US Department of Transportation
Federal Highway Administration

Sound Procedures for Measuring Highway Noise: Final Report

FHWA-DP-45-1R
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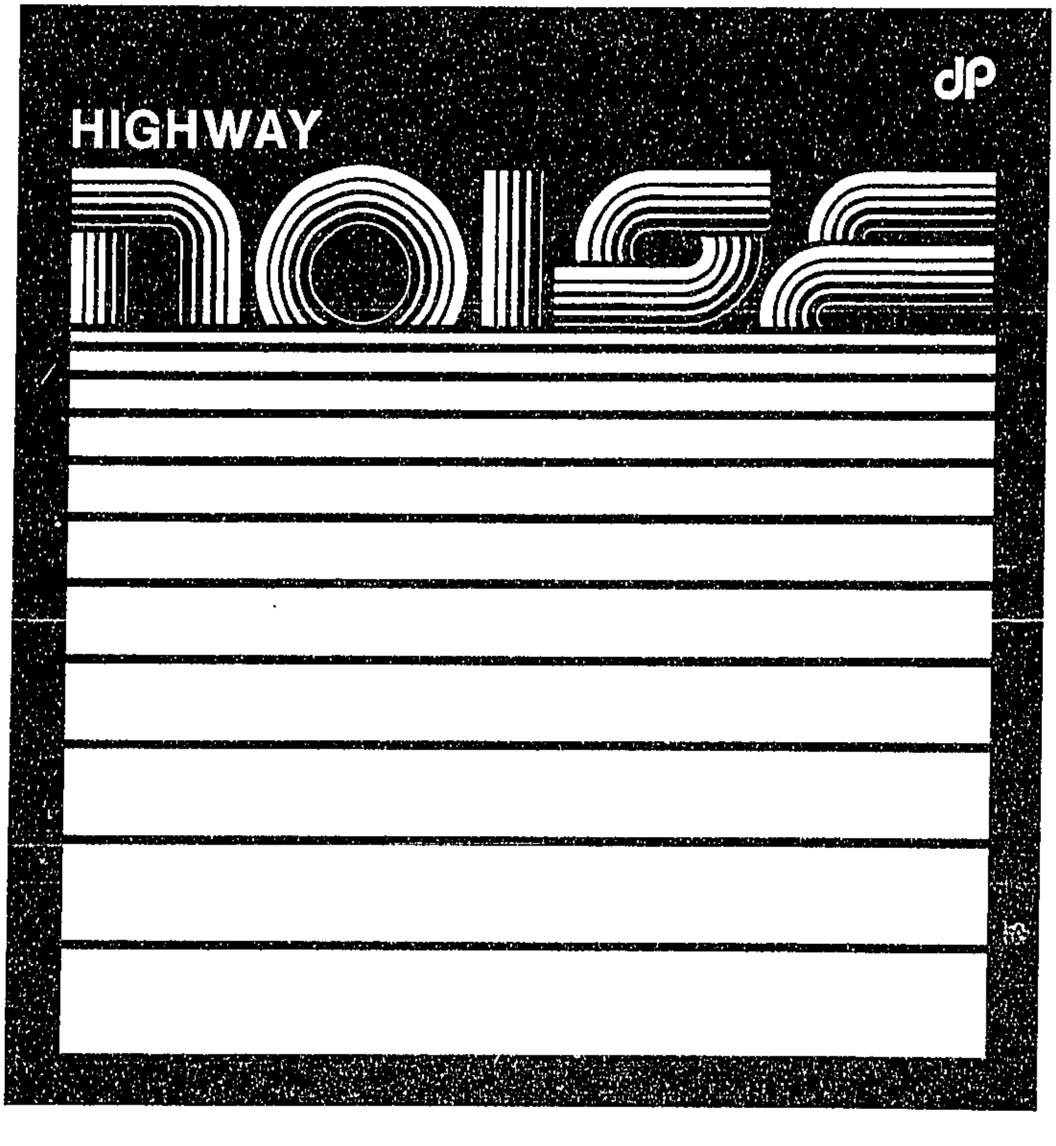

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16. Abstract
This revised manual presents noise measurement procedures for use by Federal, State, or local transportation departments. Methods are included for the measurement of traffic/existing sound levels, vehicle sound levels, barrier field insertion loss, non-traffic noise source sound levels, construction equipment noise, building noise reduction, and worker noise exposure. The required instrumentation, test site restrictions, step by step measurement procedures, and computational methods are included.

This revision incorporates two measurement procedures issued after the interim report was published: Determination of Reference Energy Mean Emission Levels, Federal Highway Administration (FHWA) Report No. FHWA-OEP/HEV-78-1, which replaces chapter 4, and Determination of Noise Barrier Effectiveness, FHWA Report No. FHWA-OEP/HEV-80-1, which replaces chapter 5.

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1.0 INTRODUCTION

1.1 BACKGROUND

Numerous studies indicate that the most pervasive sources of noise in our environment today are those associated with transportation(Ref. 1-10). Transportation agencies have routinely measured noise levels for proposed highway projects since the issuance of Federal Highway Administration (FHWA) Policy and Procedure Memorandum (PPM) 90-2, "Noise Standards and Procedures" in 1973. The only formal training for these measurements was given as part of FHWA's "Fundamentals and Abatement of Highway Traffic Noise" training course. The course taught a hand-sampling method using a sound level meter to determine the statistical descriptor L10 (noise level exceeded 10 percent of measurement period.) PPM 90-2 was revised in 1976 as Volume 7, Chapter 7, Section 3 of the Federal-aid Highway Program Manual (FHPM 7-7-3). A new sound level descriptor, the energy-equivalent sound level, Leq(h) was introduced. In addition to these general existing noise level measurements, needs developed for more specialized procedures, such as determination of noise barrier effectiveness, reduction of outdoor sound inside a building, and levels of individual vehicles.

In the past, the methods used for these and other measurements varied widely. The lack of uniformity often resulted in data being collected incorrectly or in a manner that made comparison difficult from study to study.

This document represents a revision of an interim report of the same title prepared by Dames & Moore, Inc. (Report No. FHWA-DP-45-1) and published in May 1978. The major changes are the incorporation of two subsequently issued FHWA reports that expanded upon chapters 4 and 5 of the interim report.* In addition, newer data sheets have been added where appropriate.

This revised report provides uniform noise measurement procedures for use by Federal, State, or local transportation agencies. While it is not a standard, regulation, or requirement, its use is encouraged and recommended.

Chapter 8 has also been revised to allow alternative positions for the exterior microphone, and a note on data loggers for personal noise exposure was added to chapter 9.

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*Reagan, J.A. Determination of Reference Energy Mean Emission Levels. FHWA, Report No. FHWA-OEP/HEV-78-1, Washington, D.C., 1978.

Reagan, J.A. and Hatzi, P.J. Determination of Noise Barrier Effectiveness. FHWA, Report No. FHWA-OEP/HEV 80-1, Washington, D.C., 1980.

1.2 PURPOSE AND SCOPE

The purpose of this document is to provide functional, rational and cost-effective noise measurement procedures. The data acquired by different individuals using these procedures should be comparable. These procedures establish a desired level of accuracy and precision.

These techniques may also be used to provide input data for "calibration" of various traffic noise prediction models. The vehicle noise emission measurement procedure can provide émissions levels for vehicles specific to the region in which the measurements are being made. The traffic noise measurement procedure can be used at various distances from a roadway to establish a propagation constant specific to a site's terrain. Thus, the ability to accurately predict future highway noise emissions can be improved.

Noise measurement methods are provided for the following areas:

- Traffic/Existing Sound Levels
- Vehicle Sound Levels
- Barrier Field Insertion Loss
- Non-Traffic Noise Sources
- Construction Equipment Noise
- Building Noise Reduction
- Worker Noise Exposure

1.3 ORGANIZATION

The manual is divided into two major segments plus an Appendix. Chapter 2.0 presents information regarding personnel requirements, instrumentation and equipment and other items common to the measurement procedures presented in this manual.

Chapters 3.0 through 9.0 contain the noise measurement methods listed in Section 1.2.

Methods to measure existing sound levels, or sound levels created by highway traffic, are presented in Chapter 3.0. The principal technique has been previously presented in NCHRP Report 174, "Highway Noise: A Design Guide for Prediction and Control,"[11] and should therefore be familiar to highway personnel. This method presents the procedure for measuring the A-weighted sound level exceeded 10% of the time, L_{10}, and the equivalent sound level, L_{eq}. An alternate procedure, based upon the proposed SAE Procedure XJ1075 is also presented. The alternative procedure is simpler to accomplish but provides only an estimate of the equivalent sound level. Both techniques have been field tested over the past few years, and show good agreement with sophisticated analyses of the environmental noise using tape recording equipment and statistical analyzers.

Chapter 4.0 includes methods for the measurement of noise emissions of individual vehicles operating on thoroughfares. The technique is similar to the one presented in the Department of Transportation Bureau of Motor Carrier Safety Regulations for Enforcement of Motor Carrier Noise Emission Standards.[12] Measurements of individual vehicle sound emissions can be used to calibrate highway noise prediction models. Statistical requirements for determining the number of samples in each vehicle class are included.

A technique for determining highway noise barrier insertion loss is described in Chapter 5.0. Three alternatives for obtaining sound levels at an area without a barrier for comparison with the sound levels at the area with a barrier are discussed.

Techniques for measuring the noise emissions of sources other than highway traffic are presented in Chapter 6.0. The technique for the measurement of the equivalent A-weighted sound level of stationary sources is similar to the proposed SAE Procedure XJ1075. Techniques for measuring the sound level contributions from non-highway mobile noise sources such as boats, freight trains, or airplanes are also presented. These techniques assume specific time-history patterns for the source sound levels. Nomograms are provided for evaluating the equivalent sound levels for the passby. Although sophisticated equipment can provide more accurate results, the technique presented is of importance since it only requires the use of an inexpensive sound level meter.

Sound levels emitted from a construction site should be measured using the stationary source technique described in Chapter 6.0. For individual construction machines, a noise measurement procedure is provided in Chapter 7.0. The method is based on the SAE Recommended Practice J88a and Compressed Air and Gas Institute (CAGI) Consensus Standards. SAE and CAGI techniques require a test site with numerous acoustical environmental constraints. For example, the surface between the noise source and microphone must be sealed asphalt with no large reflecting surfaces within 30 metres (98.4 feet) of the microphone or equipment. Many construction sites do not satisfy these constraints. In addition, sound levels at these sites, due to equipment other than the unit under study, are often quite high. The measurement method presented in this manual is a pragmatic, cost-effective means for successfully making these measurements. It is not intended to be a procedure which provides measurements for new product noise level verificiation and enforcement.

Chapter 8.0 describes a technique for estimating the A-weighted outdoor to indoor noise reduction for a building. Techniques which use the existing noise of a highway or an artificial sound source (loudspeaker and amplifier) are included.

A review of techniques for measuring highway personnel noise exposure is presented in Chapter 9.0. The recommended procedure uses noise dosimeters. Guidelines for the use of dosimeters are included. An alternative technique using a sound level meter and time-motion studies is discussed.

Appendix A presents a bibliography of useful references, grouped by measurement procedure. Appendix B reproduces Part II of Report No. FHWA-OEP/HEV-80-1. Part I of that report is a revision of chapter 5 of the interim version of this report, and is presented as the new chapter 5 here. Part II deals with determining people's perception of barrier effectiveness through surveying techniques. Appendix C presents a blank two-sided data sheet for manual sampling as described in chapter 3.

1.4 REFERENCES

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2. Goodfriend, L.S., "Noise in the Community", Noise Control 4, 22-28, 68 (March 1958).

3. Ostergaard, P.B. and R. Donley, "Background Noise Levels in Suburban Communities," J. Acoust. Soc. Am. 36, 435-439 (1964).

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8. Young, R.W., "Measurement of Noise Level and Exposure," presented at Symposium on Acceptability Criteria for Transportation Noise, Seattle, WA. 26-28 March 1969. Published in Transportation Noises: A Symposium on Acceptability Criteria, edited by J. D. Chalupnik, pp. 102-110, University of Washington Press, 1970.

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11. Transportation Research Board. National Research Council. Highway Noise: A Design Guide for Prediction and Control, (N.C.H.R.P. Report 174), 1976.

12. Dept. of Transportation, Bureau of Motor Carrier Safety, Regulation for Enforcement of Motor Carrier Noise Emission Standards, Title 49. Code of Federal Regulations Chapter II, Part 325, 40 FR 42437 September 12, 1975.

2.0 GENERAL RECOMMENDATIONS

2.1 INSTRUMENTATION

The procedures outlined in this manual require a minimum of acoustical instrumentation. A Type 1 or Type 2 sound level meter is required, depending on the procedure and the desired accuracy.* A "Precision" Type 1 sound level meter is more accurate and more expensive than a "General Purpose" Type 2 sound level meter. Specifications for sound level meters have been established by the American National Standards Institute and are included in ANSI S1.4-1971, Specifications for Sound Level Meters.

Type 1 sound level meters should be used with the microphone separated from the meter by an extension cable, according to the Field Methods section of ANSI S.13-1971 (R1976), Methods for the Measurement of Sound Pressure Levels.

Manufacturers' instructions for microphone orientation (either grazing or normal incidence) should be carefully followed. This will ensure maximum microphone output linearity.

Care should be taken that all auxiliary equipment are correctly used with the sound level meter. For example, filters, graphic level recorders, and headsets or earphones should have an input impedance appropriate for the sound level meter output impedance. Often these auxiliary equipment have a high input impedance. For maximum power transfer and minimum distortion, cables used with these equipment should have a matching impedance.

An acoustic calibrator provides a means for conducting an overall system check and calibration of the sound level meter. Calibrators are specifically designed for individual microphone systems so it is important that the proper calibrators be used. Otherwise, errors may result or microphones may be permanently damaged.

The sound level meter reading is adjusted to match the calibrator sound pressure level. For calibrators which emit sound at 1000 Hz, the calibration can be accomplished using any weighting network. Otherwise, sound level meters must be calibrated using the flat or C-weighting network.

Calibrator output is affected by changes in atmospheric (barometric) pressure. Care must be taken when using the calibrator at atmospheric pressures other than standard conditions. Calibrator manufacturers provide correction curves for calibrator use at atmospheric conditions other than standard.

*A Type 1 meter may be used where Type 2 is specified, but not vice-versa.

Calibration should be accomplished with the system as it will be in actual use (for example, with the microphone and cables installed). Calibrate as often as possible, preferably before and after the measurement. If calibrations before and after a measurement differ by more than 0.5 decibel, the results should be suspect. Usually it is good practice to repeat the measurements. The equipment should be checked annually by its manufacturer or other certified laboratory to verify its accuracy.

In measurement procedures where vehicle speed is required, the "radar" instruments should be calibrated according to manufacturer's instructions at the same time the sound level measurement system is calibrated.

The movement of air around a microphone causes turbulence which in turn generates undesired noise at the diaphragm of the microphone. This noise can effectively mask the sound signal under study even though it may be inaudible to the human ear. In cases where measurements must be made in the presence of wind or where wind gusts are suspect during the course of measurement, a microphone windscreen should always be employed.

Windscreens are generally either spherical or cylindrical in shape, made of foamed polyvinyl, open-celled polyurethane, or a silk-covered grid. The windscreen is attached directly over the microphone. They are limited in their effectiveness; therefore, measurements should not be made when the wind speed exceeds 19 km/hr (12 mph).

Other equipment which are needed to make the measurements presented in this manual include a wind speed indicator (accurate to ±10% at 12 mph) and a sling psychrometer for measuring humidity and temperature.

2.2 METEOROLOGICAL RESTRICTIONS

Proper meteorological conditions are necessary for accurate measurements. Measurements should not be made when it is raining or snowing, or when wind speeds exceed 19 km/hr (12 mph). Measurements should not be made when road surfaces are wet. Manufacturers' recommendations for acceptable temperature and humidity ranges for equipment operation should be followed. Typically, these ranges are from -10°C to 50°C and from 5% to 90% relative humidity.

2.3 ALTERNATIVE EQUIPMENT

Sound level distribution analyzers measure and analyze ambient sound for long periods of time. They provide a statistical description, in the form of a histogram or cumulative distribution, of the time-varying signal. Some of these analyzers also provide the equivalent sound level, L_{eq}. The manual sampling techniques discussed in many of the measurement procedures are unnecessary if statistical distribution analyzers are used. But, at present, there are no domestic or international standards to ensure their accuracy. Those units which provide cumulative distribution values and equivalent sound levels are quite expensive ($2000 and up). New hand held L_{eq} meters have recently been introduced at a price below $1000.

For simultaneous measurements ("Building Noise Reduction" and "Barrier Field Insertion Loss"), a two-channel tape recorder will be helpful. Both sound signals are recorded simultaneously and can later be analyzed in the laboratory using a number of different procedures. When using recording devices, the entire sound level measurement system should be qualified per SAE specifications:

> SAE Draft Procedure XJ184a "Qualifying a Sound Data Acquisition System"

Graphic level recorders or sound level analyzers are very helpful, if not essential, for mobile non-traffic source L_{eq} contribution measurements.

2.4 PERSONNEL

Persons responsible for conducting sound level measurement tests should be trained in the operation of sound level meters and should be familiar with the specific test procedure being used and any corrections that may have to be applied. Recommendations for the number of persons required for carrying out each procedure are provided in each procedure.

3.0 EXISTING/TRAFFIC SOUND LEVEL MEASUREMENT PROCEDURES

3.1 PURPOSE

The measurement procedures presented in this section can be used to establish existing sound levels at proposed highway sites and to establish sound levels from traffic on existing highways. Major noise sources (other than traffic) are measured using techniques described in Chapter 6.0.

3.2 INSTRUMENTATION

The following instruments are required:

- Sound Level Meter (Type 2)
- Sound Level Calibrator
- Earphones or Headphones (optional)
- Wind Speed Indicator
- Sling Psychrometer (optional)
- Windscreen
- Watch with "seconds" Display or Flashing Timer
- Data Sheet
- Microphone Cable (optional)
- Tripod
- Spare Batteries (optional)

3.3 PERSONNEL

Although it is possible for one person to carry out these measurements, a second person may be helpful, particularly when traffic counts are necessary.

3.4 SITE SELECTION

Land use maps may be used to identify existing noise sources and noise sensitive land uses. Schools, hospitals, and places of worship are especially sensitive to noise impact since these areas require quiet for communication and minimum disturbance of sleep. Residential areas should be included in a sound level survey. Sometimes one measurement site in the residential zone near the existing or proposed highway route can be used to represent the sound climate at residences along the route. If traffic conditions or topography vary significantly, noise measurements at many locations may be required. A number of sites should be specifically located near existing highways or other noise sources in the study area, while a number of measurement locations far from the highway will provide data representative of the background sound levels in the community.

Field reconnaissance is also extremely valuable for identifying and/or verifying the location of sensitive sites and noise sources.

3.5 SELECTION OF SAMPLING PERIODS

Design noise levels in FHPM 7-7-3 are based in part on the design hour traffic volume. Some measurements should therefore be made at or near the design hour. The period with the highest sound levels, however, may not be at the peak traffic hour, but instead during some period when traffic volumes are lower, but the truck mix is higher. Also, the greatest change in existing sound levels, and with it potentially high impact, may occur during other times during the day (e.g., early morning hours when sleep may be interrupted). It may also be desirable to examine the Day-Night Sound Level [L_{dn}] and 24-hour Equivalent Sound Level [$L_{eq(24)}$]. The selection of the number of sampling periods should be based on economic and potential impact considerations.

3.6 MEASUREMENT PROCEDURE FOR CHECK-OFF METHOD

The sampling program described below provides the sound level exceeded 10% of the time during the measurement period, L_{10}, and the equivalent sound level, L_{eq}. For highway noise measurements, traffic data should be colletected concurrent with noise measurements. A description of the vehicle classes used for the traffic counts is described in Section 4.8 ("Vehicle Noise Emissions Measurement Procedure").

1. A sketch of the measurement site should be prepared and appropriate distances and site features noted (see Figure 1). All information required on the data sheet should be entered.

2. Mount the microphone (or sound level meter/microphone combination if the microphone cannot be remotely mounted) on a tripod of about 1.5 metres (5 feet) above the ground and not less than 3 metres (10 feet) from any reflecting surfaces. There may be instances where measurements must be made at different heights (e.g., upper story of residences) or closer to reflecting surfaces (e.g., urban areas). If this is necessary, note these facts on the data sheet.

3. Set the meter to "slow" response and A-weighting. "Slow" response allows the meter display to be read easily. If impulsve noise is dominant (e.g., dog barking), "fast" response may be preferable. Judgment should be made by the individual as to which response should be used.

4. Calibrate the sound level meter per manufacturer's instructions.

5. Record the time the measurement is to begin.

U.S. DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION REGION 15	NOISE MEASUREMENT DATA SHEET

NAME: W.A. HENWAY DATE 8/21/81

PROJECT: NOISEVILLE BYPASS TIME:

SITE: 120' E OF NB I-999 START 9:01

(1012 HICKORY HOLLOW ROAD) END 9:0[illegible]

RESULTS: L10 76 + 2 - 3 L50 66 LEQ 70.5

HOW TO USE: 2 X 80 = 160000

FILL IN OTHER SIDE

DBA	Samples tallied	TOTAL	Multiplier	Product
89			X 80 =	0000
88			X 63 =	0000
87			X 50 =	0000
86			X 40 =	0000
85			X 32 =	0000
84			X 25 =	0000
83			X 20 =	0000
82			X 16 =	0000
81			X 13 =	0000
80			X 10 =	0000
79			X 80 =	000
78	X	1	X 63 =	[illegible]000
77	X	1	X 50 =	[illegible]000
76	XXX	3	X 40 =	[illegible]000
75	XX	2	X 32 =	[illegible]000
74	XX	2	X 25 =	[illegible]000
73	XX	2	X 20 =	[illegible]000
72			X 16 =	000
71	XXX	3	X 13 =	[illegible]000
70	X	1	X 10 =	[illegible]000
69	XX	2	X 80 =	[illegible]00
68	XXXXX	5	X 63 =	[illegible]00
67	XXX	3	X 60 =	[illegible]00
66	XXXX	4	X 40 =	[illegible]00
65	XXXXXXX	7	X 32 =	[illegible]00
64	XXXXX	5	X 25 =	[illegible]00
63	XXX	3	X 20 =	[illegible]00
62	XXX	3	X 16 =	[illegible]00
61	X	1	X 13 =	[illegible]00
60	XX	2	X 10 =	[illegible]00
59			X 80 =	0
58	X	1	X 63 =	[illegible]0
57			X 60 =	0
56			X 40 =	0
55			X 32 =	0
54			X 25 =	0
53			X 20 =	0
52			X 16 =	0
51			X 13 =	0
50			X 10 =	0
49			X 80 =	
48			X 63 =	
47			X 60 =	
46			X 40 =	
45			X 32 =	
44			X 25 =	
43			X 20 =	
42			X 16 =	
41			X 13 =	
40			X 10 =	

EQUALS 100,000 — EQUALS 10,000 — EQUALS 1,000 — EQUALS 100

DBA 10 20 30 40 50

NUMBER OF SAMPLES

TOTAL 50 DIVIDED INTO TOTAL 559130

EQUALS 11183

FIGURE 1. SAMPLE SOUND LEVEL MEASUREMENT DATA SHEET

FIGURE 1 (CONTINUED).

EQUIPMENT: METER A&B 2209 CALIBRATOR A&B 4230

CALIBRATION: START 94.0 DB END 94.2 DB

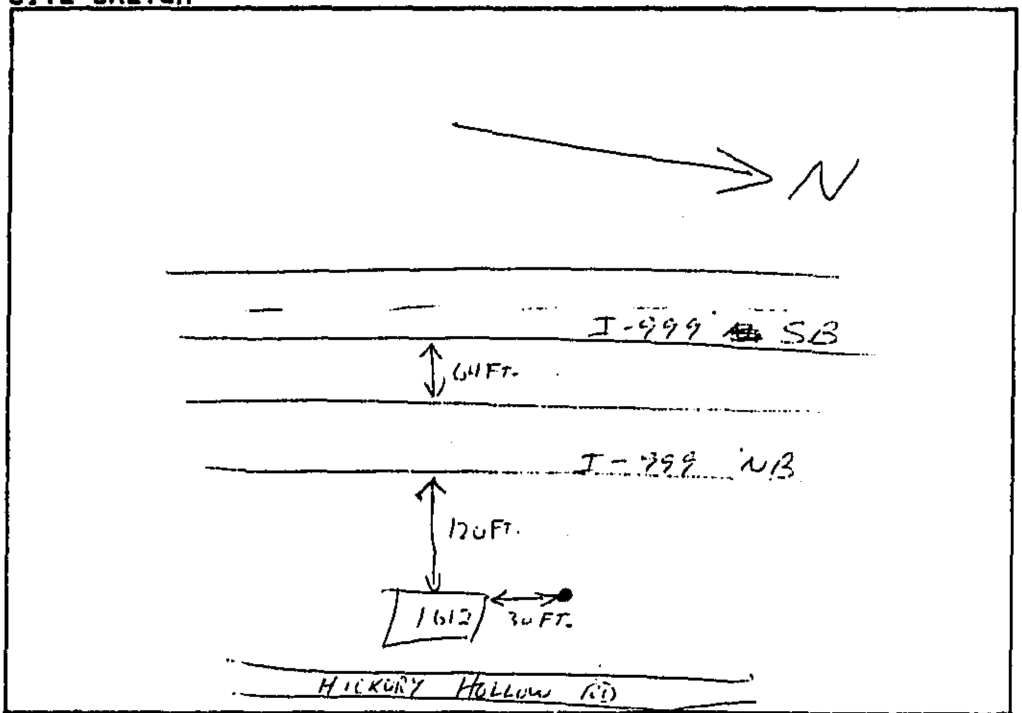
RESPONSE: ✓ FAST __ SLOW ✓ A-WEIGHTING ✓ BATTERY CHECK

WEATHER DATA CLEAR CALM 75°

TRAFFIC DATA			
ROAD	I-999 NB	I-999 SB	
AUTOS	150	200	
MED. TRKS.	12	6	
HVY. TRKS.	16	21	
DURATION	10 MIN	10 MIN	

CRITERION: ± 3DB			
NUMBER OF SAMPLES	UPPER LIMIT	L10	LOWER LIMIT
50	1ST	5TH	10TH
100	5TH	10TH	17TH
150	8TH	15TH	23RD
200	12TH	20TH	29TH

SITE SKETCH



BACKGROUND NOISE BIRDS, KIDS AT 200'

MAJOR SOURCES I-999

UNUSUAL EVENTS FIRE TRUCK (NOT SAMPLED)

OTHER NOTES CHANGED BATTERY BEFORE CALIB.

6. Read the A-weighted sound level every ten seconds, and place a check mark in the appropriate box on the data sheet (Figure 1). Work from left to right. Note if any unrepresentative sound sources influence the measurements. One method is to use a letter code for different sources. Instead of a check mark being entered on the data sheet, a letter corresponding to a particular source causing that sound level, is used (e.g., P - plane, J - jet, D - dog. Keep a running total of the number of samples on the sheet.

7. After 50 samples, test the samples using the method discussed below. If the samples meet the described criterion, the measurement program is complete. If the criterion is not met, obtain another 50 samples and repeat the test discussed below. This will yield the L_{10} sound level.

The following accuracy test is based upon a 95 percent confidence interval for ± 3dB error limits. As an option, 99 percent confidence limits may be used.

Count down from the top of the data sheet (and from left to right) and circle the data samples given in Tables 1 or 2, depending on the accuracy chosen. For example, after 50 samples have been recorded, the 1st, 5th,and 10th samples are circled. These samples constitute the L_{10} flanked by the upper and lower error limits. If the 1st and 10th samples are each within 3 dB of the 5th sample, the measurement program is complete. Otherwise, an additional 50 samples must be observed and the accuracy test is repeated for a total of 100 samples. The process is repeated for up to 200 samples.

The L_{50} is determined in much the same way, the 25th sample representing the L_{50}.

8. The Equivalent Sound Level, L_{eq} is defined as:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^{n} 10^{(L_i/10)}\right]$$

where L_i is the A-weighted sound level measured in decibels.

The L_{eq} can be evaluated after the L_{10} criterion is met from the data collected on Figure 1 by using the computational worksheet shown in Figure 2 or the right-hand portion of the front side of Figure 1:

a. Enter the number of counts per sound level in Column B. Add them to get Sum B.

TABLE 1

95 PERCENT CONFIDENCE TEST SAMPLE TABLE FOR L_{10}

Total No. of Samples	Upper Error Limit	L_{10}	Lower Error Limit
50	1st Sample	5th Sample	10th Sample
100	4th Sample	10th Sample	16th Sample
150	7th Sample	15th Sample	23rd Sample
200	11th Sample	20th Sample	29th Sample

TABLE 2

99 PERCENT CONFIDENCE TEST SAMPLE TABLE FOR L_{10}

Total No. of Samples	Upper Error Limit	L_{10}	Lower Error Limit
50	1st Sample	5th Sample	11th Sample
100	2nd Sample	10th Sample	18th Sample
150	5th Sample	15th Sample	25th Sample
200	9th Sample	20th Sample	31th Sample

FIGURE 2. SAMPLE L_{eq} COMPUTATION WORKSHEET

A SOUND LEVEL dB	B COUNT		C RELATIVE SOUND ENERGY		D RELATIVE TOTAL SOUND ENERGY
100		x	100,000	=	
99		x	79,400	=	
98		x	63,100	=	
97		x	50,100	=	
96		x	39,800	=	
95		x	31,600	=	
94		x	25,100	=	
93		x	20,000	=	
92		x	15,900	=	
91		x	12,600	=	
90		x	10,000	=	
89		x	7,940	=	
88		x	6,310	=	
87		x	5,010	=	
86		x	3,980	=	
85		x	3,160	=	
84		x	2,510	=	
83		x	2,000	=	
82		x	1,590	=	
81		x	1,260	=	
80		x	1,000	=	
79		x	794	=	
78		x	631	=	
77		x	501	=	
76		x	398	=	
75		x	316	=	
74		x	251	=	
73		x	200	=	
72		x	159	=	
71		x	126	=	
70		x	100	=	
69		x	79.4	=	
68		x	63.1	=	
67		x	50.1	=	
66		x	39.8	=	
65		x	31.6	=	
64		x	25.1	=	
63		x	20.0	=	
62		x	15.9	=	
61		x	12.6	=	
60		x	10.0	=	
59		x	7.94	=	
58		x	6.31	=	
57		x	5.01	=	
56		x	3.98	=	
55		x	3.16	=	
54		x	2.51	=	
53		x	2.00	=	
52		x	1.59	=	
51		x	1.26	=	
50		x	1.00	=	
49		x	.794	=	
48		x	.631	=	
47		x	.501	=	
46		x	.398	=	
45		x	.316	=	
44		x	.251	=	
43		x	.200	=	
42		x	.159	=	
41		x	.126	=	
40		x	.100	=	
39		x	.079	=	
38		x	.063	=	
37		x	.050	=	
36		x	.040	=	
35		x	.032	=	

1. Sum B ________ 2. Sum D ________

3. Sum D/Sum B ________ 4. L_{eq} ________

FIGURE 2 (CONTINUED). EXAMPLE

DATA REQUIREMENTS:

Each sound reading must be taken at a standard time interval between measurements

Each sound level recorded is the instantaneous level

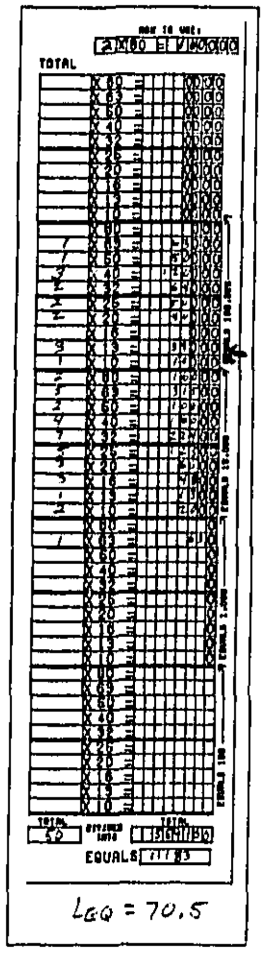
STEP	PROCEDURE
1	Enter number of counts per sound level in Column B.
2	Multiply the counts in Column B by the number in Column C and enter the result in Column D.
3	Add all values in Column B to determine Sum B, add all values in Column D to determine Sum D, and divide Sum D by Sum B.
4	Locate the value in Column C that is approximately equal to Sum D/Sum B. The corresponding value in Column A is equal to L_{eq}.

EXAMPLE

Given the data in Figure 1, compute L_{eq} using Figure 2 (below, left) and using the right-hand side of Figure 1 (below right).

A SOUND LEVEL dB	B COUNT		C RELATIVE SOUND ENERGY		D RELATIVE TOTAL SOUND ENERGY
[illegible]		x	[illegible]		
80		x	1,000	=	
79		x	794	=	
78	1	x	631	=	631
77	1	x	501	=	501
76	3	x	398	=	1194
75	2	x	316	=	632
74	2	x	251	=	502
73	2	x	200	=	400
72		x	159	=	
71	3	x	126	=	378
70	1	x	100	=	100
69	2	x	79.4	=	158.8
68	5	x	63.1	=	315.5
67	2	x	50.1	=	100.2
66	4	x	39.8	=	159.2
65	7	x	31.6	=	221.2
64	5	x	25.1	=	125.5
63	3	x	20.0	=	60
62	3	x	15.9	=	47.7
61	1	x	12.6	=	12.6
60	2	x	10.0	=	20.0
59		x	7.94	=	
58	1	x	6.31	=	6.31
57		x	5.01	=	
[illegible]		x	[illegible]	=	

1. Sum B 50
2. Sum D 5575.01
3. Sum D/Sum B 111.5
4. L_{eq} 70.5



b. Multiply the counts in Column B by the number in Column C and enter the results in Column D.

c. Add all values in Column D to determine Sum D.

d. Divide Sum D by Sum B.

e. Locate the value in Column C that is approximately equal to Sum D/Sum B. The corresponding value in Column A approximates L_{eq}.

9. Recheck calibration.

3.7 MEASUREMENT PROCEDURE FOR REPRESENTATIVE SOUND LEVEL

An alternative, less complex procedure which only provides equivalent sound level, L_{eq}, is described below:

1. A sketch of the measurement site sould be preprepared and appropriate distances and site features noted. All information required on the data sheet should be entered (see Figure 3).

2. Mount the microphone (or sound level meter/microphone combination if the microphone cannot be remotely mounted) on a tripod at a height of about 1.5 metres (5 feet) above the ground and not less than 3 metres (10 feet) from any reflecting surfaces. There may be instances where measurements must be made at different heights (e.g., upper story of residences) or closer to reflecting surfaces (e.g. urban areas). If this is necessary, note these facts on the data sheet. Calibrate the sound level measurement system.

a. Set the sound level meter to the A-weighting network and "slow" response.

b. Observe the sound level meter during a 10 ±2 second sampling period at the start of each minute and half minute and note the maximum value each period, L_A, on data sheet (see Figure 3). Take 60 readings.

3. Determine the arithmetic average sound level L_A as:

$$L_A = \frac{1}{n} (L_1+L_2+L_3+L_4+....L_n)$$

where L_1, L_2, ...L_n are those sound levels that fall within a range of from 6 decibels less than the maximum level to the maximum level (e.g., if maximum is 70 dB, all levels from 64 dB to and including 70 dB are used).

n is the number of L_A values used for computing the arithmetic average.

FIGURE 3. SAMPLE SOUND LEVEL EXPOSURE DATA SHEET

Instructions:

1. Calibrate sound level meter using acoustic calibrator.
2. Install windscreen, select A-weighting network, select "slow" response.
3. Observe for 10 ±2 seconds at the start of each minute and 1/2 minute for 30 minutes.
4. Record maximum reading L_A during each 10 ±2 second period.

Determine Arithmetic Average $\overline{L}_A$

	L_A	Remarks		L_A	Remarks
1.			31.		
2.			32.		
3.			33.		
4.			34.		
5.			35.		
6.			36.		
7.			37.		
8.			38.		
9.			39.		
10.			40.		
11.			41.		
12.			42.		
13.			43.		
14.			44.		
15.			45.		
16.			46.		
17.			47.		
18.			48.		
19.			49.		
20.			50.		
21.			51.		
22.			52.		
23.			53.		
24.			54.		
25.			55.		
26.			56.		
27.			57.		
28.			58.		
29.			59.		
30.			60.		

SUM:*____________________

*Consider for the sum only those values within 6 dB of the maximum value observed.

$\overline{L}_A$ = Sum/n: ________ n/60 ________ Correction (Table 3) ________ L_{eq} ________

Location________________ Date________________ Time________________

Wind Velocity__________mph. Temperature________°F Engineer____________

Remarks ____

Sketch site on reverse side of Data Sheet.

FIGURE 3. SAMPLE SOUND LEVEL EXPOSURE DATA SHEET (cont.)

Instructions:

1. Calibrate sound level meter using acoustic calibrator.
2. Install windscreen, select A-weighting network, select "slow" response.
3. Observe for 10 ±2 seconds at the start of each minute and 1/2 minute for 30 minutes.
4. Record maximum reading L_A during each 10 ±2 second period.

Determine Arithmetic Average $\overline{L}_A$

	L_A	Remarks		L_A	Remarks
1.	70		31.	71	
2.	68		32.	74	✓
3.	66		33.	68	
4.	75	✓	34.	62	
5.	56		35.	64	
6.	71		36.	70	
7.	78	✓	37.	72	
8.	69		38.	75	✓
9.	62		39.	61	
10.	51		40.	64	
11.	64		41.	59	
12.	72		42.	70	
13.	76	✓	43.	59	
14.	71		44.	60	
15.	64		45.	62	
16.	62		46.	69	
17.	69		47.	74	✓
18.	73	✓	48.	66	
19.	71		49.	63	
20.	79	HIGHEST ✓	50.	58	
21.	74	✓	51.	63	
22.	61		52.	71	
23.	66		53.	69	
24.	70		54.	72	
25.	75	✓	55.	70	
26.	63		56.	70	
27.	72		57.	70	
28.	64		58.	66	
29.	60		59.	64	
30.	66		60.	71	

SUM:* 753 n=10

*Consider for the sum only those values within 6 dB of the maximum value observed.

$\overline{L}_A$ = Sum/n: 75.3 n/60 0.17 Correction (Table 3) -10 L_{eq} 65.3

Location 240' E. I-999 Date 8/21/81 Time 9:20AM
Wind Velocity 0 mph. Temperature 75 °F Engineer HENWAY
Remarks

Sketch site on reverse side of Data Sheet.

TABLE 3

Corrections to $\overline{L}_A$ to Obtain L_{eq}

n/60	Correction - dB
.8 to 1	0
.7 to .8	1
.6 to .7	2
.5 to .6	3
.4 to .5	4
.3 to .4	5
.2 to .3	7
<.2	10

where n is the number of samples used in the calculation of $\overline{L}_A$

$$L_{eq} = \overline{L}_A - \text{correction}$$

4. Apply the corrections shown in Table 3 to obtain the equivalent sound level, L_{eq}.

3.8 DAY-NIGHT SOUND LEVEL CALCULATIONS

Day-night sound levels can be obtained using one of two sampling procedures. One procedure requires that equivalent sound levels, L_{eq}, be obtained for each hour of the 24 hours and then energy-averaged. The other procedure is a minimum sampling scheme which uses energy average values of sound level for representative periods.

3.8.1 Hourly Sound Level Measurements

To determine L_{dn} from hourly measurements,

1. Add 10 dBA to each hourly L_{eq} from 2200 hours to 0700 hours (nighttime).

2. Determine the number of hours represented by each L_{eq} value (for the nighttime hours, use the adjusted values from step 1), and enter these values in Column B of Figure 2.

3. For each sound level band, Column A, multiply the number of hours in Column B by the corresponding value in Column C. Enter the result in Column D.

4. Add all the values in Column D to obtain the Sum D. Divide Sum D by 24. Locate the value of Sum D/24 in Column C and note the corresponding sound level in Column A. This is the day-night sound level L_{dn}.

3.8.2 Representative Period Measurements

This minimum sound level measurement scheme requires that one measurement be made during each of the periods shown below:

Period	Time	Numbers of Hours Represented
Day	0700-1900	12
Evening	1900-2200	3
Nighttime	2200-0700	9

Figure 4 is again used to obtain an estimate of the day-night sound level, L_{dn}.

FIGURE 4. EXAMPLE OF L_{dn} COMPUTATION USING FIGURE 2

EXAMPLE: 24-HOUR SURVEY

Time of Day	Hourly L_{eq}
0700-0800	62
0800-0900	64
0900-1000	62
1000-1100	62
1100-1200	58
1200-1300	56
1300-1400	54
1400-1500	54
1500-1600	58
1600-1700	66
1700-1800	66
1800-1900	62
1900-2000	60
2000-2100	58
2100-2200	56
2200-2300	54*
2300-2400	52*
2400-0100	52*
0100-0200	50*
0200-0300	48*
0300-0400	48*
0400-0500	48*
0500-0600	48*
0600-0700	48*

*10-decibel penalties are added to these nighttime values.

A	B	C	D
66	2	39.8	79.6
65	0	31.6	
64	2	25.1	50.2
63	0	20.0	
62	6	15.9	95.4
61	0	12.6	
60	2	10.0	20.0
59	0	7.94	
58	8	6.31	50.48
57	0	5.01	
56	2	3.98	7.96
55	0	3.16	
54	2	2.51	5.02

Sum B = 24
Sum D = 308.66
Sum B/Sum D = 12.86
L_{dn} = 61 dBA

1. Enter the 11 hours for the daytime period in Column B corresponding to the equivalent sound level for this period. Similarly, enter the 4 hours for evening in Column B corresponding to this period L_{eq} values.

2. Enter the 9 hours for nighttime in Column B corresponding to the nighttime sound level plus 10 (L_{eq}+10).

3. Repeat the procedure discussed in Section 3.8.1 to obtain L_{dn}.

4.0 VEHICLE NOISE MEASUREMENT PROCEDURE

4.1 PURPOSE

This procedure describes how vehicle noise emission levels are measured (paragraphs 4.2 - 4.7) and how the reference energy mean emission levels are calculated (paragraph 4.8).

4.2 INSTRUMENTATION

The following equipment is required:

- Sound Level Meter (Type 1 or 2)
- Sound Level Calibrator
- Wind Speed Indicator
- Sling Psychrometer (Optional)
- Vehicle Speed Detection Unit (Radar)
- Windscreen
- Tripod
- Microphone Cable (Optional)
- Data Sheets
- Watch (w/seconds display - optional)
- Spare Batteries

4.3 PERSONNEL

At least two people are required to carry out the procedure. One person should make sound level measurements, and one person should identify vehicles and measure vehicle speed. A third person to record data may be helpful.

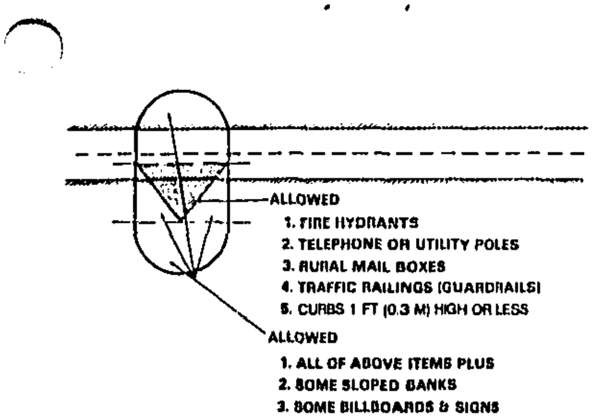
4.4 TEST SITE REQUIREMENTS

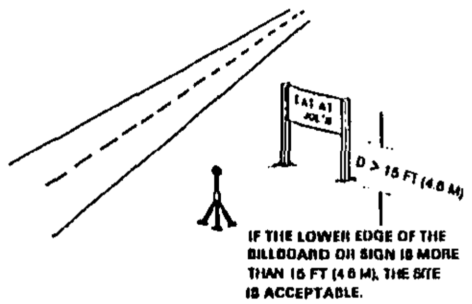
To achieve uniformity between States and reduce the need for adjustments to measure emission levels, the following test site guidelines must be met (see figure 5):

1. The test site shall consist of a level open space free of large reflecting surfaces, such as parked vehicles, signboards, buildings, or hillsides located within 30 metres (100 feet) of either the vehicle path or the microphone.

2. The microphone shall be located 15 metres (50 feet) from the centerline of the near traffic lane (see figure 6).

3. A clear line of sight to the roadway is required within an unobscured arc of 150 degrees from the 15-metre (50-feet) microphone position.





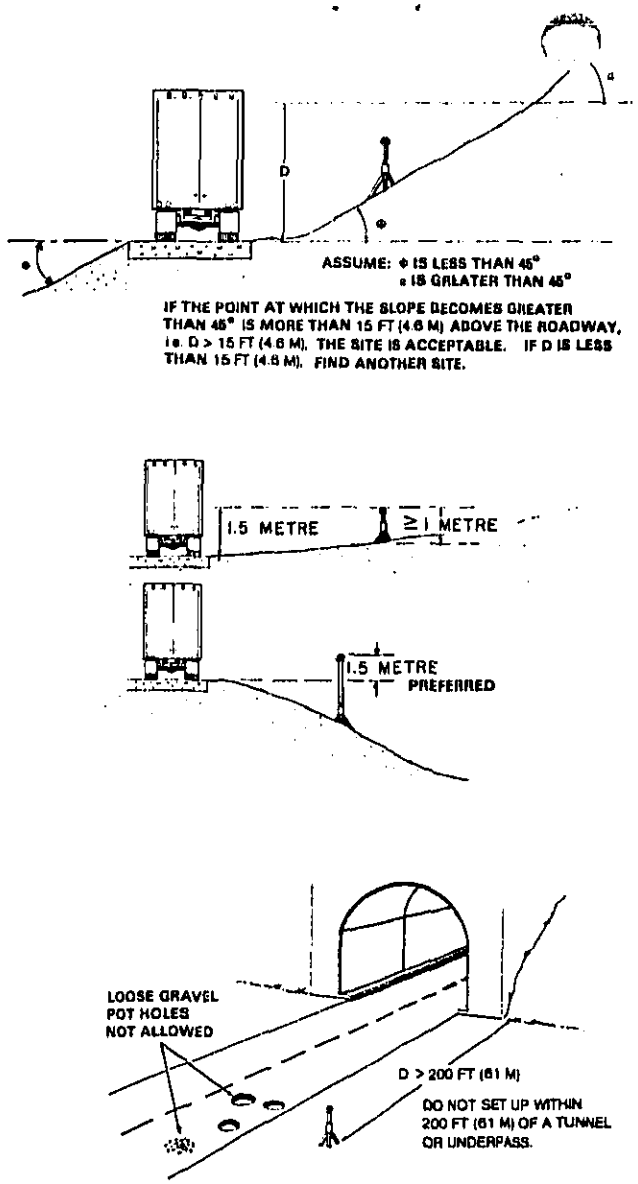


Figure 5. Site Acceptability Criteria

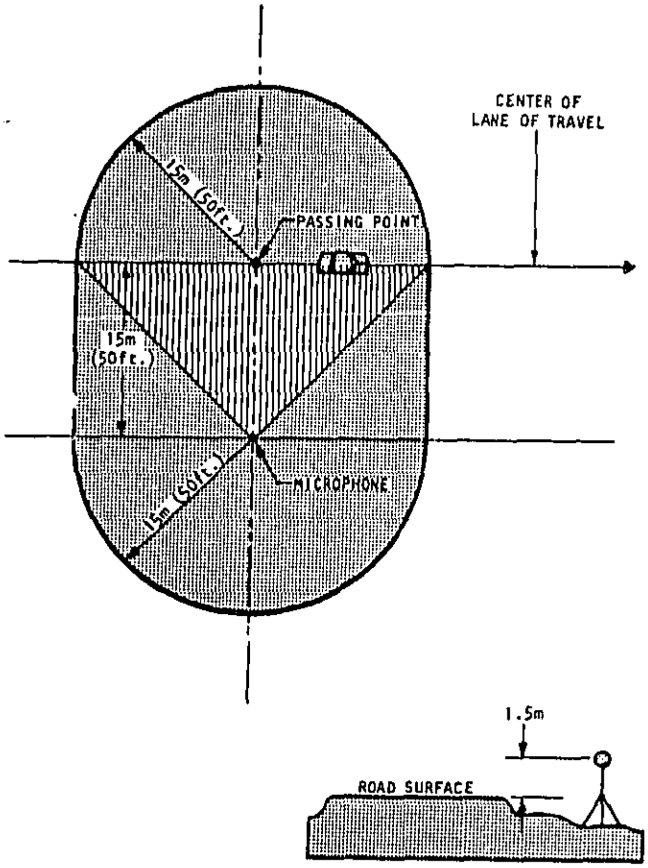


Figure 6. Preferred Roadside Test Site

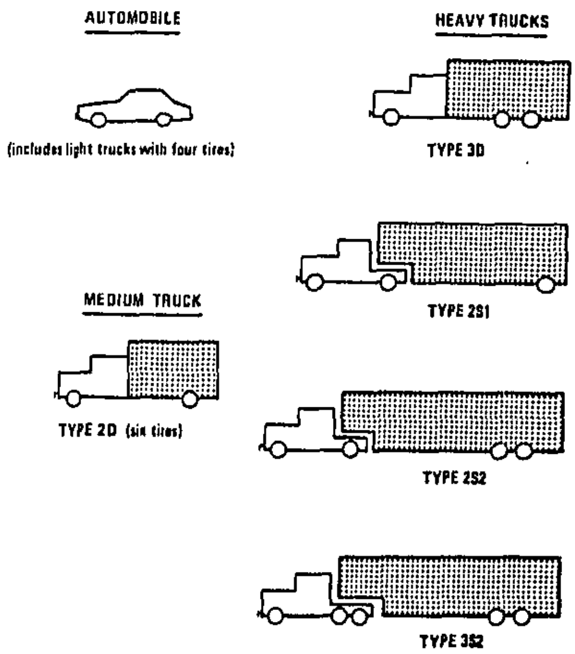


Figure 7. Vehicle Type Identification

4. The surface of the ground within the measurement area shall be free of snow and may be hard (α=0) or soft (α=½).

5. The vehicle path shall be relatively level (less than 2% grade), smooth, dry concrete or asphalt, and free of extraneous material such as gravel.

6. The existing sound level (including wind effects) coming from sources other than the individual vehicle being measured (this includes other vehicles) shall be at least 10 dBA lower than the level of the test vehicle.

4.5 VEHICLE OPERATION

Constant speed traffic operating under cruise conditions (i.e., the vehicles are not accelerating or decelerating).

4.6 MEASUREMENT PROCEDURE

1. Mount the microphone (or sound level meter/ microphone combination) on a tripod at a height of 1.5 metres ± 16 cm (5 feet ± 6 inches) above the surface on which the microphone stands (see Figure 6).

2. Locate the microphone at a distance of 15 metres (50 feet) from the centerline of the near lane of traffic.

3. Orient the microphone per the instrument manufacturer's specifications.

4. Place the vehicle speed measurement system so that the vehicle's speed can be measured as it passes the microphone.

5. Set the sound level meter (SLM) to "fast" response and the A-weighting network.

6. Observe the SLM as the vehicle passes the microphone.

7. Note the highest observed sound level measured by the SLM, i.e., the maximum pass-by sound level. This is the vehicle emission level, L_o.

VEHICLE NOISE EMISSION LEVELS Page ____ Of ___

Time ____________ Equipment ____________________

Name ____________________ Date ________________ Site ____________________________

	Autos		Med Trk 2D		Heavy Trucks 3D		2S1		2S2		3S2		Vehicle Description
Sample	S*	Lo**	S	Lo	S	Lo	S	Lo	S	Lo	S	Lo	
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													
13													
14													
15													
16													
17													
18													
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21													
22													
23													
24													
25													
26													
27													
28													
29													
30													
31													
32													
33													
34													
35													
36													
37													
38													
39													
40													
Total # of Sample													
Mean Sound Level													
Std. Dev.													
Energy Mean Level													

*Speed - Indicate if MPH or KPH **Peak Sound Level, dBA, Fast Response

Figure 8. Sample Data Sheet for Vehicle Noise Levels

8. Identify the vehicle by type. (See paragraph 4.7.1 and Figure 7 for discussion of vehicle types.)

9. Measure the vehicle's speed as it passes the microphone.

10. Record the vehicle type, emission level, and speed on the data sheet (Figure 8). Continue measurements until sufficient samples are obtained to describe the sound level for the representative vehicle class within the accuracy desired. (See paragraph 4.7.2 for discussion on the number of vehicle measurements that are needed.)

4.7 COMPUTING THE NUMBER OF SAMPLES REQUIRED

1. Past vehicle noise emission measurements have indicated that vehicles may be grouped into three acoustically similar classes.* These classes are:

   a. Automobiles (A) - All vehicles with two axles and four wheels designed primarily for transportation of nine or fewer passengers (automobiles), or transportation of cargo (light trucks). Generally, the gross vehicle weight is less than 4,500 kilograms (10,000 pounds).

   b. Medium Trucks (MT) - All vehicles having two axles and six wheels designed for the transportation of cargo or generally more than nine passengers. Generally, the gross vehicle weight is greater than 4,500 kilograms (10,000 pounds) but less than 12,000 kilograms (26,000 pounds). This category corresponds to American Association of State Highway and Transportation Officials (AASHTO) Classification 2D (see Figure 8).

   c. Heavy Trucks (HT) - All vehicles having three or more axles and designed for the transportation of cargo. Generally, the gross weight is greater than 12,000 kilograms (26,000 pounds). This category

*Highway Noise-Generation and Control, NCHRP Report 173, Transportation Research Board, Washington, D. C., 1976.

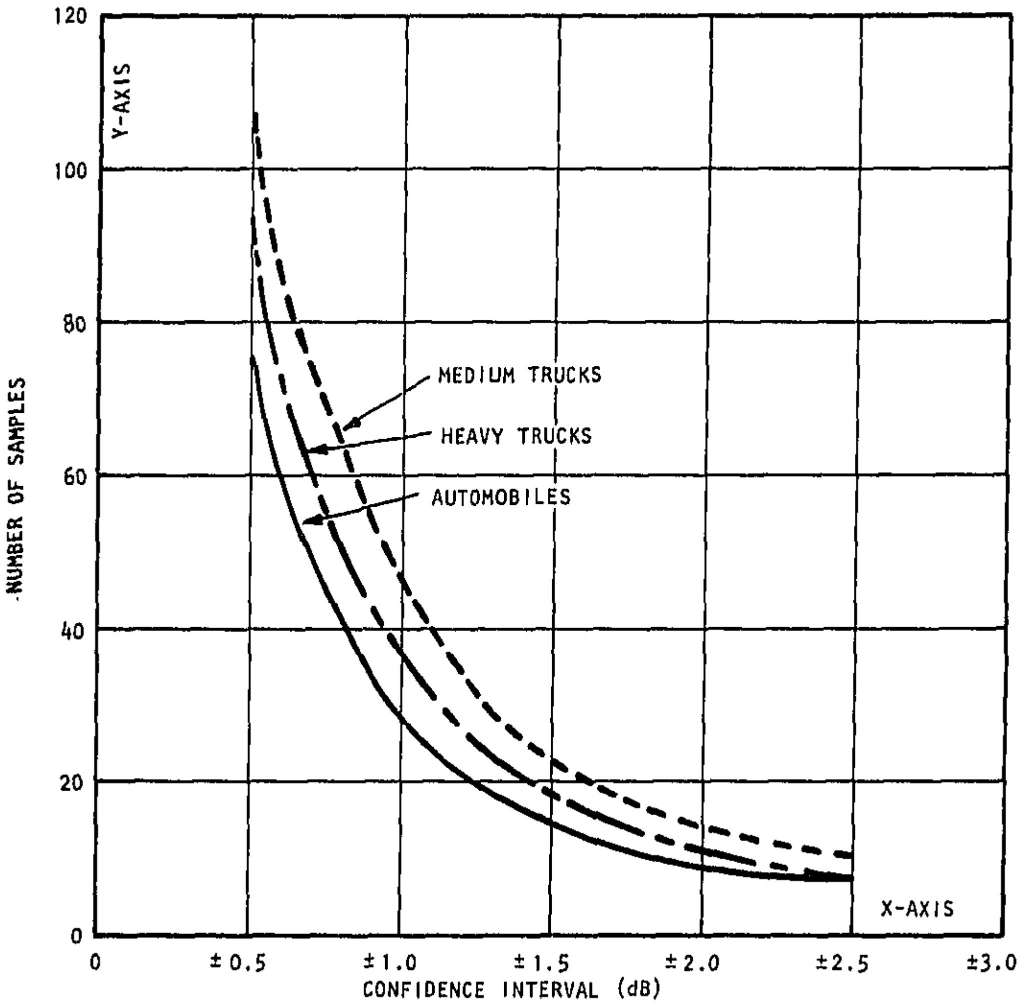


Figure 9. Sample Population Size For Vehicle Emission Sampling

95% CONFIDENCE

Note: Based on data from "Statistical Analysis of FHWA Traffic Noise Data," FHWA-RD-78-64 (Draft Final Report) July 1978.

includes AASHTO Classifications 3D, 2S1, 2S2, and 3S2 (see Figure 7), three-axle buses, and tractors without trailers.

2. Measurements should be made by vehicle type at a selected vehicle speed and recorded on Figure 8. Vehicles traveling at speeds within ±5 km/h (±3 mph) of the selected vehicle speed can be included as part of the sample in computing the sample size for a given speed. (Grouping vehicle speeds into a 10 km/h (5 mph) wide range may produce sound level measurement uncertainty of ±1.5 dBA at low speeds and ±1.0 dBA at high speeds for any given vehicle class.) The different vehicle types in the heavy truck classification may be grouped into one class for analysis. For accurate representation of the vehicle class, the number of measurements for each vehicle class at a selected speed is determined using Figure 9 as follows:

   a. Select a confidence interval (typically ±1 dBA).*

   b. Enter Figure 9 with this value.

   c. Move up from the X-axis to where this value intersects the curve corresponding to the vehicle class under consideration.

   d. Read the corresponding number of samples for this point from the Y-axis.

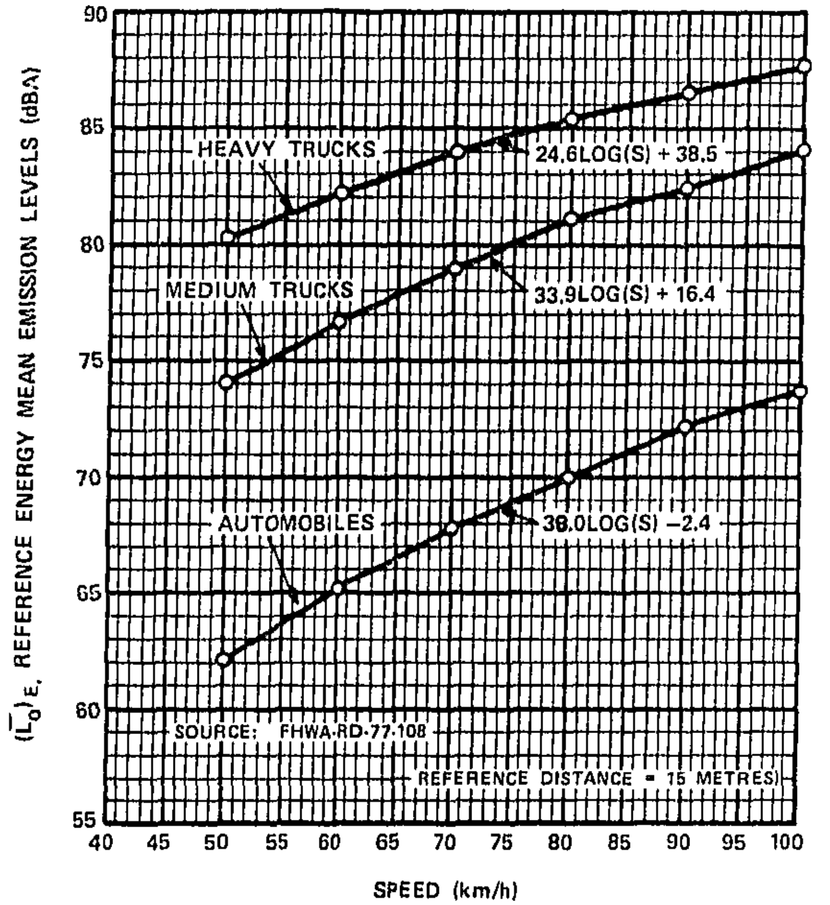
3. If fewer than the required samples are obtained during the measurement program, Figure 9 can be used to determine the accuracy with which those samples obtained describe the vehicle/ speed population.

   a. Enter the Y-axis of Figure 9 with the number of samples for a given vehicle class at a selected speed.

   b. Move across the graph to where this value intersects the curve corresponding to the vehicle class under consideration.

   c. Read the corresponding confidence interval for these samples from the x-axis.

*A 95% confidence interval of ±1 dBA means that there is a 95-out-of-100 chance that the mean emission level of the data is within ±1 dBA of the mean value of the population of vehicles of that type.



LEGEND:

1. AUTOMOBILES: ALL VEHICLES WITH TWO AXLES AND FOUR WHEELS.
2. MEDIUM TRUCKS: ALL VEHICLES WITH TWO AXLES AND SIX WHEELS.
3. HEAVY TRUCKS: ALL VEHICLES WITH THREE OR MORE AXLES.

Figure 10. Reference Vehicle Sound Emission Levels

4.8 CALCULATION OF THE REFERENCE ENERGY MEAN EMISSION LEVELS

There are several ways in which the emission level/speed data obtained from the field measurements can be used to compute the reference energy mean emission levels. Any procedure which is statistically valid is acceptable. Two of the procedures are discussed here.

1. Calculation of the reference energy mean emission levels on data collected at a single speed (±5 km/h). Computation of the reference energy mean emission level for this situation uses the formula:

$$(\overline{L_o})_{Ei} = (\overline{L_o})_i + 0.115(\sigma_o)_i^2 \qquad (1)$$

where $(\overline{L_o})_{Ei}$ is the reference energy mean emission level for the i^{th} vehicle class for a single speed;

$(\overline{L_o})_i$ is the arithmetic average sound level, L_o, of the i^{th} class;

$(\sigma_o)_i$ is the standard deviation of the emission levels of the i^{th} vehicle class for a single speed.

a. Compute the arithmetic average emission level, $(\overline{L_o})_i$, for the i^{th} vehicle class.

$$(\overline{L_o})_i = \frac{1}{n}\sum_{k=1}^{n}(L_o)_{ki} \qquad (2)$$

where $(L_o)_{ki}$ is the k^{th} measured emission level of the i^{th} class of vehicles;

n is the number of measured emission levels in the sample.

VEHICLE NOISE EMISSION LEVELS

Page 1 Of 1

Time 2 - 3 PM Equipment GENRAD 1981B

Name W. HENWAY Date 8/21/81 Site I-99; 1.5 M. EAST of NOISEVILLE

	Autos		Med Trk 2D		Heavy Trucks 3D		2S1		2S2		3S2		Vehicle Description (ALL CARS)
Sample	S*	Lo**	S	Lo	S	Lo	S	Lo	S	Lo	S	Lo	
1 ✓	52	71											
2 ✓	54	70											
3 ✓	58	67											
4	46	65											
5 ✓	52	70											
6 ✓	55	70											
7	59	73											VAN
8 ✓	55	68											
9 ✓	66	71											
10	49	70											
11 ✓	52	70											
12 ✓	56	69											
13 ✓	58	74											
14	66	78											PICK-UP
15	50	70											
16 ✓	52	71											
17 ✓	55	71											
18 ✓	57	72											
19 ✓	57	73											
20 ✓	57	70											
21	49	68											
22 ✓	52	71											
23 ✓	55	69											PICK-UP
24 ✓	54	71											
25 ✓	55	72											
26	51	70											
27	59	73											
28	51	75											VW
29 ✓	56	72											
30 ✓	57	70											
31 ✓	54	70											
32 ✓	58	73											
33 ✓	55	71											
34 ✓	56	70											
35 ✓	56	74											PICK-UP
36 ✓	52	68											
37 ✓	54	70											
38	59	73											
39 ✓	57	71											
40 ✓	56	68											
Total # of Sample	29/40	(WITHIN 52-58 MPH)											
Mean Sound Level	70.7	(OF THOSE 29)											
Std. Dev.	1.58	(OF THOSE 29)											
Energy Mean Level	71.0	(FOR A SPEED OF 55 mph)											

*Speed - Indicate if (MPH) or KPH **Peak Sound Level, dBA, Fast Response

Notes: 1. All data between 52-58 mph used as if at 55 mph.

2. Energy Mean Level = Mean Sound Level + 0.115(Std. Dev.)^2

$$= 70.7 + 0.115(1.58)^2$$

$$= 71.0 \text{ dBA}$$

3. 95% confidence interval for 29 samples is ± 1.0 dBA.

Figure 11. Example of Emission Level Determination

(b) Compute the standard deviation, $(\sigma_o)_i$, of the i^{th} class of vehicles.

$$(\sigma_o)^2_i = \frac{1}{n-1} \left[\sum_{k=1}^{n} \left\{ (L_o)_{ki} - (\overline{L_o})_i \right\}^2 \right] \quad (3)$$

where $(L_o)_{ki}$ is the k^{th} measured emission level of the i^{th} class.

2. Calculation of the reference energy mean emission levels on data collected over a wide range of speeds. This type of analysis involves curve fitting and is normally carried out using a computer with a statistical analysis program (i.e., the Social Sciences (SPSS) Version 7.2 program for an IBM 370 computer was used to develop the reference energy mean emission levels for the medium and heavy trucks shown in Figure 10). Computation of the reference energy mean emission levels still uses the form:

$$(\overline{L_o})_{Ei} = (\overline{L_o})_i + .115(\sigma_o)_i^2 \quad (4)$$

where $(\sigma_o)_i$ is the standard deviation of the i^{th} class from the regression analysis; and

where $(\overline{L_o})_i$, the mean sound level, now takes the form of the following equation:

$$(\overline{L_o})_i = A_i + (B_i)\log(\text{speed})$$

where A_i and B_i are constants computed in the regression analysis.

5.0 BARRIER FIELD INSERTION LOSS DETERMINATION PROCEDURE

5.1 PURPOSE

This chapter provides procedures that can be used to determine the field insertion loss (IL) provided by a noise barrier. The field insertion loss is the difference in sound levels at a particular microphone location caused by the construction of a noise barrier. If the sound barrier could be constructed "instantaneously," determination of IL would be simple. In this situation, a "before construction" sound level measurement would be made, the barrier would be "instantaneously" constructed, and an "after construction" sound level measurement would be made. The difference between the two levels would be the IL. Because of the time involved in building a barrier, a number of factors are introduced for which corrections must be made. These factors include changes in traffic volumes, mix and speed, changes in emission levels, and changes in terrain. The procedures presented here for determining IL are based upon measurements to the maximum extent possible.

In addition to determining the IL, people are also concerned about the accuracy of the prediction models used in the barrier design. Too often the predicted IL used during the barrier design is compared with a measured IL obtained shortly after barrier construction. This comparison may be invalid if the predicted IL and the measured IL are based on different traffic conditions. For a meaningful comparison, the conditions under which the measurements were made must be used in the prediction model. Thus, a valid comparison may be made between a measured IL and a calculated IL. Users of these procedures are urged to use the FHWA Model (see FHWA Report FHWA-RD-77-108, "The FHWA Highway Traffic Noise Prediction Model") for these calculations.

Procedures are provided in this chapter for determining field insertion loss of noise barriers for two cases. Case 1 (section 5.4) is for existing highways where "before construction" measurements can be obtained. Case 2 (section 5.5 through 5.6) is for new highways or for existing noise barriers where "before" measurements cannot be obtained. Figure 12 illustrates the decision process for determining insertion loss as explained in sections 5.4 through 5.6.

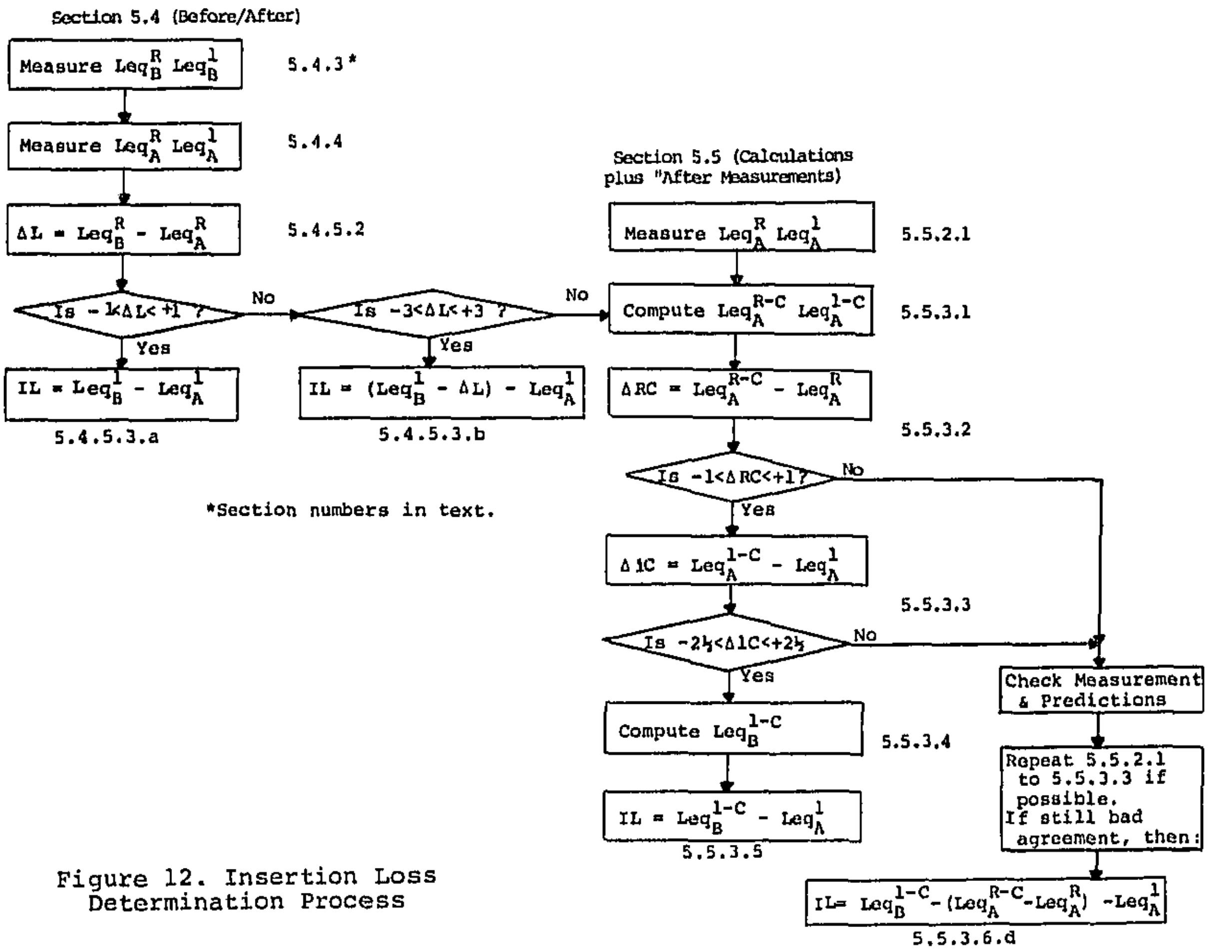


Figure 12. Insertion Loss Determination Process

5.2 INSTRUMENTATION

The following equipment is required:

- Sound Level Meters (Type 1 or 2) - 2
- Sound Level Calibrator
- Earphones or Headphones (Optional)
- Speed Detection Device (Radar)
- Stopwatches or Timers - 2
- Wind Speed Indicator
- Sling Psychrometer (Optional)
- Tripod - 2 (Optional)
- Data Sheets
- Microphone Cables - 2 (Optional)
- Windscreens - 2
- Spare Batteries

5.3 PERSONNEL

Two persons are needed to make sound level measurements. If the technique in section 5.4 is used, two other individuals will be needed to operate the speed detection equipment and to count the traffic. For the other two techniques, one person may be sufficient to count traffic. Familiarity with the FHWA Model is desirable.

5.4 TECHNIQUE FOR DETERMINING IL FOR EXISTING HIGHWAYS WHERE THE BARRIER HAS NOT BEEN BUILT

This procedure involves simultaneous measurements at "reference" and "study site" microphone locations. Two sets of measurements are made: one set before the barrier is built, and one set after the barrier is built. An adjustment is then made (if necessary) to the reference measurements, and the IL is calculated by subtracting the "after" measurement from the adjusted "before" measurement.

5.4.1 "Study Site" Microphone Location (Microphone #1)

1. Use maps and/or field reconnaissance to determine the desired "study site" location for the IL determination.

2. Once the location is selected, establish a baseline. The baseline is a line perpendicular to the centerline of the near traffic lane and passes through

microphone #1. The reference microphone will also be located along this baseline. Record the exact location of the baseline and microphone #1 (distance and elevation). Another set of measurements will be made at the same location after the barrier is built.

3. Microphone locations should not be selected within 3 metres of any vertical reflective surface. Measurements should not be taken at locations or times where extraneous sounds such as aircraft, animals, children, or traffic on side streets could influence the measurements.

4. If a comparison will be made between the measured insertion loss and a calculated insertion loss, the geometry and terrain between microphone #1 and the roadway should be as simple and uniform as possible. This will simplify the input data needed for the prediction model.

5.4.2. <u>Reference Microphone</u>

1. The reference microphone is located on the baseline determined by section 5.4.1.2.

2. The location, length, and elevation of the proposed barrier must be known before the reference microphone may be located.

3. The reference microphone must have an unobstructed view of the roadway through a subtended arc of at least 160 degrees. Once this requirement is satisfied, any of three positions may be used.

   a. Position A (refer to Figure 13)--Between the roadway and the barrier provided that the microphone is at least 7.5 metres from the centerline of the near traffic lane, and at least 3.0 metres from any reflective surface (including the barrier).

   b. Position B (refer to Figure 14)--Directly over and 1.5 metres above the top of the barrier (still be at least 7.5 metres away from the centerline of the near traffic lane).

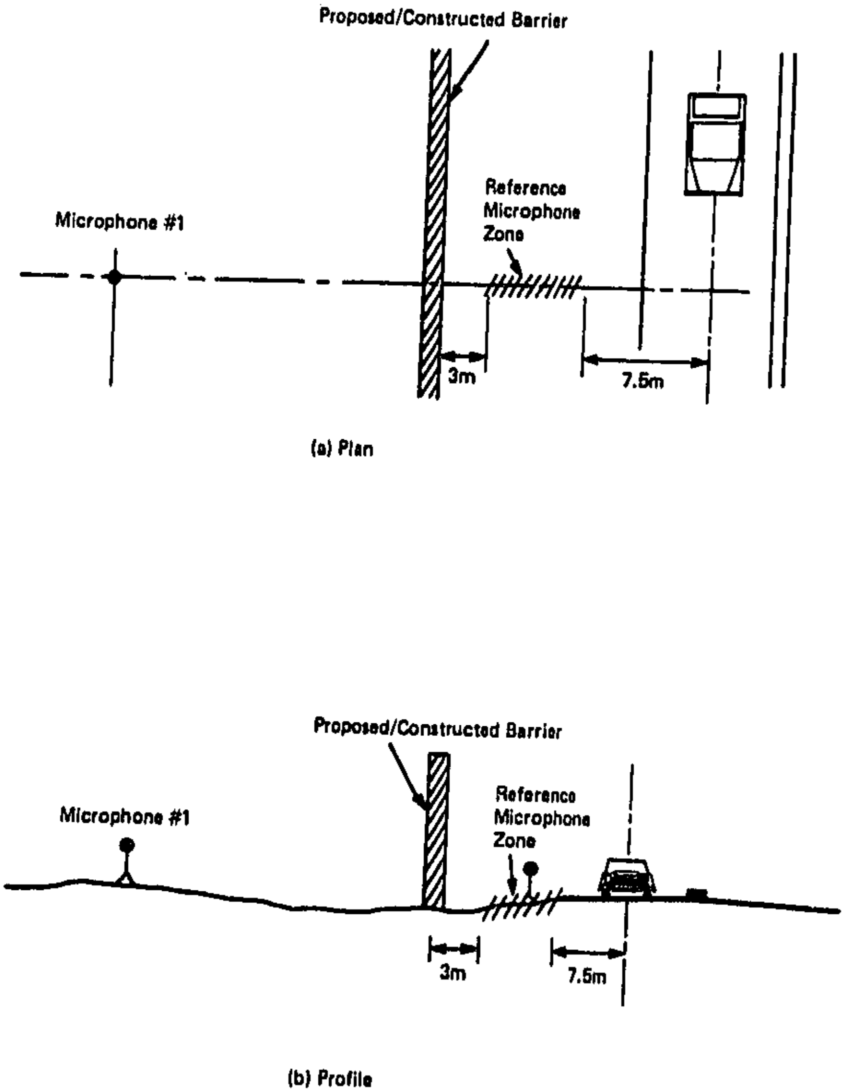


Figure 13. Reference Position A

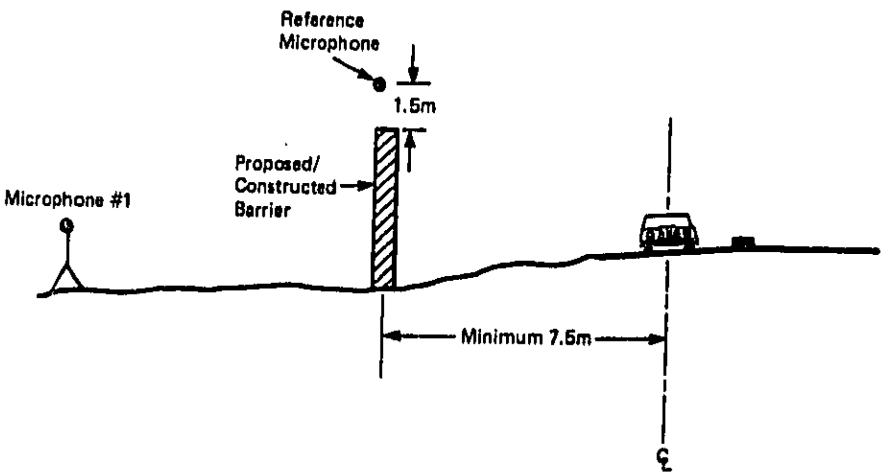


Figure 14. Reference Position B

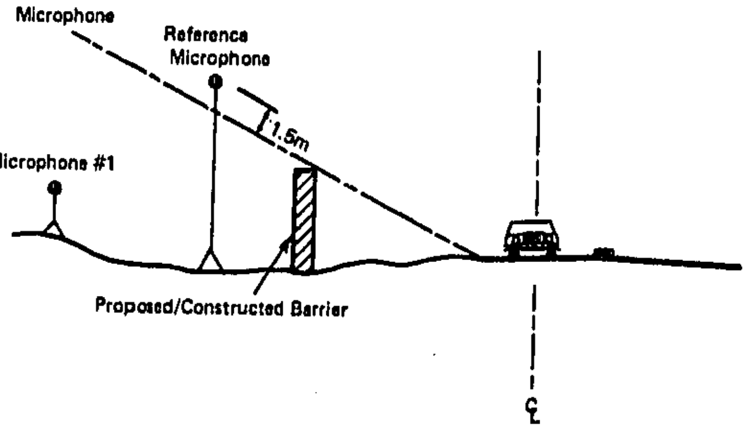


Figure 15. Reference Position C

c. Position C (refer to Figure 15)--Between the barrier and microphone #1. The reference microphone must be 1.5 metres higher (measured perpendicular) than a line drawn from the near edge of the pavement through the top front edge of the barrier.

4. If the measured IL is to be compared with a calculated IL, subsequent calculations will be simplified if the reference microphone location is exactly 15.0 metres from the centerline of the near lane.

5. Record the precise location of the reference microphone on the baseline. This location will be used for the "after" set of measurements.

5.4.3 Measurement and Calculations for the "Before Construction" Condition

1. Sound Level Measurement
Through simultaneous measurements, obtain sound level data at the reference microphone and at microphone #1. Minimum measurement period is 8 minutes and 20 seconds. Chapter 3 discusses a typical manual measurement procedure. Determine the "before" Leq(h) at the reference microphone, $Leq(h)_B^R$, and at microphone #1, $Leq(h)_B^1$. Record these values. After the barrier is built, these values will be used to determine the measured IL.

2. Traffic and Environmental Data
Concurrently with the sound level measurements, the traffic data must be measured. Vehicles must be separated into the three classes shown in Figure 16. Two-axle buses go into the medium category and three-axle buses go into the heavy category. Traffic counts volumes must be obtained for both directions of flow. Obtain representative speeds for each vehicle class (in both directions, if possible). Also, obtain information on the ground conditions, wind speed and direction, and other climatic conditions.

5.4.4 Measurements and Calculations for the "After Construction" Condition

It is important that this second set of measurements be made as soon as practical after the barrier has been completed and normal traffic flow has been restored. This will help minimize changes in traffic characteristics that could significantly alter the sound levels.

1. Microphone Location
   After the barrier has been built, use the information in sections 5.4.1 and 5.4.2 to establish both microphone locations in the field. Monitor the environmental conditions and, when these conditions are similar to those observed in section 5.4.3.2, make the second set of measurements.

2. Sound Level Measurements
   Through simultaneous measurements, obtain sound level data at the reference microphone and at microphone #1. The minimum measurement period is 8 minutes and 20 seconds. Chapter 3 discusses a typical manual measurement procedure. Determine the "after" Leq(h) at the reference microphone, $Leq(h)_A^R$, and microphone #1, $Leq(h)_A^1$. Record these values.

3. Traffic and Environmental Data
   Concurrently with the sound level measurements, the traffic data must be measured. Vehicles must be separated into the three classes shown in Figure 16. Two-axle buses go into the medium category and three-axle buses go into the heavy category. The traffic count must be according to the direction of flow. Obtain representative speeds for each vehicle class (in both directions, if possible). Carefully study the ground and vegetation conditions at the site. Record these conditions along with data on wind speed and direction and other climatic conditions.

5.4.5 Computation of the Field Insertion Loss

1. Traffic Data Compare the traffic data measured before and after barrier construction. If the traffic conditions change substantially, the procedures in section 5.5 may be needed to determine the IL.

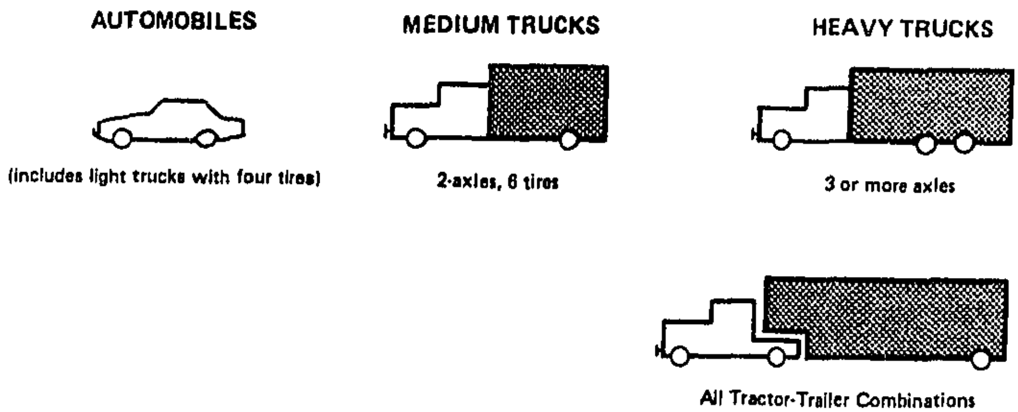


Figure 16. Vehicle Type Identification

Table 4. Criteria for Selection of Site Parameter

Situation	Drop-Off Rate
1. All situations in which the source or the receiver are located 3 metres above the ground or whenever the line-of-sight* averages more than 3 metres above the ground.	3 dBA ($\alpha = 0$)
2. All situations involving propagation over the top of a barrier 3 metres or more in height.	3 dBA ($\alpha = 0$)
3. Where the height of the line-of-sight is less than 3 metres and	
(a) There is a clear (unobstructed) view of the highway, the ground is hard and there are no intervening structures.	3 dBA ($\alpha = 0$)
(b) The view of the roadway is interrupted by isolated buildings, clumps of bushes, scattered trees, or the intervening ground is soft or covered with vegetation.	4.5 dBA ($\alpha = 1/2$)

*The line-of-sight (L/S) is a direct line between the noise source and the observer.

2. Reference Microphone Subtract the Leq(h) measured after the barrier was built from the Leq(h) measured before the barrier was built.

$$\Delta L = Leq(h)_B^R - Leq(h)_A^R \qquad (1)$$

where

ΔL is the difference in the Leq(h)'s

3. Microphone #1

a. If ΔL is $\pm$ 1 dBA or less, compute the IL according to equation 2.

$$IL = Leq(h)_B^1 - Leq(h)_A^1 \qquad (2)$$

where

IL is the field insertion loss.

b. If ΔL is $\pm$3 dBA or less, compute the IL according to equation 3.

$$IL = [Leq(h)_B^1 - \Delta L] - Leq(h)_A^1 \qquad (3)$$

c. If ΔL is greater than 3 dBA, compute the IL according to the procedures in section 5.5.

5.5 TECHNIQUE #1 FOR DETERMINING IL FOR NEW HIGHWAYS OR EXISTING BARRIERS (CALCULATIONS PLUS "AFTER" MEASUREMENTS)

This procedure uses a combination of "after" sound level measurements and the FHWA model. Basically, a set of sound level measurements is made at two carefully selected locations. These measurements are used to calibrate the FHWA model. Once the calibration is completed, a "before" sound level is calculated. The IL is then determined by taking the difference between the calculated "before" and the measured "after" sound levels.

5.5.1. Microphone Location

See sections 5.4.1. and 5.4.2.

5.5.2. Measurement and Calculations Based on Existing Barrier

1. Sound Level Measurement
   See section 5.4.4.2.

2. Traffic and Environmental Data
   See section 5.4.4.3.

5.5.3. Computation of the Field Insertion Loss

1. Using the FHWA model, compute the calculated noise level at the reference microphone, $Leq(h)_A^{R-C}$, and at microphone #1, $Leq(h)_A^{1-C}$. Divide the roadway into at least two equivalent lanes, one for each direction of flow using the traffic data obtained in section 5.5.2.2. Use Table 4 and/or experience to determine the site parameter for the reference microphone and for microphone #1.

2. Compare the calculated traffic noise level at the reference microphone, $Leq(h)_A^{R-C}$, with the measured traffic noise level, $Leq(h)_A^{R}$. If the two values agree within ± 1 dBA, it can be assumed that the emission data in FHWA model correctly represents the traffic for this site and that the site around the reference microphone has been correctly modeled. If the two values do not agree within ± 1 dBA, refer to section 5.5.3.6.

3. Compare the calculated traffic noise level at microphone #1, $Leq(h)_A^{1-C}$, with the measured traffic noise level, $Leq(h)_A^{1}$. If the two values agree within ± 2 1/2 dBA, it can be assumed that the site has been correctly modeled. If the two values do not agree within ± 2 1/2 dBA, refer to section 5.5.3.6.

4. Using the FHWA model and traffic from section 5.5.2.2, calculate the noise level at microphone #1, $Leq(h)_B^{1-C}$, as if the barrier has not been built. Base the site parameter upon the conditions that would exist if there were no barrier.

It is important to note that this calculation will be complicated for houses beyond the first row because they will receive some degree of shielding from the first row houses.

5. Compute the IL according to equation 4.

$$IL = Leq(h)_{B}^{1-C} - Leq(h)_{A}^{1} \qquad (4)$$

6. If the measured and calculated values do not meet the tolerance requirements ($\pm$ 1 dBA at the reference microphone and $\pm$2 1/2 dBA at microphone #1), locate the source of the discrepancies as follows:

   a. Check the computation of the measured Leq(h).

   b. Check the input data used in the FHWA model.

   c. If the tolerance requirement in section 5.5.3.6 still cannot be met, repeat the measurements in section 5.5.2.

   d. Repeat the steps in sections 5.5.3.1 through 5.5.3.3. If the error persists, compute the IL according to equation 5.

$$IL = \{Leq(h)_{B}^{1-C} - [Leq(h)_{A}^{R-C} - Leq(h)_{A}^{R}]\} - Leq(h)_{A}^{1} \qquad (5)$$

5.6 TECHNIQUE #2 FOR DETERMINING FIELD INSERTION LOSS FOR NEW HIGHWAYS OR EXISTING BARRIERS (UNSHIELDED LOCATION ALONG THE HIGHWAY)

One measurement is made at a noise sensitive site shielded by the barrier. A second measurement is made at a similar site along the highway where there is no barrier.

Figure 17 presents a sketch of appropriate measurement locations and specifies the geometry involved. If available, extra microphones could be used at each site at reference locations as a check on reference level similarities.

5.6.1. Microphone Locations

1. The microphone-to-roadway distance for each location must be identical $\pm$0.5 metres).

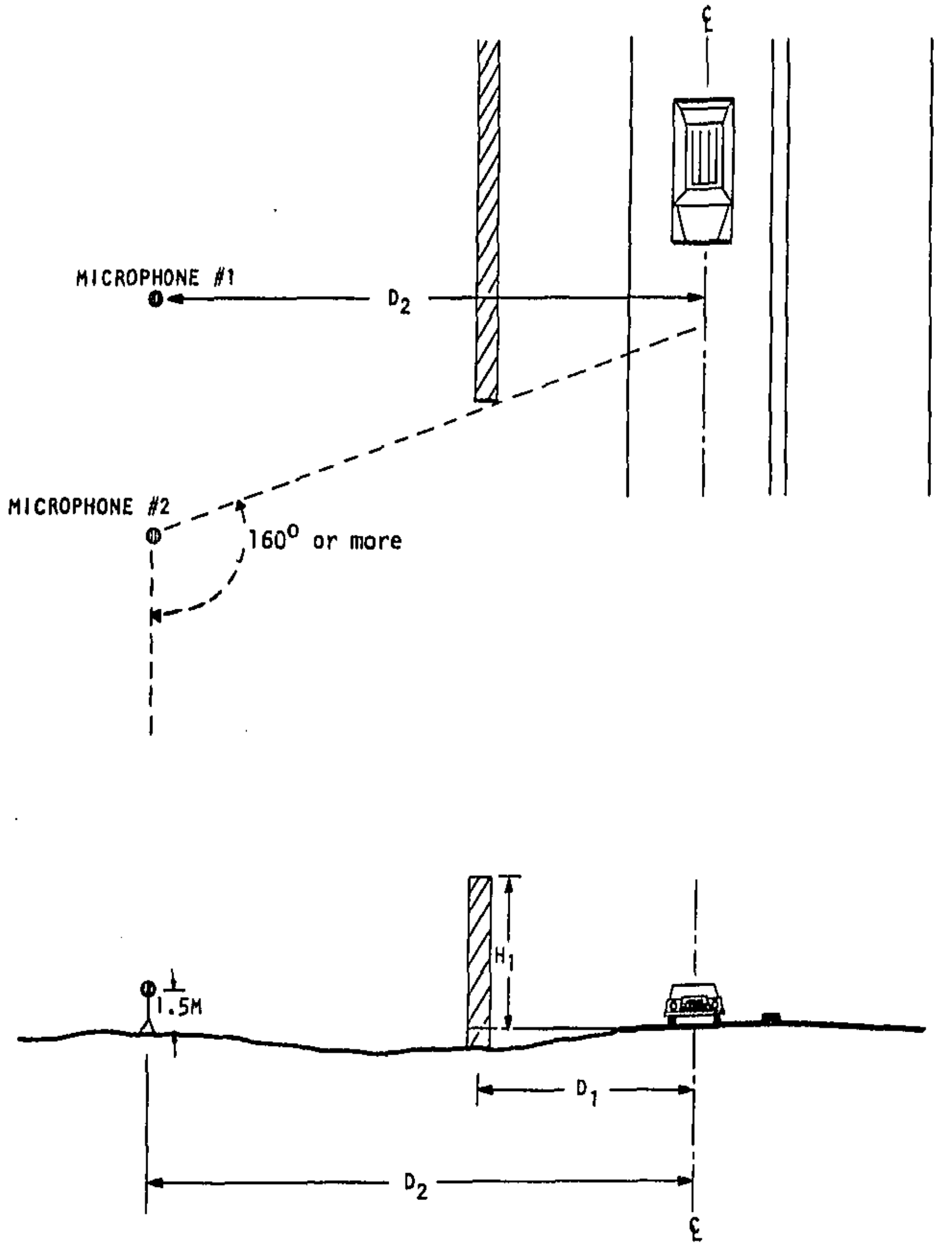


Figure 17. Microphone Locations for Simulated "Before" Site Method

2. The ground cover between the road and the microphone at each site must be similar.

3. The topography at each site should be similar.

4. The number of lanes and geometry of the roadway at each site should be identical. Road features such as median strips and guard barriers should be the same at each site.

5. Traffic flow conditions (vehicle/hour, mean vehicle speed) should be equivalent at each site.

6. The unshielded measurement location should have as great an angle of view of the highway as possible. An angle of at least 160 degrees is recommended. Both microphones are mounted on tripods at a height of 1.5 metres ±16 cm (5 feet ±6 inches) above the ground at the measurement point, or at the height of the receptor under study.

5.6.2. <u>Measurements</u>

1. <u>Sound Level Measurement</u>
Use the technique previously described in Chapter 3 to determine Leq at each microphone. Call the level at the unshielded site $Leq(h)^1_B$, and the level at the shielded site, $Leq(h)^1_A$

2. <u>Traffic and Environmental Data</u>
See section 5.4.3.2.

5.6.3. <u>Computation of the IL</u>

Use the procedure described in section 5.4.5, letting the unshielded site represent the "before" condition and the shielded site be the "after" condition. If the reference microphones were not used, the FHWA model should be used to compute the reference levels, $Leq(h)^R_B$ and $Leq(h)^R_A$. The IL will be the difference in levels at the two microphones, adjusted by differences in the reference levels.

6.0 NON-TRAFFIC NOISE SOURCE MEASUREMENT PROCEDURE

6.1 PURPOSE

This procedure is used to measure the contribution of noise sources (other than traffic) to ambient sound levels at noise sensitive land use areas. Typical of these noise sources are railroad activity, aircraft overflights, industrial plant operations, construction activity, etc. The A-weighted equivalent sound level (L_{eq}) due to the noise source is measured at the noise sensitive land use area. Two techniques are presented, one for stationary sources of sound and the other for mobile sources.

6.2 INSTRUMENTATION

The following equipment is required:

- Sound Level Meter (Type 2)
- Sound Level Calibrator
- Earphone/Headphone
- Stopwatch
- Wind Speed Indicator
- Psychrometer
- Tripod
- Microphone Cable
- Data Sheets
- Windscreen
- Spare Batteries

6.3 MEASUREMENT LOCATIONS

Measurements are made at noise sensitive land uses in the vicinity of a proposed highway, or at noise sensitive land uses along an existing route. The location should be chosen so that, if possible, noise sources other than the one being measured, have minimum influence on measurements.

6.4 PERSONNEL

The procedure can be accomplished by one person.

6.5 MEASUREMENT PROCEDURE

1. Mount the microphone (or sound level meter/microphone combination if the microphone cannot be remotely mounted on a tripod at a height of 1.5 metres ±16cm (5 feet ±6 inches) above the ground, and if practical, at least 3 metres (10 feet) from any substantial reflecting surface (e.g., buildings, vehicles, billboards).

2. Sketch the measurement locations, with site features and dimensions, on the back of the data sheet (Figure 18 or 19) to provide a record which can be used if future measurements are required. The sketch should be of sufficient detail to permit future measurements at the same location.

6.5.1 Stationary Sources

For stationary sources of noise (e.g., construction activity, industrial activity), the following procedure is used:

1. Set the sound level meter to the A-weighting network and "slow" response.

2. Observe the sound level meter during a 10 ±2 second sampling period at the start of each minute and half minute and note maximum value $\bar{L}_A$ in each period on data sheet.

   If the source is intermittent (e.g. operates for 15 minutes and then is off for 10 minutes) disregard periods when the source is not operating but continue to sample until 60 samples are acquired.

3. Disregard measurements affected by intrusive noise sources other than the identified noise source. Extend the number of half minute observations for more than 30 minutes until 60 valid measurements are obtained.

4. Determine the arithmetic average sound level $\bar{L}_A$ as:

$$\bar{L}_A = \frac{1}{n} (L_1+L_2+L_3+L_4+\ldots\ldots L_n)$$

   where L_1, L_2, ...L_n are those sound levels that fall within a range of from 6 decibels less than the maximum level to the maximum level (e.g., if maximum is 70 dB, all levels from 64 dB to and including 70 dB are used).

   n is the number of L_A values used for computing the arithmetic average.

5. Apply the corrections shown in Table 5 to obtain the equivalent sound level, L_{eq}.

6. Measurements should be made without the sound source operating to determine background ambient sound levels using the procedure presented in Steps 1-5.

FIGURE 18. SAMPLE SOUND LEVEL EXPOSURE DATA SHEET - STATIONARY SOURCES (ALTERNATIVE #1)

Instructions:

1. Calibrate sound level meter using acoustic calibrator.
2. Install windscreen, select A-weighting network, select "slow" response.
3. Observe for 10 ± 2 seconds at the start of each minute and 1/2 minute for 30 minutes.
4. Record maximum reading L_A during each 10 ± 2 second period.

Determine Arithmetic Average $\overline{L}_A$

	L_A	Remarks		L_A	Remarks
1.	______	____________________	31.	______	____________________
2.	______	____________________	32.	______	____________________
3.	______	____________________	33.	______	____________________
4.	______	____________________	34.	______	____________________
5.	______	____________________	35.	______	____________________
6.	______	____________________	36.	______	____________________
7.	______	____________________	37.	______	____________________
8.	______	____________________	38.	______	____________________
9.	______	____________________	39.	______	____________________
10.	______	____________________	40.	______	____________________
11.	______	____________________	41.	______	____________________
12.	______	____________________	42.	______	____________________
13.	______	____________________	43.	______	____________________
14.	______	____________________	44.	______	____________________
15.	______	____________________	45.	______	____________________
16.	______	____________________	46.	______	____________________
17.	______	____________________	47.	______	____________________
18.	______	____________________	48.	______	____________________
19.	______	____________________	49.	______	____________________
20.	______	____________________	50.	______	____________________
21.	______	____________________	51.	______	____________________
22.	______	____________________	52.	______	____________________
23.	______	____________________	53.	______	____________________
24.	______	____________________	54.	______	____________________
25.	______	____________________	55.	______	____________________
26.	______	____________________	56.	______	____________________
27.	______	____________________	57.	______	____________________
28.	______	____________________	58.	______	____________________
29.	______	____________________	59.	______	____________________
30.	______	____________________	60.	______	____________________

SUM:* ____________________

*Consider for the sum only those values within 6 dB of the maximum value observed.

$\overline{L}_A$ = Sum/n: ________ n/60 ________ Correction ______ L_{eq} ________

Location____________________ Date________________ Time______________

Wind Velocity____________mph. Temperature_______°F. Engineer____________

Remarks ____

____

Sketch site on reverse side

TABLE 5

Corrections to $\overline{L}_A$ to Obtain L_{eq}

n/60	Correction - dB
.8 to 1	0
.7 to .8	1
.6 to .7	2
.5 to .6	3
.4 to .5	4
.3 to .4	5
.2 to .3	7
<.2	10

where n is the number of samples used in the calculation of $\overline{L}_A$

$$L_{eq} = \overline{L}_A - \text{correction}$$

If the background ambient equivalent sound level is at least 10 decibels below the source equivalent sound level, the source equivalent sound level measurement requires no adjustment.

If the background ambient equivalent sound level is 3 to 10 decibels below the source equivalent sound level, apply corrections to the source sound levels in accordance with Table 6.

If the difference between the source L_{eq} and the background ambient is 0 to 3 decibels, no determination of the source equivalent sound level can be made.

6.5.2 Mobile Sources

The procedure, described below, can be used to measure the sound level of mobile sources which emit sounds of short duration (e.g., aircraft overflights, train passbys, etc.). Short duration sounds from mobile sources exhibit many different sound level-time patterns. As a simplification, they can be described as one of three major types shown in Figure 19 and described below. This simplification does introduce a degree of error on the order of 1-2 dB for sources where the time pattern is neither triangular or rectangular, but something in between.

Rectangular time pattern - The sound level rises rapidly, maintains a maximum level for some time and then decreases rapidly. Experience has shown that sources which cycle on and off intermittently, and passbys of freight trains measured at distant locations exhibit this type of noise-time pattern.

Triangular time pattern - The sound level rises at a constant rate from a background ambient sound level to a maximum sound level, and decreases to the background ambient sound level. The times for the sound to increase and decrease are approximately equal. Short trains, off road vehicles, and aircraft overflights typically exhibit this type of time-sound level pattern.

Combination time pattern - As the name implies, this sound level-time pattern is a combination of a short duration of higher sound followed by a steady sound. The sound level rises rapidly from the background ambient sound level to a maximum and decreases to an intermediate level. The intermediate sound level is maintained for some time until it drops to the background ambient sound level. Measurements of freight train noise at locations close to the track often exhibit this sound level-time pattern. The triangular portion is caused by the

TABLE 6

CORRECTION FACTORS FOR BACKGROUND AMBIENT SOUND LEVELS

$$L_s = 10 \log_{10} [10^{L_p/10} - 10^{L_o/10}]$$

L_s is stationary source sound level contribution

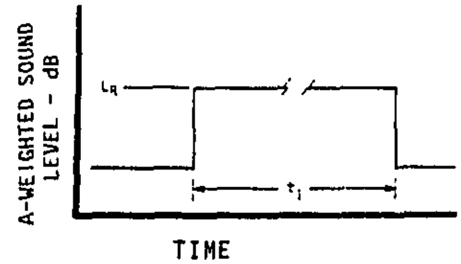
L_p is measured sound level with source operating

L_o is background sound level with source not operating

Difference between L_p and L_o	Subtract values from L_p to get L_s
0	*
1	*
2	*
3	3.0
4	2.5
5	2.0
6	1.5
7	1.0
8	1.0
9	0.5
10	0.5

*Cannot be determined. Background levels must be lower.

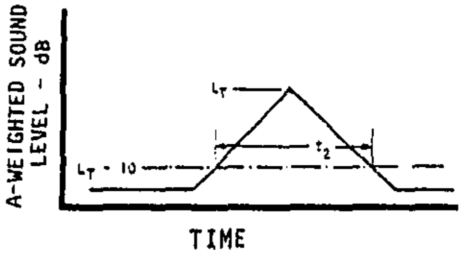
CATEGORY A RECTANGULAR



L_R = ______ dB

t_1 = ______ sec

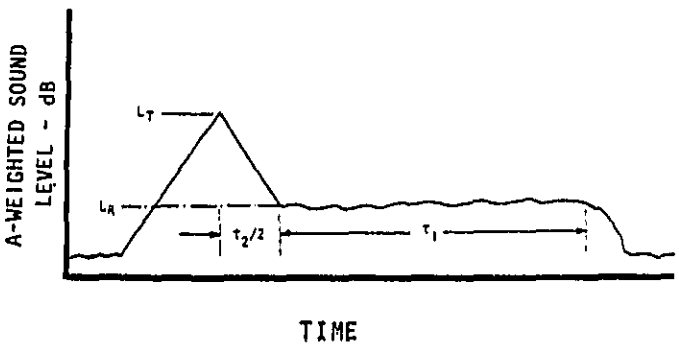
CATEGORY B TRIANGULAR



L_T = ______ dB

t_2 = ______ sec

CATEGORY C COMBINATION



L_T = ______ dB

L_R = ______ dB

t_2 = ______ sec

t_1 = ______ sec

Sketch site on reverse side

Figure 19. Mobile Sources Sound Level Time Patterns/Data Sheet

passing of the locomotive. The rectangular portion is due to the passage of freight cars.

Rectangular Time Pattern

1. Set the sound level meter for "fast" response and the A-weighting network.

2. Note the maximum sound level emitted by the source (noted as L_R) and the time period (t_1) that the source produces this level on a data sheet. (Figure 19).

3. Repeat these measurements for a number of sources (at least five).

4. Calculate the mean value for L_R and for t_1 from these samples.

Triangular Time Pattern

1. Set the sound level meter for "fast" response and the A-weighting network.

2. Note the maximum sound level produced by the source (noted as L_T) and the time required for the sound level to decrease 10 decibels below this maximum level ($t_2/2$). If the sound level does not drop 10 decibels, this technique is not valid. Multiply the latter value by 2 and enter these values (L_T and t_2) on a data sheet (Figure 19).

3. Repeat the measurements for a number of sources (at least five).

4. Calculate a mean value for L_T and for t_2 from these samples.

Combination Time Pattern

1. Note the following sound levels and time periods on a data sheet (Figure 19).

   L_T - Maximum sound level of triangular portion of time history, dB

   L_R - Maximum sound level of rectangular portion of time history, dB

   t_1 - Time that sound is at L_R, seconds

   t_2 - Twice the time for sound to decrease from the L_T to L_R, seconds

2. Repeat the measurements for a number of sources (at least five).

3. Calculate mean values for each of the variables.

6.6 ANALYSIS OF DATA

The equivalent sound level contribution of the source to the ambient sound level is evaluated from the data obtained from measurements described in Section 6.5 and data describing the operational characteristics of the source.

6.6.1 Stationary Sources

The following procedure is used to determine the equivalent sound level:

1. Calculate the fraction of time over the period being studied that the source operates. Observation of the sources over an extended period yields this information. The operator (plant superintendent, contractor, etc.) of the source may be able to supply pertinent data.

2. Enter the fraction of time in Column B of Figure 20 in the row corresponding to the equivalent sound level for the source.

3. Multiply the value in Column B by the value in Column C. Enter in Column D.

4. Locate the result in Column C. The corresponding value in Column A is the equivalent sound level contribution of the source.

   Note: An example of the use of this figure is presented in the section describing "Existing/Traffic Sound Level Measurement Procedures".

6.6.2 Mobile Sources

6.6.2.1 Rectangular Time Pattern

1. Multiply the number of occurrences per hour, n, by the mean duration $\bar{t}_1$(sec), (see Section 6.5.2).

2. Locate the value on the nt_1 axis on the nomograph in Figure 21.

3. Locate the mean maximum sound level on the L_R axis.

4. Connect these two points with a straight line.

A SOUND LEVEL dB	B FRACTION		C RELATIVE SOUND ENERGY		D RELATIVE TOTAL SOUND ENERGY
100		x	100,000	=	
99		x	79,400	=	
98		x	63,100	=	
97		x	50,100	=	
96		x	39,800	=	
95		x	31,600	=	
94		x	25,100	=	
93		x	20,000	=	
92		x	15,900	=	
91		x	12,600	=	
90		x	10,000	=	
89		x	7,940	=	
88		x	6,310	=	
87		x	5,010	=	
86		x	3,980	=	
85		x	3,160	=	
84		x	2,510	=	
83		x	2,000	=	
82		x	1,590	=	
81		x	1,260	=	
80		x	1,000	=	
79		x	794	=	
78		x	631	=	
77		x	501	=	
76		x	398	=	
75		x	316	=	
74		x	251	=	
73		x	200	=	
72		x	159	=	
71		x	126	=	
70		x	100	=	
69		x	79.4	=	
68		x	63.1	=	
67		x	50.1	=	
66		x	39.8	=	
65		x	31.6	=	
64		x	25.1	=	
63		x	20.0	=	
62		x	15.9	=	
61		x	12.6	=	
60		x	10.0	=	
59		x	7.94	=	
58		x	6.31	=	
57		x	5.01	=	
56		x	3.98	=	
55		x	3.16	=	
54		x	2.51	=	
53		x	2.00	=	
52		x	1.59	=	
51		x	1.26	=	
50		x	1.00	=	
49		x	.794	=	
48		x	.631	=	
47		x	.501	=	
46		x	.398	=	
45		x	.316	=	
44		x	.251	=	
43		x	.200	=	
42		x	.159	=	
41		x	.126	=	
40		x	.100	=	
39		x	.079	=	
38		x	.063	=	
37		x	.050	=	
36		x	.040	=	
35		x	.032	=	

FIGURE 20. SAMPLE EQUIVALENT SOUND LEVEL CONTRIBUTION WORKSHEET

5. Read the value at which the line intersects the central axis (L_{eq}). This is the hourly equivalent sound level contribution of the source.

6.6.2.2 Triangular Time Pattern

1. Multiply the number of occurrences per hour by the mean duration, $\bar{t}_2$(sec), (see Section 6.5.2).

2. Locate this value on the nt_2 axis on the nomograph in Figure 22.

3. Locate the mean maximum sound level on the L_T axis.

4. Connect these two points with a straight line.

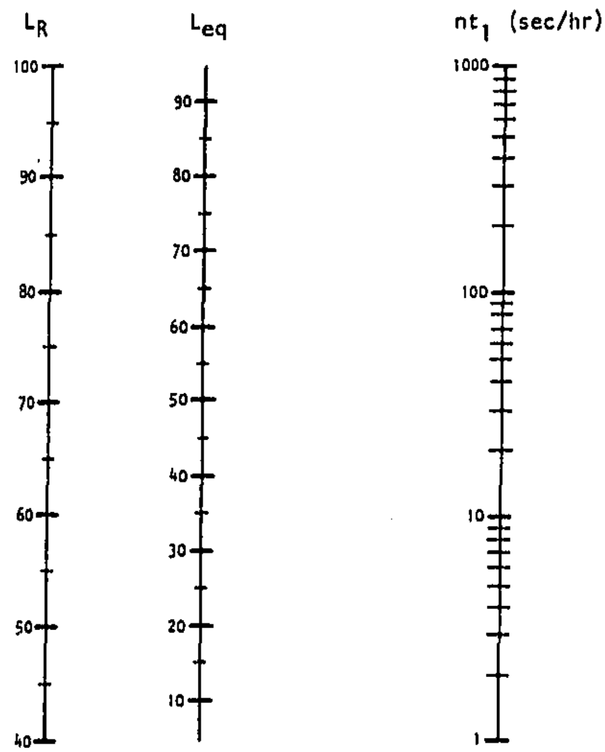
5. Read the value at which the line intersects the central axis (L_{eq}). This is the hourly equivalent sound level contribution of the source.

6.6.2.3 Combination Time Pattern

1. Calculate the hourly equivalent sound level contributions of the rectangular and triangular portions of the sound source time patterns using the techniques described in Sections 6.6.2.1 and 6.6.2.2. For the technique described in Section 6.6.2.2 to be valid, L_T-L_R must be greater than 7 decibels. If L_T-L_R is less than 7 decibels, the case reduces to a rectangular time pattern with a maximum value of L_R.

2. Combine the two hourly equivalent sound level contributions on an energy basis using Figure 23 to provide an hourly equivalent sound level contribution for the source.

$$Leq(h) = \overline{L_R} + 10\log(\overline{nt_1}) - 35.6 \text{ dBA}$$



L_R = Maximum sound level of source with rectangular time history, dB

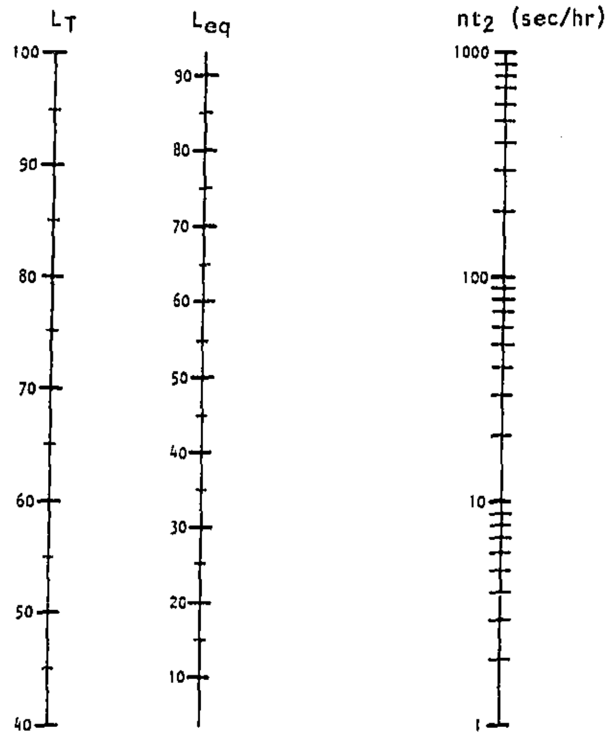
L_{eq} = Hourly equivalent sound level contribution of source, dB

n = Number of occurrences per hour

t_1 = Duration in seconds per occurrence

FIGURE 21. NOMOGRAPH FOR THE EQUIVALENT SOUND LEVEL OF A SOURCE WITH A RECTANGULAR TIME PATTERN

$$Leq(h) = \overline{L_T} + 10\log(n\overline{t_2}/2) - 35.6 \text{ dBA}$$



L_T = Maximum sound level of source with triangular history, dB

L_{eq} = Hourly equivalent sound level contribution of source, dB

n = Number of occurrences per hour

t_2 = Duration in seconds per occurrence

FIGURE 22. NOMOGRAPH FOR THE EQUIVALENT SOUND LEVEL OF A SOURCE WITH A TRIANGULAR TIME PATTERN

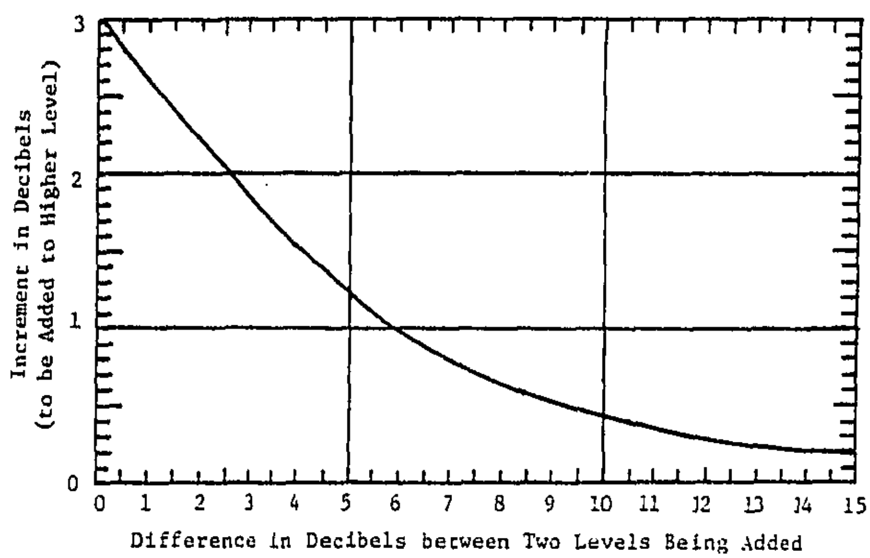


Figure 23. Chart for Combining Hourly Average Sound Levels

7.0 CONSTRUCTION EQUIPMENT NOISE MEASUREMENT PROCEDURE

7.1 PURPOSE

A procedure that can be used to measure the noise of individual construction equipment at a construction site is described. The procedure is designed to enable these measurements to be made while other equipment is operating on the site. The noise of individual equipment and its time of operation can be used to determine which equipment is the major contributor to the construction noise at the site.

The basis of the method is the Society of Automotive Engineers (SAE) Recommended Practice J88a, "Exterior Sound Level Measurement Procedure of Powered Mobile Construction Equipment", and the CAGI/PNEUROP Test Code.

7.2 INSTRUMENTATION

The following equipment is required to carry out the procedure:

- Sound Level Meter (Type 2)
- Sound Level Calibrator
- Wind Speed Indicator
- Sling Psychrometer
- Tachometer*
- Stopwatch
- Windscreen
- Data Sheet
- Tripod
- Microphone Cable
- Spare Batteries

7.3 PERSONNEL

The procedure described below can be accomplished by one person.

7.4 TEST SITE

Whenever possible, the construction equipment being tested should be moved to an area at the construction site which is as flat, open, and free from large reflecting surfaces and other noise sources as possible. Since ground surface conditions will vary from site to site (i.e., it may be "hard", concrete or asphalt; or "soft", grass or loose soil), ground conditions should be assessed and carefully noted on the data sheet.

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*Tachometers shall be compatible with both two- and four-stroke engines. An electromechanical tachometer may be required for ungoverned diesel engines.

7.5 EQUIPMENT OPERATION

Stationary equipment (e.g., pavement breakers, air compressors, cranes, concrete trucks) are operated at load and performance (i.e., rated engine speed, feed or work rate) which are typical of their normal operation.

Mobile equipment (e.g., graders, scrapers, bull-dozers) should be operated in a stationary mode.

1. Operate the equipment with all component drive systems in neutral through the following cycle "low idle to maximum governed speed (high idle at no load) to low idle" as rapidly as possible. The engine must stabilize for at least 10 seconds at maximum governed speed before returning to low idle.

2. Operate the equipment at the maximum governed speed in a stabilized condition with all auxiliary equipment operating.

Haul trucks and other vehicles whose normal operation is on the road should be tested using the vehicle noise emission measurement procedure (Chapter 4.0).

7.6 MEASUREMENT PROCEDURE

1. Set the sound level meter/microphone on a tripod at a height of 1.5 metres ±16 cm (5 feet ±6 inches) above the ground.

2. Measurements are made at a preferred distance of 15 metres ±16 cm (50 feet ±6 inches) from an imaginary reference surface forming the smallest rectangular box which completely encloses the equipment under test (see Figure 24).

3. Set the sound level meter for "slow" response and A-weighting.

4. Operate the construction equipment as outlined in Section 7.5.

5. Measurements are made at four orthogonal locations around the equipment.

6. The final reported sound level is the highest of the measured sound levels.

7. If the background ambient sound levels are within 10 decibels of the measured sound levels, either adjust the measured sound levels for other noise (section 7.7) or repeat the measurements at a distance less than 15 metres (50 feet) from the equipment (Section 7.7).

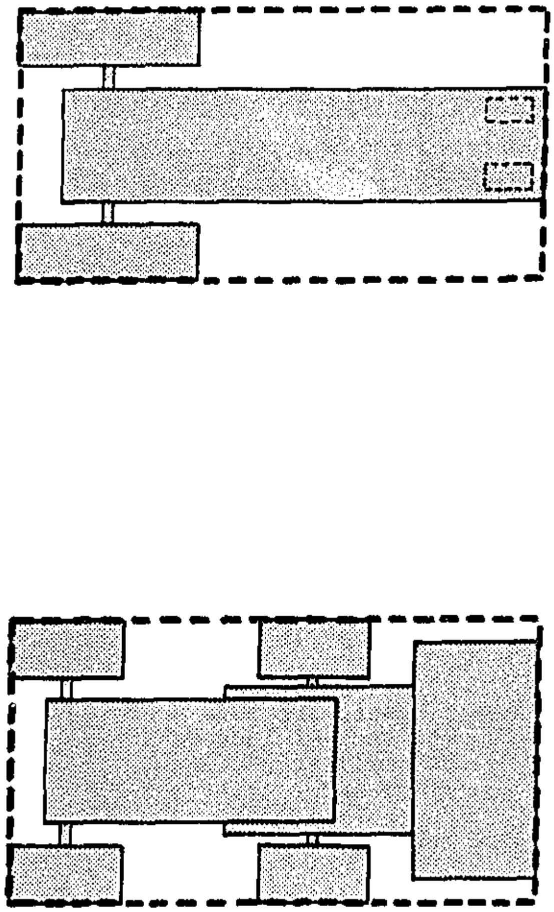

Figure 24. Reference Surface for Construction Equipment

Note: Equipment shaded.
Reference surface indicated by broken lines.

7.7 ADJUSTMENTS FOR HIGH AMBIENT NOISE CONDITIONS

Measurements are valid when the background ambient A-weighted sound levels, which include wind noise and all sources other than the equipment under test, are more than 10 decibels lower than the measured sound levels. Observe the background ambient sound level before and after each test. If these conditions are not met, two options exist:

1. Measurements can be made at locations less than 15 metres (50 feet) from the equipment being studied. The distance should be selected so that background ambient sound levels are at least 10 decibels lower than the measured sound levels. Carefully note the distance used for the measurements. Table 7 can be used to adjust the measured sound levels to a standard 15-metre (50 feet) distance. If measurements are made at distances from the equipment less than twice the equipment major dimension, near field effects can result in questionable results. Therefore, this situation should be avoided. The following alternative can be used.

2. Measurements of the source and of the background ambient sound levels are made at the 15-metre (50 feet) distance. Corrections are applied to the measured sound levels in accordance with Table 8 if the background ambient sound level is from 3 to 10 decibels below the measured sound level. If the background ambient sound level is 0 to 3 decibels below the measured sound levels, measurements closer to the source should be made, being aware of the near field effects described in Option 1 above.

7.8 USE OF THE MEASURED EQUIPMENT SOUND LEVELS

Equipment sound level measurements can be used to predict construction site sound levels. This requires knowledge of each equipment's

- sound level
- work cycle
- distance from receptor

FHWA Document, "Special Report - Highway Construction Noise - Measurement, Prediction, and Mitigation", presents techniques for calculating construction site noise levels.

TABLE 7

ADJUSTMENTS FOR MEASUREMENTS MADE AT DISTANCES OTHER THAN 15 METRES

Distance		Correction to be Added, dB	
Metres	Feet	Hard Site	Soft Site
10		-3.5	-3.5
11		-2.5	-2.5
12	40	-2	-2
13		-1	-1
14		- .5	- .5
15	50	0	0
16		.5	.5
17		1	1
18	60	1.5	1.5
19		2	2
20		2.5	3.0
21	70	3	3.5
22		3.5	4.0
23		4	4.5
24	80	4	5.0
25		4.5	6.0

TABLE 8

CORRECTION FACTORS FOR BACKGROUND AMBIENT SOUND LEVELS

$$L_s = 10 \log_{10} [10^{L_p/10} - 10^{L_o/10}]$$

L_s is stationary source sound level contribution

L_p is measured sound level with source operating

L_o is background sound level with source not operating

Difference between L_p and L_o	Subtract values from L_p to get L_s
0	*
1	*
2	*
3	3.0
4	2.5
5	2.0
6	1.5
7	1.0
8	1.0
9	0.5
10	0.5

*Cannot be determined. Background levels must be lower.

8.0 BUILDING NOISE REDUCTION MEASUREMENT PROCEDURES

8.1 PURPOSE

This section presents two techniques for measuring the noise reduction performance of building construction. In one technique, road traffic is used as a noise source. An alternate procedure utilizes a loudspeaker as a source when traffic noise levels are not sufficiently high (e.g., inside and outside of the structure, highway noise must be at least 10 dB above sound levels due to other sources). The values of noise reduction derived by the two methods may not always correspond to each other, due to different angular distributions in the incident sound fields.

These techniques reflect the latest thinking of the ISO and ASTM committees studying the subject regarding exterior microphone placement. In this, and other ways, these techniques will differ from previously recommended practices.[1]

8.2 INSTRUMENTATION

The procedures require:

- Sound Level Meter (Type 1) - 2
- Sound Level Calibrator
- Wind Speed Indicator
- Sling Psychrometer (optional)
- Tripods-2
- Microphone Cables-2 (optional)
- Data Sheets
- Windscreens-2

If an artificial sound source is used, the following additional equipement are required:

- A power amplifier with sufficient power to produce A-weighted sound levels at least 10 decibels above background ambient sound levels at exterior and interior locations without clipping the wave forms.

- A sound source. Acceptable choices are a tape recording or an electronically generated noise spectrum which is similar to typical traffic noise. This spectrum should be flat, from 31.5 Hz to 500 Hz, and decrease at six decibels per octave from 500 Hz to 4000 Hz (see Figure 25).

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1 "Insulation of Buildings Against Highway Noise", FHWA TS-77-202.

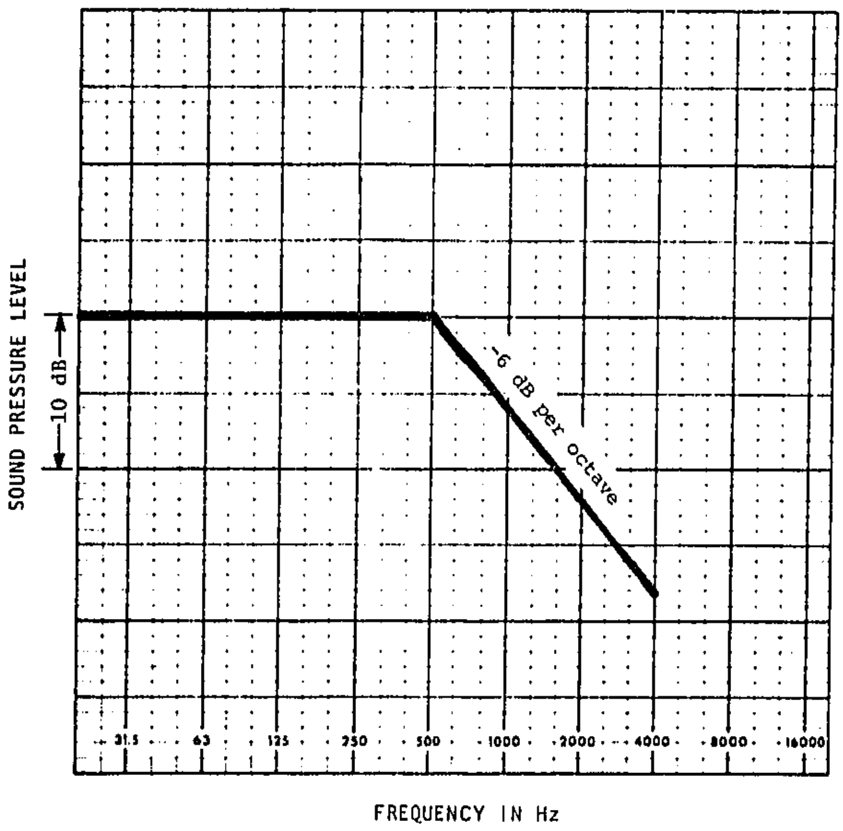

Figure 25. Artificial Sound Source Sound Pressure Level Spectrum

- One loudspeaker, enclosed except for its radiating surface. The loudspeaker's directional characteristics should be such that a 2000 Hz signal measured at 45 degrees from a perpendicular to the face of the speaker is no more than six decibels below the level measured at the same distance on the perpendicular axis. The loudspeaker should produce sound levels at least 10 decibels above the background ambient sound levels inside and outside of the structure being studied. Commercial quality loudspeakers meeting these specifications are readily available. Equipment specifications should be carefully examined to make certain that the equipment is properly chosen.

- A 120 volt A.C. power supply may also be required.

8.3 PERSONNEL

The techniques require two persons. With traffic as a noise source, two simultaneous measurements are required (inside and outside of the building). With an artificial constant noise source, one person makes the measurements while the other operates the amplification equipment.

8.4 MEASUREMENT LOCATIONS

8.4.1 Traffic Noise Source

Measurements are made simultaneously inside and outside the structure.

8.4.1.1 Interior Measurements

Locate the microphone at a point in the room where people would be impacted by the noise (above the chair, desk, or bed, for example). Do not place the microphone within 1 metre (3.5 feet) of a wall. It is very important to make measurements in the room in its typically furnished condition. Even still, levels can vary from point to point in the room. It may be necessary to make measurements at several different "sensitive" points in the room and average the resulting noise reduction. If windows will

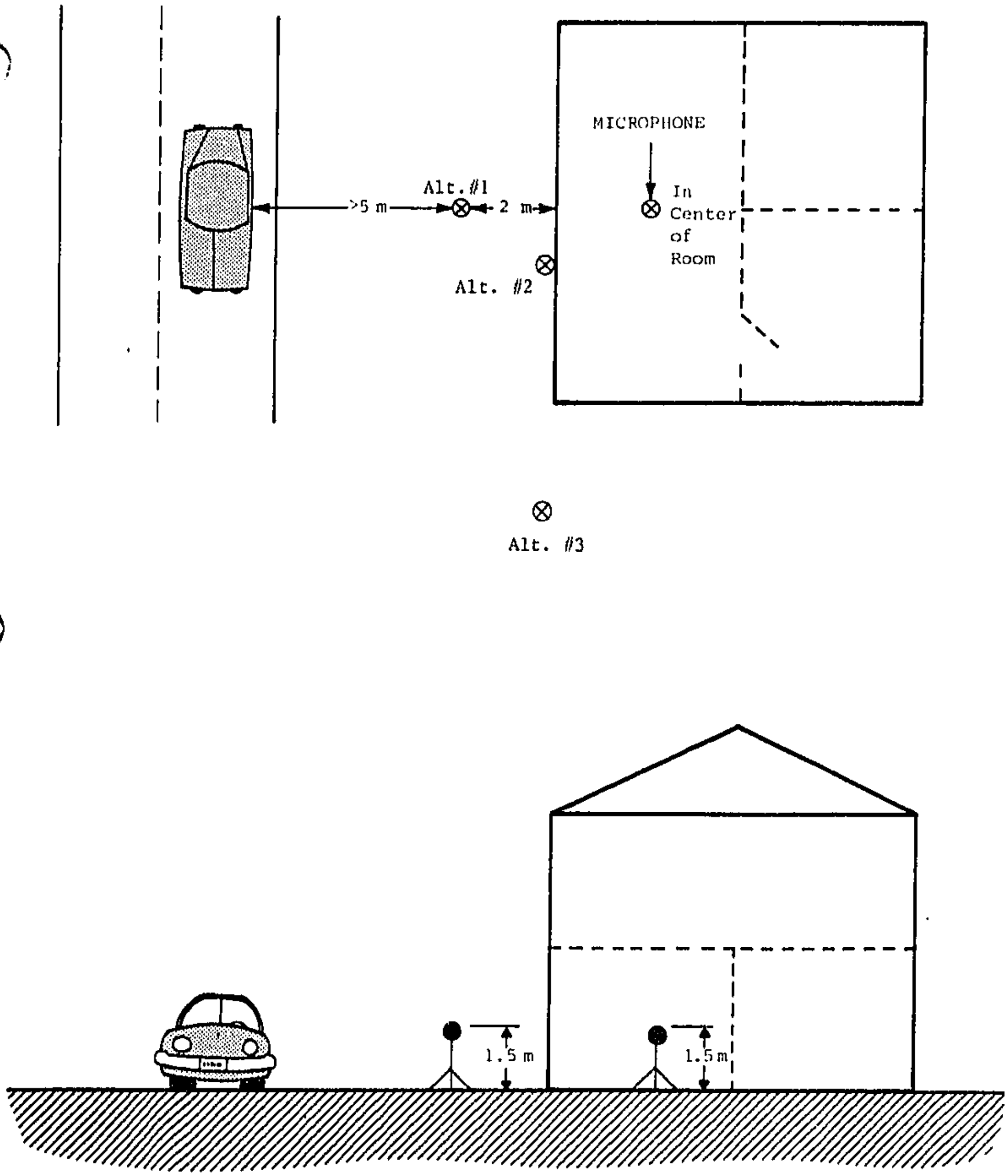

FIGURE 26. LOCATION OF INTERIOR AND EXTERIOR MICROPHONES FOR MEASUREMENTS USING TRAFFIC NOISE

be open during the portions of the year, they should be left open for the test (closed window levels may also be of interest, however, for comparison purposes).

8.4.1.2. <u>Exterior Measurements</u>

There are three possible positions for the exterior microphone as shown in Figure 26. Each position has its advantages and disadvantages, with its level being affected differently by sound reflections. The final noise reductions, however, are generally comparable. Pick the positions best suited to the site.

Point 1: Two metres (6.6 feet) from the outermost portion of the wall, at a point opposite the middle of the wall, at a height of 1.5 metres. This set-up is easily done, but may experience sound wave interference patterns and is not recommended if the building is within 7.5 metres (25 feet) of the road.

Point 2: Directly touching the wall, without a windscreen, pointing up, at a height of 1.5 metres. This setup is somewhat tricky to do and would not be good on windy days. It is, however, the most repeatable regarding sound pressure buildup due to reflections.

Point 3: Three metres (10 feet) from the side of the building, at the same distance from the road as the front wall, at a height of 1.5 metres. This set-up must be carefully done so that the microphone is not shielded from the road by the building or influenced by noise sources behind the building.

8.4.2 <u>Artificial Sound Source</u>

Measurements are made inside the structure and at an outdoor location where reflections cannot affect measurements. The microphone should be located outdoors at an equivalent distance to the artificial source as the indoor microphone position (see Figure 27).

8.4.2.1 <u>Interior Measurements</u>

Locate the microphone at the same position or positions that were used for the traffic noise source (see Section 8.4.1.1).

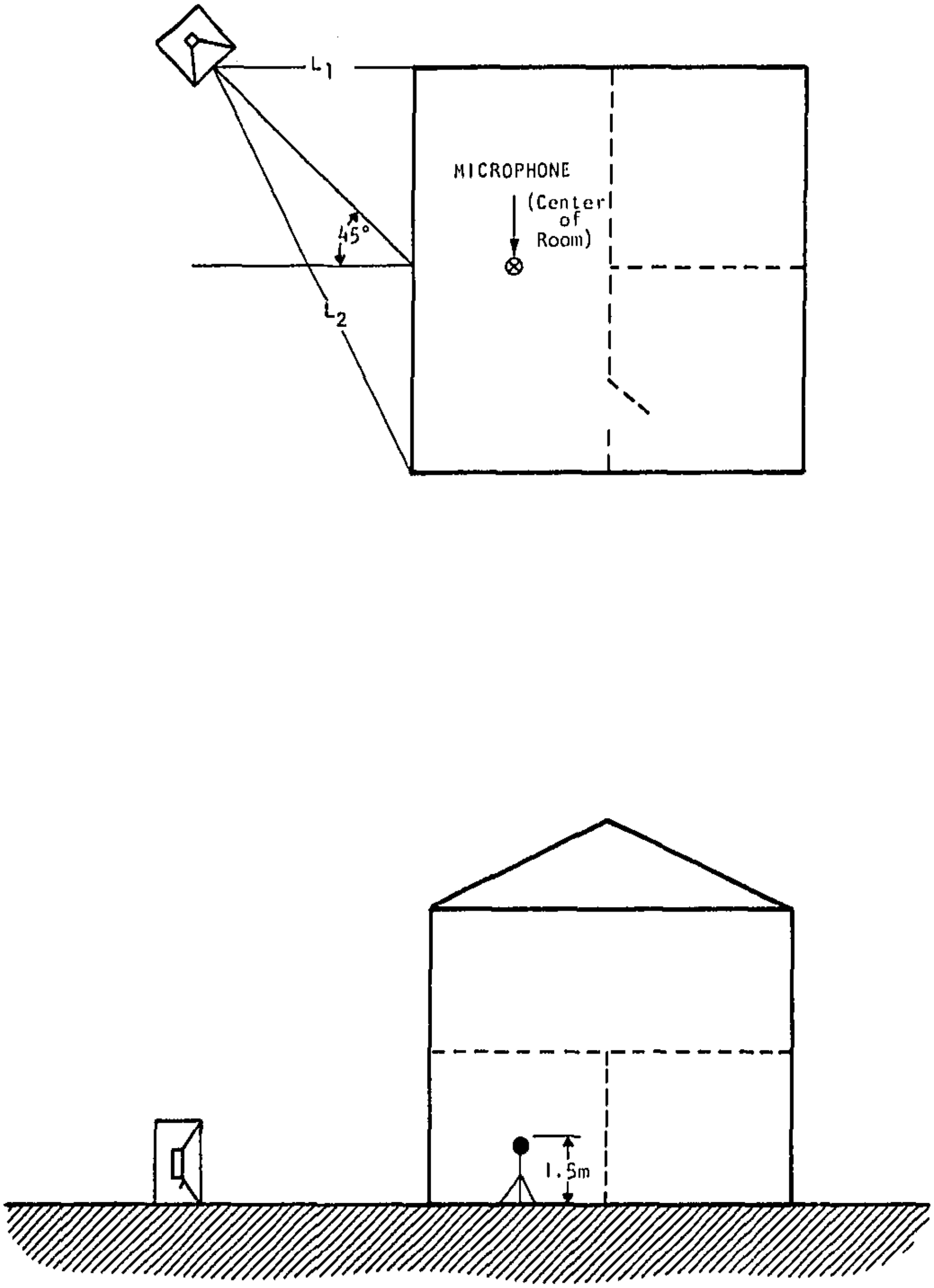

FIGURE 27. LOCATION OF INTERIOR MICROPHONE AND LOUDSPEAKER FOR MEASUREMENTS USING ARTIFICIAL SOUND SOURCE

PROJECT ______________________ DATE ______________________

LOCATION ______________________ ENGINEER ______________________

SKETCH OF MEASUREMENT LOCATION

☐ TRAFFIC NOISE SOURCE ☐ ARTIFICIAL NOISE SOURCE

Exterior Microphone to Road Distance (D_1) ____________ metres

Interior Microphone to Road Distance (D_2) ____________ metres

SLM #1 ________	S/N ________	SLM #2 ________	S/N ________
CALIBRATOR #1 ________	S/N ________	CALIBRATOR #2 ________	S/N ________
MICROPHONE #1 ________	S/N ________	MICROPHONE #2 ________	S/N ________
CALIBRATION ________	dB(pretest)	CALIBRATION ________	dB(pretest)
________	dB(post test)	________	dB(post test)

LOUDSPEAKER, S/N ______________ AMPLIFIER, S/N ______________

SOUND SOURCE, S/N ______________ ORIENTATION ______________

L_{eq} or L_{10} (exterior) ____________ dB − ____________ = ____________ dB

Uncorrected — Reflection Adj. — Corrected

L_{eq} or L_{10} (interior) − ____________ dB

Noise Reduction ____________ dB

FIGURE 28. SAMPLE DATA SHEET FOR BUILDING CONSTRUCTION NOISE REDUCTION

8.4.2.2 Exterior Measurements

To avoid outdoor measurements being affected by reflecting surfaces, select a measurement location where the loudspeaker and the microphone can be arranged in the same relative positions as interior measurements but away from the building being studied and other reflective surfaces. Other outdoor environmental features should be similar.

The microphone should be located at the distance and angle from the loudspeaker corresponding to the distance and angle from the loudspeaker at which the interior measurement position was located. (See Section 8.5.2 for the proper orientation of the loudspeaker.)

8.5 MEASUREMENT PROCEDURE

8.5.1 Traffic Noise Source

1. Prepare a sketch of the site on an appropriate data sheet (an example is given in Figure 28).

2. Set the sound level meter to "slow" response and A-weighting.

3. Begin interior and exterior measurements simultaneously.

4. Sample the sound level at both locations at the same time using one of the techniques described in "Existing/Traffic Sound Level Measurement Procedures" (Chapter 3.0).

5. Record the interior or exterior L_{eq} or L_{10}* on the data sheet.

8.5.2 Artificial Noise Source

1. Prepare a sketch of the site on an appropriate data sheet.

2. Locate the loudspeaker so that the following requirements are fulfilled. The source should be far enough from the wall so that the ratio of the distances to nearest and farthest parts of the test surfaces is no more than two-to-one (see Figure 27). The loudspeaker is located so that the angle of incidence between the normal from the facade mid-point and the line joining the source to the mid-point is 45 degrees (see Figure 28). If conditions permit additional measurements should be made at 15 degrees, 30 degrees, and 60 degrees, and the results averaged. If one angle is used, it should be 45 degrees.

---

*Either L_{eq} or L_{10} can be used, although L_{eq} is preferred.

3. At the indoor location, set the sound level meter to "slow" response and A-weighting.

4. Measure the interior sound level.

5. Move the loudspeaker and microphone to the outdoor free field positions as described in Section 8.4.2.2.

6. Measure the exterior sound level with the meter set to "slow" response and A-weighting.

8.6 COMPUTATION PROCEDURE

8.6.1 Traffic Noise Source

1. For an exterior microphone at point 1 (2 metres from wall), compute the building noise reduction (NR) as follows:

NR = Exterior Level - Interior Level - 3 dBA

The 3 dBA adjustment is for the approximate doubling of sound intensity (I) occuring at point 1 from reflections off the wall (10 log (2I/I)).

2. For an exterior microphone at point 2 (against the wall):

NR = Exterior Level - Interior Level - 5 dBA

Theoretically, the pressure of a sound wave doubles when it impacts against a hard surface. Doubling the sound pressure (p) increases the sound pressure level by 6dBA (20 log (2p/p)). Practically, the increase is only about 5dBA, which is the adjustment used here.

3. For an exterior microphone at point 3 (alongside the building):

NR = Exterior Level - Interior Level (dBA)

8.6.2 Artificial Noise Source

The difference in decibels between the indoor and outdoor data acquired as described in Section 8.5.2 is the building noise reduction.

9.0 WORKER NOISE EXPOSURE MEASUREMENT PROCEDURES*

9.1 PURPOSE

The procedure presented below may be used to measure worker noise exposure. Toll plaza and tunnel employees, highway maintenance and repair crews, highway inspectors, and laboratory personnel may be exposed to significantly high sound levels. Under Occupational Safety and Health Administration (OSHA) regulations, a worker's noise exposure is limited to A-weighted sound levels of 90 dB for an eight-hour workday. A sound level-time tradeoff of five decibels for each halving of exposure time is incorporated in the law. The upper limit for allowable exposure is 115 decibels. In addition, exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level. Table 1 presents the exposure-sound level relationship.

When an individual is exposed to a variable sound level, the total noise exposure is computed as:

$$(C_1/T_1) + (C_2/T_2) + \ldots(C_n/T_n) = \sum_{i=1}^{n} (C_i/T_i) \qquad (1)$$

where C_i is the time exposed to a sound level, and

T_i is the total exposure time allowed for that sound level.

If this sum, called the noise dose, exceeds one, the combined sound level exceeds the regulation limits.

Two methods are presented for determining worker noise exposure. The recommended method is the use of personal noise dosimeters. A second method, using a sound level meter and time and motion studies, is also acceptable.

9.2 NOISE DOSIMETERS

A noise dosimeter is a small instrument which can be placed in a worker's shirt pocket. It has a microphone which can clip onto a shirt or fit on a helmet. There are no existing standards or regulations specifically for noise dosimeters.** The A-weighting netwook used in the dosimeter should meet the American National Standards Institute standards for sound level meters. Dosimeters compute the noise dose electronically. Most models also indicate whether the worker has been exposed to an A-weighted sound level in excess of 115 dB.

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*Solely intended for in-house use. Not intended for contractor personnel.

**A proposed dosimeter specification (ANSI S1.25-197X) has not yet been adopted.

9.3 PROPER DOSIMETER USAGE

The basic steps for conducting an audio dosimeter survey are reviewed below. Before the survey begins, the individual conducting the survey should read and understand, thoroughly the manufacturer's instruction manual.

1. Check batteries and replace if necessary.

2. Check dosimeter and microphone for damage, and replace if necessary.

3. Calibrate the dosimeter before (and after) the survey. The instrument's instruction manual will normally specify the calibrator and procedure to use. If no calibration procedure is specified, the dosimeter manufacturer should be requested to supply an accurate calibration procedure.

4. Caution the wearer against conditions which may invalidate dosimeter readings:

   a. The dosimeter must be worn for the full eight-hour shift.

   b. The wearer should not talk into the microphone.

   c. The microphone should not be moved from its original position.

5. Locate the microphone where it most accurately measures the sound levels experienced by the individual. In the case of work in an open area (free field situation), the optimum microphone placement is on the subject's shoulder, parallel to the body axis. In a closed "acoustically hard" work area (reverberant field), the optimum location is the left breast pocket 90 degrees to the body axis. For typical indoor locations (semi-reverberant field), the optimum location is at the top of the shoulder oriented 90 degrees to the body axis.

6. Place a windscreen on the microphone if measurements are made in an outdoor environment.

7. Turn the instrument on.

8. Periodically visit the persons wearing dosimeters to ensure that they are being used properly.

9. Remove the dosimeter at the end of the 8-hour shift.

10. Read the dosimeter output to determine the exposure index. Note the results plus other pertinent information (e.g., name of employee, task, instrumentation, model and serial number).

11. Recalibrate the dosimeter to determine measurement validity.

If a worker remains in the same position during a workday, the dosimeter may be placed in the vicinity of the worker, instead of on his person. Care must be taken to prevent shielding of the microphone from noise sources by people, walls, or any other obstructions.

9.4 TIME AND MOTION STUDIES

An alternative to the use of dosimeters is worker time-motion studies* (log of worker activities during the day) and sound level measurements at worker stations used during the work shift. The employee is followed throughout the workday and the sound level and time spent is measured at each location. The noise exposure is calculated using this information and Equation (1) for noise dose.

A Type 1 sound level meter should be used for these measurements. It should be calibrated at intervals not to exceed two hours. Manufacturers' instructions should be followed for the proper use of the equipment.

9.5 DATA LOGGERS

Dosimeter-size measurement devices are now on the market that accumulate and store noise level exposure data in one-minute increments for an entire workday. At the end of the day, the data is read by a second device that then prints a record of the 1-minute L_{eq}'s as well as cumulative values for L_{eq} and OSHA noise doses.

*A Bibliography for time-motion studies is included in Appendix A.

APPENDIX A

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APPENDIX B

TECHNIQUES FOR DETERMINING PEOPLE'S PERCEPTION OF NOISE BARRIER EFFECTIVENESS*

1. Introduction

While the physical effectiveness of a noise barrier in reducing traffic noise is important, a more meaningful measure of noise barrier performance is people's perception of how well it works. While it is obvious that perceptions will be influenced by the insertion loss provided by the barrier, other factors appear to be equally important. Preliminary work has shown that perception of barrier effectiveness is influenced by such factors as:

a. perception of the seriousness of the traffic noise problem before the barrier is built;

b. the skill with which the State Highway Agency (SHA) dealt with the people in resolving the traffic noise problem;

c. the appearance of the barrier; and

d. the view of the highway and its surroundings after the barrier is built.

In some instances, barriers with excellent insertion losses have been rated as ineffective by the people protected by them. In other instances, barriers which provide little acoustic protection have been rated as very effective.

Determination of perception of noise barrier effectiveness requires that people be surveyed. While routinely used procedures have not yet been developed for surveying people's perception, some useful preliminary work has been done. This appendix provides general information on who and when to survey, two techniques for conducting surveys, and example questionnaires.

2. Who to Survey Probably the only meaningful way of evaluating people's perception of noise barrier effectiveness is to establish their perception of the noise impact before the barrier is built and to establish their perception of the noise impact again after the barrier is built.

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*This is reproduced, with minor editing, from Part II of Determination of Noise Barrier Effectiveness, FHWA Report No. FHWA-OEP/HEV-80-1, published in June 1980.

Consequently, the survey site must be located on an existing highway and both "before" and "after" surveys are required.

If the individual responding to the "after" survey questionnaire is different from the individual responding to the "before" survey questionnaire, there is likelihood for considerable error in the results. For this reason, every possible effort should be made to assure that the same person who answered the "before" questionnaire answers the "after" questionnaire.

People who live inside a zone that will receive an insertion loss of 3 dBA or less should not be included in the survey. This is because most people will have considerable difficulty in perceiving noise reduction of less than 3 dBA. Even people who can perceive such a small change will probably forget it. A person's sound level memory is very short. Regardless of the boundaries selected for the survey, every effort should be made to reach 100 percent of the households in the survey area. This is because the population protected by a noise barrier is usually quite small. This type of situation is not well suited to statistical sampling techniques.

3. When to Survey

It has already been indicated that demonstration of people's perception of noise barrier effectiveness will require "before" and "after" surveys. If the survey is to be meaningful, the perception of the noise barrier effectiveness must be correlated with the measured physical insertion loss of the barrier. This means that "before" and "after" noise levels must be available for each set of interviews.

In addition, the "after" questionnaire must obtain information sufficiently similar to the "before" questionnaire so that rational conclusions can be drawn. This will probably require that the "after" survey be conducted at the same time of year as the "before" survey to account for any seasonal activities such as recreational use of backyards.

Finally, the "after" survey should be conducted as soon as possible after the barrier is built. This will minimize the reduction in sample size due to people moving. More importantly, it will help avoid distortions due to a change with time in people's perception of the mitigation of traffic noise by the noise barrier.

4. Survey Techniques

The FHWA has reviewed several questionnaires and the experiences of several SHA's and others in determining people's perception of noise barrier effectiveness. Based upon this review, two survey techniques have been identified that appear to adequately address the issues--home/telephone interviews and mail interviews. Both techniques require the use of "before" and "after" questionnaires.

a. Home/Telephone Interviews. Home/telephone interviews are more expensive to conduct than mail interviews. Further, home interviews require trained interviewers. With home/telephone interviews, it is usually possible to correct misunderstood questions, an opportunity which is not available on mail-back questionnaires. In addition, home/telephone interviews have the capability of overcoming language and illiteracy barriers. The major advantage of home/telephone interviews is that they have a very high response rate.

b. Mail Interviews. Since the person surveyed is not contacted directly, the choice of wording in the mail-back questionnaire is of extreme importance. The California Department of Transportation (CALTRANS) uses a mail-back questionnaire and has experienced a response rate of about 50 percent for the "before" barrier questionnaire. There is no response rate information from it on the "after" barrier questionnaire since it has not yet been used on a highway project. The major advantage of mail-back interviews is low cost.

5. Questionnaires

To give reliable results of people's perception, the "before" and "after" evaluations must be based upon structured questionnaires. The use of structured questionnaires guarantees that each household will be asked the same questions. The following questionnaires were developed by CALTRANS and by Dr. F. L. Hall of McMaster University.* Although neither of the questionnaires has yet been tested, it appears that they contain the essential information. The questionnaires can be modified to meet the specific needs and conditions of one's own survey. The CALTRANS questionnaire was developed for use in mail interviews. Dr. Hall's questionnaire is to be used only for home/telephone interviews.

*McMaster University, Department of Civil Engineering
1280 Main Street West, Hamilton, Ontario, Canada L8S 4L7.

3. How often do you or members of your family use your yard for relaxing or playing during warm weather?

_____ every day
_____ several times a week
_____ once or twice a week
_____ less than once a week

4. a. Have you regularly been forced to close your windows because of traffic noise?

_____ Yes _____No

b. [If yes:] How often would you say this happens?

_____ once or twice a month
_____ once a week
_____ several times a week
_____ most of the time

5. What effect do you think the noise barrier has had on the traffic noise you hear while you are at home?

considerable reduction in noise	moderate reduction in noise	slight reduction in noise	no effect	slight increase in noise	moderate increase in noise	considerable increase in noise
_____	_____	_____	_____	_____	_____	_____

6. What effect do you feel the barrier and its associated landscaping have had on the general appearance of this residential area?

considerable improvement	moderate improvement	slight improvement	no effect	slight deterioration
______	______	______	____	______

moderate deterioration	considerable deterioration
______	______

7. Are there any suggestions you have regarding noise barriers we may build in the future in other areas to improve their appearance or effectiveness?

Thank you for your assistance.

Suggested Questionnaire for Post-Construction

Survey for Barrier Effectiveness*

Hello. I am from the (State) Department of Transportation. Last year, we spoke to a person in your household about problems that may be affecting people who live near highways. The person we spoke to was [describe, from Q. 10 data]. Is he/she available? [If the appropriate person is not available, try to find the best time to call back when he/she will be available.]

Now that we have completed our work on the project in this area, we would like to know how the highway is affecting people here.

1. Here is a list of problems which were mentioned in last year's survey. Please rate each of them with regard to how great a problem it is now for you and your family while you are at home.

   [Read question stem at left, and each response as written.]

	not a problem at all	a minor problem	a moderate problem	a major problem or	an extremely bad problem
Is highway dust and dirt	______	______	______	______	______
Is headlight glare	______	______	______	______	______
Is litter from vehicles	______	______	______	______	______

*Reprinted with permission from Dr. F. L. Hall, McMaster University, Ontario, Canada

	not a problem at all	a minor problem	a moderate problem	a major problem	an extremely bad problem?
Is highway noise	____	____	____	____	____
Is vibration from the road	____	____	____	____	____
Are fumes from the road	____	____	____	____	____
Are there any other road-related problems?	____	____	____	____	____
Name? Severity	____	____	____	____	____

2. How often does the noise from the road interrupt you during any of the following activities?

	never	only occasionally	several times per week	several times per day	almost all the time
conversation indoors	____	____	____	____	____
conversation outdoors	____	____	____	____	____
use of telephone	____	____	____	____	____
watching television	____	____	____	____	____
relaxing indoors	____	____	____	____	____
relaxing outdoors	____	____	____	____	____
sleeping	____	____	____	____	____

	never	only occasion-ally	several times per week	several times per day	almost all the time
relaxing outdoors	_____	_____	_____	_____	_____
sleeping	_____	_____	_____	_____	_____

4. How often do you or members of your family use your yard for relaxing or playing during warm weather?

_____ every day
_____ several times a week
_____ once or twice a week
_____ less than once a week

5. a. Have you regularly been forced to close your windows because of traffic noise?

_____Yes No_____

b. [If yes:] How often would you say this happens?

_____ once or twice a month
_____ once a week
_____ several times a week
_____ most of the time

6. Have you made any modifications to your house or yard because of the traffic noise? Yes_____ No_____ [If yes:] What?

7. Are there any other problems associated with living near the highway which you would like to mention? Yes _____ No _____

[List responses]

8. How long have you lived at this address? ______________

9. Would you or other members of your household be interested in attending a public meeting about possible solutions to some of the problems mentioned earlier? Yes _____ No _____

10. And now, a few questions about yourself to assist us in contacting you, personally, for a possible follow-up survey.

    [If name is offered by respondent at this point, write it down, and do not ask remaining items.]

    a. Sex [do not ask] male _____ female _____
    b. How old are you? _____years
    c. What is your main occupation (that is, what sort of work do you do)?

    ____

Thank you for your assistance.

Suggested Questionnaire for Pre-Construction Survey for Barrier Effectiveness*

Hello. I am from the (State) Department of Transportation, which is concerned about problems that may be affecting people such as yourself who live near to major highways. We are actively considering solutions to some of the problems in your neighborhood. We would very much appreciate a few minutes of your time to answer the following questions.

1. What are the most important things you dislike about living in this area?

   [Notes to interviewer: write down the exact thing(s) said, for later coding. Probe slightly: "Is there anything else which you dislike?" Focus on the residential environment of a few surrounding blocks.] [Whether or not road-related problems are mentioned, use the following transition phrase to move to the next question:]

   The Department of Transportation is particularly interested in things you dislike which may be related to living near a highway.

2. Here is a list of problems which other people have mentioned. Please rate each of them with regard to how great a problem it is for you and your family while you are at home. [Read question stem at left, and each response as written.]

*Reprinted with permission from Dr. F. L. Hall, McMaster University, Ontario, Canada

	not a problem at all	a minor problem	a moderate problem	a major problem	an extremely bad problem
Is highway dust and dirt	____	____	____	____	____
Is headlight glare	____	____	____	____	____
Is litter from vehicles	____	____	____	____	____
Is highway noise	____	____	____	____	____
Is vibration from the road	____	____	____	____	____
Are fumes from the road	____	____	____	____	____
Are there any other road-related problems?	____	____	____	____	____

Name? Severity?

3. How often does the noise from the road interrupt you during any of the following activities?

	never	only occasion-ally	several times per week	several times per day	almost all the time
conversation indoors	____	____	____	____	____
conversation outdoors	____	____	____	____	____
use of telephone	____	____	____	____	____
watching TV	____	____	____	____	____
relaxing indoors	____	____	____	____	____

California Department of Transportation
Transportation Laboratory

QUESTIONNAIRE *

1. Has the noise in your neighborhood environment changed since the freeway noise barrier was built?

   ☐ much less noise ☐ less noise ☐ same ☐ noisier

2. Has your awareness or notice of the freeway noise changed since the noise barrier was built?

   ☐ same ☐ somewhat less aware ☐ much less aware

3. Check those items which may have improved since the building of the barrier.

   ☐ sleep ☐ ease of conversation ☐ use of TV/stereo/radio

   ☐ use of telephone ☐ reading ☐ use of yard ☐ relaxation

   ☐ general peacefulness other____________________

4. Now that a noise barrier has been erected, how do you rank the annoyance of the following freeway features? (Put in numerical order with 1 being most annoying.)

   ____ air pollution ____ total traffic noise ____ congestion ____ truck noise

   ____ accidents ____ dust/dirt other____________________

5. How do you rank the annoyance of the following environmental noises now that there is a barrier? (Put in numerical order with 1 being most annoying.)

   ____ neighborhood noises (children, stereos, dogs, lawnmowers, etc.)

   ____ airplanes ____ freeway noise ____ sirens ____ city street noise

   ____ industrial other____________________

6. Which best describes your neighborhood now?

   ☐ very quiet ☐ quiet ☐ a little noisy ☐ noisy ☐ very noisy

*After Noise Barrier Construction Questionnaire

7. Do you find the barrier acceptable in appearance?

☐ very acceptable ☐ O.K. ☐ no

If not, why? ______________________________

8. Has the barrier met your expectations in improving the neighborhood?

☐ yes ☐ no ☐ undecided

If not, in what way? ______________________________

9. Do the advantages of the barrier outweigh the disadvantages?

☐ yes ☐ no

10. How do you feel about the barrier overall?

☐ like ☐ dislike ☐ neither (neutral)

11. Did you respond to the questionnaire sent before the barrier was constructed?

☐ yes ☐ no

12. Other comments ______________________________

____

____

____

____

____

NOTE: If you need more information or clarification of questions, please call (916) 739-2400 collect, and ask for Mr. Mas Hatano or leave a message for him.

CALIFORNIA DEPARTMENT OF TRANSPORTATION
Transportation Laboratory
QUESTIONNAIRE *

1. How many persons live in your home? ____________

2. Was the freeway here when you moved into your present home?
   Yes ☐ No ☐

3. What is the family gross income: less than $10,000/yr.
   $10,000-15,000 ☐ $15,000-20,000 ☐ $20,000-30,000 ☐ over $30,000 ☐

---

4. If there are annoying features in your neighborhood environment, list them using "1" for most annoying, "2" for the next most annoying, etc.

   1.________ 2.________ 3.________ 4.________ 5.________

5. How do you rank the following freeway features in annoyance? (Use "1" for the most annoying, "2" for the next most annoying, etc.)

   ___air pollution ___total traffic noise ___congestion
   ___truck noise ___accidents ___dust/dirt ___sirens

6. How do you consider the present noise environment in your neighborhood?

   quiet ☐ a little noisy ☐ noisy ☐ very noisy ☐

7. Number the following noises in your neighborhood in order of their annoyance, (use "1" for the most annoying, "2" for the next most annoying, etc.)

   ___non-traffic noise (stereos, TV, radio, children, power equipment, animals, etc.)
   ___sirens ___airplanes ___city street noise
   ___neighbors ___freeway noise ___industrial noise

---

8. Does the freeway noise interfere with your day-to-day activities?
   No ☐ Yes ☐

   If yes, what activities? (You may check more than one.)
   TV/radio/stereo ☐ telephone ☐ reading ☐ sleeping ☐
   conversation indoors ☐ conversation outdoors ☐
   others(list)________________________

9. Does noise keep you awake at night?
   often ☐ occasionally ☐ rarely ☐
   If often, what noises?________________________

10. Are you ever awakened from your sleep by outside noises?
    never ☐ rarely ☐ once a week ☐ more than once a week ☐

11. Has the neighborhood noise environment influenced the outdoor use of your property?

    No ☐ Yes ☐

    If yes, is it used more ☐ less ☐ much less ☐

12. Has your awareness or notice of the freeway noise changed since you first moved in (or when the freeway was first built)?

    much more aware ☐ somewhat more ☐ same ☐ somewhat less ☐
    much less ☐

13. Can you see the freeway traffic from your home? clear view ☐
    partially obstructed view ☐ view obstructed ☐
    If obstructed, by what? trees or shrubs ☐ ground features ☐
    buildings or houses ☐

14. Do you believe trees or shrubs would effectively quiet the noise?
    yes ☐ no ☐ don't know ☐

---

15. What is your present attitude toward a noise barrier planned for construction on the freeway right-of-way adjoining your neighborhood?

    favor ☐ object ☐ undecided ☐

16. After a noise barrier is built, what change in the noise do you think will it make?

    increase ☐ no change ☐ decrease a little ☐ decrease a lot ☐

17. After a noise barrier is built what do you believe would be:

    advantages(list)________________________
    disadvantages(list)________________________

---

18. Do you believe the advantages outweigh the disadvantages?

    yes ☐ no ☐

19. What material for a noise barrier would you prefer from a visual point of view?
    (Number in order of preference, using "1" to indicate highest preference, "2" next highest preference, etc.)

    no preference ___ concrete ___ earth ___ brick ___ wood ___
    concrete block ___ metal ___ stucco ___

20. Did you attend the informal public meeting held ____________ on the construction of noise barriers in your neighborhood?
    yes ☐ no ☐

21. Would you like to receive a summary of the questionnaire information submitted from your community?
    yes ☐ no ☐

    If yes, address
    Name(optional) ____________
    Street ____________
    City, zip code ____________
    Telephone No. ____________

739-2400

Note: If you need more information or clarification of questions, please call (916) [illegible] collect, and ask for Mr. Mas Hatano or leave a message for him.

Rev. 8/79

*Before Noise Barrier Construction Questionnaire

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY EDMUND G. BROWN JR., Governor

DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES AND ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY
5900 FOLSOM BLVD., P.O. BOX 19128
SACRAMENTO, CA 95819

Dear Resident: *

Prior to the erection of the Caltrans noise barrier along Highway 17, you and other residents in the first four rows of homes adjacent to the freeway were asked to respond to a questionnaire regarding neighborhood noise conditions. Now that the noise barrier is constructed, we would like to evaluate its effectiveness. That is why we also need your response to the attached follow-up questionnaire.

This questionnaire should be filled out by the same person who filled out the first questionnaire.

Your cooperation is greatly appreciated.

Very truly yours,

NEAL ANDERSEN, P.E.
Chief, Office of Transportation Laboratory

By Earl Shirley

Earl Shirley, P.E.
Chief, Enviro-Chemical Branch

Attachment

*Letter to Resident After Noise Barrier Construction

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY EDMUND G. BROWN JR., Governor

DEPARTMENT OF TRANSPORTATION
DIVISION OF STRUCTURES AND ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY
P.O. BOX 19128
SACRAMENTO, CA 95819

Dear Resident:*

The California Department of Transportation (Caltrans) is responsible for providing effective transportation facilities in the State. Our goal is to do so in harmony with the environmental and social outlooks of the people. To accomplish this, we have to know how these outlooks vary with each community. That's the purpose of this letter to you and the enclosed questionnaire.

To achieve our goal, we need to receive information from you as well as others. It is important to us to have your personal response because the more information we receive, the better guide it is for planning and carrying out transportation projects in your community in a way that will satisfy you and your neighbors.

We realize that one hundred per cent satisfaction for all citizens is unlikely because people do have different outlooks. This is another reason it is so important to receive your personal response. We would like to provide a result that fits as well as possible with everyone's expressions of fact, judgment and opinion. Your cooperation is respectfully solicited and urged.

We would like the questionnaire to be filled out by the head or heads of your household. Items included relate to family history, environment, activities and normal living habits. We found in other studies that having some information on people's backgrounds makes the analysis and understanding of the preferences and expectations they express more reliable. Reliability is important because all the information we receive will be analyzed and reflected in our future projects.

Some questions ask for your judgment or opinion, while others simply call for recording of facts. Most questions require only a check in the box which fits your answer best; a few questions may be checked in more than one box; and a few others require a short answer. It's better if responses can represent the whole

*Letter to Resident Before Noise Barrier Construction family's views, if possible.

We emphasize that your response to this questionnaire will not have any bearing on the noise barrier to be constructed in your area. As a result of unanimous community support, design of the barrier project is nearing completion and construction should begin by late Summer of 1979.

We will hold your responses anonymous and treat them confidentially in every respect.

In case you feel the need for more information or clarification, please call Mas Hatano (916-444-4800), collect.

We will deeply appreciate your early response.

Very truly yours,

NEAL ANDERSEN, P.E.
Chief, Office of Transportation Laboratory

By Earl Shirley

Earl Shirley, P.E.
Chief, Enviro-Chemical Branch

P.S. If you would like to have a summary of the findings from your community's responses, please indicate this at the end of the questionnaire.

APPENDIX C - BLANK DATA SHEET FOR EXISTING NOISE LEVEL MEASUREMENTS

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
REGION 15

NOISE MEASUREMENT DATA SHEET

NAME: ______________________ DATE ________

PROJECT: ______________________ TIME:

SITE: ______________________ START ______

______________________ END ______

RESULTS: L10 ____ + ___ - ___ L50 _____ LEQ _____

HOW TO USE: 2 X 80 = 160000

FILL IN OTHER SIDE

TOTAL

DBA	TOTAL		Factor	
9		X	80	= 0000
8		X	63	= 0000
7		X	50	= 0000
6		X	40	= 0000
5		X	32	= 0000
4		X	25	= 0000
3		X	20	= 0000
2		X	16	= 0000
1		X	13	= 0000
0		X	10	= 0000
9		X	80	= 000
8		X	63	= 000
7		X	50	= 000
6		X	40	= 000
5		X	32	= 000
4		X	25	= 000
3		X	20	= 000
2		X	16	= 000
1		X	13	= 000
0		X	10	= 000
9		X	80	= 00
8		X	63	= 00
7		X	50	= 00
6		X	40	= 00
5		X	32	= 00
4		X	25	= 00
3		X	20	= 00
2		X	16	= 00
1		X	13	= 00
0		X	10	= 00
9		X	80	= 0
8		X	63	= 0
7		X	50	= 0
6		X	40	= 0
5		X	32	= 0
4		X	25	= 0
3		X	20	= 0
2		X	16	= 0
1		X	13	= 0
0		X	10	= 0
9		X	80	=
8		X	63	=
7		X	50	=
6		X	40	=
5		X	32	=
4		X	25	=
3		X	20	=
2		X	16	=
1		X	13	=
0		X	10	=

EQUALS 100,000 — EQUALS 10,000 — EQUALS 1,000 — EQUALS 100

DBA 10 20 30 40 50
NUMBER OF SAMPLES

TOTAL ____ DIVIDED INTO TOTAL ____

EQUALS ____

EQUIPMENT: METER ____________ CALIBRATOR ____________

CALIBRATION: START ____________ DB END ____________ DB

RESPONSE: ___FAST ___ SLOW ___A-WEIGHTING ___BATTERY CHECK

WEATHER DATA____

TRAFFIC DATA			
ROAD			
AUTOS			
MED. TRKS.			
HVY. TRKS.			
DURATION			

CRITERION: ± 3DB			
NUMBER OF SAMPLES	UPPER LIMIT	L10	LOWER LIMIT
50	1ST	5TH	10TH
100	5TH	10TH	17TH
150	8TH	15TH	23RD
200	12TH	20TH	29TH

SITE SKETCH

BACKGROUND NOISE ____

MAJOR SOURCES ____

UNUSUAL EVENTS ____

OTHER NOTES ____

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