SPECIAL REPORT

HIGHWAY CONSTRUCTION NOISE:

MEASUREMENT, PREDICTION AND MITIGATION

HIGHWAY NOISE

Prepared by:

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

Special Report

Highway Construction Noise: Measurement, prediction and mitigation

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PREFACE

In early 1976, the Federal Highway Administration (FHWA) initiated a two-part program designed to study, evaluate and provide guidance in the area of construction noise. Part one was a short-range effort to prepare a manual for use by highway oriented groups and individuals in coping with construction noise during the various stages of project development. The manual would be a state-of-the-art review dealing with measurement, prediction and mitigation. Part two was the sponsorship of a workshop on the mitigation of construction noise. The purpose of the workshop was to develop long-range strategies for controlling construction noise.

This manual represents the completion of part one of the program. This manual does not represent FHWA policy. It is an attempt to summarize the rapidly evolving technology in controlling and mitigating construction noise. This manual represents a logical starting point into the evaluation and control of highway construction noise. Users of this manual are encouraged to update this material as better information becomes available.

ACKNOWLEDGEMENT

This manual could not have been prepared without the full cooperation of the Washington Headquarters, with special thanks to reviewers from the Office of Environmental Policy, Office of Highway Operations, Office of Engineering and Office of Research.

The authors especially appreciate the guidance and encouragement given by Mr. Harter M. Rupert, Office of Environmental Policy.

Special thanks is extended to Ms. Beverly J. Williams and Mrs. Juanita B. Proctor for the proofreading and typing of this manual.

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CHAPTER 1

1.0 BACKGROUND

In our ever expanding quest for an improved environment, we are concerned with the evaluation and control of transportation noise. For several years, Federal, State, and local attention has been directed toward operational noise impacts resulting from the operation and movement of transportation vehicles. Recently, considerable concern, particularly in urban areas, has been focused on the construction noise associated with the development of the transportation facility. This manual deals specifically with the measurement, prediction, and mitigation of highway construction noise.

1.1 EVALUATION AND CONTROL OF CONSTRUCTION NOISE

In order to evaluate and control highway construction noise, the following information must be known:

1. The existing noise environment.
2. The expected construction noise levels.
3. The criteria that relate the existing noise environment and the expected construction noise levels to human responses.
4. Mitigation strategies that can be used to control the construction noise.

The first three items are used to evaluate the noise associated with the construction of the highway to see if a noise impact does exist. If a noise impact does exist, the last item provides mitigation strategies that can be used to control construction noise.

1.2 CONSTRUCTION NOISE CRITERIA

Section 1.1 indicated that criteria were needed before construction noise impacts could be quantified in terms of human response. While progress is being made in this area, criteria for evaluating construction noise have not been developed. It appears that several years will elapse before such criteria are established. In the interim, the user of this manual must select his own criteria. In selecting such criteria, the following factors should be considered:

1. The difference between the existing noise environment and the expected construction noise levels.

2. The absolute level of expected construction noise.

3. Adjacent land uses.

4. The duration of construction.

1.3 NOISE METRIC

While it is not possible to provide criteria for evaluating construction noise impacts, a noise metric must be selected which can be used to describe noise levels. A noise metric to describe construction noise should meet the following criteria:

1. It should be an easily measurable quantity.

2. It should account for the temporal variations in the noise levels of individual pieces of equipment.

3. It should account for the temporal variations in the overall noise level (site).

4. It should be an easily predictable quantity.

5. It should relate to people's subjective responses to construction noise.

The metric chosen for use in this manual is the hourly, A-weighted equivalent sound level (energy basis), $L_{eq}(h)$. This metric satisfies the first four requirements. It may also satisfy the fifth requirement, but there is not enough information presently available to select any metric on this basis.

1.4 MANUAL ORGANIZATION

Chapter 2 discusses noise measurements. Unfortunately, only limited measurements of highway construction noise have been made. The data available in the literature are often quite vague on what noise levels were measured and how they were measured. While measurement procedures are being developed, they have not yet evolved to the point where they have been standardized.

In Chapter 3, a prediction procedure is presented. The prediction procedure describes a method that can be used to calculate the noise levels resulting from a construction operation. It also permits the evaluation of alternative strategies to control the noise level.

Chapter 4 discusses mitigation methods and techniques. Methods of lessening the impacts of noise produced by construction activities are outlined, ranging from equipment modification to community awareness. Included in this chapter are examples of regulations or specifications that may be used in controlling construction noise. The sample specifications have been devised and used by various agencies to abate construction noise. In some cases, the construction noise specifications are not strictly highway related, but may be applicable in many situations.

Appendix A lists noise levels for various types of construction machinery. This section gives the reader a very basic indication as to the wide range of noise levels produced by different individual pieces of equipment. It should be noted that the levels provided in Appendix A are peak values based on limited data. Users of this manual are encouraged to supplement, refine, and update these values.

Appendix B provides the measurement procedures referenced in the manual.

CHAPTER 2

NOISE MEASUREMENTS

2.0 BACKGROUND

Excluding Occupational, Safety and Health Administration (OSHA) requirements, noise measurements related to highway construction are generally made for only one purpose: to obtain information needed to identify, evaluate and mitigate highway construction noise impacts. Basically, three types of information may be needed:

1. The existing sound levels in the vicinity of the project prior to the start of construction.

2. The sound levels generated by the individual pieces of equipment.

3. The overall sound levels associated with the construction of the project.

Obviously, the amount of information needed will vary from project to project. In some environmental assessments, it may be possible to obtain all of the information needed without any measurements.

In this manual, all of the information needed to identify and evaluate highway construction noise impacts is expressed in terms of the hourly, A-weighted, equivalent sound level, $L_{eq}(h)$. Although equipment is available that will measure this metric directly, this manual assumes that only a hand-held sound level meter (SLM) is available. Therefore, it will be necessary to record the instantaneous sound levels measured by the SLM and compute the $L_{eq}(h)$. This is illustrated graphically in Figure 1.

This approach was chosen for two reasons. First, it was felt that the hand-held SLM was in more common use than the L_{eq} meters among highway agencies. Secondly, standardized measurement procedures for construction noise are now under development by several national and international organizations. Unfortunately, these organizations have not adopted a standard metric to describe construction noise. Use of the $L_{eq}(h)$ permits the use of the measurement procedures that have been developed to date and allows data comparisons to be made using a common metric.

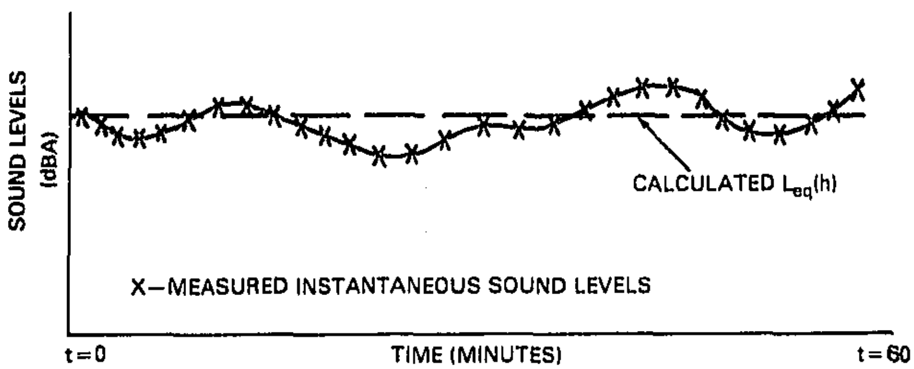

Figure 1: Sound Level Versus Time

The remainder of this chapter discusses measurement procedures that can be used to measure the existing sound levels (Section 2.1), the sound levels of individual construction equipment (Section 2.2), and the overall construction sound level (Section 2.3). Each section will define the sound level being discussed, indicate when the measurements are made, what uses are made of the sound levels, and how they are measured.

2.1 EXISTING SOUND LEVELS

Existing sound levels describe the acoustical environment prior to modification of an existing highway or construction of a new one. The existing sound levels include all natural and manmade sounds present at the site.

Information on existing sound levels is routinely developed during the noise studies for a highway project. If the project involves the reconstruction of an existing highway, or if the new project is located near another highway, and if the existing sound levels are predominantly due to highway traffic, the $L_{eq}(h)$ can be computed. This can be done using the traffic noise prediction models. In other situations, sound level measurements are needed to quantify the existing acoustical environment. In either case, the information on existing sound levels is normally developed in the early stages of project development, often years before construction of the project is started. In some situations, it may be necessary to reevaluate the existing levels prior to the start of construction.

The existing sound levels serve as a reference where the magnitude of the increase in sound levels, due to some changed highway condition, is indicative of the degree of impact. Construction noise impacts can be expected whenever the expected sound levels significantly exceed the existing sound levels.

Chapter 3 of the text[1], "The Fundamentals and Abatement of Highway Traffic Noise," discusses environmental or existing noise measurements. Information is provided on the use of sound level meters, the selection of measurement sites and when the measurements should be made. In addition, a detailed measurement procedure is provided for determining and recording the existing instantaneous sound levels. Based upon these sound level observations, a procedure and a criterion are given which insure computation of a statistically valid L_{10} for the time interval over which the measurements were made. Although this time interval is generally shorter than one hour, it is assumed that the sound levels are constant over one hour and the calculated L_{10} value is representative of an $L_{10}(h)$.

Once a statistically valid $L_{10}(h)$ has been obtained, the $L_{eq}(h)$ can be calculated as follows:

$$L_{eq}(h) = 10 \log \frac{1}{N} \sum_{i=1}^{N} n_i \, 10^{Li/10} \qquad (2\text{-}1)$$

Where $L_{eq}(h)$ is the hourly, A-weighted, equivalent sound level,

N is the number of sound level readings taken to obtain a statistically valid L_{10}.

n_i is the number of sound level readings in the i^{th} class.

L_i is the level of the i^{th} sound level reading taken during the measurement period.

Problem No. 1: Compute the $L_{eq}(h)$ of the sound level readings shown in figure 2.

$L_{10} = 49 \,{}^{+1}_{-3}$ dBA

L_{10} Criterion met after 50 samples

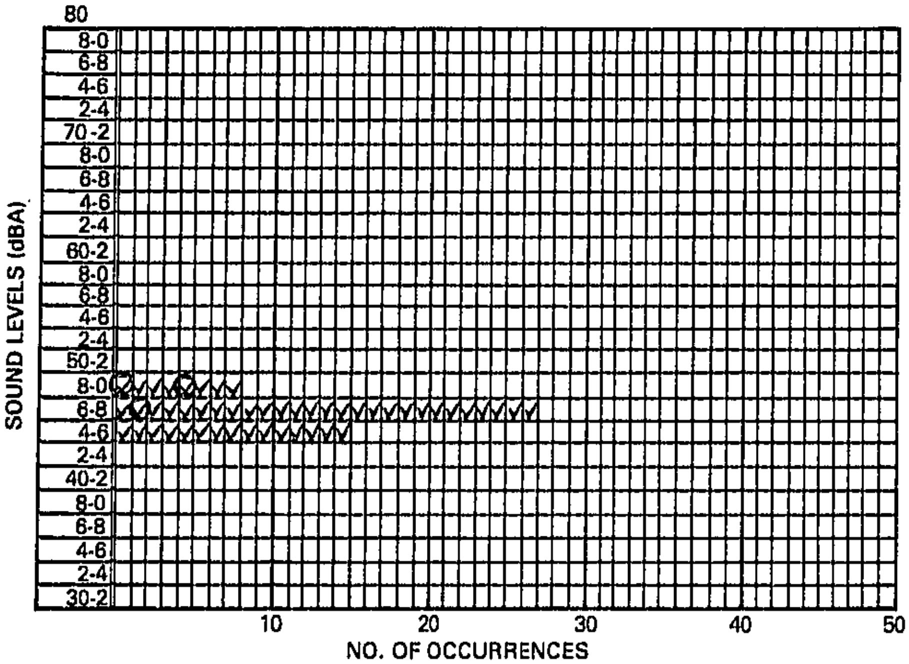

Figure 2: Noise Level Readings
(Source: Sketch 3.4, page 3.9, Fundamentals and Abatement of Highway Traffic Noise)

Solution: $L_{eq}(h) = 10 \log \frac{1}{N} \sum_{i=1}^{N} n_i \, 10^{Li/10}$

$$L_{eq}(h) = 10 \log \frac{1}{50} \left[\Sigma \, (8)(10^{49/10}) + (27)(10^{47/10}) + (15)(10^{45/10}) \right]$$

$$= 10 \log 2463010/50 = 10 \log 49260$$

$$= \underline{47 \text{ dBA}}$$

Problem No. 1: (Continued)

Alternately, the following procedure could be used.

Table 1: Alternate Computation of L_{eq} by dB Addition

Measured Sound Level L	No. of Occurrences (N)	10 log N	L + 10 log N	dB Sum (dB addition)
49	8	9	58	
47	27	14	61	64
45	15	12	57	

$$L_{eq}(h) = \text{dB Sum} - 10 \log N$$
$$= 64 - 17 = \underline{47\ \text{dBA}}$$

Problem No. 2: Compute the $L_{eq}(h)$ of the sound level readings shown in Figure 3.

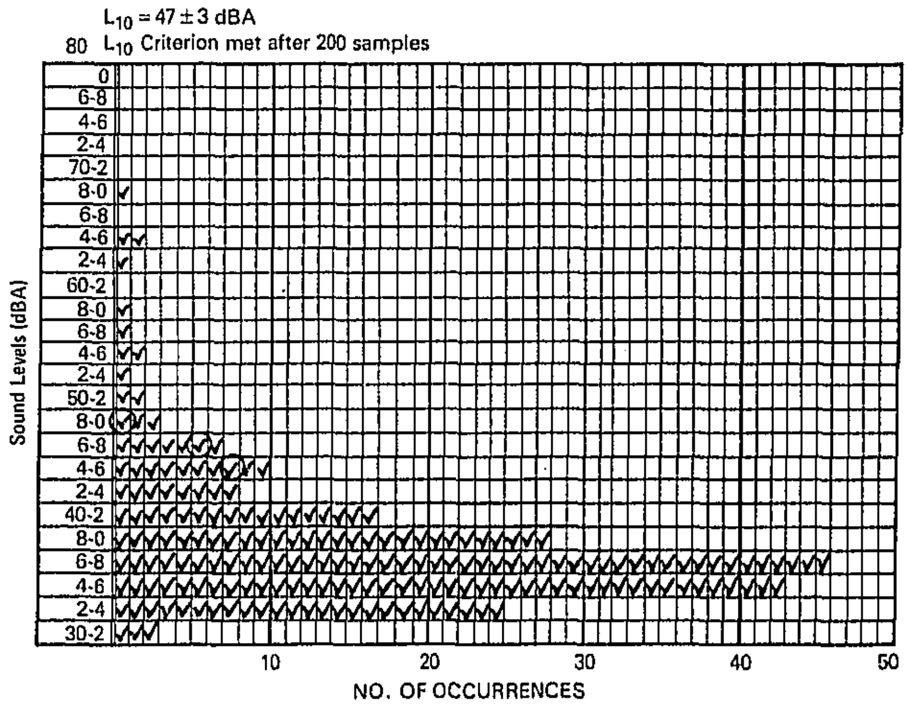

Figure 3: Noise Level Readings
(Source: Figure 3.2, Fundamentals and Abatement of Highway Traffic Noise)

Solution:

$$L_{eq}(h) = 10 \log \frac{1}{N} \sum_{i=1}^{N} n_i \, 10^{Li/10}$$

$$= 10 \log \frac{1}{200} \Big[\Sigma(10^{69/10}) + (2)(10^{65/10}) + (10^{63/10}) + (10^{59/10}) + (10^{57/10}) + (2)(10^{55/10}) + (10^{53/10}) + (2)(10^{51/10}) + (3)(10^{49/10}) + (7)(10^{47/10}) + (10)(10^{45/10}) + (8)(10^{43/10}) + (17)(10^{41/10}) + (28)(10^{39/10}) + (46)(10^{37/10}) + (43)(10^{35/10}) + (25)(10^{33/10}) + (3)(10^{31/10}) \Big]$$

$$= 10 \log \frac{1}{200} (20563972) = 10 \log 102820$$

$$= \underline{50.1} \text{ dBA (Note: } L_{10} - L_{eq} = -3.1 \text{ dBA)}$$

2.2 CONSTRUCTION EQUIPMENT SOUND LEVELS

In this manual, construction equipment sound levels are the sound levels emitted by the equipment under actual field operating conditions.

Construction equipment operates under two primary modes - mobile and stationary. Mobile equipment such as dozers, scrapers, graders, etc., operate in a cyclic fashion in which a period of full power is followed by a period of reduced power. Stationary equipment can be subdivided into two groups. One group contains such items as pumps, generators, compressors, etc., and generally operates at a fixed power and produces a fairly constant sound level under normal operation. The other group contains impact equipment such as pile drivers, jackhammers, pavement breakers, etc. Figure 4 shows typical idealized graphs of instantaneous sound levels as a function of time under field operating conditions for each group. This figure also indicates that the variations in sound levels are actually a function of the work cycle.

Data on equipment sound levels can be obtained by two methods: review of current technical publication and by measurements. Information on equipment sound levels being published in technical publications should be used with caution. These values are often peak values and must be adjusted to account for the variations in sound levels over the work cycle. Appendix A presents information on peak sound levels developed by the American Road Builders Association (ARBA). These values, once they are converted to $L_{eq}(h)$, are suitable for use in the environmental assessments conducted in project development. Appendix A also provides L_{eq} values for air compressors developed by EPA. Accurate equipment sound levels can best be developed by measurement. These values can be measured at any time, and if the equipment is well maintained, need only be measured once. Detailed evaluation of mitigation strategies generally require accurate equipment sound levels.

Equipment sound levels have two basic uses:

1. They provide overall sound levels that can be used for comparing the noise emission levels from different makes or models of equipment.

2. They can be used as emission models in noise prediction models.

To maximize their usefulness in these functions, the sound level must be in terms of the A-weighted, equivalent sound level measured over the equipment's work cycle. This requires a different measurement procedure for each of the three groups of equipment shown in figure 4. Unfortunately, standardized measurement procedures have not yet been developed. Until they are standardized, the following procedures can be used:

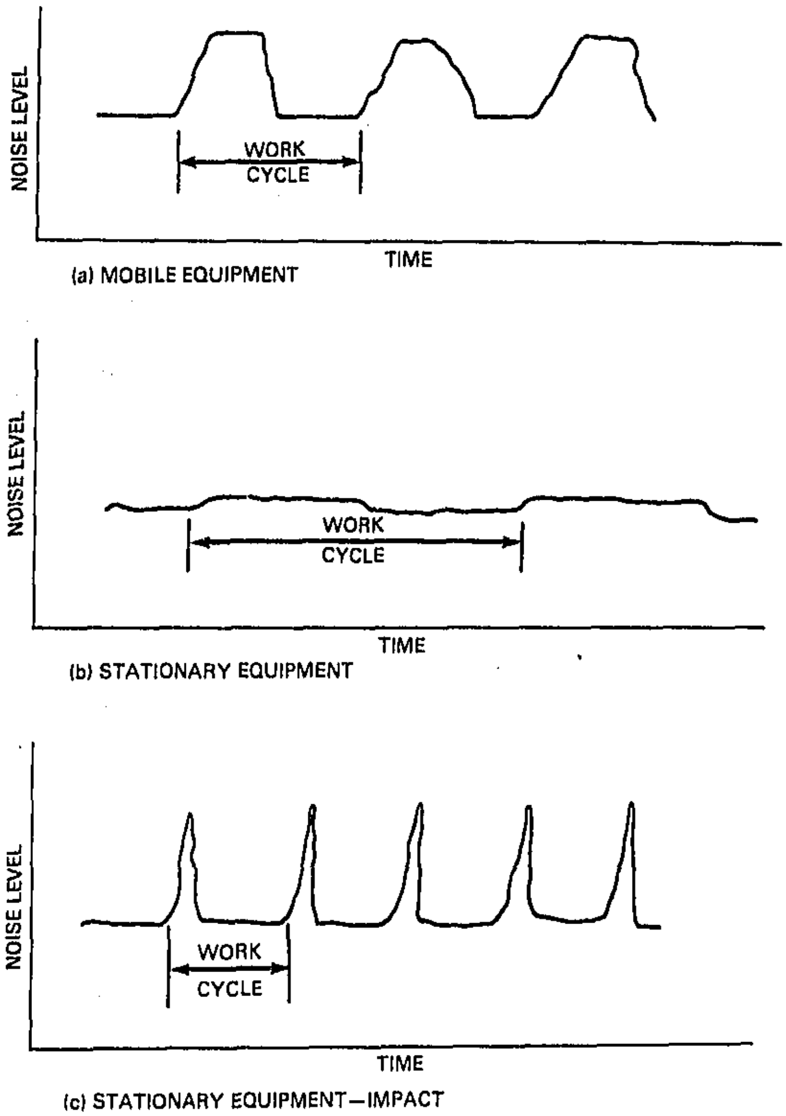

Figure 4: Sound Level Versus Time for Construction Equipment

MOBILE EQUIPMENT

The Society of Automotive Engineers (SAE) test, J88a, "Exterior Sound Level Measurement Procedure for Powered Mobile Construction Equipment," sets forth a procedure for measuring the exterior noise level for the certification of construction equipment. The sound levels obtained during these tests "...are repeatable and are representative of the higher ranges of noise levels generated by the machinery under actual field conditions, but do not necessarily represent the average sound level over a field use cycle." Figure 5 illustrates the differences between the SAE J88a sound level, the instantaneous sound levels produced by the equipment, and the equivalent sound level. Thus, the first steps in determining the equivalent sound level of the equipment is to measure the sound level using the SAE J88a test procedure. A copy of this procedure is included in Appendix B.

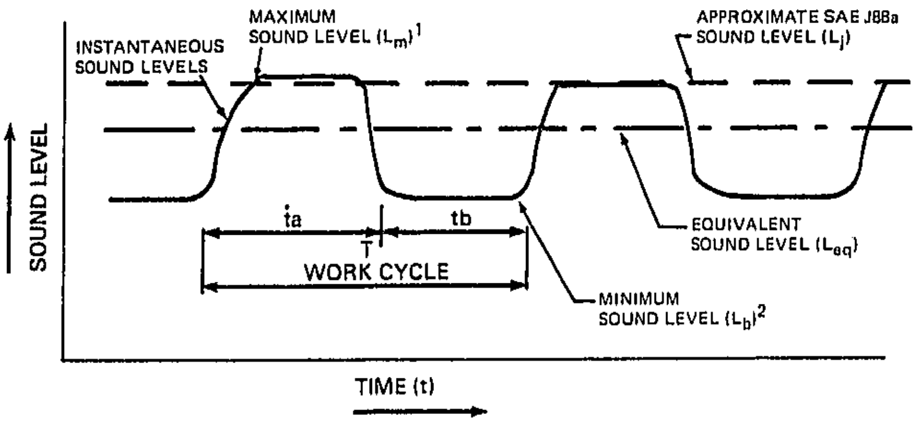

Figure 5: Sound Level Versus Time at 15.2m

1. The maximum sound level (L_m) measured during the duty cycle is assumed to be approximately equal to the SAE J88a Sound level (L_j) when L_m is measured at 15.2 meters.

2. The minimum sound level (L_b) is measured during the duty cycle at the same distance as L_m. In this figure, it is at 15.2 meters.

To convert the SAE J88a sound level, L_j, to an L_{eq}, the time spent at the various sound levels must be accounted for. Since mobile equipment produces an instantaneous sound level curve that is rectangular in form, an approximate $L_{eq}(h)$ can be calculated as follows (see Figure 5):

$$L_{eq}(h) = 10 \log[\frac{ta10^{L_m/10} + tb10^{L_b/10}}{ta + tb}] \qquad (2\text{-}2)$$

Since $L_m \approx L_j$ equation 2-2 reduces to

$$L_{eq}(h) = L_j + 10 \log \frac{ta}{T} + 10 \log (1 + \frac{tb}{ta}\ 10^{-(L_m - L_b)/10})$$

Where: $L_{eq}(h)$ is the A-weighted equivalent sound level assuming that the work cycle is repeated continuously over a one-hour period.

L_j is the sound level measured using the SAE J88a test procedure.

t_a is the time spent at the maximum level (L_m) during the work cycle.

L_m is the maximum sound level (approximately = to L_j).

L_b is the reduced sound level of the work cycle.

t_b is the time spent at the reduced sound level.

T is equal to $t_a + t_b$ and represents the work cycle time.

In this manual the expression

$$10 \log \frac{ta}{T} + 10 \log \left[1 + \frac{tb}{ta}\ 10^{-(L_m - L_b)/10}\right] \qquad (2\text{-}3)$$

will be called the equivalency factor (E.F.).

Therefore, equation 2-2 reduces to

$$L_{eq}(h) = L_j + E.F. \qquad (2\text{-}4)$$

Table 2 contains E.F.'s based on the difference between the maximum and minimum sound level, L_m and L_b, and the percent of time spent at the maximum level. L_m and L_b can be measured at any distance, but both values must be measured at the same distance. Note that L_m is approximately equal to L_j when L_m is measured at 15.2 meters. This procedure was chosen because it allows the calculation of L_j by a standardized procedure that is readily available. The measurements of the absolute levels for L_m and L_b are not critical since the maximum difference ($L_m - L_b$) is the parameter needed.

Table 2: Equivalency Factors (E.F.) in dBA

Lm-Lb (dBA)	ta/T									
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.
0	0	0	0	0	0	0	0	0	0	0
1	−1	−1	−1	−1	0	0	0	0	0	0
2	−2	−2	−1	−1	−1	−1	−1	0	0	0
3	−3	−2	−2	−2	−1	−1	−1	0	0.	0
4	−3	−3	−2	−2	−2	−1	−1	−1	0	0
5	−4	−3	−3	−2	−2	−1	−1	−1	0	0
6	−5	−4	−3	−3	−2	−2	−1	−1	0	0
7	−6	−4	−4	−3	−2	−2	−1	−1	0	0
8	−6	−5	−4	−3	−2	−2	−1	−1	0	0
9	−7	−5	−4	−3	−2	−2	−1	−1	0	0
10	−7	−6	−4	−3	−3	−2	−1	−1	0	0
11	−8	−6	−4	−3	−3	−2	−1	−1	0	0
12	−8	−6	−5	−4	−3	−2	−1	−1	0	0
13	−8	−6	−5	−4	−3	−2	−1	−1	0	0
14	−9	−6	−5	−4	−3	−2	−1	−1	0	0
15	−9	−7	−5	−4	−3	−2	−2	−1	0	0

Thus, to obtain an $L_{eq}(h)$, the following steps can be used:

1. Determine L_j using the SAE J88a test procedure or use the sound level given in Appendix A. (Note: The ARBA's sound levels in the Appendix are peak values measured at 15.2 meters and are approximately equal to L_j. The EPA values are L_{eq} values and need no adjustment.)

2. Measure the maximum (L_m) and minimum (L_b) sound levels of the equipment in the field, at the same distance and concurrently, measure the time spent at these levels.

3. Subtract the minimum from the maximum sound level (approximately $L_m - L_b$) and compute the time the equipment operates at its maximum sound level over the cycle (t_a/T).

4. Determine E.F. from Table 2.

5. Compute $L_{eq}(h)$ using equation 2-4.

<u>Problem No. 3:</u> Compute the $L_{eq}(h)$ for a D-8 dozer which has an L_j of 92 dBA. Under a normal work cycle, the dozer operates at a maximum sound level of 81 dBA for 30 seconds. This is followed by a reduced level of 70 dBA for 20 seconds.

Solution:

$L_{eq}(h) = L_j + EF$	
$L_m - L_b = 81 - 70 = 11$ dBA	(Step 3)
$ta/T = 30/50 = .6$	(Step 3)
From table 2, E.F. = −2	(Step 4)
$L_{eq}(h) = 92 - 2 = \underline{90 \text{ dBA}}$	(Step 5)

STATIONARY EQUIPMENT

The procedure used to determine the $L_{eq}(h)$ for all stationary equipment, except impact equipment, is identical to that used for mobile equipment with one exception. For stationary equipment, L_j is measured using SAE J952b, "Sound Levels for Engine Powered Equipment." A copy of this procedure is included in Appendix B.

STATIONARY EQUIPMENT - IMPACT

There are no current procedures for measuring the $L_{eq}(h)$ for impact equipment. The measurement of sound levels for this type of equipment will require an impulse sound level meter. It is suggested that the instantaneous sound levels be determined over an extended period with particular attention given to peak values and that $L_{eq}(h)$ be computed from this curve. The measurement setup should conform to that used in SAE J952b. Additional information in this area will be developed by the Federal Highway Administration (FHWA) and furnished at a later date.

2.3 OVERALL OR BOUNDARY NOISE LEVELS

Overall or boundary noise levels are the resultant sound levels produced by a particular construction operation at some point outside the construction site boundary. These values represent the sound levels heard by the community.

The construction of a highway is accomplished in several different phases. These phases can usually be characterized by the following:

1. Mobilization
2. Clearing and grubbing
3. Earthwork
4. Foundations
5. Bridge Construction
6. Base Preparation
7. Paving
8. Cleanup

Each of these operations occurs over some period of time. A simplified construction schedule using the above phases is presented in Figure 6.

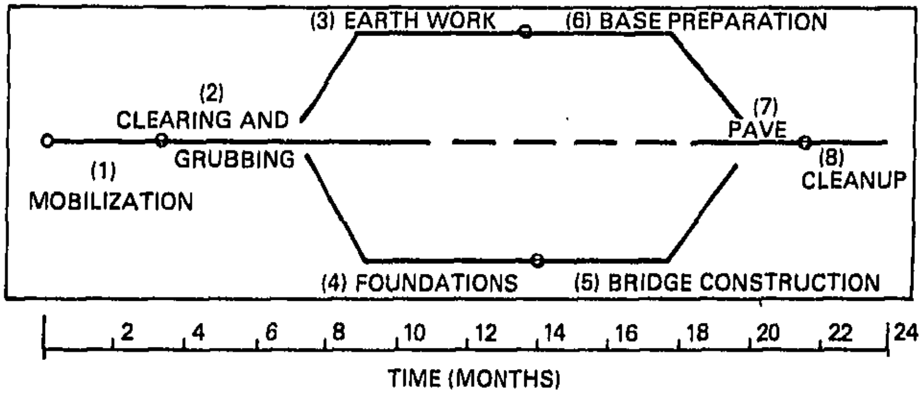

Figure 6: Simplified Construction Schedule

Each phase will have its own noise level. Thus, the expression "construction noise" is rather meaningless unless it is expressed as the noise level during some phase of the construction operation.

Obviously, overall or construction noise measurements can only be made after construction starts. These values can be used for the following purposes:

1. Assessing construction noise impacts.

2. Evaluating the effectiveness of different mitigation strategies.

3. Enforcing noise control regulations.

4. Evaluating the accuracy of noise prediction models.

Draft No. 7, "SAE Recommended Practice: Measurement Procedure for Determining a Representative Sound Level at a Construction Site Boundary Location," can be used to compute and approximate L_{eq}. A copy of this procedure is included in Appendix B. Users of this manual should recognize that this is a draft procedure.

CHAPTER 3

PREDICTION OF CONSTRUCTION NOISE

3.0 BACKGROUND

The purpose of this chapter is to present a prediction methodology that can be used to estimate the construction noise levels associated with the construction of a highway. This prediction methodology serves two useful purposes.

1. It provides a mechanism for identifying potential noise impact areas prior to the start of construction.

2. It provides a mechanism for assessing the potential noise reduction resulting from certain mitigation strategies.

To completely fulfill the first purpose, the prediction methodology must provide as accurate an estimate of the construction noise level as the situation warrants. For example, during the early stages of project development, only a rough estimate of the expected construction noise effects is needed. This estimate is used to define general areas where construction noise may have an adverse effect. Conversely, a contractor preparing a bid on a project may need an accurate estimate of the expected construction noise levels. This estimate may indicate the extensiveness of abatement measures needed. This would likely influence the bid the contractor will submit.

To completely fulfill the second purpose, the prediction methodology must be sensitive to changes in the input parameters. This sensitivity allows the evaluation of those strategies for mitigating construction noise which are affected by the input parameters. Indeed, a knowledge of the relative effects of various mitigation measures will aid in the selection of the most cost effective abatement measure or measures.

The remainder of this chapter is organized into three sections. Section 3.1 presents the construction noise prediction methodology. Section 3.2 discusses how the prediction method can be used to identify construction noise impact areas. Section 3.3 deals with the evaluation of alternative measures.

3.1 CONSTRUCTION NOISE PREDICTION METHODOLOGY

The basic methodology presented here for predicting construction noise is identical to that used in predicting highway traffic noise. It requires:

1. A noise metric to describe the magnitude of the construction noise level and its variation with time.

2. An emission model to determine the noise generated by the equipment at some reference distance.

3. A propagation model that shows how the noise level will vary with distance.

These three items can be related by the following expression:

$$L_{eq}\ \text{equipment} = E.L. + 10 \log U.F. - k \log D/D_0 \qquad (3\text{-}1)$$

Where:

L_{eq} equipment is the A-weighted, equivalent sound level at a receptor resulting from the operation of a single piece of equipment over some time period.

E.L. is the noise emission level of the particular piece of equipment based on its work cycle, i.e., recall equation 2.4: E.L. = L_j + E.F. @ 15.2 meters (D_0 = 15.2 meters)

K is a constant that accounts for topography and geometric spreading.

D is the distance from the receptor to the piece of equipment.

D_0 is the reference distance at which the noise emission level was measured from the piece of equipment.

U.F. is a usage factor that accounts for the percent time that the equipment is in use over the time period.

Our primary interest lies in the overall construction noise level produced by the simultaneous operation of several pieces of equipment. The overall construction noise level at some point is simply the sum (on an energy basis) of the individual contributions of each piece of equipment. Mathematically, the overall construction noise level at some point is expressed as:

$$L_{eq}(h)\ \text{site} = 10 \log \sum_{i=1}^{n} 10^{L_{eq}(\text{equipment})/10} \qquad (3\text{-}2)$$

Where: L_{eq} equipment is given by equation 3-1.

L_{eq} site is the A-weighted, overall equivalent construction noise sound level obtained by summing the individual equipment noise levels on an energy basis, and n is the number of pieces of equipment included in the summation.

The accuracy of Equation 3-2 depends upon the accuracy of the input parameters. This is shown in Table 3.

Table 3: Estimate of Accuracy of Prediction Method

PROJECT STATUS	ASSUMED PARAMETERS	ACCURACY OF ESTIMATE ** (dBA)
Environmental Studies	Equipment, E.L., K., D., U.F.	Unknown
PS&E Preparation	Equipment, E.L.,* K., D., U.F.	Unknown
Contract Award	K., U.F.	+ or − 5
Under Construction	None	+ or − 2

* Maximum values may be specified in plans.
** Estimate based on limited data (see references 3, 6, 7, and 8).

Equation 3-2 can be used to identify potential construction noise impact areas or it can be used to evaluate various mitigation measures.

3.2 IDENTIFICATION OF POTENTIAL CONSTRUCTION NOISE IMPACT AREAS

Equation 3-2 can be used to identify potential construction noise impact areas by providing an estimate of the expected construction noise level. The accuracy of this estimate is directly related to the accuracy of the input parameters. This can best be shown considering the two extreme situations, that is, where equation 3-2 provides its least accurate estimates and when it provides its most accurate estimate.

Least Accurate Estimate

For projects not under construction, equation 3-2 can be used to provide a rough estimate of the expected construction noise levels. Equation 3-2 provides its least accurate estimate when conditions or values must be assumed for all of the input parameters. This generally occurs during the early stages of project development. In an example of this situation, the following assumptions are used.

1. One hour is selected as the time period of interest. This is reasonable since most construction equipment operates continuously for a one-hour period; the usage factor (U.F.) then becomes unity and 10 log U.F. is equal to zero.

2. Free field conditions are assumed, ground effects are ignored. Since each piece of construction equipment acts as a point source, the expression k log D/D_0 reduces to 20 log D/D_0.

3. A representative noise emission level for a class of construction equipment is used. Note that E.L. = L_j + E.F., i.e., the equipment hourly sound level at 15.2 meters is the noise emission level.

4. The equipment is assumed to operate on the centerline of the highway.

With these assumptions, equation 3-2 reduces to

$$L_{eq}(h)\ \text{site} = 10 \log \sum_{i=1}^{n} 10^{L_{eq}(\text{equipment})/10} \qquad (3\text{-}3)$$

Where:

L_{eq}(equipment) = (E.L. - 20 log D/D_0) equipment. L_{eq}(h) site is the one-hour, A-weighted, overall equivalent construction noise level, and D_0 equals 15.2 meters.

One additional problem exists with the prediction of construction noise for projects not under construction. An assumption must be made about the numbers and types of equipment at the site. It appears at this time, that the overall construction noise level is governed primarily by the noisiest pieces of equipment.[3] The quieter pieces do not effect the overall level, but they do reduce the magnitude of the fluctuations in the noise level. Therefore, a rough estimate of the noise level need only incude the noisiest pieces of equipment expected at the site. Problem No. 4 illustrates this procedure.

Problem No. 4: Consideration is being given to the construction of a two-lane road on new alignment between two towns. The project has advanced to the point where a preliminary assessment of potential construction impacts is needed. Make a preliminary rough estimate of the hourly equivalent sound level that will be generated for each construction phase. Average distance from the centerline of the road to the ROW line is 30.5m.

Solution

Step 1: Identify the main construction operations or phases which must be performed to complete the project. This will require a simplified construction schedule which is shown in Figure 7.

Step 2: Determine the types of equipment that will be needed to complete each construction phase identified in Step 1. Appendix A can be used to determine a representative noise emission level for each type of equipment.

Step 3: Based upon the results of Step 2, prepare a list, complete with representative noise emission levels, of the two noisiest types of equipment that will be used in each phase. This list is shown in columns B and C, Table 4.

Step 4: Use equation 3-3 to compute the L_{eq}(h) for each type of equipment at 30.5 meters (distance to ROW line). The result of this calculation in column E, Table 4.

Step 5: Compute the overall sound level for each phase using dB addition. The results are shown in Table 4, Column F.

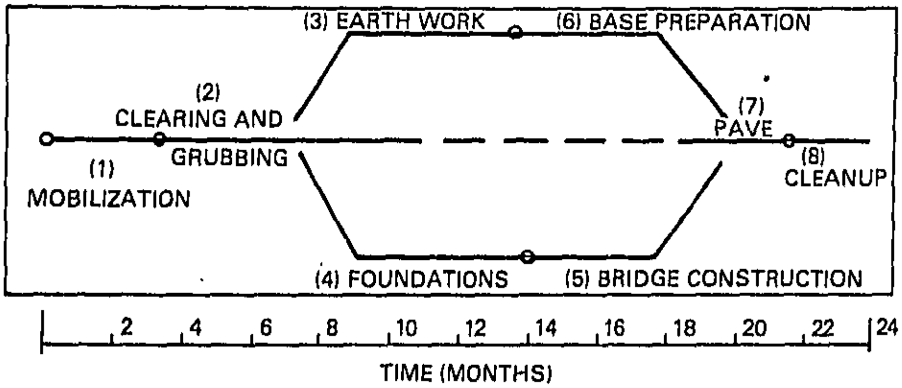

Figure 7. Simplified Construction Schedule

Table 4: Calculations, Problem 4

A PHASE	B EQUIPMENT	C[1] EMISSION LEVELS (dBA)	D DISTANCE FROM EQUIPMENT TO OBSERVER (meters)	E EQUIPMENT $L_{eq}(h)$ AT RECEPTOR (dBA)	F OVERALL $L_{eq}(h)$ AT RECEPTOR FOR EACH PHASE (dBA)
Mobilization	—	—	—	—	—
Clearing and Grubbing	Dozer Backhoe	87 85	30.5 30.5	81 79	83
Earthwork	Scraper Dozer	88 87	30.5 30.5	82 81	85
Foundation	Backhoe Loader	85 84	30.5 30.5	79 78	82
Superstructure	Crane Loader	88 84	30.5 30.5	82 78	83
Base Preparation	Trucks Dozer	88 87	30.5 30.5	82 81	85
Paving	Paver Trucks	89 88	30.5 30.5	83 82	86
Cleanup	—	—	—	—	—

1. E.L. = L_J + E.F. where L_J is the peak value from appendix A. (A representative E.L. was chosen and it was assumed that Lm-Lb>10 dBA and ta/T = 50%).

Most Accurate Estimate

Equation 3-2 provides its best estimate when all of the input data are measured, i.e., the project is under construction.

For projects under construction, some investigators have recently reported good agreement between measured and predicted noise levels (± 2 dBA) using equations which have the general form of equation 3-2. However, to achieve this agreement, precise measurements of the following parameters were required:

1. The site topography.
2. The noise emission level of each piece of equipment used at the site.
3. The location of each piece of equipment while it was working.
4. The % of the time that the equipment was in use during the measurement period.

As a result of these measurements, accurate values were determined for the E.L., D and k for each piece of equipment operating at the construction site. This presents a problem in assessing construction noise impacts. Item 1 can be determined any time after the highway location is established. However, items 2, 3, and 4 can only be measured after construction begins. Consequently, the most accurate predictions of construction noise can only be made after construction begins. This is illustrated in Problem No. 5.

Problem No. 5: The project discussed in example 4 has now progressed to the point where contractors are bidding on the project. The special provisions require that the exterior $L_{eq}(h)$ on school grounds be less than 75 dBA during school hours. A long fill is to be constructed adjacent to a school. One prospective contractor would like to use two dozers and three scrapers to construct this fill. The contractor has collected the following data on his equipment from previous projects.

	L_j	L_m-L_b	T_a/T
Dozer 1	86	10	.5
Dozer 2	88	12	.5
Scraper 1	86	12	.3
Scraper 2	84	12	.3
Scraper 3	82	12	.3

Compute the noise emission level of the equipment and estimate the $L_{eq}(h)$ at the school.

Solution

Step 1: The noise emission levels ($L_{eq}(h)$ at 15.2m) of the equipment is calculated by:

$$E.L. = L_j + E.F.$$

The noise emission levels are shown in table 5.

Table 5: Computation of Noise Emission Levels

EQUIPMENT	L_j (dBA)	E.F. (Table 1)	NOISE EMISSION LEVEL (dBA)
Dozer 1	86	3	83
Dozer 2	88	3	85
Scraper 1	86	5	81
Scraper 2	84	5	79
Scraper 3	82	5	77

Step 2: Assign at average location to each piece of equipment.
This is shown in figure 8.

Problem No. 5: (Continued)

Step 3: Compute the $L_{eq}(h)$ for each piece of equipment using equation 3-1 and the overall construction noise level using equation 3-2. The results are shown in table 6. The construction $L_{eq}(h)$ of 80 dBA exceeds the specified goal by 5 dBA.

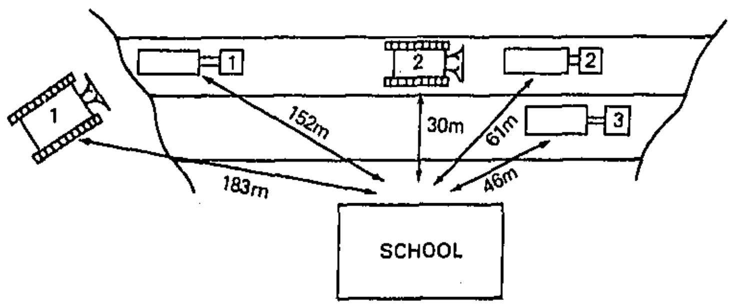

Figure 8: Construction Site

Table 6: Calculation, Problem 5

A PHASE	B EQUIPMENT	C NOISE EMISSION LEVEL (dBA)	D DISTANCE FROM EQUIPMENT TO OBSERVOR (meters)	E EQUIPMENT $L_{eq}(h)$ AT RECEPTOR (dBA)	F OVERALL $L_{eq}(h)$ AT RECEPTOR (dBA)
Earthwork	Dozer No. 1	83	183	61	
	Dozer No. 2	85	30	79	
	Scraper No. 1	81	152	61	
	Scraper No. 2	79	61	67	
	Scraper No. 3	77	46	67	80 dBA

The 80 dBA value in column F was obtained by dB addition. The value could also have been determined by:

$$L_{eq}(h) \text{ site} = \Sigma L_{eq}(h) \text{ equipment}$$
$$= 10 \log \Sigma 10^{6.1} + 10^{7.9} + 10^{6.1} + 10^{6.7} + 10^{6.7} = 80 \text{ dBA}.$$

3.3 EVALUATION OF DIFFERENT MITIGATION STRATEGIES

Chapter 4 contains a detailed discussion of various mitigation strategies. The relative effects and effectiveness of a few of these strategies can be determined by the use of equation 3-2. This is done by holding all input parameters constant except the one affected by the particular mitigation strategy under study. Problem No. 6 illustrates how this is done.

Problem No. 6: Problem No. 5 indicates that the expected construction noise level exceeds the specified goal by 5 dBA. Evaluate different mitigation strategies that would give a reduction of 5 dBA.

Step 1: Analysis of table 6 indicates that Dozer No. 2 must be quieter if the desired goal of 75 dBA is to be met. If possible, one strategy would be to exchange Dozer No. 2 for Dozer No. 1.

Dozer No. 1: $L_{eq}(h) = 83 - 20 \log \frac{30}{15.2} = 77$ dBA

Dozer No. 2: $L_{eq}(h) = 85 - 20 \log \frac{183}{15.2} = 63$ dBA

$L_{eq}(h)$ site $= 10 \log \left[10^{7.7} + 10^{6.3} + 10^{6.1} + 10^{6.7} + 10^{6.7}\right] = 78.1$ dBA

Continued

The expected noise level exceeded the goal by 3 dBA. This strategy, by itself, is not enough.

Step 2: One mitigation strategy would be to replace Dozer No. 2. What would be an acceptable noise emission level for the replacement dozer 30 meters from the school? To answer this question, set the overall construction noise level equal to 75 dBA in equation 3-2 and solve.

$L_{eq}(h)$ site $= 10 \log \Sigma 10^{L_{eq}\,(\text{experiment})/10}$

$75 \text{ dBA} = 10 \log \left[10^{x/10} + 10^{6.3} + 10^{6.1} + 10^{6.7} + 10^{6.7}\right]$

$\frac{75}{10} = \log \left[10^{x/10} + 10^{7.1}\right]$

$10^{7.5} - 10^{7.1} = 10^{x}$

$10^{7.28} = 10^{x/10}$ $\quad 7.28 = x/10$

3 $\quad L_{eq}(h) = 73$ dBA at 30 meters.

$L_{eq}(h)$ equipment $= \text{E.L.} - 20 \log \frac{D}{D_0}$

$73 \text{ dBA} = \text{E.L.} - 20 \log \frac{30}{15.2}$

E.L. = 73 + 6 = 79 dBA.

Conclusion: This strategy accomplishes the desired goal.

CHAPTER 4

MITIGATION

4.0 BACKGROUND

The effective control of highway construction noise can be achieved in much the same manner as operational traffic noise is controlled by using a three-part approach. This consists of:

1. Control of the noise at the source.

2. Control along the path of the noise.

3. Control at the receptor.

The three-part approach was taken in developing this portion of the manual.

This chapter presents various state-of-the-art methods and techniques of noise control that can be used to reduce noise impacts associated with highway construction. Most of the measures presented have been contained in either construction specifications, special provisions, or supplemental contract documents. The measures can be employed independently or in combination, depending on the scope of the project and the resultant effects that are desired. Section 4.1 outlines the factors necessary for identification and selection of an appropriate abatement measure to control construction noise. Section 4.2 details various methods that can be used. This section includes five subsections. Each subsection explains the methodology in general terms and then presents specific control strategies found under these broad methodologies. The control strategy is described, the dB reduction resulting from implementation is provided if known, the advantages and disadvantages are given, and a brief discussion is provided listing other characteristics of the specific control strategy. Sample specifications or examples are provided for each methodology. (Note: Values used in the specifications may not be practical or achievable. The manual user is encouraged to develop his own criteria.)

4.1 IDENTIFICATION AND SELECTION OF CONTROL MEASURES

After the potential impacts resulting from the construction activities have been established, the final step in the process is the selection of appropriate control measures to be implemented on the project. This can be approached in two stages:

1. Identification of feasible measures.

2. Final selection of mitigation strategies.

The first stage involves identification of control strategies that could be implemented that would bring about the desired reductions in noise impacts. Some of the factors that influence this identification process include:

1. Amount of reduction needed.

2. Local sentiment toward the proposed project.

3. Local noise ordinances.

4. Length of the construction period.

5. Effectiveness of control strategies.

6. Cost of control strategies.

On the basis of these and other factors, different noise mitigation strategies can be examined to determine what measures could be implemented for a specific project.

The last stage is the selection of a reasonable control strategy from the group examined in the identification stage. The measure or measures chosen should be weighed as to their benefits compared to their adverse effects. This weighing should take into consideration the monetary costs involved, problems with implementation of the measures, the sensitive receptors in the area, and the degree of noise reduction achievable.

4.2 APPROACHES TO CONSTRUCTION NOISE CONTROL

Techniques for abating construction noise may vary from simple, inexpensive, easily implemented measures such as a requirement that all engines be equipped with a properly operating muffler, to more expensive, elaborate methods, such as equipment enclosures.

The control techniques outlined in this manual have been divided into five general categories. These categories have been further divided into different specific strategies. Figure 9 shows the breakdown and indicates how the remainder of this chapter is organized.

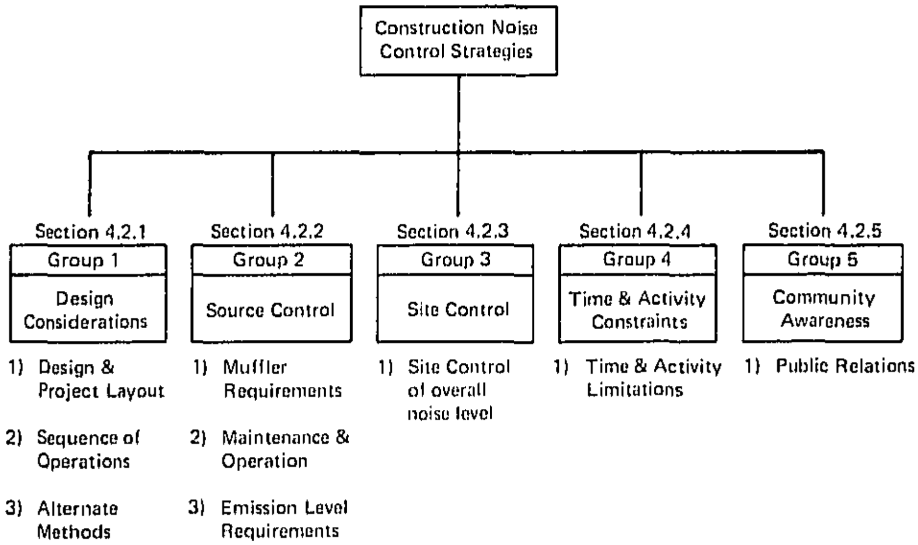

Figure 9: Control Strategies

It should be noted that a measure that may be suitable in one situation may not be suitable in another. Care should be taken in selecting the appropriate mitigation measure.

4.2.1 DESIGN CONSIDERATIONS AND SPECIFIED ALTERNATIVE CONSTRUCTION METHODS

Noise impacts to senstive receptors can occur on any project involving the construction or reconstruction of a highway facility. While the magnitude of these impacts may not be known precisely early in the project development stages, certain measures can be implemented during the design phase that can reduce the anticipated noise impacts.

These measures fall into three categories:

1. Design considerations and project layout.

2. Sequence of operations.

3. Alternate construction methods.

The measure outlined are typically decided upon in the early stages of project development and included in the project plans and contract documents. Ideally, these strategies should be used in conjunction with other control methods.

Mitigation Group One

Mitigation Strategy One

DESIGN CONSIDERATIONS AND PROJECT LAYOUT

Description:

During the early design stages of project development, the sensitive noise receptors can be established. By identification of these receptors, steps can be taken to lessen the construction noise impacts. During location studies, natural and artificial barriers such as ground elevation changes and existing buildings can be considered for use as shielding against construction noise. During design, waste material dump and storage sites can be designated in areas where they also serve as noise barriers. Haul roads can be designated in locations where the noise impacts caused by truck traffic will be reduced.

dB Reduction:

Undeterminable at the design stages of project development.

Advantages:

These techniques provide early consideration of the impacts caused by construction activities. A better understanding of potential problems can be obtained.

Disadvantages:

Design changes and modification to project layout are not always practical or feasible. The magnitude of the dB reduction is difficult to determine prior to construction.

Discussion:

The responsibility for development of these measures is born by the designer. The problem is analyzed prior to preparation of plans and other documents. The measures to be implemented are then placed in the contract documents at the appropriate time in the project development.

Mitigation Group One

Mitigation Strategy Two

SEQUENCE OF OPERATIONS

Description:

When planning for construction of a highway project, certain steps can be taken in scheduling work operations. Several noisy operations can be scheduled concurrently to take advantage of the fact that the noise levels produced will not be significantly greater than the level produced if the operations were performed separately. Noise barriers ultimately to be constructed as part of the project for traffic noise abatement can be constructed in the initial stages of construction to reduce the noise impacts of the construction.

dB Reduction:

Undeterminable at the design stages of project development.

Advantages:

These techniques tend to lessen the ongoing impacts as the project progresses.

Disadvantages:

The magnitude of reduction is difficult to determine in the early planning stages. These measures may not be feasible or practical to implement.

Discussion:

These measures are typically used in conjunction with other control measures and are contained in the project documents.

Mitigation Group One

Mitigation Strategy Three

ALTERNATE CONSTRUCTION METHODS

Description:

Certain phases of highway construction work such as pile driving may produce noise levels in excess of acceptable limits, even when feasible noise reduction methods are used. The impacts resulting from this type of situation may be lessened or avoided by using alternate methods of construction. Generally, piling is driven using an impact hammer. This operation often produces excessive noise levels. Some reduction can be attained by various dampening and shielding methods discussed later. However, such methods rarely reduce the noise level to an acceptable level for the sensitive receptors close to the site. As an alternative to driving piles, vibration or hydraulical insertion can be used. Drilled holes for cast in place piles are another alternative that may produce noise levels significantly lower than the traditional driving method.

dB Reduction:

Significant reductions may be realized by using less noisy construction methods.

Advantages:

New and innovative methods of construction may be evolved by considering alternate methods.

Disadvantages:

Alternate methods produce their own noise impacts and may produce other adverse effects that have to be weighed.

Discussion:

Great care should be exercised in choosing alternate construction methods. The choice should be weighed as to its desirablility and feasibility (The measures decided upon are placed in the contract documents.)

4.2.2 SOURCE CONTROL

In devising construction noise control strategies, one important option is controlling the noise at the source. By specifying and/or using less noisy equipment, the noise impacts produced by construction of a highway facility can be greatly reduced or even eliminated. Source control requirements may have the added benefits of promoting technological advances in the development of quieter equipment.

Lessening the impacts from highway construction through source control techniques may be approached from three different ways:

1. Muffler requirements.

2. Maintenance and operational requirements.

3. Equipment emission level requirements.

These methods may be used separately or in combination in order to achieve the desired results.

Mitigation Group Two

Mitigation Strategy One

MUFFLER REQUIREMENTS

Description:

Most construction noise originates from equipment powered by either gasoline or diesel engines. A large part of the noise emitted is due to the intake and exhaust portions of the engine cycle. A remedy for controlling much of the engine noise is the specification and use of adequate muffler systems.

dB Reduction:

Reductions of 10 dBA or more can be achieved with optimal muffler systems.[6]

Advantages:

Muffler requirements can be easily written in contract specifications, complied with and enforced. Inspection and enforcement are simple and easily done. They are effective in reducing engine produced noise at a low cost to the user.

Disadvantages:

Only effective for machinery powered by internal combustion engines. Does not effect operational noises, i.e., the noise produced by doing the work.

Discussion:

This noise control strategy would lead to replacement of worn mufflers and to retrofitting where mufflers are not in use. The user of the equipment has the responsibility to comply with the specifications provided in the contract documents. Routine field inspection will be necessary by both the contractor and enforcement personnel to ensure compliance.

Example Specification: Mitigation Group Two - Source Control

Mitigation Strategy One - Muffler Requirements

Sound Control Requirements.--The Contractor shall comply with all Federal, State, and local sound control and noise level rules, regulations, and ordinances which apply to any work performed pursuant to the contract. In addition, each internal combustion engine, used for any purpose on the job or related to the job, shall be equipped with a properly operating muffler of a type recommended by the manufacturer. No internal combustion engine shall be operated on the project without said muffler.

This specification is provided for example purposes only. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

Mitigation Group Two

Mitigation Strategy Two

MAINTENANCE AND OPERATION OF EQUIPMENT

Description:

Poor maintenance of equipment may cause very high noise levels. Faulty or damaged mufflers, loose engine parts, rattling screws, bolts, or metal plates all contribute to increasing the noise level of a machine. Careless or improper handling and operation of equipment can also increase construction noise levels. Poor loading, unloading, excavation and hauling techniques are some examples of how lack of adequate guidance may lead to increased noise levels. Specifications can be written to require that all equipment be regularly inspected for deficiencies in the maintenance area. Likewise, specifications can require that equipment users be properly trained in the use of construction equipment.

dB Reduction:

Significant reductions are achievable through correction of maintenance problems and adequate training in the use of equipment.

Advantages:

Proper maintenance can result in less down time for equipment, thereby shortening the time the equipment may be required in the area. Repair costs resulting from improper maintenance can be avoided.

Proper training increases the efficiency of the operation as well as reducing the equipment produced noise levels.

Disadvantages:

There is no procedure for determining the magnitude of noise level decreases prior to operation of the equipment. This type of specification is weak when used by itself.

Examples Specification: Mitigation Group Two - Source Control

Mitigation Strategy Two - Maintenance and Operation of Equipment

Noise Abatement Measures

The Contractor shall take such noise abatement measures that are necessary to comply with the requirements of this contract, consisting of, but not limited to the following:

Proper maintenance of all equipment to insure that noise is kept to a minimum.

Conducting truck loading, unloading and hauling operations so taht noise is kept to a minimum.

Routing of construction equipment and vehicles carrying spoil, concrete or other materials over streets that will cause the least distrubance to residents in the vicinity of the work. The Engineer shall be advised in writing of the proposed haul routes prior to the Contractor securing a permit from the local government.

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Mitigation Group Two

Mitigation Strategy Three

EQUIPMENT EMISSION LEVEL REQUIREMENTS

Description:

One of the most effective methods of diminishing the noise impacts associated with individual pieces of construction equipment is to employ less noisy machinery. This may be accomplished by specifying the quietest available equipment. Specifications can be provided that set an upper noise level for equipment, or they may be worded so as to group certain pieces into a single category and then set upper limits for that category.

Modifications such as dampening of metal surfaces is quite effective in reducing noise due to vibration. Another possibility is the redesign of a particular piece of equipment to achieve quieter noise levels. These modifications can usually only be done by the manufacturer or with factory assistance and can be costly, time consuming, and possibly ineffective in reducing the overall noise levels.

Another method of source control is employing shields that are physically attached to the particular piece of equipment. For stationary equipment and in cases where considerable noise reduction is required, enclosures have proven to be effective.

dB Reduction:

The reduction is controlled by the imposed limits and on the technical capabilities of the manufacturer or the equipment user. Noise reductions of up to 5 dBA can be achieved using dampening materials.[6]

Shields such as sound skins may achieve reductions of 20 dB at high frequencies and 10 dB in the middle frequency range. Sound aprons may achieve noise reductions up to 10 dBA.[6]

Advantages:

Significant noise reductions are achievable through emission level requirements.

New equipment emission level standards provided by the Environmental Protection Agency (EPA) can be specified for use for various types of construction equipment.

Disadvantages:

Noise level limits may be relatively difficult to set. Enclosures are not practical if they interfere with the machines function or impede air circulation or servicing of the piece of equipment. Modifications or adjustments to the particular piece of equipment may not be feasible because of the costs involved or technical limitations.

Discussion:

The EPA is in the process of developing noise emission level standards for new equipment. Standards are currently set for portable air compressors. Work is progressing in setting standards for wheel and crawler tractors, mobil earth moving equipment, and pavement breakers and earth drills. Once identified as a potential noise source, other construction equipment may be regulated. Source control techniques may be limited to employing shields that are physically attached to the particular piece of equipment. This type of shield is used to reflect, contain or absorb the noise emitted from construction machinery. Sound aprons and sound skins are two examples of such shields.

Sound aprons generally take the form of sound absorptive mats hung like curtains from the piece of equipment or on a specially built frame physically attached to the equipment. The aprons can be constructed of rubber, lead-filled fabric, or PVC layers with sound absorptive material covering the side facing the machine. Additionally, quilted material is currently available. Sound aprons are useful when the shielding must be frequently removed or if only partial covering is possible.

Sound skins are similar to sound aprons but differ in that they should be close fitting and air tight. Allowance must be made, however, to let air in for cooling. Any openings should be equipped with mufflers or angled air ducts lined with sound absorptive materials.

Enclosures for stationary work may be constructed of wood or any other suitable material and should be lined with sound absorptive material to prevent an increase of sound levels within the structure. They should be designed for ease of erection and dismanteling.

These source control methods are generally initiated or devised by the contractor in order to meet the noise emission level specifications or site noise levels. However, they may be actually specified in the contract documents.

1. <u>Example Specification:</u> Mitigation Group Two - Source Control

Mitigation Strategy Three - Equipment Emission Level Requirements

Equipment Regulations:

Effective January 1, 19__, construction equipment on the project is prohibited from exceeding the prescribed limits shown in the following table, measured in dB(A) at a distance of 15m, in conformance with SAE Standard J 952 and SAE Recommended Practice J 184.

Equipment Regulations

EQUIPMENT (dB(A) measured at 15 m)	1 JAN. __
EARTHMOVING EQUIPMENT	
FRONTLOADER	75
BACKHOES	75
DOZERS	75
TRACTORS	75
SCRAPERS	80
GRADERS	75
TRUCKS	75
PAVERS	80
MATERIALS HANDLING EQUIPMENT	
CONCRETE MIXER	75
CONCRETE PUMPS	75
CRANE	75
DERRICK	75
STATIONARY EQUIPMENT	
PUMPS	75
GENERATORS	75
COMPRESSORS	75
IMPACT EQUIPMENT	
PILE DRIVERS	95
JACK HAMMERS	75
ROCK DRILLS	80
PNEUMATIC TOOLS	80
OTHER EQUIPMENT	
SAWS	75
VIBRATOR	75

This specification is provided for example purposes only. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

The values given may not be practical or achievable.

2. <u>Example Specification</u>: Mitigation Group Two - Source Control

Mitigation Strategy Three - Equipment Emission Level Requirements

<u>Construction Equipment Noise</u>

Powered equipment, truck or power hand tools that produces a maximum sound level exceeding the following limits shall not be used during construction operations. The sound level limits specified are referenced to a distance of 50 feet from the equipment. Sound levels shall be measured in substantial conformity with Standards and Recommended Practices established by the Society of Automotive Engineers, Inc., including the latest revisions to SAE J366a and SAE J952b.

Where required by agencies having jurisdiction, certain noise producing work may have to be performed during other than regular working hours or only at specified periods.

Type of Equipment	Sound Level Limits
(a) Construction and Industrial machinery, such as crawler-tractors dozers, rotary drills and augers, loaders, power shovels, cranes, derricks, motor graders, paving machines, off-highway trucks, ditchers, trenchers, compactors, scrapers, wagons, pavement breakers, compressors, and pneumatic power equipment.	90 dBA
(b) Highway Trucks	88 dBA

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The values given may not be practical or achievable.

3. Example Specification: Mitigation Group Two - Source Control

Mitigation Strategy Three - Equipment Emission Level Requirements

Noise Abatement Measures

The Contractor shall provide such equipment, sound-deadening devices, and take such noise abatement measures that are necessary to comply with the requirements of this contract, consisting of, but not limited to the following:

(a) Shields or other physical barriers to restrict the transmission of noise.

(b) Soundproof housing or enclosures for noise producing machinery.

(c) Efficient silencers on air intakes of equipment.

(d) Efficient intake and exhaust mufflers on internal combustion engines.

(e) Line hoppers and storage bins with sound deadening material.

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4.2.3 SITE CONTROL

The ultimate purpose of construction noise control is to reduce the impacts on the sensitive receptors. In order to achieve this goal, another abatement technique is to specify and employ site noise limits and noise control measures. Site noise control typically involves limiting the amount of noise reaching the sensitive receptors. Specifications may be written that set certain limits at the receptors, thus allowing the equipment user to devise his own methods for meeting the requirements or they may directly specify certain actions that may be taken to achieve a noise reduction at the receptors.

Description:

In order to meet site or receptor limits, various methods to reduce noise impacts have proven successful. The methods described are normally used in conjunction with other mitigation strategies to achieve an overall noise level reduction at identified locations.

One way to reduce the noise impacts at sensitive receptors is to operate stationary equipment such as air compressors, generators, etc. as far away from the sensitive receptors as practical. Pit areas or excavate portions on the job site may provide suitable locations for stationary construction activities and at the same time serve as noise barriers.

In some cases, activities such as form building, bridge and culvert construction, or other work involving stationary activities can effectively be accomplished inside an enclosure in order to reduce the noise impacts. In all cases where enclosures and excavation are involved, proper ventilation, access, egress and safety for the construction worker must be considered and maintained.

In some situations, such as in urban areas or on isolated sections of a project, it may be beneficial and indeed necessary to construct barriers adjacent to the work area.

dB Reduction:

The reduction in noise levels will vary with the method employed. Measurements are necessary to determine the exact levels.

Advantages:

Site noise limits are useful and advantageous because they tend to allow the contractor more freedom in developing means to reduce the noise impacts to the surrounding areas.

If properly designed and erected, barriers can not only be very effective in reducing sound propogation from the work area, but can also serve as physical, safety barriers to the site.

Disadvantages:

It may become very complex to set reasonable yet effective limits. Limits can not be set so low as to make the specification impossible or impractical to meet. Limits should not be set so high as to make the specification meaningless.

This type of control is extremely difficult to enforce, particularly when the noise metric involves long term averaging, i.e., L_{eq} (24).

In employing some site control methods, the noise levels in certain areas within the construction area boundaries may be increased which will in turn affect project personnel working in the area.

Some measures may be costly and not easily implemented. Care must be taken to insure that if some type of barrier is used it will not create a hazard for the traveling public or the project personnel.

Discussion:

Special prefabricated panels are currently manufactured that can be relatively easily moved and erected. These may be ideally suited for controlling overall site noise in some situations.

Example Specification: Mitigation Group Three - Site Control

Mitigation Strategy One - Site Control

The noise level from the Contractor's operation shall not exceed:

1. x dBA @ y metres;
2. y dBA @ ROW or
3. z dBA @ t receptor

This requirement in no way relieves the Contractor from responsibility for complying with local ordinances regulating noise level.

The Contractor shall purchase, modify, and operate equipment; erect barriers; attach aprons and skins; etc., and take any other measures necessary to meet the specified site noise limits.

Said noise level requirement shall apply to all equipment on the job or related to the job, including but not limited to trucks, transit mixers or transient equipment that may or may not be owned by the Contractor. The use of loud sound signals shall be avoided in favor of light warnings except those required by safety laws for the protection of personnel.

Full compensation for conforming to the requirements of this section shall be considered as included in the prices paid for the various contract items of work involved and additional compensation will be allowed therefore.

This specification is provided for example purposes only. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

4.2.4 TIME AND ACTIVITY CONSTRAINTS

Construction activity and the associated noise can be quite annoying and disruptive during leisure hours, during the hours of sleep, and, any time where loud continuous noises may effect certain special activities. Time constraints and use of equipment regulations can be very effective in reducing the impacts caused during these hours of the day.

Description:

During leisure hours and during periods of sleep, disturbance from equipment use can be kept to a minimum. The basis for the noise control strategy is to limit the times that certain noise construction activities may be prosecuted. Generally, this can be accomplished by requiring the contractors to perform such work during daylight hours when the majority of individuals who would ordinarily be affected by the noise are either not present or are engaged in less noise sensitive activities or limit nighttime work to that which is less than certain specified values.

Loud continuous noises around such critical noise receptors as schools, hospitals, etc., are disturbing at all times. Time constraints that restrict the construction activity to limited time periods can be effective in lessening these impacts.

dB Reduction:

During hours that the activity is restricted there is no impact associated with the particular activity.

Advantages:

.Time constraints are effective in reducing noise impacts during critical periods of the day.

Disadvantages:

Time limitations may increase the overall length of time necessary to complete the project.

1. <u>Example Specification</u>: Mitigation Group Four - Time Constraints

Mitigation Strategy One - Time Constraints

<u>Noise Control</u> - The Contractor's construction operations shall be performed in such a manner that noise levels established for designated land use activities and time periods, when measured at designated distances from the Right-of-Way, will not exceed those shown in Table I-1. However, this provision is not applicable if the ambient noise (noise caused by sources other than construction operations) at the doing of reception is in excess of the construction noise level at that point.

The Department reserves the right to monitor construction operations as deemed necessary. In the event construction noise level(s) exceeds those levels shown in Table I-1, the Contractor shall take such action as necessary to conform with this provision prior to proceeding with his operation. The Contractor shall be responsible for all costs arising from delay of operation(s) due to non-compliance with this noise control provision.

TABLE I-1
MAXIMUM ALLOWABLE CONSTRUCTION NOISE LEVELS

LAND USE ACTIVITY	MAXIMUM ALLOWABLE EXTERIOR NOISE LEVELS dB (A)	APPLICABLE TIME PERIOD
residential, hospitals, nursing homes, schools, churches, libraries, offices, parks, picnic areas, recreational areas, playgound, active sport areas	88	6 a.m. - 8 p.m.
	67	8 p.m. - 6 a.m.

This specification is provided for example purposes only. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

2. Example Specification: Mitigation Group Four - Time Constraints

Mitigation Strategy One - Time Constraints

Mobile Equipment

Sound levels from mobile construction equipment shall not exceed the following:

Residential Areas

Daily, except Sundays & Legal Holidays 7:00 a.m. to 7:00 p.m.	85 dBA
Daily, except Sundays & Legal Holidays 7:00 p.m. to 7:00 a.m.	65 dBA
7:00 p.m. Saturday to 7:00 a.m. Monday & Legal Holidays	65 dBA

Business - Commercial Area:

Daily, including Sunday & Legal Holidays, all hours, a maximum of 90 dBA.

Stationary Equipment

Sound levels from stationary equipment shall not exceed the following:

Residential Areas

Daily, except Sundays & Legal Holidays 7:00 a.m. to 7:00 p.m.	70 dBA
Daily, except Sundays & Legal Holidays 7:00 p.m. to 7:00 a.m.	55 dBA
7:00 p.m. Saturday to 7:00 a.m. Monday & Legal Holidays	55 dBA

Business - Commercial Areas:

Daily, including Sundays & Legal Holidays, all hours, and maximum of 75 dBA.

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The values given may not be practical or achievable.

4.2.5 COMMUNITY AWARENESS

Although not a physical method of noise abatement, public relations and community awareness is a positive method of lessening the impacts of construction-related noise and disturbances. There are numerous instances during the various phases of activity where noise reduction is not feasible or warranted. In these cases, it is especially helpful for the impacted property owners to be made aware of the upcoming activity. It is also possible to forestall a great deal of adverse community reaction by implementing early public involvement into the project.

Description:

There are various techniques that may be employed to inform the public of upcoming noise impacts related to the construction activity. Depending on the scope of the project, the lengths of time involved in a particular phase of work, and the degree of unavoidable impact, the methods used can be as simple as distributing flyers to the adjacent property owners or may be as complex as conducting public informational meetings. The most important consideration in any method chosen is early communication. The scope of the proposed work and when possible, the time span of the activity should be spelled out in order to allow residents to plan their activities accordingly.

Advantages:

This method promotes better relations between the public, the contracting agency and the contractor.

Disadvantage:

This method may not physically reduce the construction noise impacts.

Discussion:

The contracting agency should also take an active role in insuring that the communication lines are open and the public is properly informed of upcoming construction activity. This may be accomplished by seeing to it that all questions and inquiries from the general public are courteously and reasonably responded to.

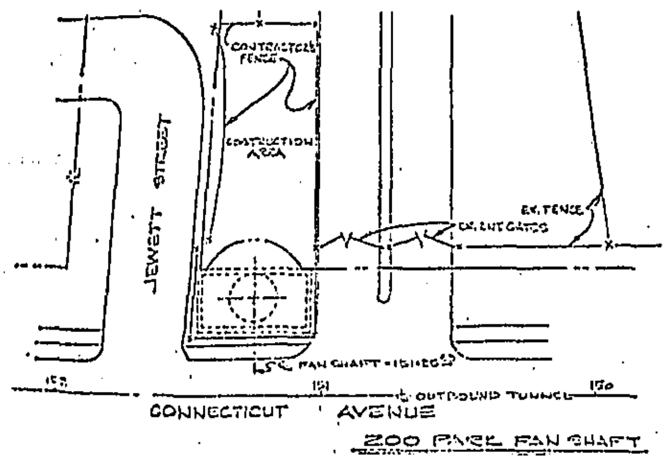
The highway agency may require the contractor to alert the public in a timely manner in the contract documents or the agency may take on the public relations function itself.

Example: Mitigation Group Five - Community Awareness

Mitigation Strategy One - Public Relations

TO THE PUBLIC

Our purpose in distributing this curcular is to keep you informed concerning the Metro Construction in your neighborhood. As is METRO policy, it is our aim to cooperate with property owners, tenants, businessmen, businesswomen and ordinary citizens who are directly affected or inconvenienced by the work. In turn, we would appreciate your indulgence during the construction period. Inquires should be directed to Resident Engineer.



Description of Work: Drill and blast 20' diameter shaft 150' deep through rock. Blasting will be monitored by instruments to insure against any damages to adjacent buildings.

Duration of Work: April 1 to February 1.

Days of Operation: Monday through Friday 7:00 a.m. to 10:00 p.m.

This is provided for example purposes only. The contents do not necessarily reflect the official views or policy of the Department of Transportation.

REFERENCES

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2. "Exterior Sound Level Measurement Procedure for Powered Mobile Construction Equipment," SAE Recommended Practice; J88a

3. "Noise From Construction Equipment and Operations, Building Equipment, and Home Appliances," NTID 300.1, EPA, December 1971

4. "Background Document for Portable Air Compressors," EPA 550/9-76-004, December 1975.

5. W. N. Patterson, R. A. Ely, and S. M. Swanson, "Regulation of Construction Activity Noise," Bolt Beranek and Newman, Inc., Report No. 2887 prepared under EPA Contract No. 68-01-1547, November 1974 (unpublished as of May 1976).

6. P.D. Schomer and B. Homans, Construction Noise: Specification, Control, Measurement, and Mitigation, Technical Report E-53, Construction Engineering Research Laboratory, April 1975.

7. Construction Noise Survey, NC-P2 (4/74), New York State Department of Environmental Conservation, April 1974.

8. D. J. Martin and A. V. Solaini, Noise of Earthmoving at Road Construction Sites, TRRL Supplementary Report 109 UC, Transportation and Road Research Laboratory, Department of the Environment, England.

9. P.D. Schomer, F. M. Kessler, R. C. Chanand, B. L. Homans and J. C. McBryan, "Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing," Draft Technical Report, CERL, May 1976.

APPENDIX A

CONSTRUCTION EQUIPMENT NOISE LEVELS AND RANGES

The noise emission levels listed for various types of construction related machinery are, with the exception of the compressor data, based on limited samples. The values are presented in order to give the reader a basic understanding of where particular pieces of machinery fit on a noise-range spectrum of levels. Additional data and updated material should be added when it becomes available.

The majority of the data was provided by the American Road Builders Association. This data was taken during a 1973 survey in which member contractors were asked to secure readings of noise exposure to operators of various types of equipment. Additionally, the contractors were asked to take readings at 50 feet from the machinery. These 50-feet peak readings are provided in the appendix. The data was produced under varying condition and degrees of expertise, however, the values are relatively consistant.

The data provided for portable air compressors was taken from the U.S. Environmental Protection Agency publication EPA 550/9-76-004 which was used in the development of the final Portable Air Compressors Regulation. The data represents average noise level readings taken at 7m(23 ft.) using the CAGI/PNEUROP measurement method.

Construction Equipment Noise Levels*

*Based on Limited Data Samples

Manufacturer	Type or Model	Exhaust	Peak Noise Level (dBA)	Remarks
<u>Cranes</u>				
Northwestern	80D		77	Within 15m 1958 mod
"	8		84	" 1940 mod
"	6		72	" 1965 mod
American	7260		82	" 1967 mod
"	599		76	" 1969 mod
"	5299		70	" 1972 mod
"	4210		82	" 1968 mod
Buc Ere	45C		79	" 1972 mod
"	30B		74	" 1968 mod
"	30B		73	" 1965 mod
"	30B		70	" 1959 mod
"				
Link Belt	LS98		76	" 1956 mod
Manitowoc	4000		94	"
Grove	RF59		82	" 1973 mod
Koehr	605		76	" 1967 mod
	435		86	" 1969 mod
	405		84	" 1969 mod
<u>Backhoe</u>				
Link Belt	4000		92	Within 15m 1971 mod
John Deer	609A		85	" 1971 mod
Case	680C		74	" 1973 mod
Drott	40 yr.		82	" 1971 mod
Koehr	1066		81 & 84	" 2 tested

*Except where noted, all data was provided by ARBA

Construction Equipment Noise Levels*

Manufacturer	Type of Model	Exhaust	Peak Noise Level (dBA)	Remarks
Front Loaders				
Caterpillar	980		84	Within 15m 1972 mod
"	977K		79	" 1969 mod
"	977		87	" 1971 mod
"	977		94	" 1967 mod
"	966C		84	" 1973 mod
"	966C		85	" 1972 mod
"	966		81	" 1972 mod
"	966		77	" 1972 mod
"	966		85	" 1966 mod
"	955L		90	" 1973 mod
"	955K		79	" 1969 mod
"	955H		94	" 1963 mod
"	950		78 & 80	" 1972 mod
"	950		75	" 1968 mod
"	950		88	" 1967 mod
"	950		86	" 1965 mod
"	944A		80	" 1965 mod
"	850		82	" 1968 mod
Michigan	75B		90	" 1969 mod
"	475A		96	" 1967 mod
"	275		85	" 1971 mod
"	125		87	" 1967 mod
Hough	65		82	" 1971 mod
"	60		91	" 1961 mod
"	400B		94	"
"	H90		86	"
Trojan	3000		85	" 1956 mod
"	RT		82	" 1965 mod
Payloader	H50		85	" 1963 mod

*Except where noted, all data provided by ARRA

Manufacturer	Type or Model	Exhaust	Peak Noise Level (dBA)	Remarks
<u>Dozers</u>				
Caterpillar	D5		83	Within 15m 1967 mod
"	D6		85	"
"	D6		86	" 1964 mod
"	D6		81	" 1967 mod
"	D6B		83	" 1967 mod
"	D6C		82	" 1962 mod
"	D7		85	" 1956 mod
"	D7		86	" 1969 mod
"	D7		84	" 1969 mod
"	D7		78	" 1970 mod
"	D7		78	" 1972 mod
"	D7E		86	" 1965 mod
"	D7E		78	" 1970 mod
"	D7E		84	" 1973 mod
"	D7F		80	" 1972 mod
"	D8		92	" 1954 mod
"	D8		95	" 1968 mod
"	D8		86	" 1972 mod
"	D8H		88	" 1966 mod
"	D8H		82	" 1972 mod
"	D9		85	"
"	D9		94	"
"	D9		90	" 1963 mod
"	D9		87	" 1965 mod
"	D9		90	" 1965 mod
"	D9		88	" 1968 mod
"	D9		92	" 1972 mod
"	D9G		85	" 1965 mod
Allis Chalmers	HD41		93	" 1970 mod
International	TD15		79	" 1970 mod
"	TD20		87	" 1970 mod
"	TD25		90	" 1972 mod
"	TD8		83	" 1970 mod
Case	1150		82	" 1972 mod
John Deer	350B		77	" 1971 mod
"	450B		65	" 1972 mod
Terex	8230		70	"
"	8240		93	" 1969 mod
Michigan	280		85	" 1961 mod
"	280		90	" 1962 mod
Caterpillar	824		90	" 1968 mod

Manufacturer	Type or Model	Exhaust	Peak Noise Level (dBA)	Remarks
Graders				
Caterpillar	16		91	Within 15m 1969 mod
"	16		86	" 1968 mod
"	140		83	" 1970 mod
"	14E		84	" 1972 mod
"	14E		85	" 1971 mod
"	14C		85	"
"	14B		84	" 1967 mod
"	12F		{82 72-92	" 1961-72 mod
"	12E		{81.3 80-83	" 1959-67 mod
"	12		{84.7 82-88	" 1960-67 mod
Galion	T500		84	" 1964 mod
Als Chalmer			87	"

Manufacturer	Type or Model	Exhaust	Peak Noise Level (dBA)	Remarks
Scrapers				
Caterpillar	660		92	Within 15m
"	641B		85	" 1972 mod
"	641B		86	"
"	641		80 & 84	" 1972 mod
"	641		83 & 89	" 1965 mod
"	637		87	" 1971 mod
"	633		87	" 1972 mod
"	631C		89	" 1973 mod
"	631C		83	" 1972 mod
"	631B		94	" 1969 mod
"	631B		84-87 85 avg.	" 1968 mod
"	621		90	" 1970 mod
"	621		86	" 1967 mod
"	613		76	" 1972 mod
Terex	TS24		87 84-91	" 1972 mod
"	TS24		82 81-83	" 1971 mod
"	TS24		94 92-98	" 1966 mod
"	TS24		94.7 94-95	" 1963 mod
"	TS14		82	" 1969 mod
"	S35E		84	" 1971 mod

Noise Levels of Standard Compressors*

Manufacturer	Model	Silenced or Standard	Type Eng.	Type Comp.	Test Cond. (cfm,psi)	Avg. Noise Lev. (dBA) at 7m*
Atlas	ST-48	Standard	Diesel	Reciprocal	160,100	83.6
Atlas	ST-95	Standard	Diesel	Reciprocal	330,105	80.2
Atlas	VSS-170Dd	Silenced	Diesel	Reciprocal	170,850	70.2
Atlas	VT-85Dd	Standard	Gas	Reciprocal	85,100	81.4
Atals	VS-85Dd	Silenced	Gas	Reciprocal	85,100	75.5
Atlas	VSS-125Dd	Silenced	Diesel	Reciprocal	125,100	70.1
Atlas	STS-35Dd	Silenced	Diesel	Reciprocal	125,100	73.5
Atlas	VSS-170Dd	Silenced	Diesel	Reciprocal	170,100	
Gardner-Denver	SPHDA/2	Silenced	Diesel	Rotary-Screw	1200,000	73.3
Gardner-Denver	SPQDA/2	Silenced	Diesel	Rotary-Screw	750,000	78.2
Gardner-Denver	SPHGC	Silenced	Gas	Rotary-Screw	185,000	77.1
Ingersoll-Rand	DXL 1200	Standard	Diesel	Rotary-Screw	1200,125	92.6
Ingersoll-Rand	DXL 1200 (doors open)	Standard	Diesel	Rotary-Screw	1200,125	
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	76.0
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	75.1
Ingersoll-Rand	DXLCU1050	Standard	Diesel	Rotary-Screw	1050,125	90.2
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	75.3
Ingersoll-Rand	DXL 900S	Silenced	Diesel	Rotary-Screw	900,125	75.0
Ingersoll-Rand	DXL 900	Standard	Diesel	Rotary-Screw	900,125	89.9
Ingersoll-Rand	DXL 750	Standard	Diesel	Rotary-Screw	750,125	87.7
Jaeger	A	Standard	Gas	Rotary-Screw	175,100	88.2
Jaeger	A(doors open)	Standard	Gas	Rotary-Screw	175,100	
Jaeger	E	Standard	Gas	Vane	85,100	81.5
Jaeger	E(doors open)	Standard	Gas	Vane	85,100	
Worthington	160 G/2Qt	Silenced	Gas	Vane	160,100	74.2
Worthington	750-QTEX	Silenced	Diesel	Rotary-Screw	750,100	74.7

*Data taken from EPA Report - EPA 550/9-76-004.

APPENDIX B

Measurement Procedures

The measurement procedures referenced in the text are provided for easy referral.

EXTERIOR SOUND LEVEL MEASUREMENT PROCEDURE FOR POWERED MOBILE CONSTRUCTION EQUIPMENT—SAE J88a

SAE Recommended Practice

Report of Vehicle Sound Level Committee approved November 1972 and last revised June 1975. Rationale statement available.

1. Scope—This SAE Recommended Practice sets forth the instrumentation and procedure to be used in measuring exterior sound levels for the certification test of powered mobile construction equipment of 20 rated bhp and over. It is not intended to cover operation of safety devices (such as backup alarms), air compressors, jack hammers, pile drivers, pavement breakers, and machinery designed primarily for operation on highways or within factories, aircraft, or recreational vehicles such as snowmobiles and boats. The sound levels obtained by using the test procedures set forth in this SAE Recommended Practice are repeatable and are representative of the higher range of sound levels generated by the machinery under actual field operating conditions, but do not necessarily represent the average sound level over a field use cycle.

2. Instrumentation

2.1 A sound level meter which meets the Type 1 or S1A requirements of the American National Standard Specification for Sound Level Meters, S1.4—1971.

2.2 As an alternative to making direct measurements using a sound level meter, a microphone or sound level meter may be used with a magnetic tape recorder and/or graphic level recorder or indicating instrument, providing the system meets the requirements of SAE Recommended Practice J184 Qualifying a Sound Data Acquisition System.

2.3 An acoustical calibrator (see paragraph 4.2.4—accuracy within ±0.5 dB).

2.4 A microphone windscreen shall be used that does not permit the effect on the microphone and frequency response to exceed ±0.5 dB to 5 kHz and ±2.0 dB to 12 kHz.

2.5 An anemometer or other device for measurement of ambient wind speed and direction (accuracy within ±10%).

2.6 A power source rpm indicator (accuracy within ±2%).

2.7 A thermometer for measurement of ambient temperature (accuracy within ±1°).

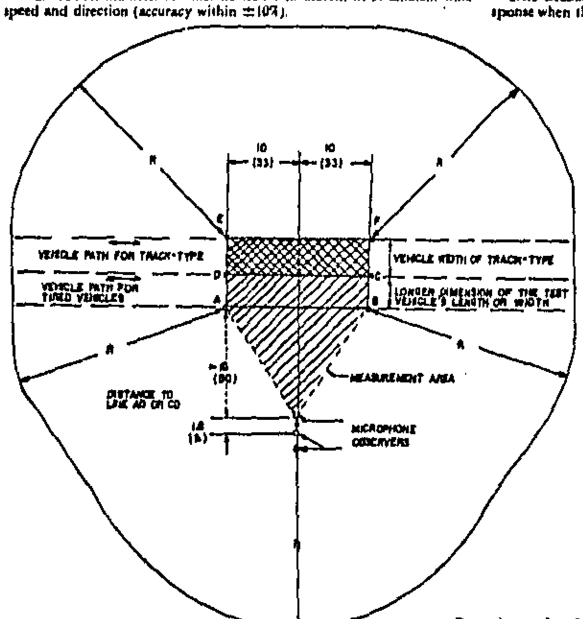
2.8 A barometer for measuring atmospheric pressure (accuracy within ±1%).

3. Procedure

3.1 Test Site—The test area shall consist of a flat open space free of any large reflecting surfaces, such as a signboard, building or hillside, located within 30 m (100 ft) of either the microphone or the machinery being measured (see Fig. 1). It is recommended that measurements be made only when the wind speed is below 19 km/h (12 mph).

3.1.1 The minimum measurement area (see Fig. 1) shall consist of the triangle formed by the microphone location, points A and B, and the rectangle formed by points A, B, C and D. Both designated areas shall be smooth concrete or smooth and sealed asphalt or a similar hard and smooth surface. The rectangle formed by points C, D, E and F shall consist of hard-packed earth. The planes between the microphone location and line AB and planes encompassed by points A, B, C, F, E and D shall form a continuous, uniform plane. If a minimum measurement area test site is used, it will require reorientation of the machine for each major surface measurement during the stationary tests, and the moving tests will have to be run in two opposite directions. The other option is to have a larger measurement area test site and relocate the microphone for the series of prescribed test conditions with the machine is one position for stationary tests and driving by in only one direction for the moving tests.

3.1.2 Because bystanders have an appreciable influence on the meter response when they are in the vicinity of the construction machinery or micro-



NOTE: R=30(100) RADIUS MINIMUM DIMENSIONS ARE M(FT)

FIG. 1—TEST SITE CONFIGURATION

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phone, not more than one person, other than the observer reading the meter, shall be within 17 m (56 ft) of the construction machinery and 1.8 m (6 ft) of the measuring microphone, and that person shall be directly behind the observer who is reading the meter, on a line through the microphone and the observer (see Fig. 1).

3.1.3 The ambient sound level due to sources other than the construction machinery being measured (including wind effects) shall be at least 10 dB lower than the sound level of the machinery being measured. (See paragraph 3.3.3.)

3.1.4 The surface between and under the construction machinery and microphone shall be smooth and free of acoustically absorptive material, such as snow or grass.

3.1.5 For all stationary tests the machinery shall be located on the hard surface area formed by points A, B, C and D in Fig. 1.

3.1.6 Moving Tests

3.1.6.1 For moving tests of all rubber tired machines, the path of travel shall be across the area defined by points A, B, C and D in the directions shown in Fig. 1.

3.1.6.2 For moving tests of all steel wheel, steel drum or track-type machines the path of travel shall be across the area defined by C, D, E and F in the directions shown in Fig. 1.

3.2 Tests Required

(a) For mobile construction machinery that is used primarily in a stationary mode, test per paragraphs 3.2.1.1, 3.2.1.2, and if applicable 3.2.1.3.

(b) For self-propelled construction machinery that is used primarily in a mobile mode, test per paragraphs 3.2.1.1, 3.2.1.2, 3.2.1.3 and 3.2.2. For construction machines which have an auxiliary power source, such as a truck mounted crane, the main engine and auxiliary engine shall be run separately during tests 3.2.1.1 and 3.2.1.2 with the other engine shut down.

During test 3.2.1.3 only the auxiliary engine shall be run and only the main propulsion engine run during the test prescribed in 3.2.2. For combined construction machinery (such as small loader with backhoe) test per paragraphs 3.2.1.1, 3.2.1.2, 3.2.1.3 and 3.2.2.

3.2.1 Stationary Tests with Ground Propulsion Transmission Shift Selector in Neutral Position.

3.2.1.1 Operate all mobile construction machinery engines at no load with all component drive systems in neutral position and maximum governed speed (high idle at no load) at a stabilized condition.

3.2.1.2 Operate all mobile construction machinery engines at no load with all component drive systems in neutral position through the cycle "low idle-maximum governed speed (high idle at no load) low idle" as rapidly as possible, but allowing the engine to stabilize for at least 10 s at maximum governed speed (high idle at no load) before it is permitted to return to low idle.

3.2.1.3 With the engine at the maximum governed speed (high idle at no load) in a stabilized condition, activate the appropriate hydraulic circuits, mechanical, electrical, hydrostatic, or torque converter drive systems to cycle the major components or component from the most retracted and/or lowered position to fully extended and/or maximum height position and then back to original position. This cycling should be done as fast as practical, taking into consideration all the pertinent safety factors that can be accomplished without blowing relief valves. For safety reasons and undesirability of change of location of major noise source in relation to microphone, a major portion of the mobile machine, such as the tractor of a scraper unit, drum of a compactor, or the upper rotational structure of an excavator, shall not be moved or placed in a vibratory mode of operation during this stationary machine test.

3.2.2 Constant Speed Moving Test—Self-propelled construction machinery shall be operated in a forward intermediate gear ratio at no load at a location as specified in paragraphs 3.1.6.1 or 3.1.6.2. The power source shall be operated at full governor control setting. Intermediate is intended to mean second gear ratio for machines with three or four gear ratios, third gear ratio for machines with five or six gear ratios, fourth gear ratio for machines with seven or eight gear ratios, etc. (Gear ratio refers to overall gear reductions.) If there is a problem with the transmission shifting up or down in this phase of this test, one gear lower or higher may be used to eliminate the problem. Hydrostatic or electric drive machinery will be operated as near as possible to one-half its maximum ground speed. Machinery that has major noise-generating components which could be used at the above ground speed, such as on an elevating scraper or on a vibrating compactor, shall have these major components in operation during this moving test.

3.2.3 Construction machinery that has a major attachment that is normally used for the main operating function shall be equipped with this attachment. Examples of this are buckets on loaders and dozers on either wheel or track-type tractors. For all tests these attachments shall be in a minimum transport position of 0.15 m (6 in.) to 0.3 m (12 in.) for dozers, scrapers, etc., and for loaders use carry position as specified by SAE Standard J732 Specifications Definitions—Front End Loader.

3.3 Measurements

3.3.1 The microphone shall be located at a height of 1.2 m (4 ft) above the ground plane.

3.3.2 The sound level meter shall be set for slow response and the A-weighting network.

3.3.3 The ambient wind-speed and direction, ambient temperature, atmospheric pressure, and ambient A-weighted sound level shall be measured and recorded at the height of 1.2 m (4 ft) and within at least 3 m (10 ft) of the one specified location of the microphone as shown in Fig. 1.

3.3.4 The stabilized maximum governed engine speed shall be measured and recorded.

3.3.5 The sound level meter needle movement shall be observed during each test sequence at the specified microphone location. The highest value observed, disregarding sounds of short duration that are out of character with the test on the machine, (example) impact sound such as bucket rack against stops, shall be recorded for each test sequence. For stabilized test conditions (3.2.1.1) a single reading shall be recorded for each measurement point. For cycling and moving test conditions (3.2.1.2, 3.2.1.3 and 3.2.2) a minimum of three readings shall be taken for each measuring point. If none of these readings are within 2 dB of each other, then additional readings shall be taken until there are two that are within 2 dB of each other. The reported value shall be the average of these two values that are within 2 dB of each other. If there are two pairs of readings that are within 2 dB of each other, report the average of the higher pair. The final result for each test mode shall be the highest reading for stabilized test conditions and the highest average for the cyclic or moving tests and must include the location of the microphone.

3.3.6 For stationary tests, record the sound level obtained at a distance of 15 m (50 ft) normal to the centers of the four major surfaces of the equipment at the microphone height. Generally, four major surfaces refer to front, rear, and sides of an imaginary box that would just fit over the machine but does not include attachment items such as buckets, dozers, and booms (see Fig. 2). In the case of a crane or an excavator, the upper (revolving superstructure) fore-and-aft centerline should be in line with the lower fore-and-aft centerline. Operate the machine in a manner as specified in paragraphs 3.2.1.1, 3.2.1.2 and 3.2.1.3.

3.3.7 For moving tests, take measurements at a distance of 15 m (50 ft) measured in a direction normal to a major side surface which is parallel to the machine path, as shown in Fig. 1. Operate the machine in a manner specified in paragraph 3.2.2.

3.3.8 The final reported sound level per this SAE Recommended Practice shall be the highest of the reported values obtained in paragraphs 3.3.6 and 3.3.7; the test report shall include the test mode, the machine operating conditions during the reported test mode, the stabilized maximum governed engine speed, the location of the microphone in relation to the construction machine, the surface description over which the machine operated and the sound level measurements were made.

4. General Comments

4.1 It is recommended that persons technically trained and experienced in the current techniques of sound measurements select the instrumentation and conduct the tests.

4.2 Proper use of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer should be referred to for both recommended operation of the instrument and precautions to be observed. Specific items to be considered are:

4.2.1 The type of microphone which shall be oriented with respect to the source so that the sound strikes the diaphragm at the angle for which the

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microphone was calibrated to have the flatest frequency response characteristic over the frequency range of interest.

4.2.2 The effects of ambient weather conditions on the performance of all instruments (for example: temperature, humidity, and barometric pressure). Instrumentation can be influenced by low temperature and caution should be exercised.

4.2.3 Proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems.

4.2.4 Proper acoustical calibration procedure, to include the influence of extension cables, etc. Field acoustical calibration shall be made immediately before and after each test sequence of a piece of construction machinery.

5. References

5.1 ANSI S1.1—1960 (R1971), Acoustical Terminology

5.2 ANSI S1.2—1962 (R1971), Physical Measurement of Sound

5.3 ANSI S1.4—1971, Specification for Sound Level Meters

5.4 ANSI S1.13—1971, Methods for the Measurement of Sound Pressure Levels

5.5 ISO R362—Measurement of Noise Emitted by Vehicles

5.6 SAE Recommended Practice J184, Qualifying a Sound Data Acquisition System

5.7 SAE Standard J732c—Specification Definitions—Front End Loader

5.8 C.A.G.I.—PNEUROP Test Code for Measurement of Sound for Pneumatic Equipment

Applications for copies of the ANSI and ISO documents should be addressed to:

American National Standards Institute, Inc.
1430 Broadway
New York, New York 10018.

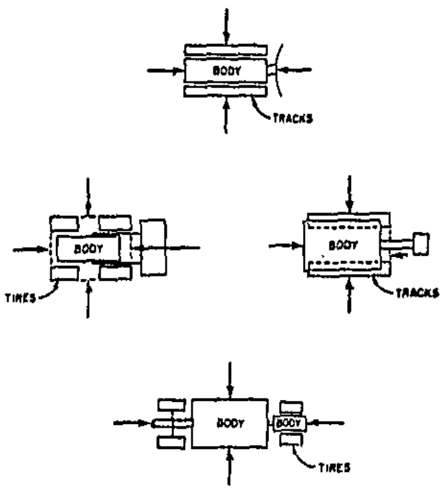

FIG. 2—MAJOR SURFACE OUTLINES

SOUND LEVELS FOR ENGINE POWERED EQUIPMENT—SAE J952b

SAE Standard

Report of Construction and Industrial Machinery Technical Committee approved May 1966 and last revised by Vehicle Sound Level Committee January 1969. Editorial change June 1973

1. Introduction—This SAE Standard establishes maximum sound levels for engine powered equipment and describes the test procedure, environment, and instrumentation for determining these sound levels. It does not include machinery designed for operation on highways or within factories and building areas.

2. Maximum Sound Levels—See paragraph 3.2 and Table 1.

3. Instrumentation

3.1 A sound level meter which meets the requirements of International Electrotechnical Commission Publication 179, Precision Sound Level Meters.

3.2 A sound level calibrator (see paragraph 5.5).

3.3 A calibrated windscreen (see paragraph 5.4).

4. Procedure

4.1 Test Site—The test area shall consist of a flat open space free of any large reflecting surfaces such as a signboard, building, or hillside located within 100 ft of either the microphone or the equipment being recorded.

4.1.1 Bystanders may have an appreciable influence on meter response if such persons are in the vicinity of the equipment or the microphone. No person other than the observer reading the meter shall be near the microphone.

4.1.2 The ambient sound level (including wind effects) due to sources other than the equipment being measured shall be at least 10 dbA lower than the level of the tested equipment.

4.1.3 The path of equipment travel shall be over a surface which is typical of the particular machine application.

4.2 Equipment Operations—Operate the equipment at the combination of load and speed which produces the maximum sound level without violating the manufacturer's operation specifications.

4.3 Measurements

4.3.1 The microphone shall be located at a height of 4 ft above the ground plane.

4.3.2 The meter shall be set for "fast" response and the A-weighting network.

4.3.3 For equipment which is not traveling, record the highest sound level obtained at 50 ft from the nearest surface of the equipment.

4.3.4 For traveling equipment, take measurements at 50 ft normal from the centerline of the path of straight line travel. The applicable reading will be the highest sound level obtained from the loudest side as the equipment moves along the line of travel.

4.3.5 The sound level which is reported shall be the average of the two highest applicable readings which are within 2 dB of each other.

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TABLE 1

Type of Equipment	Max Sound Level dB(A) at 50 ft (A-Weighting Network)
1. Construction and industrial machinery encompassing only mobile equipment, powered by internal combustion engines, such as crawler tractors, dozers, loaders, power shovels, and cranes, motor graders, paving machines, off-highway trucks, ditchers, trenchers, compactors, scrapers, and wagons	See SAE J874*
2. Engine powered equipment of 5 hp or less intended for use in residential areas at frequent intervals. Typical pieces of such equipment are lawn mowers, small garden tools, riding tractors, and snow removal equipment. This specifically excludes commercial equipment not intended for frequent use in residential areas	70
3. Engine powered equipment exceeding 5 hp but not greater than 20 hp intended for use in residential areas at frequent intervals. Typical pieces of such equipment are lawn mowers, small garden tools, riding tractors, and snow removal equipment. This specifically excludes commercial equipment not intended for use in residential areas	76
4. Engine powered commercial equipment of 20 hp or less intended for infrequent use in a residential area	86
5. Farm and light industrial tractors	88

*For test procedure, see SAE J88.

5. General Comments

5.1 It is strongly recommended that technically trained personnel select equipment and that tests be conducted only by qualified persons trained in the current techniques of sound measurement.

5.2 An additional 2 dB allowance over the sound level limits is recommended to provide for variations in test site, vehicle operation, temperature gradients, wind velocity gradients, test equipment, and inherent differences in nominally identical vehicles.

5.3 Instrument manufacturer's specifications for orientation of the microphone relative to the source of sound and the location of the observer relative to the meter should be adhered to.

5.4 When a windscreen is required, a previously calibrated windscreen should be used. It is recommended that measurements be made only when wind velocity is below 12 mph.

5.5 Manufacturer's recommended calibration practice of the instruments should be followed. Field calibration should be made immediately before and after each test sequence. Either an external calibrator or internal calibration means is acceptable for field use, providing that external calibrating is accomplished before or after field use.

5.6 Horsepower sizes utilized in determining equipment categories in paragraph 2 shall be in accordance with SAE J816 or SAE J607.

6. Reference Material—Suggested reference material is as follows:

USASI S1.1-1960, Acoustical Terminology.

USASI S1.2-1962, Physical Measurement of Sound.

International Electrotechnical Commission Publication 179, Precision Sound Level Meters (available from USASI).

(Applications for copies of these documents should be addressed to U.S.A. Standards Institute, 10 East 40th Street, New York, N.Y. 10016)

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DRAFT

15 January 1976

DRAFT NO. 7

SAE RECOMMENDED PRACTICE:
MEASUREMENT PROCEDURE FOR DETERMINING
A REPRESENTATIVE SOUND LEVEL
AT A CONSTRUCTION SITE BOUNDARY LOCATION

1. Scope

This SAE Recommended Practice sets forth procedures and instrumentation to be used for determining a representative sound level during a representative time period at selected measurement locations on a construction site boundary. It concerns the community adjacent to the construction site, and it is not intended for use in determining occupational hearing damage risk.

2. Introduction

The procedure set forth in this document may be used by construction site management for self regulation and construction site planning or by state and local officials for the enforcement of construction site noise regulations. As is demonstrated in the companion document (Reference 1) to this recommended practice, the representative sound level obtained using this procedure approximates the "energy" equivalent sound level, L_{eq}, (Reference 2) obtained from more sophisticated data acquisition and analysis techniques. Use of this recommended practice provides sound level data representative of the complex time-varying sounds emitted by construction activities which may be applied using various methods (Reference 1) to estimate community reaction to the construction activity.

3. Definitions

Construction Site - That area within the defined boundaries of the project. This includes defined boundary lines of the project itself, plus any staging area outside those defined boundary lines used expressly for construction or demolition.

Boundaries of the Construction Site - The outermost limit lines of the construction site.

Noise Sensitive Area - Inhabited property such as that used for public, commercial, religious or educational purposes, or home dwellings, parks, and other special purpose areas where the background ambient sound is less than the construction site sound level.

Background Ambient Sound - The all encompassing sound associated with the given environment, when the construction site is inactive, being usually a composite of sounds from many sources far and near.

Representative Sound Level, $\bar{L}_A$ - It is the average of sound level samples accomplished in accordance with procedures outlined in 6.1.1.-6.1.5.

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4. Instrumentation

4.1 A sound level meter which meets Type 1 requirements of the American National Standards Specifications for sound level meters, S1.4-1971 (Reference 3).

4.2 As an alternative to making direct measurements with the sound level meter, a microphone or sound level meter may be used with a magnetic tape recorder and/or graphic level recorder or data analysis instrumentation (either analog or digital) providing the system meets the requirements of SAE Recommended Practice: Qualifying a Sound Data Acquisition System, J-184 (Reference 4).

4.3 An acoustic calibrator with an accuracy of 0.5 decibel (see Paragraph 7.2.4).

4.4 A windscreen (see Paragraph 7.3).

4.5 An anemometer with ±10 percent accuracy.

5. Site Determination

5.1 Obtain specific drawings, survey stake locations, and other pertinent information in order to sketch the boundaries of the construction site and noise sensitive areas on a facsimile of Figure 1.

5.2 Obtain information in sufficient detail necessary to determine location and activity pattern of the construction site during the period used for measurement, as well as the locations of noise sensitive areas, in order to aid in the selection of sound level measurement locations.

6. Measurement

6.1 Sound level measurements at construction site boundary adjacent to noise sensitive areas shall be taken in the following manner:

6.1.1 Calibrate the sound level meter before and after each measurement period, using an acoustic calibrator.

6.1.2 Locate the microphone at five feet (1.5m) above the ground and, if practical, 10 feet (3.1m) from walls, buildings, or other sound reflecting structures when they appear at the construction site boundary. When circumstances dictate, measurements may be made at greater distances and heights and closer to walls, providing these facts are noted.

6.1.3 Set the sound level meter to the A-weighting network and slow response. Observe the sound level meter during a 10 ±2 second sampling period at the start of each minute and one-half minute for any representative 30-minute period of construction activity. If, during any of these observations, the measurements are affected by any intrusive noise sources outside the construction site, such as aircraft, emergency signals, and surface transportation, measurements made during these periods should not be considered, but the number of one-half minute observation periods should be extended until 60 valid measurements are obtained.

On/off highway vehicles, such as dump trucks, truck/mixers, etc., which occasionally enter, operate on, and leave the site, shall be considered as part of the construction activity while within the site boundaries. However, pass-by of such vehicles, in the area of the measurement location causing difficulty in obtaining valid measurements, shall be considered as intrustions, and handled as in the preceding paragraph. An alternative measurement system, Paragraph 4.2, may be required to augment the direct measurements for these construction site conditions.

6.1.4 Tabulate the maximum values, L_A, observed during the sample period, using a data sheet such as shown in Figure 2.

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6.1.5 Determine the representative sound level, $\bar{L}_A$, using:

$$\bar{L}_A = (\sum_{1}^{n} L_A)/n$$

Arithmetic average of L_A values.

L_A values: those sound levels which fall within a range of from 6 decibels less than the maximum level to the maximum level.

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

The use of this technique provides a result which is comparable to "energy averaging" all of the observed values. Corrections may be applied (see Table 1) which results in a computation of L_{eq} for the representative measurement period.

7. General Comments

7.1 It is often desirable to obtain the background ambient sound level on the same day as the sound survey to obtain representative construction site sound levels. It is suggested that this be accomplished when the construction site is inactive, such as before start-up, during the luncheon break, or after shut-down. The above procedure (6.1.1-6.1.5) should be used.

7.2 It is recommended that persons technically trained and experienced in the current techniques of sound measurements select the equipment and conduct the tests.

7.3 Proper usage of all test instrumentation is essential to obtain valid measurements. Operating manuals or other literature furnished by the instrument manufacturer should be referred to for both the recommended operation of the instrument and precautions to be observed. Specific items to be considered are:

7.3.1 The type of microphone, its directional response characteristics, and its orientation relative to the ground plane and source of noise.

7.3.2 The effects of ambient weather conditions on the performance of all instruments (for example, temperature, humidity, and barometric pressure). Instrumentation can be influenced by low temperature and caution should be exercised.

7.3.3 Proper signal levels, terminating impedances, and cable lengths on multi-instrument measurement systems.

7.3.4 Proper acoustical calibration procedure, to include the influence of extension cables, etc. Field calibration shall be made immediately before and after each test sequence. Internal calibration means is acceptable for field use, provided that external calibration is accomplished immediately before or after field use.

7.4 A microphone windscreen shall be used provided that its effect on the total sound level measuring system does not degrade the system below the requirements of ANSI S1.4-1971, for Type 1 sound level meters. It is recommended that measurements be made only when wind velocity is below 12 mph (19 km/hr).

7.5 Measurements should not be made if significant changes in extraneous and non-construction related noise-making activities or patterns occur during the sampling period. Examples of changes in noise-making activities or patterns which affect the data are:

(1) Nearby noise sources, such as power mowers, pavement breakers, brush cutters, or power saws.

(2) Changes in vehicular traffic flow, such as closed street, detours, or shift-change periods near industrial plants.

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REFERENCES

1. Companion Document SAE Report #   , date

2. EPA, Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety, 550/9-74-004, March 1974.

3. American National Standard S1.4-1971, Specifications for Sound Level Meters.

4. SAE J184 Sound Level Acquisition System.

5. American National Standard S1.1-1960, Acoustical Teminology

6. American National Standard S1.2-1962, Physical Measurement of Sound.

TABLE 1

Corrections to $\bar{L}_A$ 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

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____
(Construction Site)

1. Sketch Appropriate Site Boundaries, Adjacent Communities, and Measurement Locations

____

2. Construction Site__________ Type__________

3. Sound-Level Meter: Manuf.__________ Model__________ S/N__________

4. Weather Conditions __________

5. Remarks __________

Figure 1 Sample Sketch Format

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CONSTRUCTION NOISE EXPOSURE DATE 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 ½ minute for 30 minutes.
4. Tabulate maximum reading L_a.

Construction: ( ) Activity ( ) No Activity

Determine Arithmetic Average $\bar{L}_A$

L_A (dBA)

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(A) of the maximum value observed.

$\bar{L}_A$ = Sum/n :

Construction Site______ Date______ Time______

Wind Velocity______ mph, Temperature______ °F, Engineer______

Remarks ______

______

Figure 2 Sample Construction Noise Exposure

Data Sheet

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