Field Testing of the Effectiveness of Open-Graded Asphalt Pavement in Reducing Tire Noise from Highway Vehicles

KENNETH D. POLCAK

Over the last several years, highway pavement rehabilitation projects have incorporated open-graded asphalt, also referred to as "popcorn pavement" for its skid-resistant properties. Subjective observations have noted a decrease in overall noise levels in areas where popcorn pavement has been used. The results are presented of a field testing program conducted in June 1989 along the Baltimore Beltway (I-695) to determine the difference in the overall noise level from typical highway traffic traveling on concrete versus open-graded asphalt pavement. Noise levels were measured simultaneously adjacent to the concrete and asphalt surfaces to determine the difference in noise level, and classified traffic counts were made to determine the effect of truck percentage in the traffic stream on the overall noise reduction attributable to the open-graded pavement. An analysis of the third-octave band frequency spectrum for traffic on the concrete and open-graded asphalt is also presented. The results showed a consistent 2- to 4-dBA reduction in the overall L_{eq} that could be attributed to the open-graded pavement. In the higher-frequency bands, 1,000 to 5,000 Hz, the third-octave band analysis showed a significant reduction (2 to 4 dB at 1,000 Hz to 6 to 7 dB at 2,000 to 4,000 Hz). Future studies are planned to expand the baseline data to include other ages and types of concrete and asphalt surfaces, as well as to determine whether aging of the pavement affects its noise reduction capacity.

Over the course of the last several years, the Maryland State Highway Administration (MSHA) has found the need to undertake numerous projects for rehabilitation of the aging Interstate highway system. The Interstate highways, many of which have existed since the early to mid-1960s, consist of mostly reinforced concrete slabs with expansion joints. The rehabilitation projects involving this type of road surface have utilized a system of asphalt overlays coupled with rigid joint replacement. The existing concrete road surface is milled or grooved before the overlay of asphalt.

A part of the overall goal of the rehabilitation projects is to improve safety. The type of asphalt surface that has been used in a number of locations is an open-graded asphalt mix, which was originally developed as a skid-resistant surface to reduce hydroplaning of tires on wet pavement. This type of surface has also been referred to as "popcorn pavement." Several layers of impervious asphalt are first laid, with the final course a ¾-in. layer of the porous open-graded mix.

Subjective observations have been received from both the public and agency personnel indicating a decrease in noise levels in areas where popcorn pavement has been used. The observations described comparisons between concrete and asphalt surfaces. Some observations indicated that the overall noise level adjacent to the highway was reduced with the asphalt resurfacing, whereas others described a change in the character of the noise. When it was riding on the asphalt surface, noise levels inside the vehicle also seemed to be reduced.

This report presents the results of a field testing program conducted in June 1989 along the Baltimore Beltway (I-695) to document the differences in the overall characteristics of the noise emissions from typical highway traffic traveling on concrete versus open-graded asphalt pavement.

Maryland State Highway Administration, Landscape Architecture Division, 707 N. Calvert St., Baltimore, Md. 21202.

SITE SELECTION AND CRITERIA

The first task involved in this study was to find suitable sites on which to conduct the comparison of the two pavement types. The goal in the site selection process was to find sites that would allow for the most direct comparison of the field data without the need for computer simulations or adjustments to account for variations in traffic flow (such as volume, speed, and vehicle mix) or terrain features.

The most direct comparison would be accomplished with sites with uncomplicated yet similar geometry adjacent to a straight roadway section with minimal or no grade. To avoid variations in the traffic parameters, sites were sought along the Interstate system where traffic speeds were high and relatively constant and where the pavement transition between the concrete and asphalt surfaces occurred between interchanges.

Site selection criteria were based on acceptable FHWA procedures (*1*).

SITE DESCRIPTION

One area was identified that met the selection criteria. The area is located west of Baltimore, along I-695 between the interchanges for US Route 40 and I-70 (see Figure 1). The present highway consists of a six-lane section with auxiliary lanes in both directions, and is oriented in a north-south direction. Resurfacing with open-graded asphalt pavement was completed in 1984 and ended approximately midway between the two interchanges. The asphalt surface tested was approximately 4½ years old. The remaining section of road has a

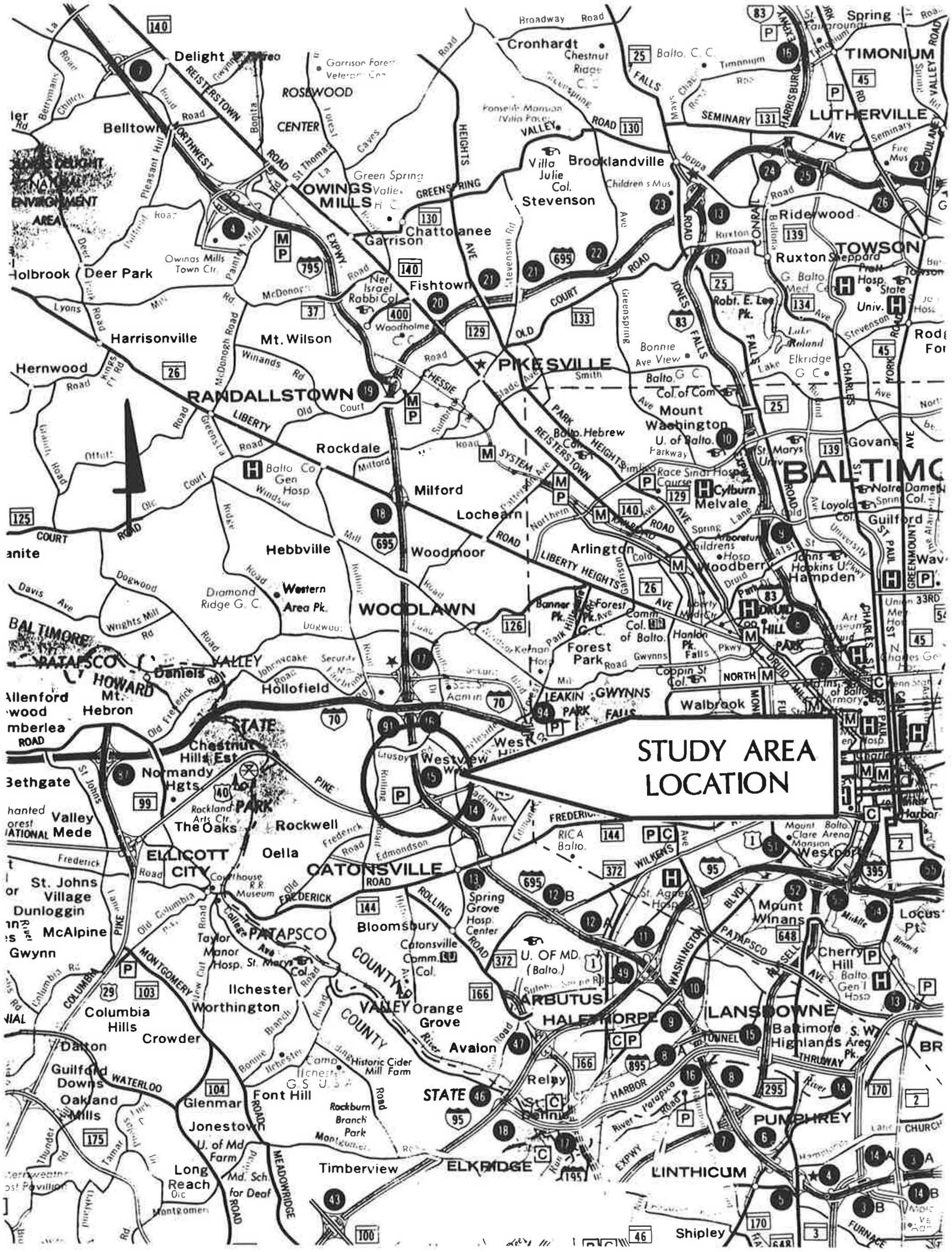

FIGURE 1 Study area location.

reinforced-concrete surface, which was about 25 years old at the time of the study. The road section dates back to 1962 and 1966 (when a lane in each direction was added to the median of the original roadway). A slight upgrade of 1.5 to 2 percent was noted in the southbound direction. The grade as noted was determined to be acceptable on the basis of FHWA criteria (*1*).

The surface of the concrete pavement is severely eroded, with the aggregate readily visible. Although some uneven joints between the pavement slabs were noted, none of the measurement sites was in close proximity to these areas. The asphalt surface was in good condition with no notable surface irregularities.

For the study, four sites were selected, two on each side of the highway. Figure 2 shows the relationship of the various test sites. Sites 1 and 4 are adjacent to the asphalt pavement section, and Sites 2 and 3 are adjacent to the concrete pavement. The reason for selecting sites on both sides of the highway was to determine the effect, if any, of the upgrade on the southbound roadway. Each measurement site was located 50 ft from the centerline of the closest travel lane and a minimum of 470 ft from the pavement transition point. The sites were chosen as far from the pavement transition point as possible to minimize noise influence from the adjacent pavement. Figure 3 shows a cross-sectional view of Sites 1 and 2 (northbound side), and Figure 4 gives a similar view of Sites 3 and 4 (southbound side).

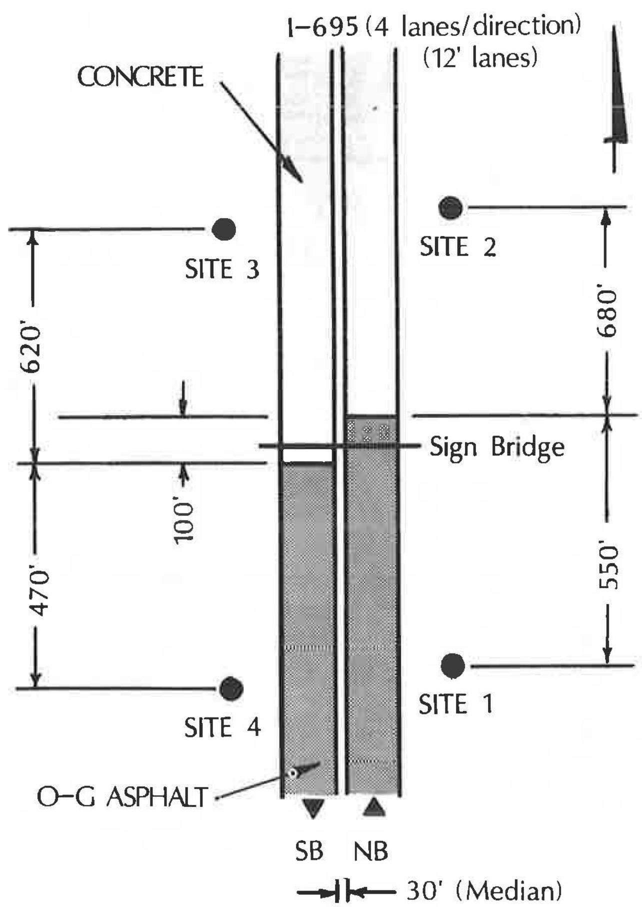

FIGURE 2 Site diagram.

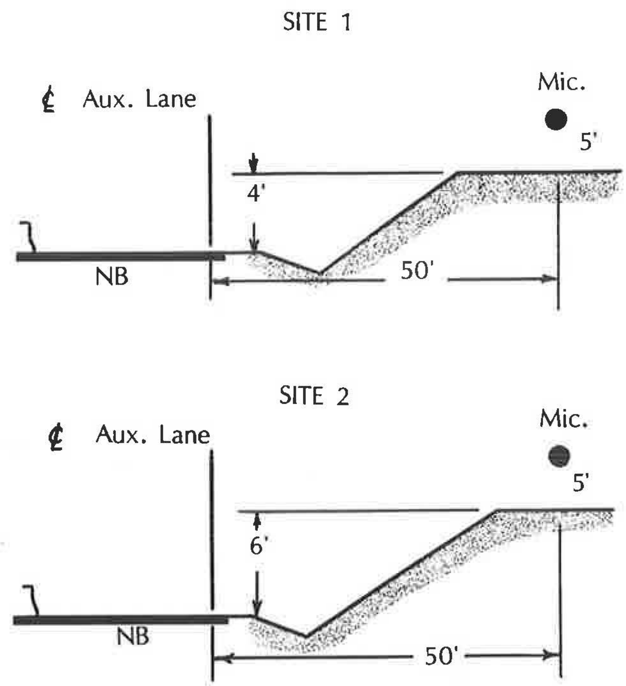

FIGURE 3 Cross sections of measurement Sites 1 and 2 along northbound roadway.

The geometrics between Sites 1 and 2 were considered acceptable on the basis of FHWA criteria (*1*) in that the intervening ground at both sites was grassy and the effective height of the microphones above the pavement elevation was similar, ranging approximately 9 to 11 ft.

The elevation at Sites 3 and 4 was such that the effective microphone height above the pavement elevation was more on the order of about 4 ft. The drainage ditch that runs parallel to the highway (as shown in Figure 4) is present at both sites; however, the ditch is lined with concrete in front of Site 3 and gets progressively deeper toward Site 4. This dissimilarity was considered a possible source of reflections at Site 3, particularly in the third-octave band study. At Site 4, the ditch is depressed sufficiently below the level of the road so that the potential for reflections is minimal. Consistency with the results from Sites 1 and 2 would be examined to validate or discount the data results gathered at Sites 3 and 4.

INSTRUMENTATION

The sound-level meters (SLMs) used in this study were Metrosonics Model dB-308 Metrologgers and meet specifications for Type I SLMs in accordance with ANSI S1.4. Each microphone was located 5 ft (±0.5 ft) above the ground. The tests yielded A-weighted L_{eq} noise levels at each of the four sites. Calibration of each meter was performed before and after each monitoring session.

In addition to the A-weighted L_{eq} measurements, a third-octave band analysis was also conducted at the same four sites to examine the frequency content of the overall noise emissions from the same traffic on the two pavement types. Output from a Bruel & Kjaer (B&K) Type 2231 modular precision SLM was fed to a B&K Type 2515 vibration analyzer, which

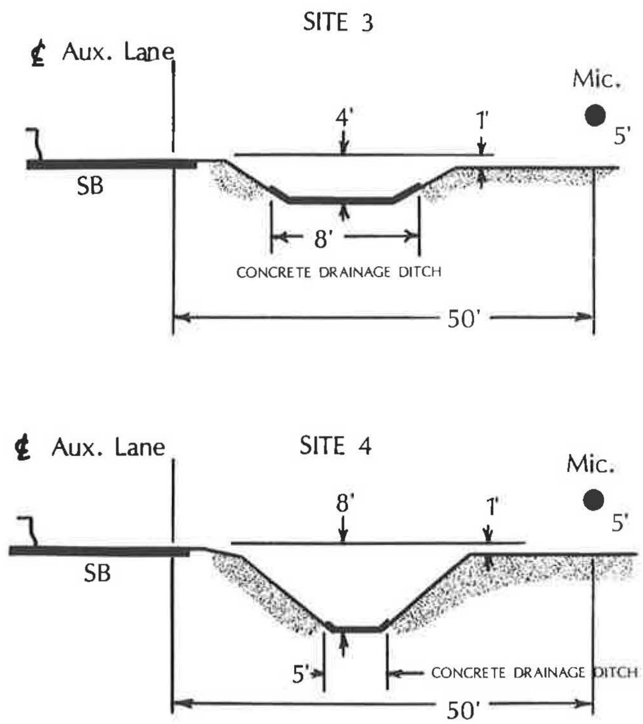

FIGURE 4 Cross sections of measurement Sites 3 and 4 along southbound roadway.

is a single-channel fast Fourier transform analyzer. The L_{eq} for each test was also obtained for comparison with the other data. Microphone heights and locations were identical to those in the A-weighted L_{eq} tests. Calibration was also conducted before and after the test session.

FIELD MEASUREMENTS

The study was conducted in two parts. The first part involved simultaneous measurement of the A-weighted sound levels at all four sites. In the second part of the study a third-octave band spectrum of noise emissions from traffic was obtained for the asphalt versus the concrete pavement.

L_{eq} noise level data were gathered for consecutive 5-min intervals for a total period of 1 hr on two different days. Simultaneously with each measurement interval, classified traffic counts were made identifying automobile, medium trucks, and heavy-duty trucks as defined by FHWA (*1*) to document the percentage of trucks in the traffic stream. Also, random checks of travel speeds of the overall traffic stream were made during each test.

For the third-octave band analysis, Sites 1 through 4 were monitored at the same locations as in Part 1 of the study. It was decided to use the same 5-min test interval as a starting point to be consistent with Part 1. During the initial test, the various third-octave band levels were observed on the analyzer's CRT screen to determine whether the 5-min test interval would yield a stable third-octave band spectrum. The CRT display stabilized after approximately 3 min. Therefore, the 5-min test interval was deemed acceptable, and was also used for the other three sites. At the end of each test interval, a printout of the third-octave band spectrum and the A-weighted L_{eq} noise level was obtained.

RESULTS

A-Weighted L_{eq}

The results of Part 1 of the study are presented in Table 1, which shows the 5-min L_{eq} noise level for each test interval and the corresponding traffic count (for both directions). In addition, the cumulative 1-hr L_{eq} is also given.

For Sites 1 and 2 (along the northbound side), the L_{eq} noise level for traffic on the asphalt pavement (Site 1) was 2.1 to 4.0 dBA less than the level for the same traffic on the concrete pavement (Site 2). The difference in the 1-hr L_{eq} was 2.8 to 2.9 dBA.

Similarly, at Sites 3 and 4 (southbound side), the L_{eq} level for traffic on the asphalt section was 2.3 to 3.6 dBA less than the same traffic on the concrete section. The difference in the 1-hr L_{eq} was 2.9 to 3.1 dBA.

During these tests, the random speed checks noted that the majority of the vehicles were traveling 55 to 65 mph consistently for all the tests.

There was some concern regarding the distance between the sites and the lag time (the time it takes for each vehicle to pass both sites), and the possibility that lane changes might change the individual vehicle-to-microphone distance. However, the large number of test intervals and the consistency of the data seem to indicate that these factors were not a significant source of potential error.

The traffic data gathered concurrently with the noise measurements were then analyzed to determine whether any correlation existed between the noise reduction between the two pavement sections and a variation in the percentage of trucks. The hypothesis is that because trucks have two other major noise-producing components (engine and exhaust) in addition to tire noise, an increase in the number of trucks in the traffic stream may offset some of the reduction of the tire noise component obtained with the open-graded asphalt pavement, thus making it a less effective option for situations in which large percentages of trucks are found. Figures 5 and 6 show plots of the noise reduction attributable to the open-graded surface against the percentage of trucks counted during each measurement interval. The scattering of the values shows no clear trend supporting the hypothesis. It is suspected that the wide variation in noise emission levels of individual trucks in the general truck population is overriding the effect caused by increases or decreases in the number of vehicles, and that the engine and exhaust noise from the trucks is still a major contributor to the overall level.

Third-Octave Band Analysis

For this part of the study, comparisons of the third-octave band spectra were made between Sites 1 and 2, and between Sites 3 and 4. Figures 7 and 8 present the data. In both cases, significant reductions were noted in the higher-frequency bands (1,000 to 5,000 Hz). At Site 1 adjacent to the asphalt pavement, a reduction of 3 to 4 dB was seen at 1,000 Hz and 6 to 7 dB in the 2,000- to 4,000-Hz range compared with Site

TABLE 1 PAVEMENT NOISE TEST SERIES 1 AND 2 DATA FOR BALTIMORE BELTWAY (I-695) BETWEEN U.S. 40 AND I-70

TIME	TRAFFIC DATA			Leq NOISE LEVELS (dBA) - 5 MINUTE INTERVALS					
	AUTOS	MT	HT	SITE 1	SITE 2	DIFF. (1-2)	SITE 3	SITE 4	DIFF. (3-4)
2:00	600	48	64	78.5	82.0	3.5	80.5	77.9	2.6
2:05	581	38	42	77.2	79.9	2.7	78.6	75.0	3.6
2:10	698	32	70	77.7	80.5	2.8	79.2	76.1	3.1
2:15	660	41	57	77.2	79.7	2.5	79.0	75.5	3.5
2:20	677	45	44	77.4	79.5	2.1	78.8	75.3	3.5
2;25	675	35	64	77.5	80.4	2.9	79.7	76.8	2.9
2:30	641	24	48	77.9	80.3	2.4	78.6	75.7	2.9
2:35	748	39	67	78.3	81.4	3.1	78.7	75.7	3.0
2:40	796	45	64	77.7	80.3	2.6	79.0	76.0	3.0
2:45	678	36	38	77.3	79.6	2.3	78.3	75.0	3.3
2:50	853	23	47	78.0	81.3	3.3	78.5	75.3	3.2
2:55	890	43	60	77.6	80.7	3.1	79.5	76.2	3.3
CUMULATIVE Leq(h) -				77.7	80.5	2.8	79.1	76.0	3.1
11:30	580	17	76	77.7	80.2	2.5	77.7	75.2	2.5
11:35	577	33	64	76.4	79.1	2.7	77.7	74.9	2.8
11:40	590	31	65	77.3	80.0	2.7	78.5	75.2	3.3
11:45	632	23	70	77.4	81.4	4.0	78.1	75.2	2.9
11:50	636	34	60	76.7	79.4	2.7	77.3	74.3	3.0
11:55	601	28	58	76.7	79.6	2.9	78.0	74.9	3.1
12:00 N	598	28	60	77.1	79.9	2.8	78.0	75.2	2.8
12:05	620	30	51	77.0	80.4	3.4	77.4	74.1	3.3
12:10	643	23	67	77.1	79.9	2.8	77.0	74.4	2.6
12:15	627	29	46	76.2	78.5	2.3	77.6	74.4	3.2
12:20	599	36	45	76.8	79.6	2.8	77.7	75.4	2.3
12:25	621	17	67	77.1	79.9	2.8	78.2	75.6	2.6
CUMULATIVE Leq(h) -				77.0	79.9	2.9	77.8	74.9	2.9

2 adjacent to the concrete pavement. Similarly, between Sites 3 and 4, a 2-dB reduction at 1,000 Hz and a 7-dB reduction at 2,000 Hz were attributable to the asphalt surface.

Corresponding A-weighted L_{eq} levels for the same tests showed a reduction of 3 to 4 dBA attributable to the asphalt surface.

EVALUATION OF RESULTS AND CONCLUSIONS

The results of the L_{eq} noise level comparison showed a consistent 2- to 4-dBA reduction that could be attributable to the 4½-year-old open-graded asphalt surface in this study location. Table 2 presents a summary of the data from the study.

Earlier studies by FHWA (*2*) involving comparison of various pavement types and different tire tread designs showed a 2-dBA reduction in the average noise level with all types of tire tread designs considered together. The reduction was attributed to the open-graded asphalt surface as compared with portland cement concrete pavement.

A substantial reduction in the high-frequency content of noise from traffic on open-graded asphalt was noted compared with the same traffic on concrete pavement. Given that individuals are more sensitive to high-frequency sound, this may indeed explain the positive responses, which seem to be greater than would be anticipated if one only considered the reduction in the L_{eq} noise level.

For this series of tests, no correlation was found between the variation in truck percentage and the noise reduction effects attributable to the open-graded asphalt surface. The additional components of engine and exhaust noise, which still make the truck noise dominant, and the wide variation in noise emission levels of trucks in the traffic stream seem to offset the effect of changes in the number of trucks. It is suspected that a wider variation in truck percentage than was seen in this study would be needed to establish a correlation.

Additional study that is needed relative to this topic is as follows:

- Expanding the data base to include more sites, and additional testing at the original test sites to cover different seasons of the year (to study site vegetation effects).
- More testing involving only automobiles, or small fractions (1 to 2 percent) of trucks, to more closely identify how much reduction in tire noise can be obtained by using open-graded asphalt pavement.
- Developing more data for a wider range of vehicle speeds, pavement types, and pavements of differing ages.
- Monitoring the effects of aging on the noise reduction capacity of the open-graded pavement.

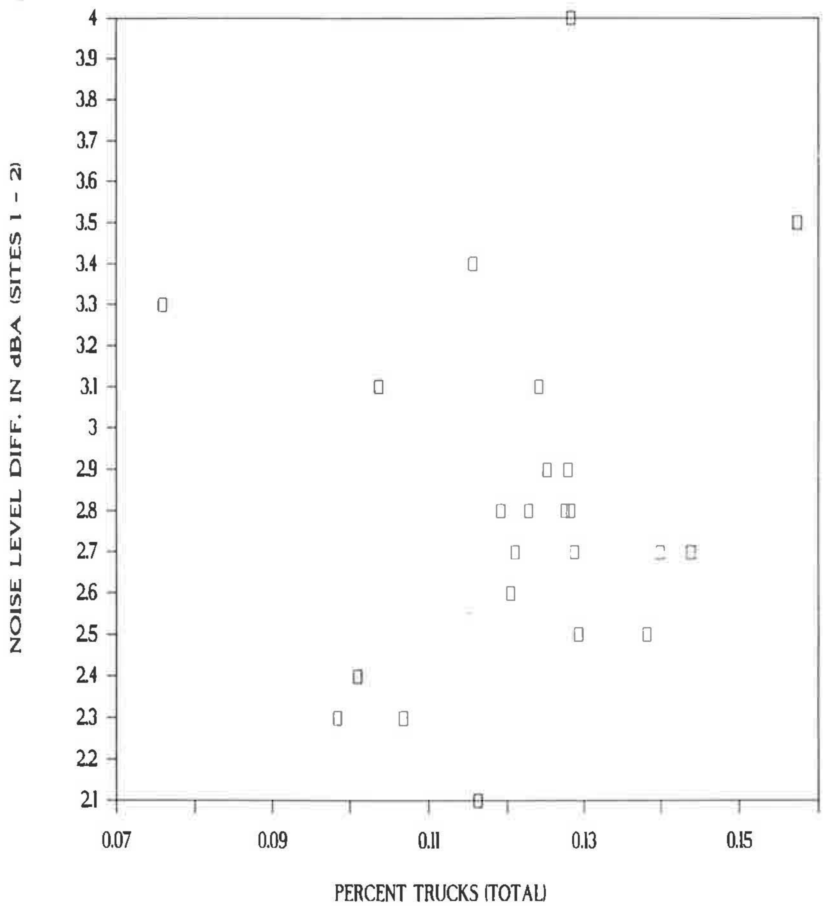

FIGURE 5 Comparison of truck percentage and the measured noise level difference between Sites 1 and 2.

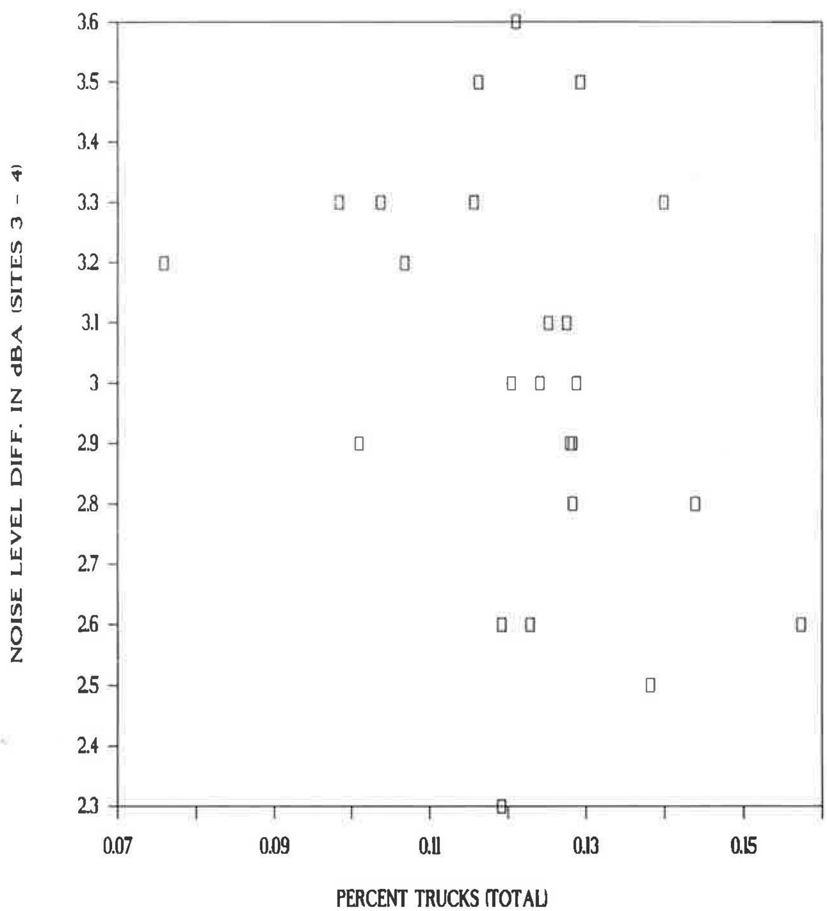

FIGURE 6 Comparison of truck percentage and the measured noise level difference between Sites 3 and 4.

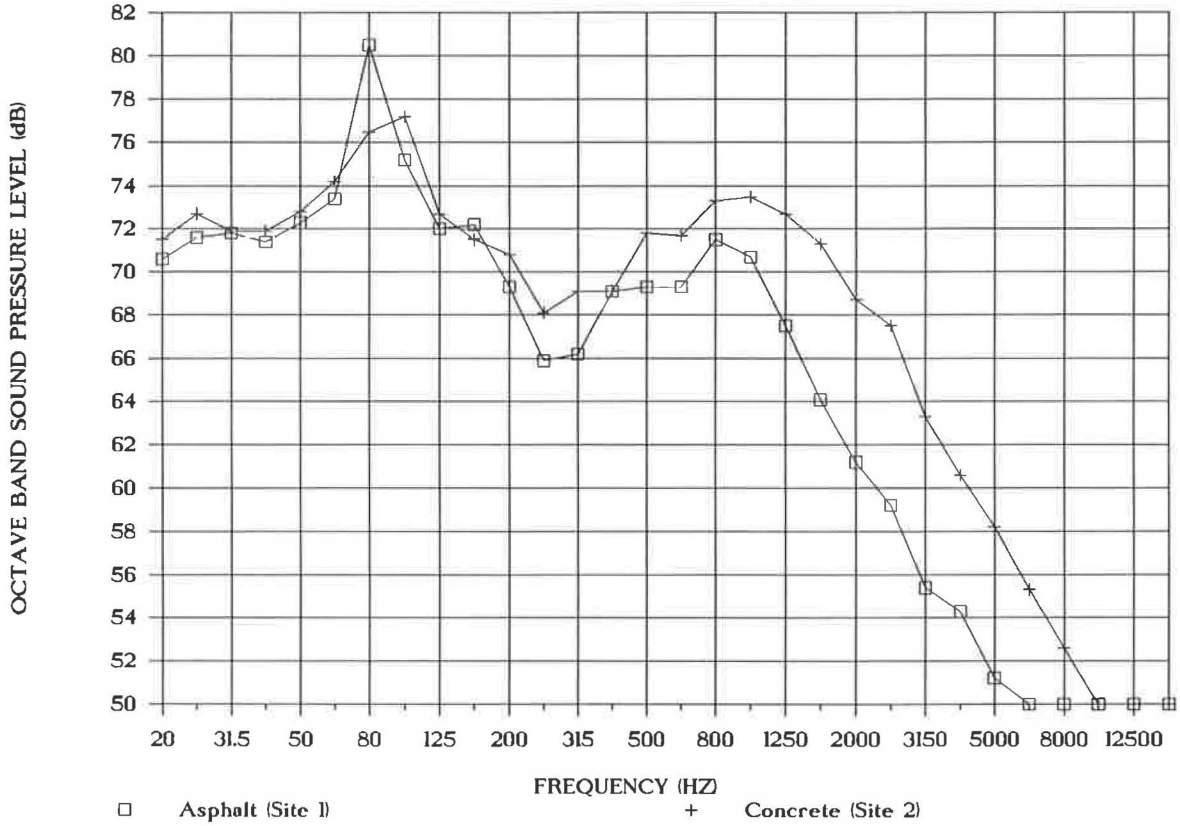

FIGURE 7 Comparison of the third-octave band spectra for Sites 1 and 2.

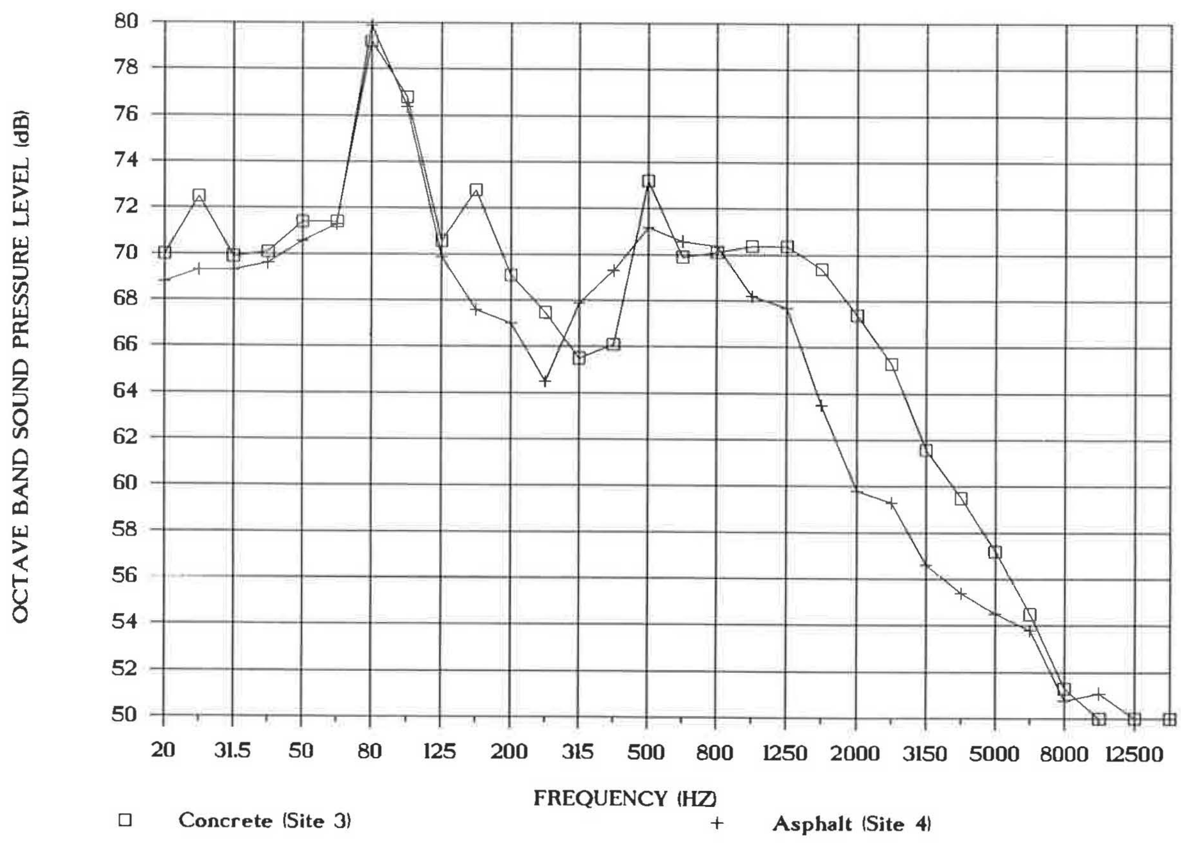

FIGURE 8 Comparison of the third-octave band spectra for Sites 3 and 4.

TABLE 2 SUMMARY OF RESULTS: COMPARATIVE MEASUREMENT OF L_{eq} NOISE LEVEL FROM TRAFFIC ON CONCRETE VERSUS OPEN-GRADED ASPHALT PAVEMENT

Site	$L_{eq}(5)$(dBA) Measured	Calculated[a]	Cumulative L_{eq}(h)(dBA)
1—asphalt	76–79	77	77–78
2—concrete	79–82	81	80–81
L_{eq} difference	2–4	4	3
3—concrete	77–81	79	78–79
4—asphalt	74–78	76	75–76
L_{eq} difference	2–4	3	3

[a]Obtained from the third-octave band spectrum analysis data.

- Evaluating the cost-effectiveness of using open-graded pavement as a noise abatement measure.

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