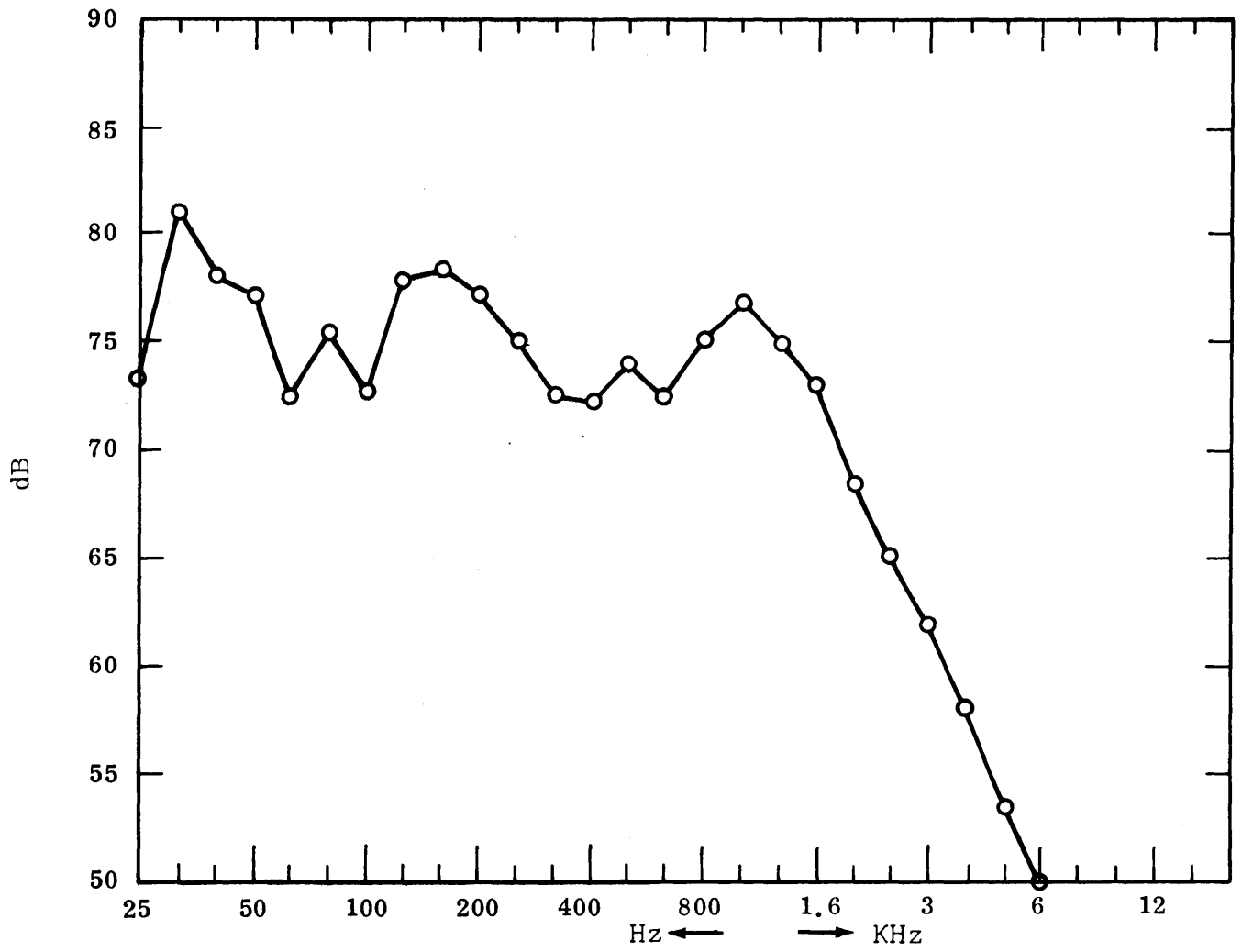


Figure B10. One-third octave spectrum of the maximum overall sound pressure level for site 16.