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Experimental Study of the Effect of the Difference Between "Hard" and "Soft" Ground Surfaces on Truck Noise Measurements

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EXPERIMENTAL STUDY OF THE EFFECT OF THE DIFFERENCE BETWEEN "HARD" AND "SOFT" GROUND SURFACES ON TRUCK NOISE MEASUREMENTS

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ABSTRACT

Data on truck noise measurements have been gathered for two trucks, operating in accordance with the Bureau of Motor Carrier Safety Noise Regulations, over "hard" and "soft" sites, and for various intermediate surface conditions. The results, averaged for all operating conditions, indicate a difference between hard and soft sites that increases with both the percentage of site hardness and with microphone distance. The generally accepted difference of + 2 dB(A) between hard-site and soft-site data specified in the BMCS regulations is seen to be approximately correct for IMI tests, but about 1 dB(A) low for passby tests at 50 ft. These results confirm those reported by other investigators.

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1. INTRODUCTION

The Department of Transportation Bureau of Motor Carrier Safety Regulations for Enforcement of Motor Carrier Noise Emission Standards (49 CFR 325) specify in some detail the requirements for sites at which motor carrier noise is to be measured for enforcement purposes. Included in these requirements are the provisions that measurements must be made between 35 and 83 ft (10.7 m and 25.3 m) away from the center line of the traffic lane traveled by the vehicle and that the results are to be interpreted differently for "hard" and "soft" sites.

The regulations define a "hard" site as "any test site having the ground surface covered with concrete, asphalt, packed dirt, gravel, or similar reflective material for more than 1/2 the distance between the [traveled lane] and the microphone location point." A "soft" site is "any test site having the ground surface covered with grass, other ground cover, or similar absorptive material for 1/2 or more of the distance between the [traveled lane] and the microphone location point."

The regulations indicate that the difference between noise levels observed at hard sites and at soft sites will be + 2 dB(A), regardless of the distance between the measurement microphone and the traveled lane. The purpose of the work described here was to obtain limited additional experimental data on the difference in noise levels between hard and soft sites, particularly for microphone spacings of less than 50 ft (15.2 m). In addition, information was obtained pertinent to the possibility of enforcing truck noise limits with measurements made at distances less than the 35 ft (10.7 m) minimum distance allowed by the regulations.

2. RESULTS AND CONCLUSIONS

The results and conclusions, based upon measurements of two trucks, can be summarized in four major points.

First, the difference between maximum truck noise levels observed at "hard" sites and corresponding levels observed at "soft" sites is a strong function of the percentage of surface hardness, and this difference increases with the percentage of hardness.* For example (see Fig. 6.1), at a measurement distance of 50 ft (15.2 m), the difference ranges from about 1 dB(A) for a 25% hard site to 3 to 4 dB(A) for a 100% hard site.

Second, the hard-site-to-soft-site difference is a function of microphone distance: The greater the microphone distance, the greater the difference. For example (see Fig. 6.2), going from a 100% hard site to a typical soft site yields a difference of 1.5 dB(A) at 25 ft (7.6 m), and about 2.5 dB(A) at 50 ft (15.2 m).

Third, the results of this study generally confirm the results of previous investigators for IMI/low-speed-acceleration truck operations. However, for truck passby operations, the present results indicate a hard-site-to-soft-site difference about 0.5 dB(A) less than reported by others.

Finally, these data indicate that the 2 dB(A) difference between hard- and soft-site truck noise levels specified in BMCS regulations is slightly low, but approximately correct. However, it can vary by ± 1 dB for the range of conditions that could occur in field enforcement practices.

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*"Percentage of surface hardness" is defined here as the percentage of pavement along the shortest path from the vehicle track to the microphone. See Table 5.1.

3. BACKGROUND

3.1 Analysis

Although a considerable body of experimental data has been accumulated on the subject, the effect of the ground surface on the propagation of sound from a source to a receiver is still imperfectly understood. (Appendix C contains the bibliography of literature reviewed for this report.) As stated by Piercy *et al.* [7], this is "an intricate and rambling subject both mathematically and conceptually." Some of the reasons why this is so are that the propagation losses are intimately dependent upon the geometry of the configuration, the acoustic impedance (complex) of the ground, and local atmospheric inhomogeneities. Some of these parameters cannot be controlled, or even defined, for any given test configuration.

Consider the geometry of Fig. 3.1. Two sound ray paths are possible between the source, S, and the receiver, R: The direct path has a length, r_1, and a longer reflected path has a total length, r_2. If we assume plane waves (i.e., no spherical divergence) and a locally reacting ground surface, the ratio, C, of the acoustic pressure of the reflected wave at R to that of the direct wave is:

$$C = \frac{p_{reflected}}{p_{direct}} = \frac{Z_g \sin\theta - \rho c}{Z_g \sin\theta + \rho c} . \qquad (3.1)$$

This is called the reflection coefficient of the ground, where ρc is the characteristic impedance of the air.

If the ground surface is acoustically very hard and the reflections are specular (i.e., as from a mirror), then $Z_g >> \rho c$ and:

$$C = 1. \qquad (3.2)$$

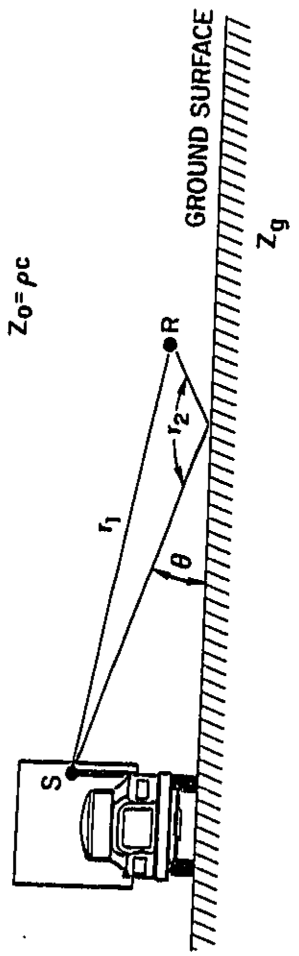

FIG. 3.1. TWO SOUND PATHS FROM A NOISE SOURCE (S), TO A RECEIVER (R), NEAR THE GROUND.

In this perfect-reflection case, the two waves will add together at the receiver when $r_2 - r_1$ is an integral number of wavelengths, and they will interfere or cancel when $r_2 - r_1$ is an odd number of half wavelengths. Obviously this summation or cancellation effect will be a function of sound frequency and geometry.

On the other hand, if the ground is acoustically very soft (i.e., $Z_g << \rho c$), then C approaches - 1, and there is a 180° phase reversal of the wave upon reflection. Then the interference pattern reverses, and the direct and reflected waves cancel for $r_2 - r_1$ equal to an integral number of wavelengths, and they add for $r_2 - r_1$ equal to an odd number of half wavelengths.

Finally, for any finite value of Z_g, a 180° phase reversal ($C = -1$) occurs for grazing incidence as θ approaches zero. Because r_1 essentially equals r_2 at grazing incidence, the two waves cancel and plane-wave propagation cannot occur.*

The impedance of the ground, Z_g, is a complex function of frequency and angle of incidence. It changes with the type of ground cover, water content, and other climate-dependent variables. In the same way, the effective lengths of the direct and reflected sound paths r_1 and r_2 change because of local atmospheric inhomogenities and differences in the heights of the many separate noise sources of a truck. Finally, the ground is seldom perfectly flat, and the surface irregularities that are comparable to or larger than the sound wavelength can produce sound scattering rather than specular reflection. It is because of these complexities that the prediction of sound propagation near the ground is far more

*This is not true for the more general case of spherical waves, however. For spherical waves, a ground-wave term analagous to that existing in electromagnetic propagation takes over to provide some signal under grazing-incidence conditions.

complicated than the simple description that we have given here. In general, any real configuration, such as that used for motor carrier noise emission regulation, cannot be handled analytically and must be treated empirically, with some guidance provided from the simplified analytical picture.

3.2 Prior Experimental Work

Other investigators have published data on the effects of soft vs hard sites on truck noise measurements. Several of these studies are summarized in Table 3.1. An interesting trend is revealed by comparing the first three rows — data for trucks accelerating at low speed — with the second three rows — data for trucks passing by under power. The former indicate a hard-site-to-soft-site difference of 2 dB(A); the latter indicate a corresponding difference of about 3 dB(A). This trend is also noted in Ref. 3, where the author cautions that it is in need of further verification. Of course, the generally accepted difference is 2 dB(A) for all test conditions, as specified in the regulation and other literature [4].

TABLE 3.1. RESULTS OF MEASUREMENTS OF TRUCK NOISE AT SOFT VS HARD SITES, AS REPORTED BY OTHER INVESTIGATORS.

Noise Source	Operating Mode	Distance	Hard Site % Hard	Hard Site Number of Trucks	Soft Site % Hard	Soft Site Number of Trucks	Δ dB(A)	Δ %H	Refs.
Three Trucks	Acceleration per SAE-J366b (20 to 30 mph)	50 ft (15.2 m)	91	51	32	55	2.0	59	2,3
Transient Trucks	Acceleration at < 30 mph (48 km/h)	50 ft (15.2 m)	100	406	32	406	1.8	68	3
Transient Trucks	Acceleration at < 35 mph (53 km/h)	50 ft (15.2 m)	?	(large)	?	(large)	~2	68 ?	4,3
Three Trucks	Power passby, about 55 mph (88 km/h)	50 ft (15.2 m)	91	23	32	50	3.1	59	2,3
Transient Trucks	Power passby, 45 to 60 mph (72 to 97 km/h)	50 ft (15.2 m)	74	29	32	226	2.4	42	2,3
Transient Truck	Power passby, 45 to 60 mph (72 to 97 km/h)	50 ft (15.2 m)	100	78	32	226	3.5	68	2,3
Free-flowing Traffic	Power passby	Empirical fit to measured data indicates change from 3 dB/dd over hard sites to 4.5 dB/dd over soft sites.							5

4. MEASUREMENTS

4.1 General

Field measurements were performed July 27, 28, 31, and August 1, 1978, at Westfield-Barnes Airport in Westfield, Massachusetts. An abandoned runway, currently unused but maintained, was used as the "road." This runway is about 3300 ft long and 150 ft wide. It has an asphalt surface, with both shoulders grassy and level.

Westfield-Barnes Airport was chosen because of the excellent condition of the unused runway and its relative proximity to Bolt Beranek and Newman's Cambridge offices. A runway, rather than a highway, was selected as the ideal test site because its width allowed a large working area for microphone layout and because there were no paved shoulders. (See Fig. 4.1.) Receiver locations could then be varied incrementally, from soft to hard. That is, the locations could be all on the grass beside the runway (soft); there could be various combinations of partially hard, partially soft locations; or all the locations could be on asphalt (hard).

Aircraft activity at the airport was light. When an occasional aircraft produced noise that might have interfered with the truck noise measurements, the truck noise measurements were repeated.

The weather during the measurement period varied somewhat, but conditions were generally fair, clear, and cool. Temperatures averaged 60°F; wind speed ranged from 0 mph to 10 mph. No measurements were taken during occasional wind gusts of up to 15 mph. The coolness assured that the pavement did not get hot and soft, and its characteristics are believed to have remained constant.

FIG. 4.1. VIEW ACROSS 150 FT WIDE RUNWAY USED FOR VEHICLE NOISE TESTS.

Five 10-ft (3-m) wide lanes were marked out with traffic cones and spray paint. Lane 1 was nearest the edge of the runway and Lane 5 farthest from it. (See Fig. 4.2.) Tests were run with the noise source vehicle in each of the five lanes. The microphones were moved with each lane change to maintain a constant distance from the source. In this way, the percentage of hard surface between the source and the microphones was varied.

4.2 Instrumentation

GenRad 9601 microphones were placed at distances 25, 31, 36, and 50 ft (7.6, 9.4, 11, and 15.2 m) from the centerline of the lane being used for the tests. A reference microphone was placed 50 ft (15.2 m) from the lane centerline on the opposite side. All microphones were at a height of 4 ft (1.2 m). Each microphone was connected through a cable to a GenRad 1982 Sound Level Meter, which provided a digital read-out of the maximum sound level obtained on the "fast" response scale. See Fig. 4.3. These meters hold this maximum reading until they are manually cleared. An anemometer was used to record wind speeds. Details of the sound measurement equipment are listed in Appendix A.

4.3 The Trucks

Two trucks were used: a gasoline-fueled and a diesel-powered truck. The gas, or straight truck, was a rented U-Haul, as shown in Fig. 4.4. This truck has a V-8 engine of 330 cu in. displacement, and a manual four-speed transmission. It is 28 ft long. (Its U-Haul equipment number is S633TP6092C.)

The diesel truck was a tractor semitrailer. This truck is a 1975 Brockway, Model KL-360. See Fig. 4.5. The engine is rated at 425 horsepower; it is manufactured by Caterpillar and has six

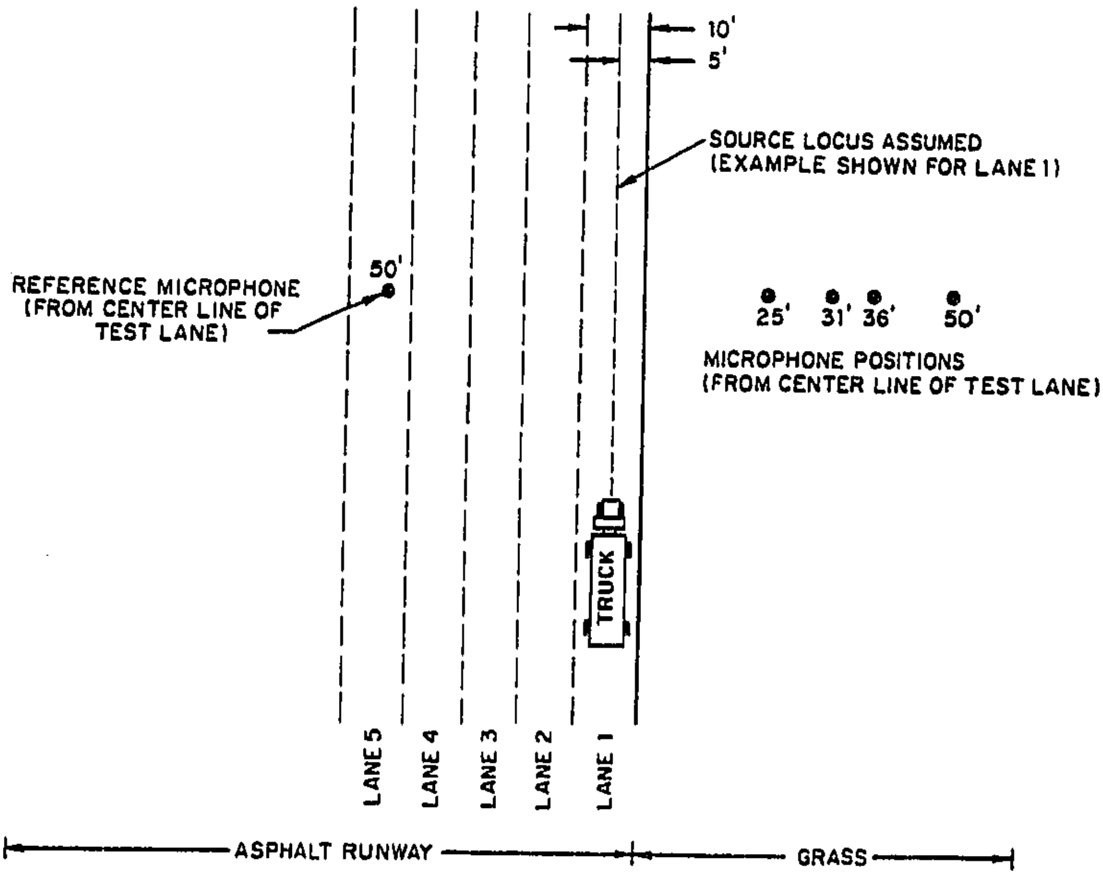

FIG. 4.2. SCHEMATIC DIAGRAM OF TEST SITE
WESTFIELD-BARNES AIRPORT, WESTFIELD, MA.

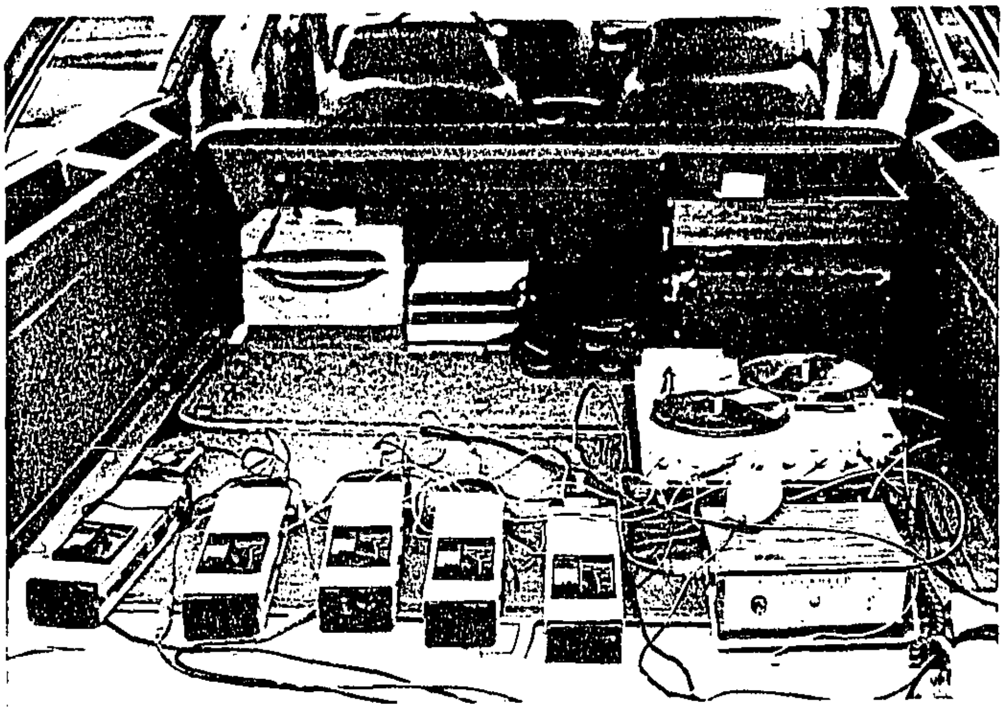

FIG. 4.3. INSTRUMENTATION USED TO RECORD NOISE DATA.

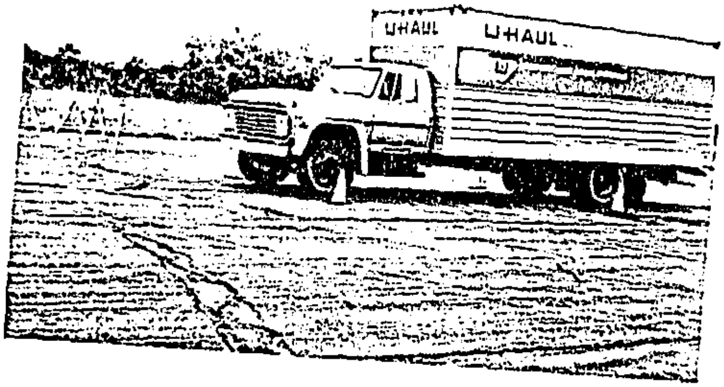

FIG. 4.4. GASOLINE-POWERED "STRAIGHT TRUCK" USED AS NOISE SOURCE.

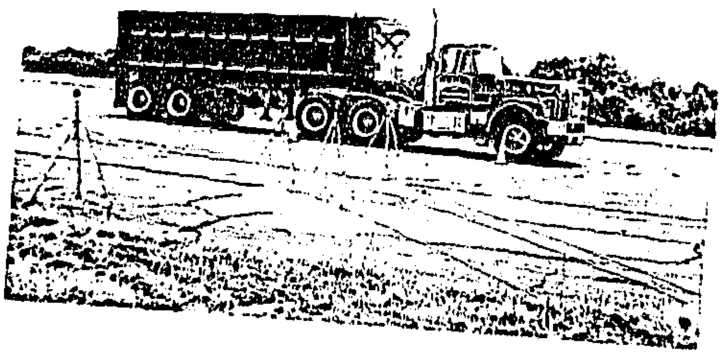

FIG. 4.5. DIESEL-POWERED TRACTOR SEMITRAILER TRUCK USED AS NOISE SOURCE.

cylinders. The exhaust system is manufactured by Riker. The exhaust is from a high stack on the right side of the cab. The trailer is 24 ft long.

The use of only two trucks limits the general applicability of the data reported here.

4.4 The Tests

Two types of tests were performed with each truck in each lane. One was a stationary test, the other a passby. For the stationary test, the truck first was run at idle, then was revved up to full throttle, and the accelerator was then immediately released. This test is referred to as an Idle-Max-Idle (IMI) test, and noise measurements were made on both the right and left side by turning the truck around. This was repeated five times in each lane, on each side.

Passbys were also done in each lane, on each side. These tests were done at two speeds: a low speed of 30 to 35 mph, and a higher speed of 40 to 50 mph. Speeds for each passby were recorded. Because of a very slight grade in the runway, the speeds were slightly greater during the downgrade runs than during the upgrade runs.

The test procedure was as follows: After the instrumentation was set up for Lane 1, five IMI tests for both the left side and the right side of the straight truck were performed. Then, again with the straight truck, 35-mph passbys and then 45-mph passbys were run, also five times per side. The maximum sound level at each receiver location was recorded for every run. Since the truck ran both up and down the runway, both right- and left-side passby results were quickly acquired. The entire procedure was then repeated in the same lane with the diesel truck. Measurements of the diesel truck were taken with and without the trailer, and the presence of the trailer did not appear to affect the noise levels, but there were, then, more tests performed with the diesel truck than with the gasoline truck. After all tests on both trucks were completed, the entire procedure was then repeated for Lanes 2, 3, 4, and 5.* By changing to lanes farther from the shoulder while maintaining constant source-to-microphone spacings, the sound path was changed from being essentially all over a soft surface (Lane 1), to partially over soft and partially over hard, until ultimately, in Lane 5, the path was essentially all over a hard surface. Each time the lane being used was changed, all the microphones were moved to maintain the 25, 31, 36, and 50 ft (7.6, 9.4, 11, and 15.2 m) distances from the lane centerline. All the data, averaged over the five runs in each configuration, are given in Appendix B.

*No passby data were acquired with the diesel truck in Lane 2.

5. DATA ANALYSIS PROCEDURE

After calculating means and standard deviations for the five runs of each test case, five basic steps were used to determine the relative change in noise level with response to the number of feet of "hard" surface (asphalt) vs "soft" surface (grass) over which the sound had traveled. All analyses were done with the five-run averages listed in Appendix B.

Step 1

The "percent of surface hardness" along the sound path from the source to each microphone was determined for each test lane configuration. These values are tabulated below.

TABLE 5.1. PERCENTAGE OF SURFACE HARDNESS USED IN SUBSEQUENT COMPUTATIONS.

Lane	Hard-Surface Distance from Centerline to Edge of Pavement	Distance from Noise Source to Microphone (ft)			
		25	31	36	50
1	5	20%	16%	14%	10%
2	15	60	48	42	30
3	25	100	81	69	50
4	35	100	100	97	70
5	45	100	100	100	90

Step 2

For each truck and truck-operating condition, and for each microphone position applicable to that truck and operating condition, the data for the five lanes were grouped together. Within each such group, the level observed at the reference (far-side) microphone during truck operation in Lane 5 was arbitrarily selected as a standard. Each of the differences between this reference level and the reference levels observed during truck operations in the other lanes was then applied to the corresponding *measured data* for the other lanes, for that microphone spacing.

This procedure normalized the measured levels for each microphone spacing and corrected for any change in truck noise output from lane to lane.

Step 3

For each of the groups of measurements normalized in Step 2 (i.e., for the normalized data from five lanes of operation corresponding to each microphone spacing, truck, and operating condition), a linear regression of the form $L = a(\%H) + b$ was computed for the five data points. The values of percent hardness (%H) were taken from Table 5.1. Using this equation, the noise levels that would have been observed at 0%, 25%, 50%, 75%, and 100% hardness were estimated.

This procedure yields levels at each microphone spacing that are directly comparable, in terms of percentage of hard surface under the sound paths.

Step 4

The level at 50 ft (15.2 m) for 0% hardness from Step 3 was then selected as a reference and subtracted from all other levels for various microphone spacings and hardness percentages for each of the following truck operating conditions:

- IMI - diesel - right side
- IMI - diesel - left side

- IMI - gas - right side
- IMI - gas - left side
- Passbys - diesel - right side - 35 mph
- Passbys - diesel - left side - 30 to 35 mph
- Passbys - diesel - right side - 45 to 55 mph
- Passbys - diesel - left side - 45 to 50 mph
- Passbys - gas - right side - 35 mph
- Passbys - gas left side - 35 mph
- Passbys - gas - right side - 45 mph
- Passbys - gas - left side - 40 mph.

This yielded changes in level (ΔL) as a function of distance and % hardness that are plotted on Figs. 5.1 through 5.12.

Step 5

Linear regression equations were computed of ΔL as a function of microphone spacing (distance, D) for each of the data sets on Figs. 5.1 through 5.12. The equations are shown on the figures.

The results of all IMI tests were then combined; they are illustrated on Fig. 5.13. The combined results of all passby tests are shown on Fig. 5.14. Finally, the combined results of all tests are illustrated on Fig. 5.15.

Note that each of the "data" points on Figs. 5.1 through 5.15 represents a difference (Step 4) between interpolated numbers (Step 3), normalized (Step 2) from averages of raw data. Thus, the actual number of raw data observations contributing to each of these points is obscured. In general, however, each point on Figs. 5.1 through 5.4 and 5.9 through 5.12 is interpolated from regressions fitted to 25 raw data points (averages of five runs for each of five lanes). Each point on Figs. 5.5 through 5.8 is interpolated from regressions fitted to 40 data points (averages from five runs, for four lanes, with and without the trailer). Each point on Fig. 5.13 is similarly based upon 100 raw data values, and each point on Fig. 5.14 is derived from 260 raw values. The points on Fig. 5.15 are derived from 360 raw observations.

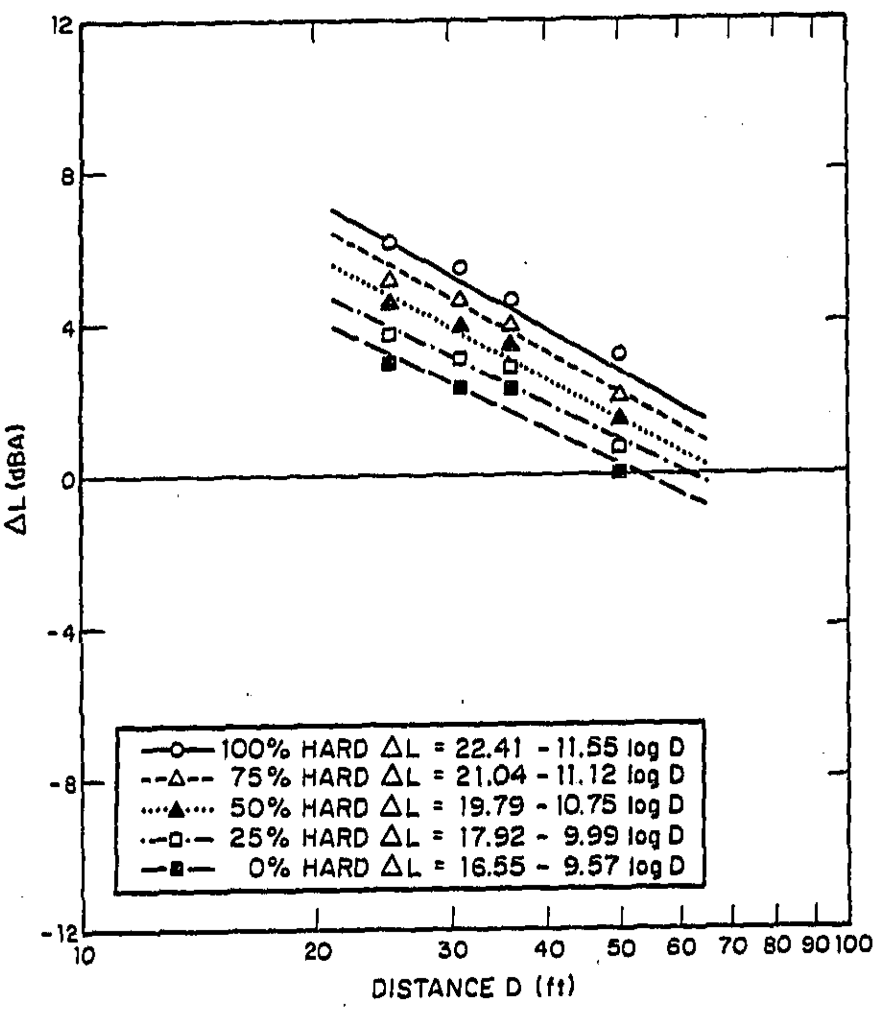

FIG. 5.1. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: IMI — DIESEL — RIGHT SIDE.

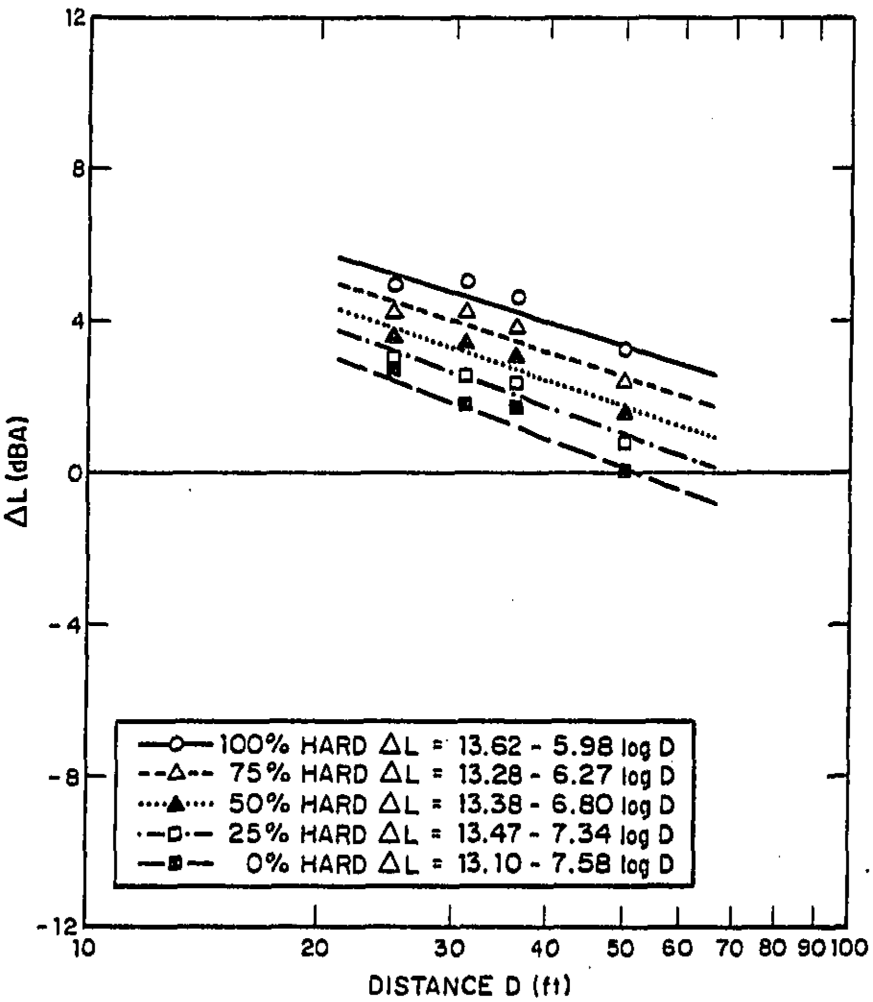

FIG. 5.2. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: IMI — DIESEL — LEFT SIDE.

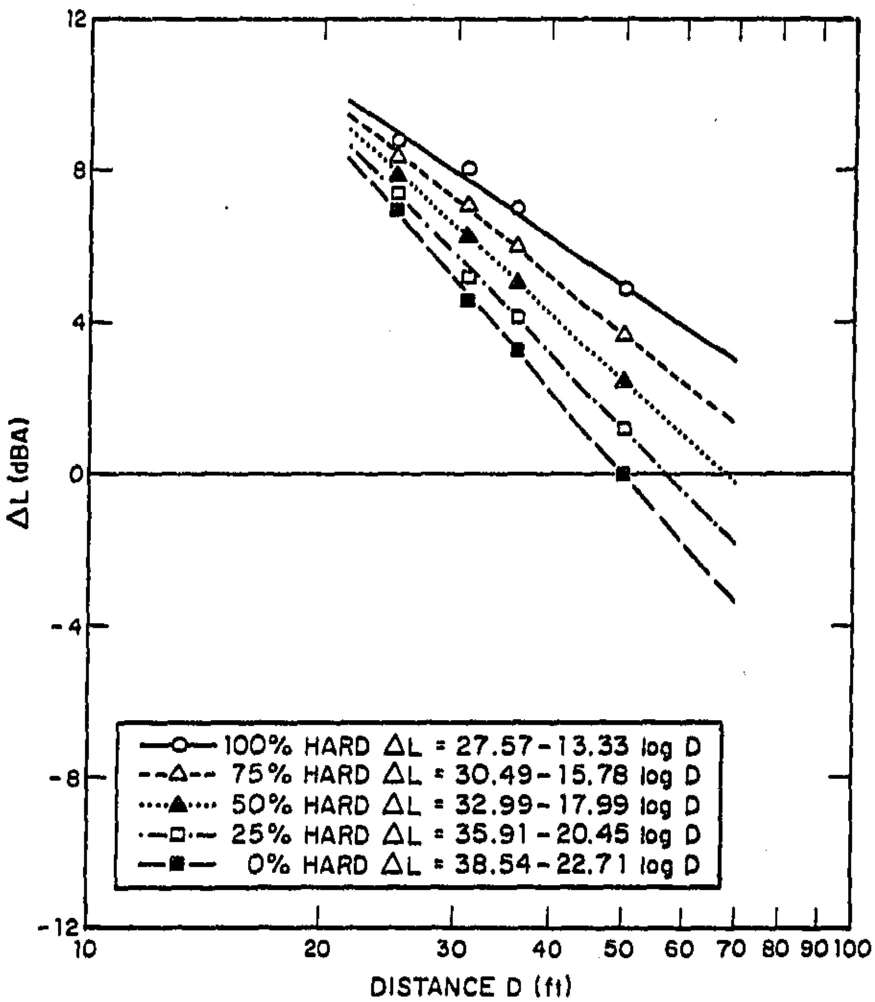

FIG. 5.3. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: IMI — GAS — RIGHT SIDE.

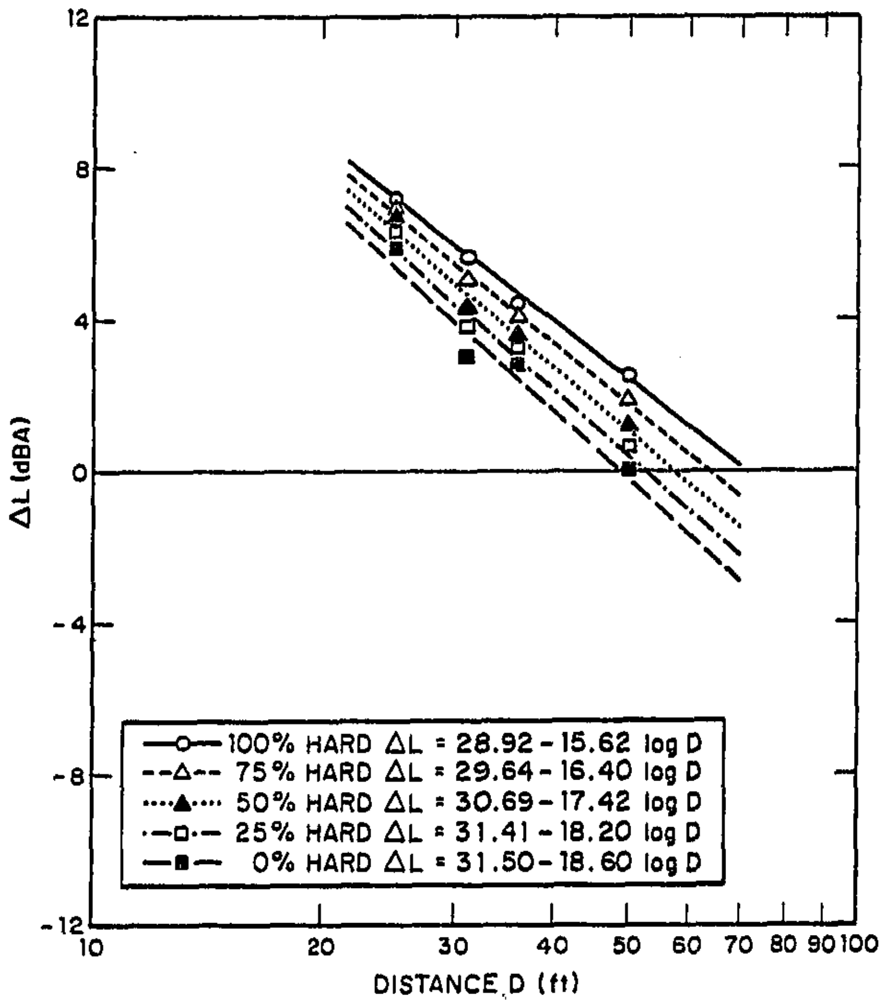

FIG. 5.4. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: IMI — GAS — LEFT SIDE.

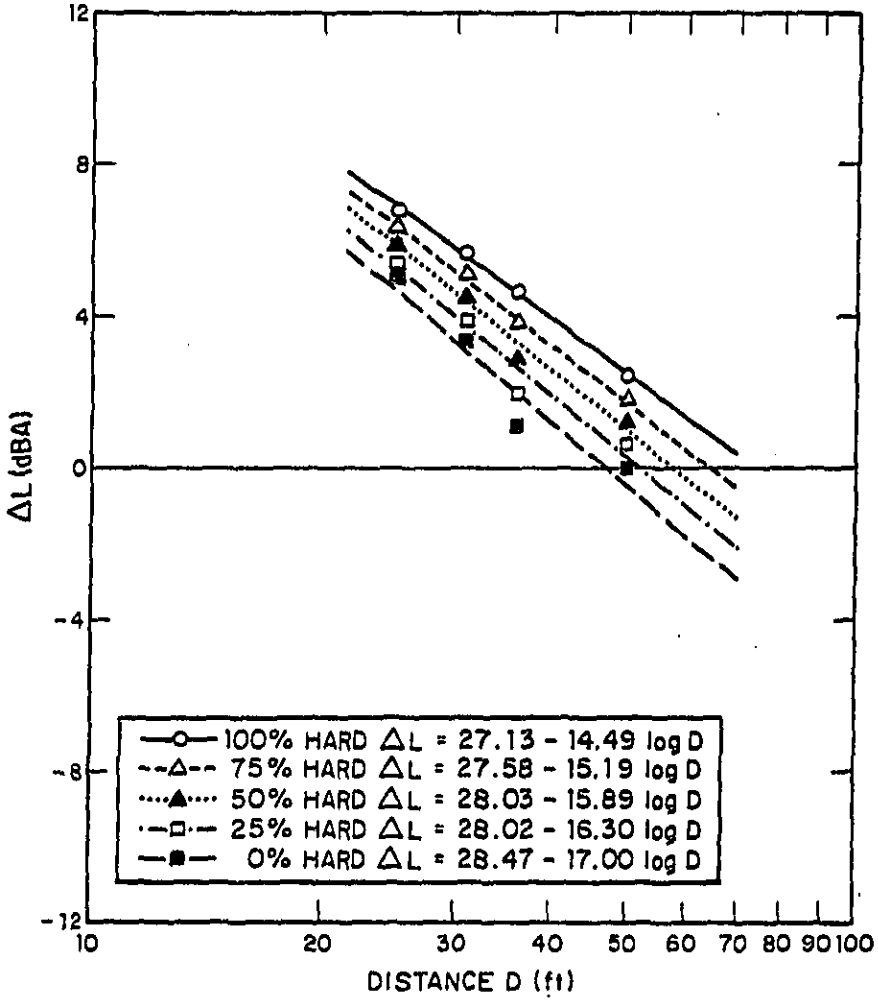

FIG. 5.5. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: DIESEL PASSBYS — 35 MPH — RIGHT SIDE.

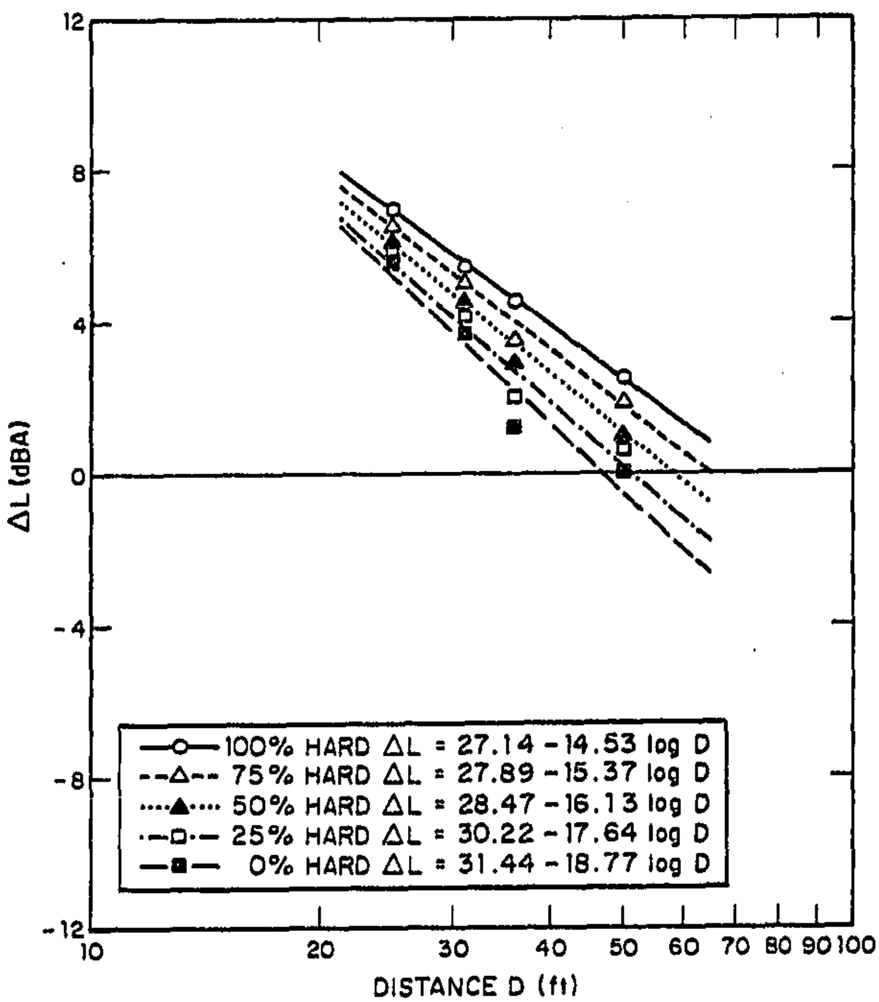

FIG. 5.6. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: DIESEL PASSBYS — 30 TO 35 MPH — LEFT SIDE.

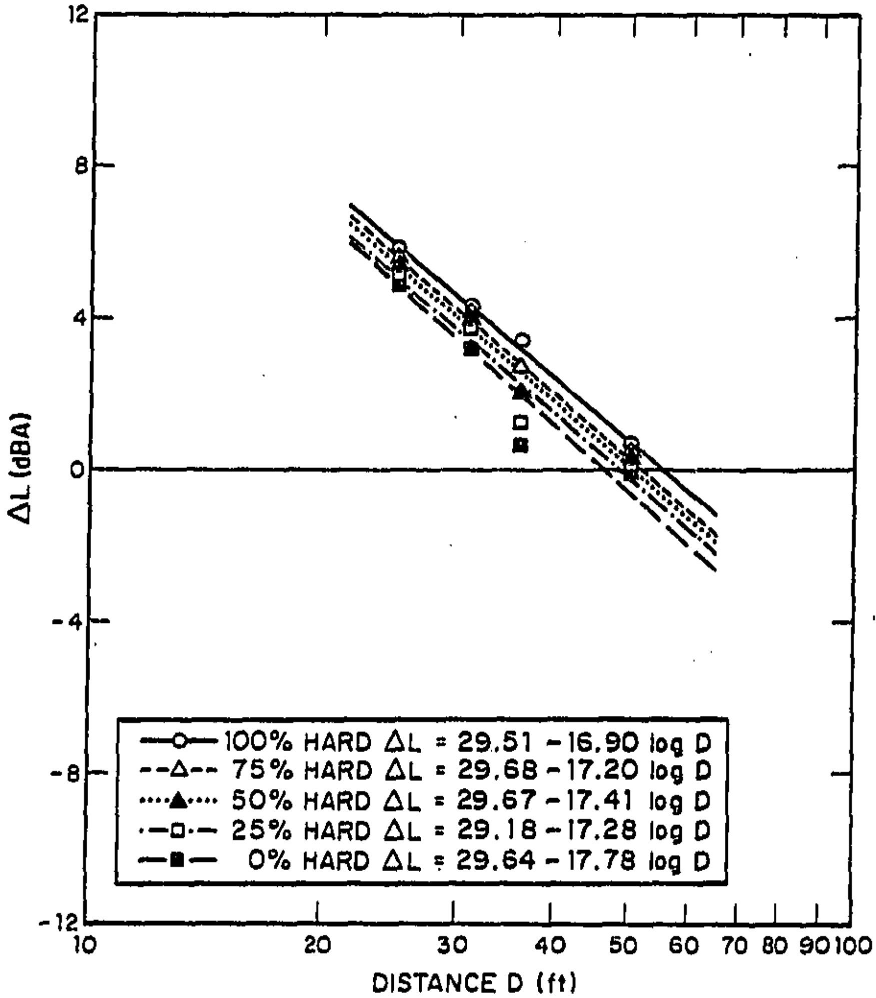

FIG. 5.7. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: DIESEL PASSBYS — 45 TO 55 MPH — RIGHT SIDE.

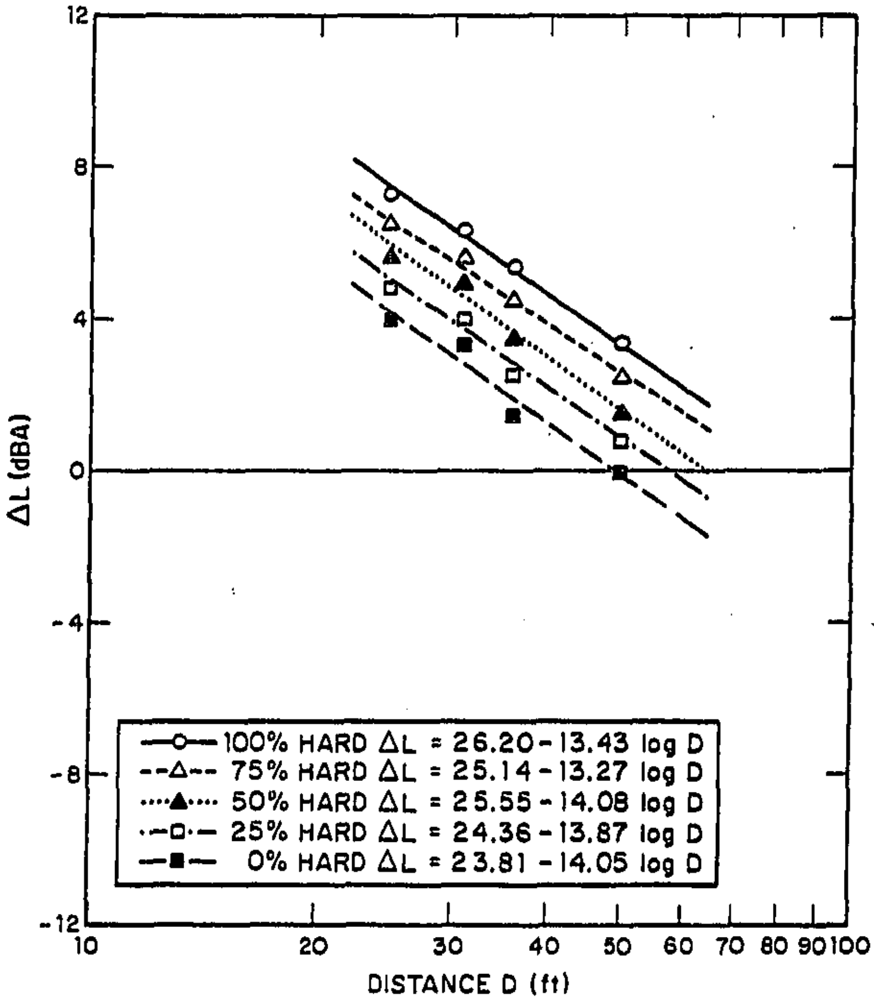

FIG. 5.8. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: DIESEL PASSBYS — 45 TO 50 MPH — LEFT SIDE.

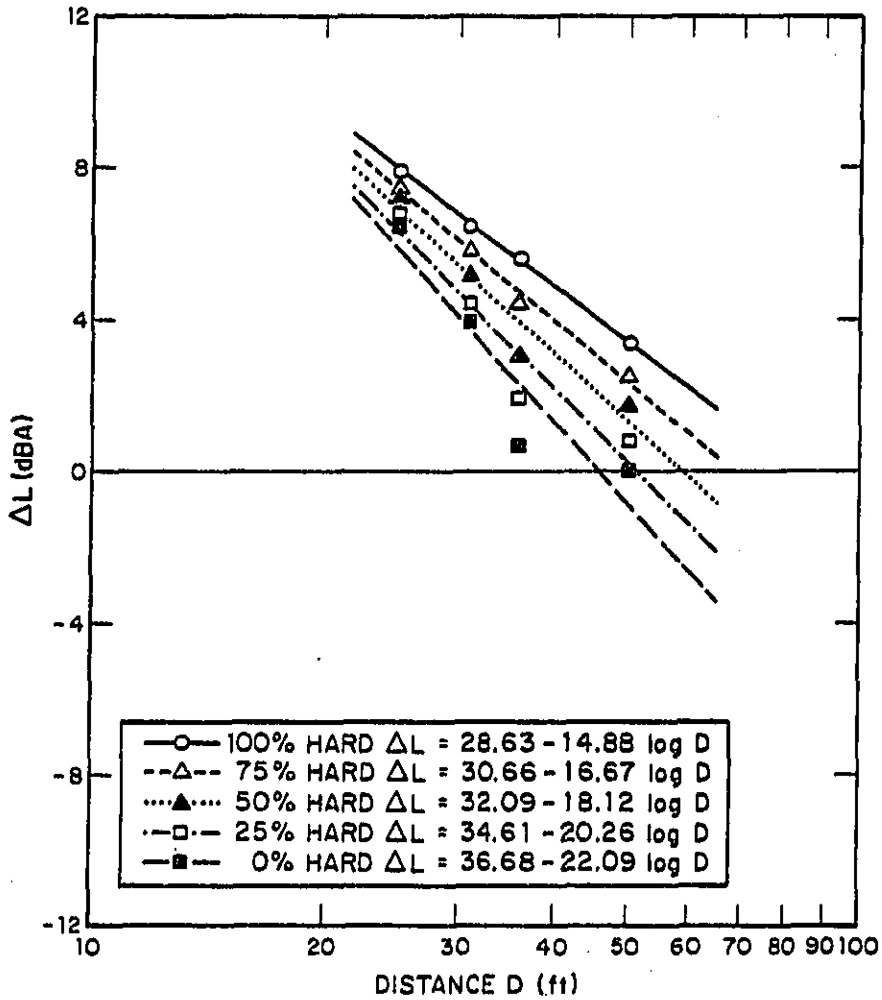

FIG. 5.9. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: GAS PASSBYS ~ 35 MPH — RIGHT SIDE.

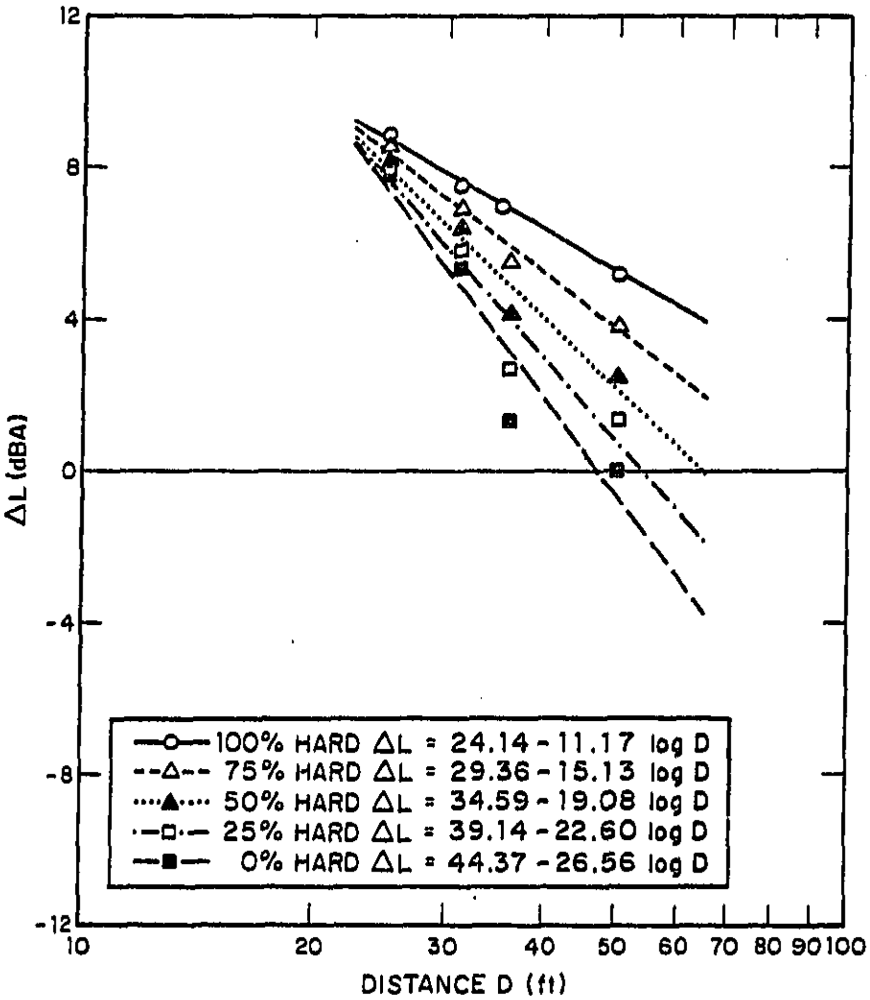

FIG. 5.10. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: GAS PASSBYS — 35 MPH — LEFT SIDE.

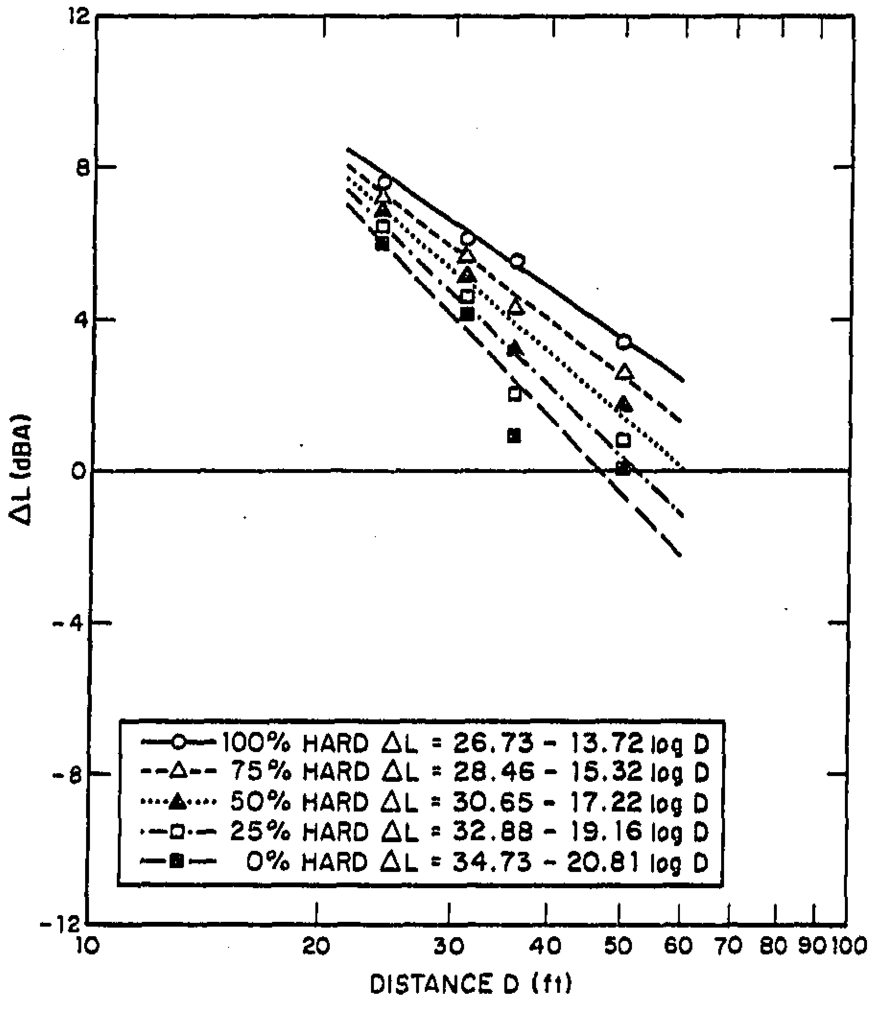

FIG. 5.11. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: GAS PASSBYS — 45 MPH — RIGHT SIDE.

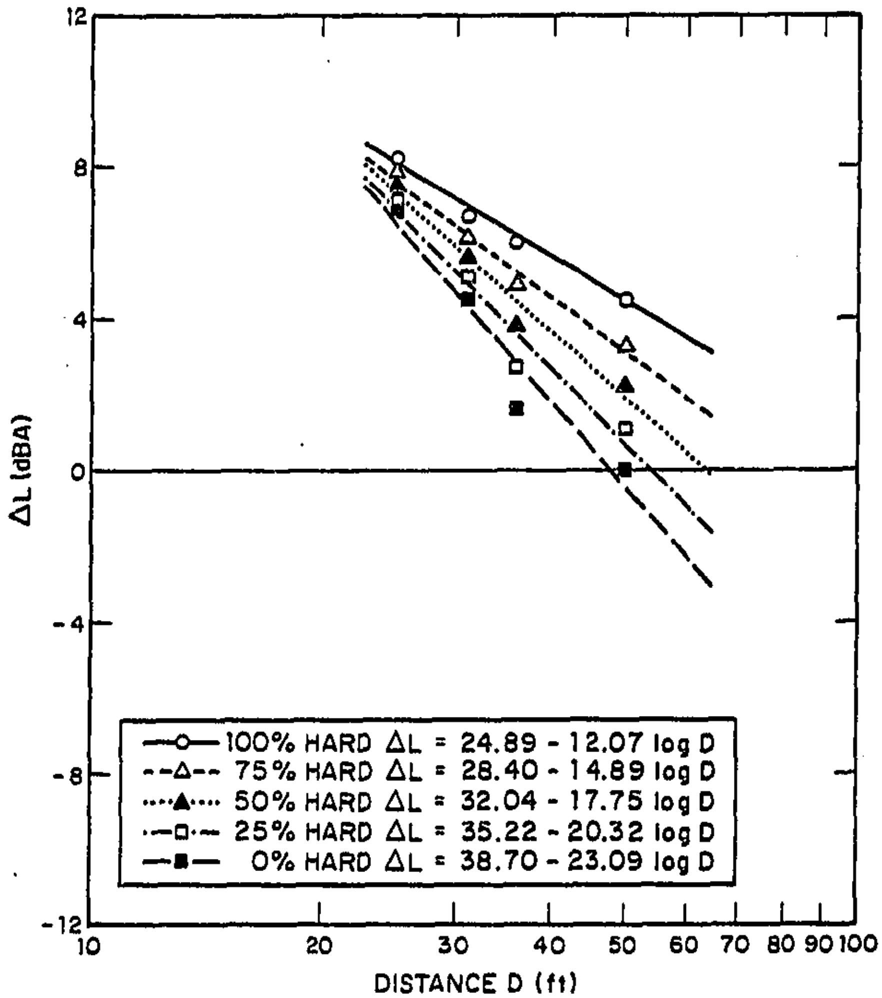

FIG. 5.12. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: GAS PASSBYS — 40 MPH — LEFT SIDE.

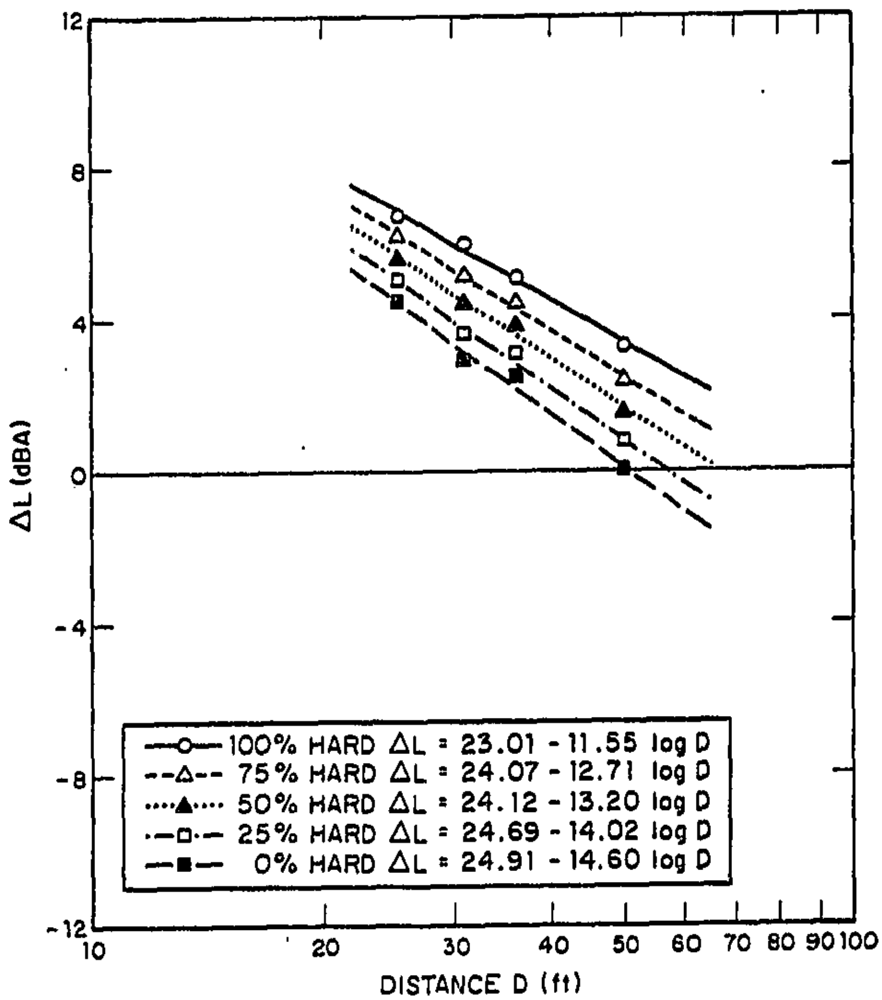

FIG. 5.13. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: TOTAL IMI.

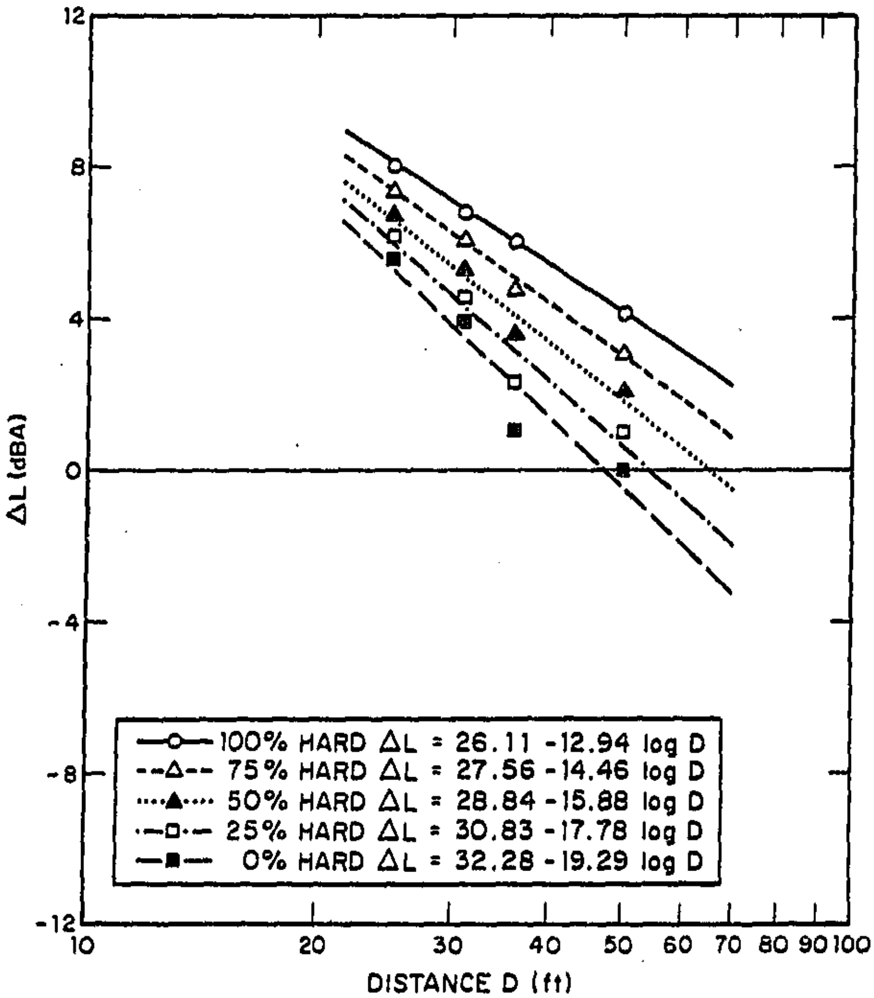

FIG. 5.14. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: TOTAL PASSBYS.

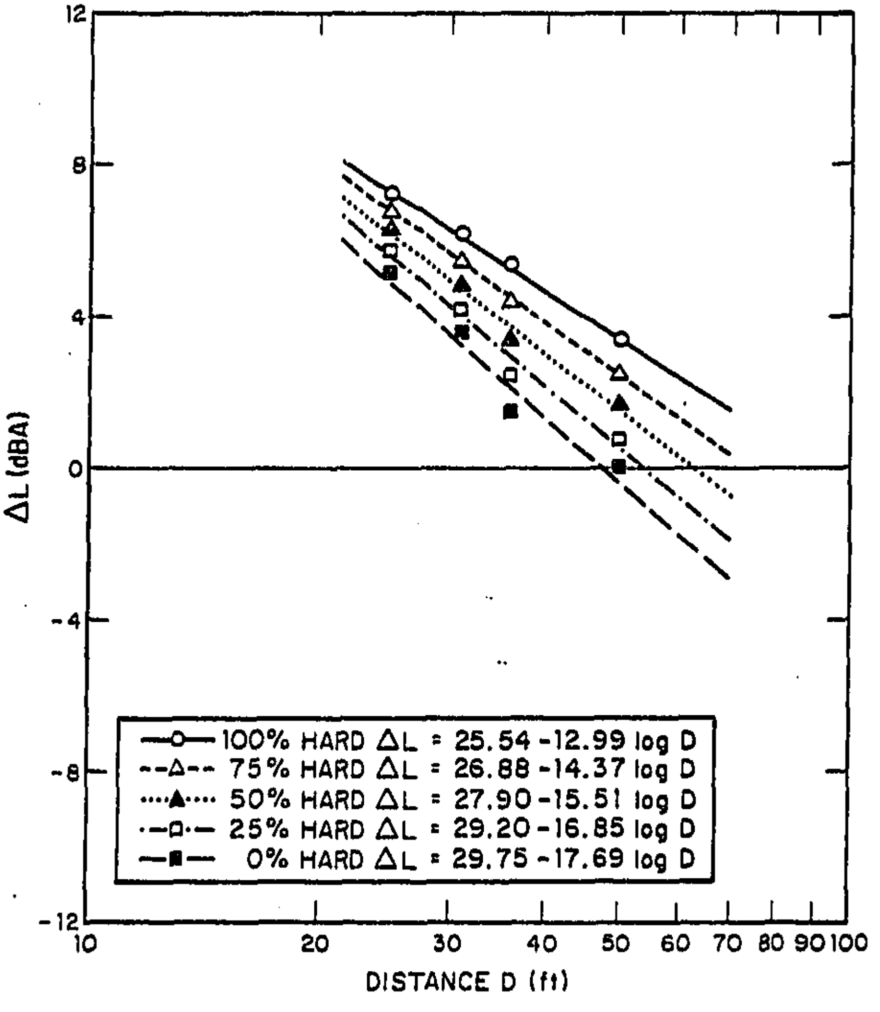

FIG. 5.15. HARD SITE/SOFT SITE NOISE LEVEL DIFFERENCES AS A FUNCTION OF MICROPHONE DISTANCE: ALL DATA.

6. DISCUSSION OF RESULTS

The BMCS regulations define a "hard" site as one paved for more than 50% of the sound path. A "soft" site has 50% or less pavement (see Sec. 1 for exact definitions). In practice, a soft site is rarely less than 32% hard, because it is underlaid by half the active vehicle lane and a paved shoulder or breakdown lane [3]. However, fully hard sites are common.

The IMI test procedure used in this study is generally accepted as being most comparable to results obtained with trucks accelerating at low speed during roadway operations [4]. Using this information and the "percentage site hardness" observation mentioned in the previous paragraph, it is possible to compare the results of the present study with those of previous investigators, as they are summarized in Table 3.1. This comparison is illustrated in Fig. 6.1. The locations of the data points from prior studies on the abscissa of Fig. 6.1 are based upon the *differences* in the percentage of surface hardness between "hard" and "soft" sites as reported by the previous investigations. See the next to last column of Table 3.1.

It is seen that the present results for IMI operations are quite comparable to those from previous studies. However, the present results for passbys are about 0.5 dB(A) lower than previous results. The reasons for this difference are unknown, but could be caused by the very small sample of trucks used in this study.

In any case, there is a clear indication that the noise level difference increases with percentage site hardness, rather than being constant as implied in the BMCS regulations. Furthermore, the present results confirm the observation of

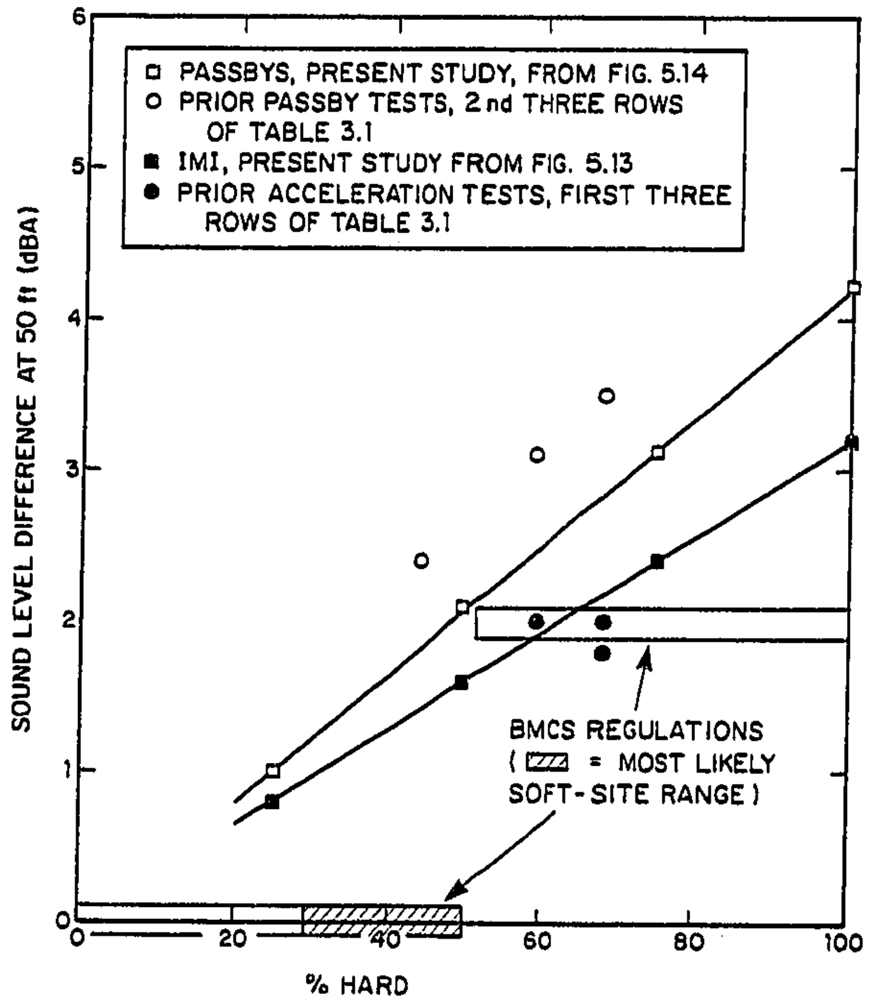

FIG. 6.1. COMPARISON OF RESULTS FROM PRESENT EXPERIMENTS WITH THOSE OF PREVIOUS STUDIES, AT 50 FT. HARD SITE MINUS SOFT SITE NOISE LEVEL DIFFERENCE vs PERCENTAGE OF SITE HARDNESS.

Ref. 3 — that a greater hard-site-to-soft-site noise level difference occurs for passbys than for IMI tests.

The British data indicated in the last row of Table 3.1 are based upon L_{10} levels for free-flowing traffic and can not be directly compared with the present data for individual trucks. However, note (Fig. 5.15) that the slope of sound-level difference vs distance does indeed decrease with increasing percentage of site hardness, going from about 5.2 dB/dd at 0% hardness to 3.9 dB/dd at 100% hardness, a difference of 1.3 dB/dd.

In general, the decrease in sound level with distance does not approach the classic 6 dB/dd for the data reported herein. This suggests that the measurements at distances of less than 50 ft from the trucks are in the near field of the noise source, and/or in a region of pronounced ground-reflection effects.

Finally, there is definitely a trend of increasing sound level difference with increasing microphone distance, as illustrated in Fig. 6.2. In this figure, the difference in sound levels for a 100% hard site and for a "typical" (i.e., 32% hard) soft site is plotted as a function of microphone distance. The hard-site-to-soft-site difference is about 1 dB(A) less at 25 ft than at 50 ft for typical site conditions.

Note that the results illustrated on Fig. 6.2 would shift up or down relative to the BMCS-specified correction, depending upon the choice of percentage of site hardness selected.

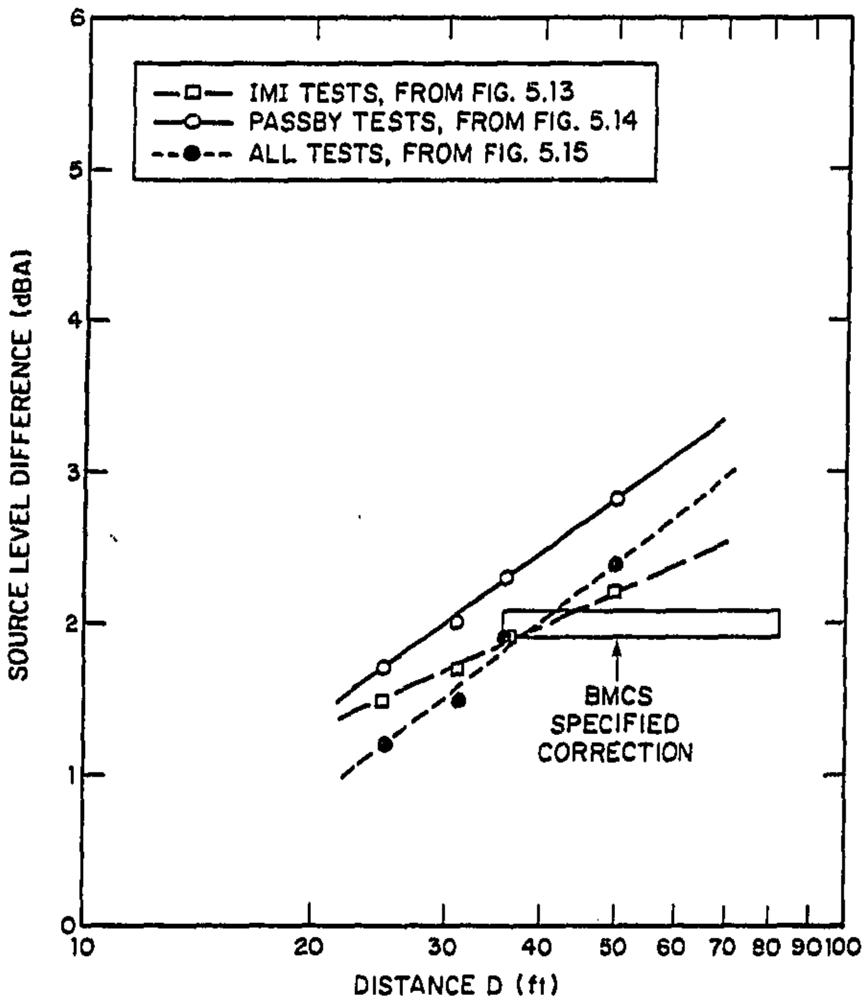

FIG. 6.2. SOUND LEVEL DIFFERENCE BETWEEN A 100% HARD SITE AND A TYPICAL "SOFT" (i.e., 32% HARD) SITE, AS A FUNCTION OF MICROPHONE DISTANCE.

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APPENDIX A

TABLE A.1. SERIAL NUMBERS OF INSTRUMENTS USED FOR HARD SITE/SOFT FIELD MEASUREMENTS.*

System	25 ft	31 ft	36 ft	50 ft	Ref.
Microphone 9R1962-9601	6727	5121	2306	1012	5189
Preamplifier 9RP.42	498	1797	1776	1934	1910
SLM: 9R1982	0890	0905	0701	0205	1130
Power Supply: BBN No.	17	18	23	28	29

*The same equipment was used for each lane, therefore, the 25, 31, 36, 50, and reference equipment were the same in every case.

APPENDIX B

MEASURED TRACK-NOISE DATA, AVERAGED FOR THE FIVE RUNS IN EACH TEST CONFIGURATION

TABLE B.1. MEASURED SOUND LEVELS. EACH VALUE IS THE AVERAGE OF FIVE MEASUREMENTS.

Test Information			Average Sound Levels in dB(A) Observed at Specified Distances from the Truck									
Truck	Test	Lane	Ref.		25 ft		31 ft		36 ft		50 ft	
			$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Diesel	IHI - right	1	94.3	.6	93.6	.33	92.7	1.1	92.4	1.0	89.7	.7
"	IHI - left	1	91.6	.6	92.9	.31	92.4	.3	92.4	.2	90.4	.2
Diesel, w/trailer	IMI - right	2	92.9	.3	94.8	.4	93.6	.2	92.7	.4	91.6	.4
"	IMI - left	2	92.0	.4	94.7	.2	93.8	.4	94.0	.4	92.1	.7
"	IMI - right	3	93.0	.6	95.5	.4	94.8	.6	94.1	.8	90.6	.6
"	IMI - left	3	92.1	.7	95.3	.2	95.5	.2	93.9	.5	91.3	.6
"	IMI - right	4	93.8	.4	95.2	.4	94.2	.5	93.3	.2	90.8	.6
"	IMI - left	4	92.0	.5	95.1	.4	95.1	.2	95.2	.1	93.7	.6
"	IMI - right	5	93.6	.6	96.1	.4	95.4	.3	94.5	.4	92.5	.5
"	IMI - left	5	92.0	.5	96.0	.4	95.7	.5	95.3	.8	93.3	1.0
Gas truck, loaded	IMI - right	1	83.0	.5	86.9	.5	84.5	.6	83.4	.5	79.9	.2
"	IMI - left	1	82.5	.2	86.6	.3	83.6	.2	83.2	.2	80.5	.5
"	IMI - right	2	83.0	.3	87.6	.2	86.1	.3	84.2	.4	81.3	.3
"	IMI - left	2	83.0	.3	87.9	.2	85.6	.3	84.8	1.3	81.5	.5
"	IMI - right	3	83.0	.1	87.9	.2	86.4	.5	85.3	.4	81.8	.4
"	IMI - left	3	82.2	.4	87.6	.3	85.8	.2	84.6	.4	82.1	.4
"	IMI - right	4	82.4	.3	87.7	.2	86.5	.3	85.1	.2	82.6	.2
"	IMI - left	4	82.5	.4	87.3	.2	85.2	.2	84.2	.3	82.6	.2
"	IMI - right	5	82.3	.3	88.1	.2	87.6	.3	86.5	.1	83.1	.2
"	IMI - left	5	82.5	.4	87.9	.1	86.5	.2	85.2	.3	82.2	.3
Gas truck	35mph passby right	1	73.3	.6	76.6	.4	74.5	.4	70.9	.7	70.8	.2
"	35mph left	1	75.4	.9	78.9	.7	76.9	1.0	72.3	.5	72.4	.9
"	35mph right	2	73.6	.8	78.1	1.0	75.2	.6	73.5	.6	70.7	1.0
"	35mph left	2	75.7	.8	80.0	.7	77.9	1.1	76.3	1.4	71.7	.8
"	35mph right	3	75.8	1.3	80.1	1.0	78.7	.9	77.5	.8	74.2	1.0
"	35mph left	3	75.4	.7	79.4	1.0	77.8	.9	76.9	.8	74.0	1.0
"	35mph right	4	73.9	.5	78.1	.6	76.5	.7	75.2	.6	73.7	.5
"	35mph left	4	75.5	.6	79.9	.6	78.8	.3	77.6	.6	75.5	.3
"	35mph right	5	74.5	.7	79.6	1.1	78.3	.8	77.2	1.1	74.0	.8
"	35mph left	5	75.5	1.2	79.9	.6	79.0	.6	77.9	.7	75.6	1.0
"	45mph right	1	79.3	.4	82.3	.5	80.6	.6	76.9	.2	76.8	.7
"	40mph left	1	77.6	.6	80.4	.7	78.4	.5	74.8	.3	74.2	.6
"	45mph right	2	78.6	.8	83.2	1.2	80.9	1.2	79.6	1.0	76.6	1.2
"	40mph left	2	77.9	.8	82.3	.5	79.6	.4	78.4	.5	74.7	.2
"	45mph right	3	77.9	.9	82.3	.7	80.6	.6	79.3	.9	76.1	.6
"	40mph left	3	77.5	.2	81.9	.3	80.4	.3	79.6	.4	76.5	.5
"	45mph right	4	77.3	.8	81.4	.6	79.7	.6	78.8	.7	77.0	.4
"	40mph left	4	78.7	.9	82.4	1.0	80.6	.6	79.5	.5	77.9	.6
"	45mph right	5	78.1	.6	83.2	.4	81.7	.4	80.7	.5	78.2	.3
"	40mph left	5	77.5	.7	81.8	.3	80.7	.4	79.5	.3	77.4	.5

TABLE B.1. *(Continued)*

Test Information			Average Sound Levels in dB(A) Observed at Specified Distances from the Truck									
Truck	Test	Lane	Ref.		25 ft		31 ft		36 ft		50 ft	
			$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
Diesel, loaded	35mph right	1	87.3	1.0	89.3	1.2	87.4	1.5	86.9	1.4	83.8	1.4
"	30mph left	1	89.9	1.5	92.3	1.0	90.8	1.3	90.2	1.5	87.4	1.4
Diesel & trailer unloaded	35mph right	1	87.7	1.2	91.4	1.2	90.0	1.1	86.2	1.1	86.8	1.2
"	30mph left	1	86.5	1.1	90.9	1.1	89.9	1.6	85.8	.9	86.2	1.4
"	35mph right	3	85.8	2.3	90.5	1.4	88.7	1.7	87.4	1.5	84.6	1.7
"	30mph left	3	84.0	.5	89.0	.9	87.6	1.1	86.6	.8	83.6	1.6
Diesel - cab only	35mph right	3	84.8	1.4	88.4	1.0	86.9	1.1	85.5	1.4	83.4	1.1
"	35mph left	3	84.3	1.3	88.9	1.7	87.1	1.6	85.5	1.4	83.3	1.7
"	35mph right	4	84.7	.5	88.8	.7	87.5	.5	86.6	.7	84.0	.3
"	35mph left	4	83.6	1.4	88.2	2.4	86.9	2.3	66.0	2.2	83.6	1.8
Diesel w/trailer unloaded	35mph right	4	86.0	.6	90.0	1.1	89.0	.9	87.6	.7	85.0	.8
"	35mph left	4	84.9	1.5	88.7	1.3	87.4	1.4	86.5	1.2	84.2	1.3
"	35mph right	5	85.9	.4	90.5	1.0	89.5	.9	88.3	.6	85.6	1.1
"	35mph left	5	85.4	.8	90.2	1.5	88.8	1.6	87.9	1.6	85.3	1.6
Diesel - cab only	35mph right	5	85.2	.4	89.6	.4	88.8	.8	87.6	.9	85.0	.9
"	35mph left	5	83.7	.4	89.7	.5	88.9	.9	87.6	.7	85.4	.2
Diesel - no load	50mph right	1	90.1	.5	94.8	.8	93.2	.4	88.4	.6	89.7	1.0
"	45mph left	1	89.1	1.2	92.2	1.2	90.8	1.1	86.7	.9	87.1	1.1
Diesel - cab	55mph right	1	87.5	1.0	90.0	1.0	88.5	1.2	87.6	1.4	85.4	1.7
"	50mph left	1	84.7	1.5	86.7	2.5	86.5	1.4	86.8	2.0	83.0	1.4
Diesel & trailer unloaded	45mph right	3	87.4	1.0	92.9	1.3	91.2	1.2	89.6	1.3	86.4	1.2
	45mph left	3	88.2	1.0	93.9	1.4	92.5	1.3	91.0	1.1	88.1	1.2
Diesel - cab only	45mph right	3	86.2	1.5	90.2	1.7	88.5	1.9	87.4	1.8	84.2	2.2
"	45mph left	3	85.3	1.9	90.4	1.6	88.5	2.0	87.5	2.0	85.1	1.5
"	45mph right	4	87.6	3.7	90.9	1.3	88.9	1.5	87.8	1.4	85.1	1.3
"	45mph left	4	88.6	2.5	93.0	.6	91.6	.6	90.9	.8	88.2	.8
Diesel w/trailer	45mph right	4	88.6	1.2	92.3	1.1	90.7	.8	89.7	.7	87.4	.7
"	45mph left	4	88.9	.9	94.2	1.1	92.5	1.3	91.1	1.2	88.6	1.4
"	45mph right	5	88.5	.6	92.9	.5	91.9	.6	90.8	.8	88.3	.9
"	45mph left	5	88.5	.6	93.4	1.1	92.5	1.1	91.7	.8	88.8	1.0
Diesel - cab only	45mph right	5	86.9	2.1	91.2	1.8	90.3	1.4	89.4	1.0	86.4	.7
"	45mph left	5	85.7	1.8	91.6	.9	91.6	.9	90.5	1.1	87.6	1.5

APPENDIX C

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