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CONSTRUCTION SITE NOISE IMPACT

February 1978

Office of Noise Abatement and Control
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Washington, D.C. 20460

NOISE IMPACT ASSESSMENT MANUAL

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16. ABSTRACT

This manual presents a procedure for assessing the noise impact of construction activity. The manual presents methods for measuring and estimating baseline sound levels, for estimating construction site sound levels, and for assessing noise impact and compliance with state and local noise regulations. Also included is a section describing construction equipment and construction process noise control methods.

A construction site noise model is presented which uses equipment sound levels and usage factors. Worksheets and graphs are provided to assist in the computations. Acoustical computational procedures,as well as equipment sound levels and and usage factors, state and local regulations, and illustrative examples, are presented in Appendices.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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This report has been approved for general availability. This report does not constitute a standard, specification, or regulation.

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PREFACE

This Construction Noise Assessment Manual has been prepared by Dames & Moore for the Office of Noise Abatement and Control of the U.S. Environmental Protection Agency under Contract 68-01-3388. This manual provides techniques to be used to estimate offsite community average sound levels due to the operation of numerous pieces of construction equipment on a site. The validity of sound level estimations is dependent upon the quality of information used as input. The computed construction site sound levels can be used to assess potential community noise impact or non-compliance with adopted ordinances or standards and can be used to select cost-effective construction equipment and site noise control approaches.

Comments regarding this manual are welcome and should be submitted to:

U.S. Environmental Protection Agency
Office of Noise Abatement and Control (AW-471)
Technology and Federal Programs Division
Washington, D. C. 20460

1.0 INTRODUCTION

Construction site activity is recognized as a source of significant community noise pollution.[1] Recent studies[2,3,4] of construction site noise have led to the development of models for estimating site noise. This manual summarizes the present state-of-the-art in construction site noise prediction. It provides a straightforward approach to predicting offsite community average sound levels. The methods presented are not intended for use in estimating construction worker exposure to equipment and construction process noise.

It is not intended that the user of this manual be trained in engineering or acoustics. However, a knowledge of some fundamentals of sound and nomenclature would be helpful.

Chapter 2.0 presents a general description of the construction process. Chapter 3.0 contains a description of techniques which can be used to measure baseline sound levels representative of the community sound environment prior to the construction of the proposed project. Descriptors of construction equipment operational data and noise levels are presented in Chapter 4.0. A method for estimating construction site noise levels emitted from the site to the adjacent community is provided in Chapter 5.0. The estimated construction site noise together with baseline community sound levels provide the major elements needed to assess non-compliance with applicable regulations or the degree of impact. Chapter 6.0 provides some guidelines for accomplishing this assessment. Feasible construction noise control methods are described in Chapter 7.0. They form the basis for mitigative actions needed to reduce impacts or comply with community noise standards.

The manual concludes with five appendices:

Appendix A - Acoustical Concepts, Decibel Addition and Bibliography

Appendix B - Construction Equipment Noise Levels

Appendix C - Construction Equipment Usage Factors

Appendix D - Illustrative Examples

Appendix E - Current State and Local Noise Regulations

1.1 References

1. "The Urban Noise Survey," EPA 550/9-77-100, August 1977.

2. Schomer, P.D., Kessler, F.M., et al, "Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing," CERL Interim Report N-3, July 1976.

3. Reagan, F.A. and Grant, C.A., "Highway Construction Noise - Measurement, Prediction, and Mitigation," U.S. DOT/FHWA Special Report, January 1977.

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

2.0 CONSTRUCTION PROCESS

2.1 Introduction

The construction process includes the demolishing of old buildings, roads, and other structures, the removal or moving of earth, the preparation of supporting foundations, as well as the above grade assembling or modification of structures. The installation of services (i.e., water, gas, electricity) and the final landscaping are also included in the construction process.

2.2 Construction Project Categories, Phases, and Schedules

2.2.1 Construction Project Categories

Construction projects are typically classified into four categories. These categories are:

a) Residential buildings:

1) One- to four-family

2) Five-family and larger

b) Non-residential buildings:

1) Office buildings, hospitals and hotels

2) Schools, public works buildings

3) Parking garages

4) Stores, service stations, recreational buildings, and religious buildings

c) Industrial

d) Public works (e.g., sewers, water mains, municipal streets and highways)

2.2.2 Phases

Construction, whether it is for an urban residential building or for a nuclear power plant, is carried out in several reasonably discrete steps, each with its own scope and mix of equipment, and consequently, its own noise characteristics. In the case of larger projects, several of these steps may or may not coincide.

In general, a construction project consists of the following phases:

- Demolition

Demolition can be carried out by workmen using pavement breakers, explosive charges, cranes and wrecking balls, and hand tools. The material is then removed from the site. This operation may require cranes, bulldozers and dump trucks of various capacities.

- Clearing and Grading

Trees and brush are removed either by logging procedures (for possible sale), or, where the cover is less dense, by using bulldozers.

Earth and rock are removed, in some instances by drilling and blasting operations, and the site is graded or leveled in preparation for the next phase. Trucks may be required to transport earth from, to, and within the site.

- Foundation Excavation and Backfilling

Powered shoveling tools, bulldozers and dump trucks are commonly used during this phase.

• Foundation Forming and Placing

If required due to local geological conditions, piles are driven to provide bearing members for the foundation. The concrete is then poured to form the foundation, requiring the use of concrete trucks, concrete pumps and vibrators, and cranes.

• Erection - Framing and Exterior

The processes and equipment used vary, depending on the type of structure and the primary structural material.

Erection of the structure may require structural steel work or carpentry work, depending on the project. Concrete structures require additional concrete work with attendant trucks, concrete pumps and cranes. A process common to all projects is material supply, usually requiring a large number of trucks.

• Finishing - Interior and Exterior Details

Noise emitted in this phase is generally not of great concern since heavy equipment is seldom used. Instead, manual jobs are performed often with powered hand tools.

The boundaries of a construction site are a function of the type of construction which is in progress. The physical boundaries of a construction site are considered to be the outermost limits of a site which is under the control of the contractor. Construction of an interstate highway, for example, will have completely different boundaries than the construction of residential housing. Although for most sites the physical boundaries are fairly constant, temporary boundaries may exist as the work progresses.

2.2.3 Typical Construction Schedules

The type and location of a project will affect the specific construction processes and/or equipment to be used. For example, a project planned for a heavily wooded site will require clearing of trees, a process not generally required in an urban setting. This, in turn, will affect the noise expected during construction.

To illustrate the variability and complexity of construction schedules, two examples are presented in Appendix D which reflect the differences in scope and duration of construction processes.

2.3 Construction Plans

2.3.1 Physical Data

The preparation of an Environmental Impact Statement for construction of a specific project requires certain information such as the size, dimensions, and location of the site. A plot plan, showing the general features of the proposed construction, is helpful in locating where specific construction activities will take place. The access roads to the site should be shown since transportation of equipment and materials is often a substantial noise producing element.

Also, the location of the site as well as principal noise sensitive land use areas (e.g., schools, churches, homes, etc.) should be indicated on an area map. Distances from these noise sensitive land use areas to the locations of principal construction activities should be carefully noted.

2.3.2 Scheduling Data

The evaluation of construction noise impact requires a construction schedule (for examples, see Appendix D) which details the various phases of construction, their duration, and the activities occurring during each phase. In addition, an equipment use schedule is required. The subject of equipment usage will be discussed in detail in Chapter 4.0.

A construction schedule and an equipment use schedule should be obtained from the contractor or architect/engineer responsible for the project. Important details, regarding the time and duration of each phase as it relates to the other construction phases, must be supplied. The total number of processes being carried out on the site at any given time due to one or more phases of construction are used to determine the length of time and identify of the noisiest time period.

If the assessment is being prepared during the very early conceptual phase of the project, and the construction and equipment use schedules have not been determined, a schedule for construction of a similar facility can often be used. Because certain construction phases depend on the type of site being considered, knowledge of site topography and geology is necessary to determine the applicability of these substitute phases.

References 1, 2, and 3 provide information describing typical construction site scenarios for the major categories of construction projects (see Section 2.2.1):

1. Residential building construction
2. Non-residential building construction
3. Industrial construction
4. Public works and highway construction

The data provided by these referenced documents are from national averages and may not lend themselves to accurate estimates of construction schedules for specific cases. This is particularly true for large scale projects with unusual site features. These data should only be used for guidance in the absence of more site specific data.

2.4 References

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

2. Patterson, W.N., Ely, R.A., Swanson, S.M., "Regulation of Construction Activity Noise," Bolt Beranek and Newman Report No. 2887, November 27, 1974.

3. "Noise from Construction Equipment and Operations, Building Equipment and Home Appliances," Environmental Protection Agency NTID 300.1, December 1971.

3.0 MEASUREMENT OF BASELINE SOUND LEVELS

3.1 Need for a Baseline Survey

The magnitude of the noise impact of a construction site depends on both the noise contribution from the site and the existing ambient sound levels. A survey of pre-construction baseline sound levels is therefore necessary to fully assess construction site noise impact.

3.2 Selection of Measurement Locations

The first step in performing a baseline sound level survey is to determine where measurements are to be made. The purpose of these measurements is to describe existing sound levels:

1) At the principal noise sensitive land use areas, and

2) Around the boundaries of the construction site.

It is desirable to survey all the noise sensitive areas in the vicinity of the project. Noise sensitive land use areas are described as follows:

1) Residential - This category includes all areas where people reside. It also includes potential residential areas (residentially zoned areas where housing may not yet exist).

2) Schools, religious institutions, or hospitals - These areas are especially sensitive to noise, since quiet is important to their operation.

3) Pristine areas - This category includes wilderness, rural, or park areas which are valued for the low level of ambient sound.

It is helpful to acquire topographical, road, zoning and population distribution maps of the area surrounding the project. From these maps, noise-sensitive areas can be determined and existing noise sources located. Note that certain noise sources such as highways, airports, and railroads can establish high noise levels in an area that would otherwise be quiet. Therefore, more than one location in the same area may need to be surveyed to characterize different sound climates.

Measurement locations should be chosen as close to the site as possible, since these locations will experience the greatest impact. In choosing the measurement locations, a maximum radius of 3-4 miles from the center of the site should be used as a limit. This maximum would typically be used when the study is for a very large project. Smaller projects will require considerably smaller radii. If no noise sensitive land use areas lie at a site boundary, an additional separate location at the site boundary nearest to the center of construction activity should be used. Other possible sound level survey locations include:

1) The site center: This is used as a reference point for documentation. Impact analysis at this point is not required.

2) Access roads: If there are roads which will carry most of the truck and worker traffic to and from the site, it may be necessary to select sampling locations at sensitive land use areas along these roads. In this way, the noise impact due to movement of construction-related vehicles over and above the normal traffic on the road can be analyzed.

After the preliminary measurement locations are chosen, a site visit will help to determine the choices. It is useful to select more measurement sites than will actually be surveyed, and then reduce the final list after the site visit. The precise location of the final measurement sites selected should be designated on the map which identifies the noise sensitive areas. To reduce costs, the site visit is often made in conjunction with the start of the baseline sound level survey. Reasons for eliminating measurement locations include:

1) Change in land use from that indicated on maps. If the maps are not very recent, certain features may have changed. Residential areas not indicated on the map may now exist; new roadways may have been built; schools may have been relocated.

2) The activity taking place near a tentatively selected location may not be typical. For example, if there is some other construction project already being carried out near a location, measurements will not reflect typical ambient sound levels.

3) The site may be unsuitable from an acoustical standpoint. For instance, measurement locations should be away from large reflecting surfaces or noise sources not typical of the general area.

An example of selecting baseline measurement locations, shown in Appendix D, is for a project to construct a new parking garage for a New Jersey suburban hospital.[1]

3.3 Sampling Periods

Ambient sound levels, in general, are not steady with time. Due to varied activity and the operation of many different noise sources, ambient sound levels fluctuate considerably over time. Figure 3.1 illustrates the variation of urban sound levels when measured during a typical day.[2] Ideally,

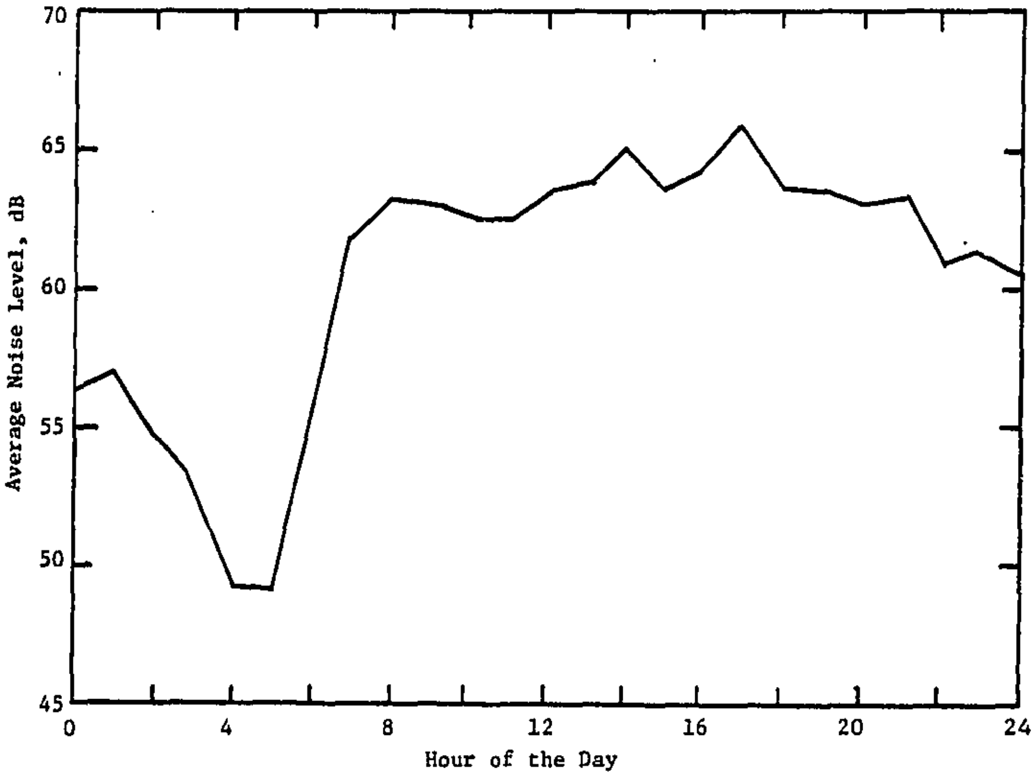


Figure 3.1 - Variation throughout a Day of Average Noise Levels in an Urban Site. Time-Averaging of the Noise Levels Carried Out over 1-Hour Intervals.[1]

an actual record of the sound levels throughout the day is desired. From such data, two useful descriptors, the Equivalent Sound Level (L_{eq}) and the Day/Night Sound Level (L_{dn}) can be computed quite accurately. For those unfamiliar with these descriptors, they are explained in Appendix A. In the absence of continuous measurements, short-duration measurements made at selected times of the day will permit adequate estimates of these descriptors for a typical location.

It has been recommended that measurements be taken during the following time periods:[2]

- The midday period (9:00 a.m. to 4:00 p.m.)
- The local traffic rush hour (7:00 a.m. to 9:00 a.m. or 4:00 p.m. to 6:00 p.m.)
- The evening period (6:00 p.m. to 12:00 midnight)
- The early morning period (12:00 midnight to 7:00 a.m.)

It is most meaningful to perform these measurements during a weekday, since construction activity usually occurs on a Monday through Friday schedule. If noise in the area under study fluctuates widely throughout the day, additional measurement periods are necessary to obtain an accurate description of the typical sound climate. Certain state noise regulations define the periods during which measurements are to be taken. Table 3.1 is an example of a sampling schedule from a New York State Regulation.[3] Should the construction project be of a long term nature, it may be desirable to obtain noise measurements during different seasons. For instance, where foliage and

TABLE 3.1 EXAMPLE OF SAMPLING SCHEDULE REQUIRED BY STATE REGULATION

NEW YORK STATE PUBLIC SERVICE COMMISSION SOUND SURVEY GUIDELINES[3]

NOISE SAMPLING PERIODS

Season	Day	Time
Winter	Monday through Friday*	Daytime
"	"	Evening
"	"	Nighttime
"	Saturday or Sunday	Daytime
"	"	Evening
"	"	Nighttime
Summer	Monday through Friday*	Daytime
"	"	Evening
"	"	Nighttime
"	Saturday or Sunday	Daytime
"	"	Evening
"	"	Nighttime

Note:			
	Daytime	7:00 A.M. -	7:00 P.M.
	Evening	7:00 P.M. -	10:00 P.M.
	Nighttime	10:00 P.M. -	7:00 A.M.

*The requirement is for any of the five weekdays.

human activity depend heavily on the time of year, sound levels vary sufficiently to justify separate measurements.

3.4 Recommended Measurement Methodology

This method requires a few hours time of someone trained in the use of a sound level meter and the sampling procedure. It can be used to monitor both baseline ambient sound levels and sound levels during construction.

The sound level meter should meet Type 2 requirements of the American National Standards Institute specifications for sound level meters (ANSI S1.4-1971). Also, a sound level meter calibrator with an accuracy of ±1 dB and a windscreen whose effect on the measurements is less than 1 dB are necessary. A sound level meter and accessories may be rented from various sources. The procedure for making sound level measurements is as follows:[4]

1) Calibrate the sound level meter before each measurement period.

2) Locate the microphone 1.5 meters (5 ft) above the ground and at least 3 meters (10 ft) from walls, buildings, or other major sound reflecting surfaces. If these conditions cannot be met, the measurement may still be made, but the condition must be properly noted.

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

4) Observe and note the maximum sound level during a 10 ±2 second period at the start of each minute and half minute for any representative 30-minute period (a total of 60 measurements). If, during any of the 10 ±2 second observations, the measurements are affected by abnormal sound sources, such as emergency signals, someone speaking close to the microphone, vehicle stopped by the measurement location, etc., measurements made during

these measurement periods should not be considered, but the number of measurements should be extended until 60 valid measurements are obtained. Figure 3.2 shows a typical data sheet for use with this procedure.

5. Find the arithmetic average A-weighted sound level, $\overline{L}_A$, using

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

where the L_A values are those sound levels which fall within six decibels of the maximum level observed, and n is the number of L_A values used for computing the arithmetic average. Corrections may then be applied in accordance with Table 3.2 to obtain L_{eq} from $\overline{L}_A$.

6. Measurements should not be taken when the wind exceeds 5 m/sec (12 mph).

3.4.1 Alternative Measurement Methods

A more sophisticated and accurate method of acquiring the necessary ambient sound level data is the use of one of the many digital data acquisition systems now available.

These systems usually are self-contained units which are placed in the field and left for a period of time during which samples of the sound levels are recorded in digital form on either a 1/8 inch magnetic tape cassette or an internal memory device. The data are then processed either by the unit or by a companion unit (often a desk-top programmable calculabor) to yield Equivalent Sound Levels (L_{eq}).

A drawback of such a system is that the data, available only in digital form, provide no indication of the sound sources. Therefore, there is no way of determing whether the sound was caused by typical environmental sources or by non-typical sound sources such as those resulting from the presence

FIGURE 3.2 CONSTRUCTION NOISE DATA SHEET

Instructions:

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

Determine Arithmetic Average $\overline{L}_A$

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

SUM:* ______________________

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

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

Location______________________ Date_______________ Time_______________

Wind Velocity____________ mph. Temperature_______ °F. Engineer_______________

Remarks ____

____

TABLE 3.2

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

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

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

where n is the number of $\overline{L}_A$ values used in computing the average of the data acquisition system itself (e.g., person talking into the microphone, insect landing on windscreen). The advantages of these units include ease of operation, long term acquisitions resulting in increased statistical reliability, and the ability to measure Equivalent Sound Levels and Day/Night Sound Levels, directly and accurately.

The cost of these units can be quite high. They range from approximately $3,000 to $10,000 depending on their capabilities. They may be rented, although this still requires a substantial outlay. (As a general rule, a monthly rental fee for such equipment is approximately 1/10 of the total purchase price.)

Another method of measuring sound levels is to make an analog tape recording for later analysis. An advantage of this technique is that it provides a permanent record of the actual sound at the measurement locations. Therefore, it permits the identification of particular noise sources and the use of different analysis techniques. The tape recorder used for these measurements must meet stringent technical specifications and for most applications must have a self-contained power supply.

The tape recorded data can then be analyzed using a strip chart recorder, if available, after the output signal is corrected using an A-weighting network. Equivalent Sound Levels can be computed using the method described in Appendix A-2.4.

Equipment is also available which will provide statistical analysis of the tape recorded data. These analysis systems consist of a computer or sophisticated desk calculator and a real time sampling system. This equipment is generally quite costly and complex.

3.5 Nonmeasurement Methods of Estimating Baseline Ambient Sound Levels

If actual field measurements of ambient noise levels cannot be made, there are alternative methods which can be employed to estimate the baseline sound levels. The use of nonmeasurement methods is discouraged andactual measurements recommended, since ambient sound levels are usually very dependent upon the specific site. Estimates based upon data found in the literature may not reflect the actual sound climate peculiar to the site being studied. An error of greater than 10 decibels in an estimate of this nature is not unusual, and it can make the difference between construction noise projections yielding major or minor impact. Nonmeasurement estimates should be used only when absolutely necessary.

The primary sources for ambient sound level estimates are environmental impact statements accomplished for nearby projects. Inquiries should be made at local community Environmental Commissions and Planning Baords. The state's Department of Environmental Protection may be aware of results of sound surveys conducted in the vicinity of the proposed project. Current federal government literature can be used as a source of community sound level data. A large number of surveys, with the goal of describing the range of the United States sound climate, have been carried out in the past 20 years.

These may be used as a means to estimate the approximate ambient sound levels in the area under consideration. Figure 3.3 provides representative sound levels for land use categories and data typical of past surveys.[5]

A site visit is suggested, perhaps during various day and night periods, in order to obtain a description of the physical and acoustical environment. Even without a sound level meter, the investigator should be able to identify various noise sources present in the area. Where no dominant noise sources (industrial plant, highway, etc.) are observed, the noise climate of the area is principally due to local automobile traffic noise. The Day/Night sound level, L_{dn}, for these areas may be estimated from a knowledge of the community's population density. The approximate relationship between population density and L_{dn} is

$$L_{dn} \doteq 10 \text{ Log } p + 22 \text{ dB}$$ [6]

where p is the population density in people per square mile.

Typical values of L_{dn} obtained from this equation are presented in Table 3.3.[6]

If a site's sound climate is established by a nearby airport, sound level contours may be available from the Federal Aviation Administration's local office or the local airport staff. These contours can be used to estimate sound levels at the site under study. Composite noise rating (CNR) or noise exposure forecast (NEF) contours can be translated to L_{dn} values by the following approximate relationships:

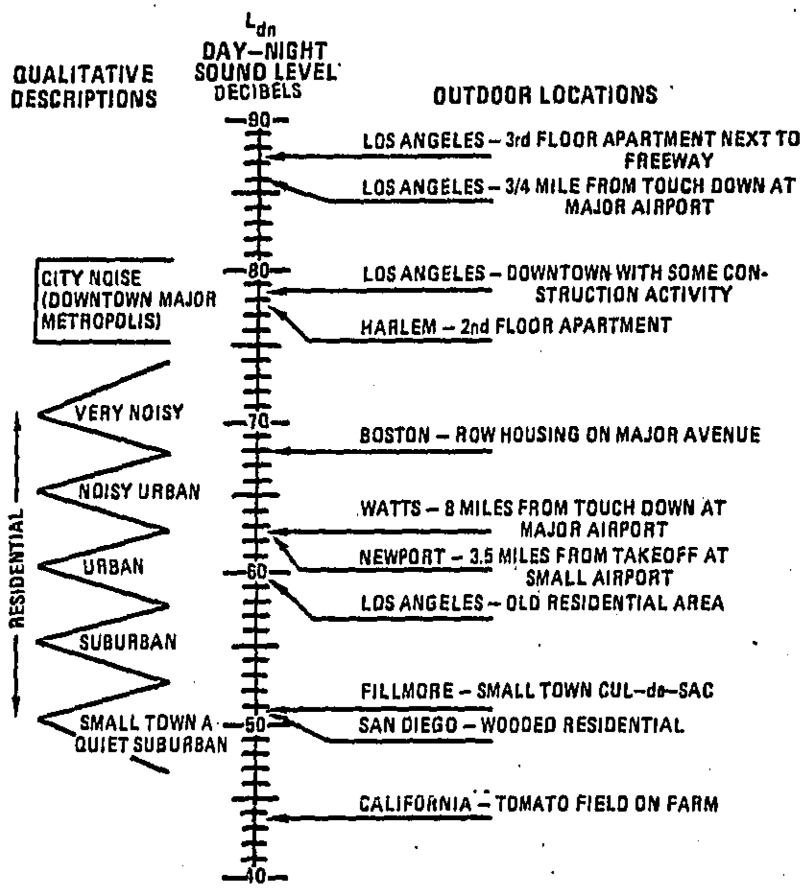


Figure 3.3 - Outdoor Day-Night Sound Level in Decibels (re 20 microPascals) at Various Locations[5]

Table 3.3 Typical Values of Yearly Day-Night Sound Level for Various Residential Neighborhoods Where There Are No Well Defined Sources of Noise Other Than Usual Transportation Noise[6]

Description	Population Density (People/Sq. Mi.)	L_{dn} (dB)
Rural (undeveloped)	20	35
Rural (partially developed)	60	40
Quiet Suburban	200	45
Normal Suburban	600	50
Urban	2000	55
Noisy Urban	6000	60
Very Noisy Urban	20000	65

$$L_{dn} \doteq NEF+35 \doteq CNR-35$$

For most situations involving aircraft noise, these relationships are valid within a ±3 dB tolerance. If CNR or NEF contours are not available, a method of roughly estimating them is presented in the "Noise Assessment Guidlines," prepared by the U.S. Department of Housing and Urban Development.[7]

3.6 References

1. "Environmental Impact Statement, Overlook Hospital, Summit, New Jersey," Dames & Moore, July 1976.

2. "Community Noise Monitoring - A Manual for Implementation," Wyle Laboratories Research Report WR76-8, July 1976.

3. "State of New York Public Service Commission Regulations," Part 75, June 4, 1973.

4. "Recommended Practice: Measurement Procedure for Determining a Representative Sound Level at a Construction Site Boundary," Society of Automotive Engineers, Draft #7, XJ1075, August 1977.

5. "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety," U.S. Environmental Protection Agency, 550/9-74-004, March 1974.

6. "Guidelines for Preparing Environmental Impact Statements on Noise," Report of Work Group G9 on Evaluation of Environmental Impact of Noise, CHABA, National Academy of Sciences, 1977.

7. "Noise Assessment Guidelines," Department of Housing and Urban Development Circular TE/NA-171.

4.0 CONSTRUCTION EQUIPMENT NOISE LEVELS

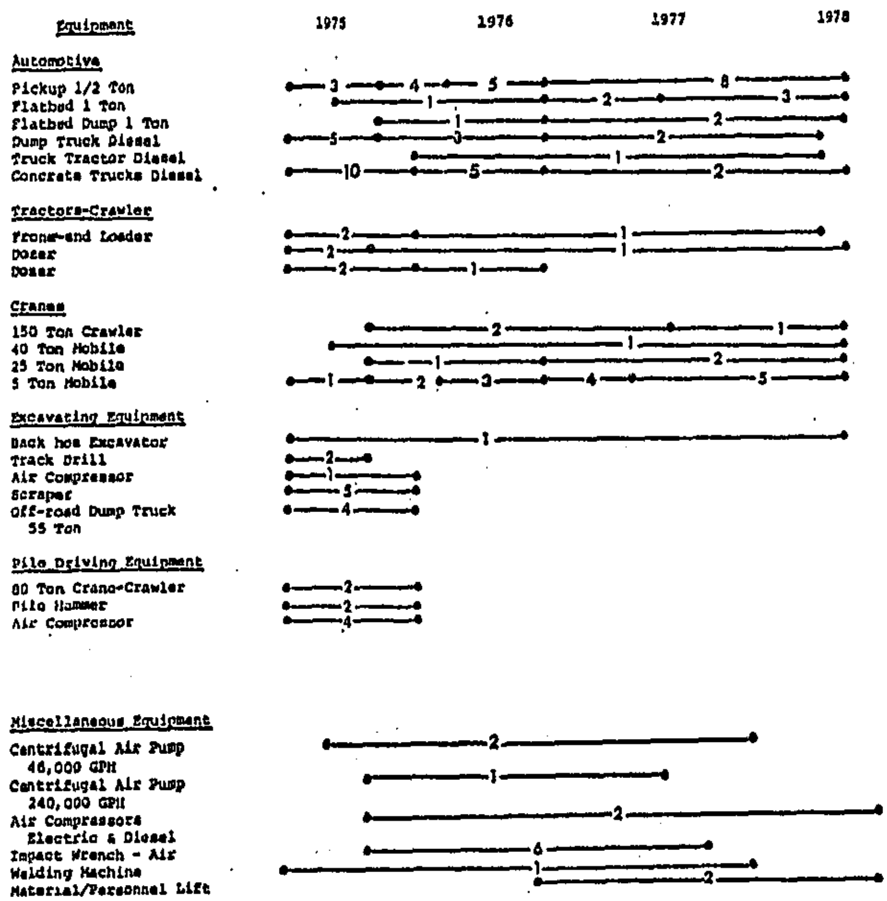
4.1 Introduction

To assess the potential noise impact of a construction site, information regarding the equipment to be used must be obtained. This information is required to estimate overall construction site sound levels. It should include an equipment usage schedule for each construction phase that contains when, what kind, and how many items of equipment.

4.2 Equipment Usage Schedule

An equipment list may be compared with the construction schedule to determine the total number of equipment types used during each phase of construction activity. Table 4.1 presents a typical equipment schedule for a fossil fuel electric generating plant.

An equipment schedule can often be obtained from the contractor or architect/engineer in charge of the project. If an equipment schedule is not available, it may be prepared jointly by the contractor and the individual making the noise assessment based upon experience on similar projects and available information regarding the project and project site. If the project is at too early a stage for these schedules to be prepared, various sources can be used to develop a representative equipment use schedule. EPA document 550/9-76-004, "Background Document for Portable Air Compressors,"[1] includes equipment lists for each construction phase for the four major categories of construction projects. Note that usages given in



NOTES:

1. All work to be performed 8:00 a.m.-4:30 p.m. Monday-Friday
2. Truck deliveries throughout entire project-average five per day
3. 300 rail car deliveries from January 1976 to April 1978
4. Blasting if required done during normal working hours
5. ●——2——● Estimated number pieces of equipment

Figure 4.1 - Sample Equipment Usage Schedule for Construction of Fossil Fuel Generating Station

this document are only averages obtained from a national survey of construction projects. Thus, an unknown degree of error may be incurred by using these data for a specific project.

4.3 Equipment Noise Levels

Noise levels of equipment to be used during the construction project are needed. A list should be prepared which includes 1) a description of each item of equipment, with its specific model number, if possible; 2) the A-weighted sound level measured during the noisiest mode of operation; 3) the position and distance from the unit at which the sound level was measured; and 4) the source of the data. The significance of each of these items to the equipment noise level data is discussed below. Knowledge of the type, model and manufacturer of a piece of equipment will often expedite identification of noise levels. If the specific type or model is unknown, a class (such as range of horsepower) should be estimated.

During operation, the sound levels produced by the equipment while in its noisiest mode (as typically used) is required. This information, along with the usage factors for the equipment (see Section 4.4 and Appendix C), will be used to esmate the Equivalent Sound Levels for construction activity at the site. These data are availble from various sources. The most desirable source is, of course, actual sound levels provided by the manufacturer of units which are similar to those considered for the proposed project.

In the event that manufacturer data are not available, it may be possible to obtain sound level data from other sources. The literature (particularly, that promulgated by EPA) contains information regarding equipment operational sound levels. Sources include:

- U.S. EPA 550/9-76-004, "Background Document for Portable Air Compressors," December 1975.[1]
- NTID 300.1, "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances," December 1971.[2]
- Construction Engineering Research Laboratory, Department of the Army, "Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing."[3]

A table of typical A-weighted sound levels for various types of construction equipment is included as Appendix E.

The distance at which the sound level measurements were made should always be included. Since the sound level will vary with distance from the source, this information is necessary to estimate sound levels at different distances from the site under study. Note that data obtained at short distances from the construction equipment (less than three times the machine's major dimension) cannot be used with confidence to estimate sound levels at distances far from the equipment (more than seven times the machine's major dimension).

The source from which the sound level data were obtained should be included in the event that substantiation is required at some later data. Sound level information should be obtained from as reliable a source as possible. EPA data are available, as explained, but these data are usually averages. The range of equipment sound levels is large, and extreme care must be taken when using averages.

4.4 Usage Factors

Since sound levels produced by construction equipment vary cyclicly with construction activities, some method of including these variations must be used when calculating construction site noise. The Equivalent Sound Level, L_{eq}, is defined as that sound level which, for a given period of time, would provide the same acoustic energy as the time-varying sound (see Appendix A-2.4). To compute this Equivalent Sound Level, the maximum sound level of the equipment and its usage factor are used. The usage factor is determined from a typical cycle of equipment performance and the number of cycles which occur in the time period being considered (one hour, an eight-hour shift, etc.). The usage factor, as used in this manual, is the ratio of the time the equipment operates in its noisiest mode to the total time for one cycle of operation <u>multiplied</u> by the ratio of the time for the total number of cycles to the time period being considered.[4] This concept assumes that sound level contributions for modes other than the noisiest mode are not significant.

Acquiring these data may prove difficult. Appendix B presents a detailed description of usage factors, how they are used, and sources for obtaining them. Usage factors as used in other EPA documents[1,2] are based upon averages and are obtained from data relating to the number of equipment at a site, construction phases, and construction sites. Whenever possible, usage factors should be determined from actual measurements or predictions for the specific project at hand.

4.5 References

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

2. "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances," USEPA NTID 300.1, December 1971.

3. "Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing," Interim Report N-3, Construction Engineering Research Laboratory, Department of the Army, July 1976.

4. "Highway Construction Noise, Report on Symposium February 1-2, 1977," Federal Highway Administration Contract No. DOT-FH-11-9191 (to be published).

5.0 ESTIMATING CONSTRUCTION SITE NOISE

Estimates of construction site sound levels at selected noise-sensitive land use areas should be made for each phase of construction activity. The construction site sound level is estimated by adding construction equipment Equivalent Sound Levels and extrapolating these levels to the location of interest. In this chapter, a technique is presented which simplifies this process.

This estimating technique provides the construction site Equivalent Sound Level, L_{eq}, for the time period of interest, i.e., one hour, one shift, one day, etc. Some state and local jurisdictions have adopted criteria other than Equivalent Sound Levels for enforcement or environmental impact assessment. Some of these criteria can be approximated using the construction noise estimating technique presented here.

5.1 Construction Activity Worksheets

The Construction Activity Worksheet, presented as Figure 5.1, can be used to aid in estimating sound levels. It organizes the information obtained from the architect/engineer, contractor, owner, or other sources to ease the computations which follow. The worksheet contains room to sketch the construction site and indicate the locations of major equipment to be used during a particular construction phase. Distances from the centers of construction activities to noise sensitive land use areas can be shown and tabulated. As much detail as necessary is included. The equipment, used during the phase

Figure 5.1 - Construction Activity Worksheet "A"

Project Name ______________________

Construction Phase ________________

Construction Activity _____________

Site Map Designation ______________

Duration of Activity ______________

Hours of Daily Activity ___________ *

*Excludes mealtime

Sketch of Site Area

Equipment List

Type	Model	# of Units	L_A (dB)	Distance (meters)	Usage Factor	Noise Sensitive Land Use	Location	Distance to Construction Activity (Meters)

being studied, are also listed. An example is presented in Appendix D which illustrates how the worksheet is used.

5.2 Estimating Construction Site Noise Levels

The procedures discussed below are used to estimate construction site Equivalent Sound Levels, L_{eq}, for the time period of interest. It may also be used to estimate maximum sound levels emitted from the site. This is accomplished by assuming that each equipment unit operates in its noisiest mode continuously, i.e., the usage factor is equal to unity.

A recent study[1] has indicated that the construction site Equivalent Sound Level, L_{eq}, and the sound level exceeded 10 percent of the time, L_{10}, are approximately related by:

$$L_{10} = L_{eq} + 2 \text{ dB}$$

The above relationship is suggested when L_{10} criteria must be used for meeting state or local standards.

5.2.1 Stationary and Almost Stationary Sources

At a construction site, a large number of machines are usually at work at numerous locations, each performing its function using different work cycles. The methods provided in this and the following sections are used to calculate the off-site sound levels. In this section, those sources which are stationary, or nearly so, as they carry out their task are considered. Section 5.2.2 presents a method to compute the noise from sources which move from point to point. Figures 5.2 and 5.3 are worksheets which may be used to calculate offsite noise from stationary equipment. Most of the information

Figure 5.2 - Construction Activity Worksheet "B" -

Project__________ Phase__________ Construction Period__________ Hours of Construction__________

(1) Activity Description	(2) Equipment Type	(3) L_A (dB)	(4) Dist. (M)	(5) L_A @ 15m (dB)	(6) # of Units	(7) Unit Adjustment	(8) Usage Factor	(9) Usage Factor Adjustment	(10) L_{eq} @ 15 m (dB)	(11) Total L_{eq} @ 15 m (dB)

Figure 5.3 - Construction Activity Worksheet "C"

Project__________________________Phase_______________Construction Period______________

(1) Noise Sensitive Land Use Area	(2) Construction Activity	(3) Distance	(4) Activity L_{eq} @ 15m (dB)	(5) Distance Adjustment	(6) Const. L_{eq} (dB)	(7) Total Const. Contribution L_{eq}(dB)	(8) Background Ambient L_{eq} (dB)	(9) Est. T Ambien Noise L_{eq} (dB

required to complete the forms should have been obtained and entered on the construction activity worksheet, Figure 5.1.

Steps necessary to complete the worksheets are given below. An example illustrating these steps is presented in Appendix D.

Worksheet "B" - Figure 5.2

1) Enter the project name, construction phase (e.g., foundation, erection, etc.), the construction period (e.g., month of year, weeks after start, etc.), hours of construction (e.g., 0700-1800).

2) For each activity at the site, enter the activity description, Column (1); equipment used at the activity, Column (2); equipment sound levels, Column (3); distance at which noise measurements were made, Column (4); number of units, Column (6); and applicable usage factor, Column (8).

3) Calculate the equipment sound level at 15 meters (50 ft) and enter this in Column (5). Equipment sound levels may have been provided for distances other than 15 meters (50 ft). This calculation normalizes the distance for all subsequent noise calculations. Use one of the methods described in Appendix A to make this calculation.

4) Determine the adjustment to the equipment sound level for the use of more than one piece of equipment and enter the adjustment value in Column (7). Use Figure 5.4 to determine this adjustment.

5) Determine the usage factor adjustment using Figure 5.5 and enter this value in Column (9).

6) Add the values in Column (5), Column (7) and Column (9) to obtain the value of L_{eq} at 15 meters (50 ft) for each equipment type. Enter this value in Column (10).

7) Combine the L_{eq} values in Column (10) for each activity description by adding them on an energy basis (see Appendix A-2.3) to obtain an activity L_{eq}. Enter this value in Column (11) and in Column (4) of Worksheet "C," Figure 5.3.

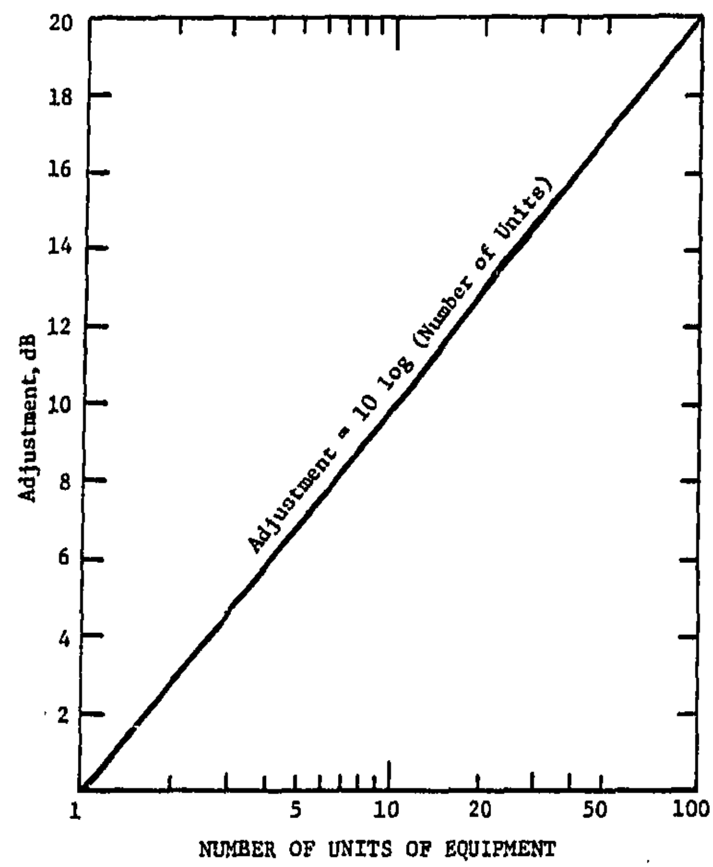


Figure 5.4 - Adjustment in Sound Level for Multiple Units in Use (Column 7 of Worksheet B)

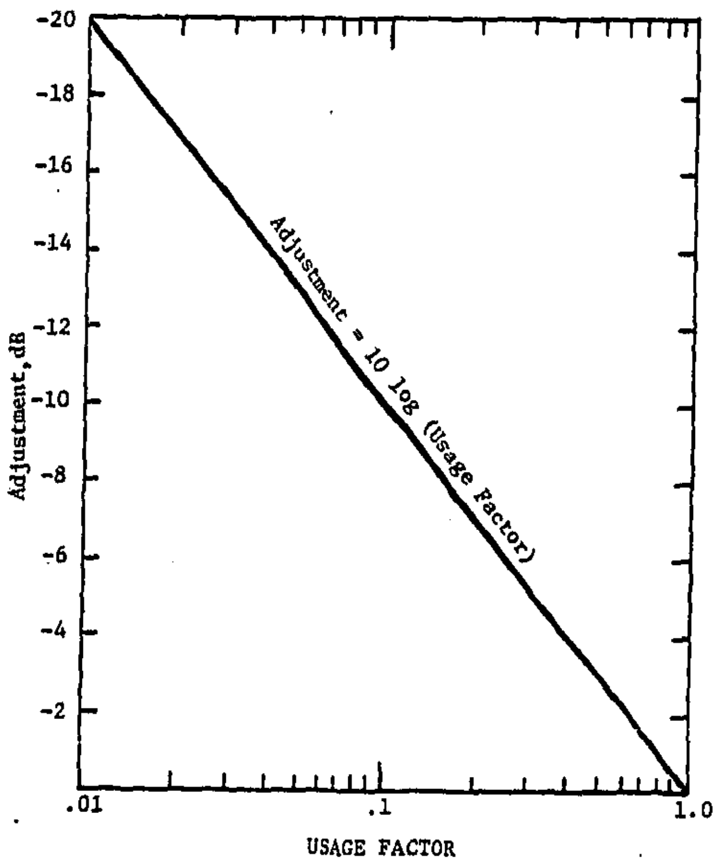


Figure 5.5 - Adjustment in Sound Level for Usage Factor (Column 9 of Worksheet B)

Worksheet "C" - Figure 5.3

1) For each noise sensitive land use area (e.g., school, residential area, hospital, etc.) and each construction activity, list the distance from each activity to the noise sensitive land use area in Column (3), activity L_{eq} at 15 meters (50 ft) in Column (4), and the background ambient L_{eq} (see Chapter 3.0) in Column (8).

2) Determine the distance adjustments using techniques described in Appendix A-2.6 and enter these adjustments in Column (5).

3) Add the activity L_{eq}, Column (4), and the distance adjustment, Column (5), to determine the activity contribution to the ambient sound at the noise sensitive land use area. Enter this value in Column (6).

4) Add the values in Column (6), using addition techniques presented in Appendix A-2.3, for activities contributing to each noise sensitive land use area. These results are entered in Column (7).

5) The construction site contribution, Column (7), and the background ambient sound levels, Column (8), must be added on an energy basis (see Appendix A-2.3) to obtain the estimated ambient average during the construction phase for each noise sensitive land use area. Enter the resulting value in Column (9).

5.2.2 Mobile Sources

For noise sensitive land use areas which are far from the construction site (e.g., more than five times the major site dimension), mobile sources and fixed sources are treated the same. The location for all sources is assumed to be the general center of construction activity.

The computational procedures described in Section 5.2.1 are complicated if the equipment moves an appreciable distance on the site. This is not unusual for dump truck or earthmoving equipment which transfer material from one location to another. If the equipment path length is comparable to the distance from the noise source to the observer, then the construction operation cannot be considered stationary. The various categories into which equipment can be classified are:

> Category 1: Equipment moves from one point on a site to another. The transit time is short and the equipment spends most of its time being stationary. Pile drivers, rock drills, and dozers are examples of this type of equipment.
>
> Category 2: Equipment moves in a simple predictable pattern from one point on the site to another and spends the majority of its time moving. A road grader is an example of equipment operation for this category.
>
> Category 3: Equipment moves in a random or complex path, spending part of the time in motion and part of the time stationary. Examples of equipment for this category are delivery trucks and water trucks.

These various categories are illustrated in Figure 5.6. Fully illustrative examples are given in Appendix D.

The first category is dealt with by assuming that the equipment spends all its time at the different site locations. Transit time is ignored. The equipment is entered once on the construction noise worksheet for each location at which it operates. The equipment usage factor is adjusted to reflect the separate location operations. A separate usage factor is used for subsequent calculations for each location.

Calculations for Category 2 are somewhat more complex. To apply the calculation technique presented below for Category 2 mobile operations, the distance between source and

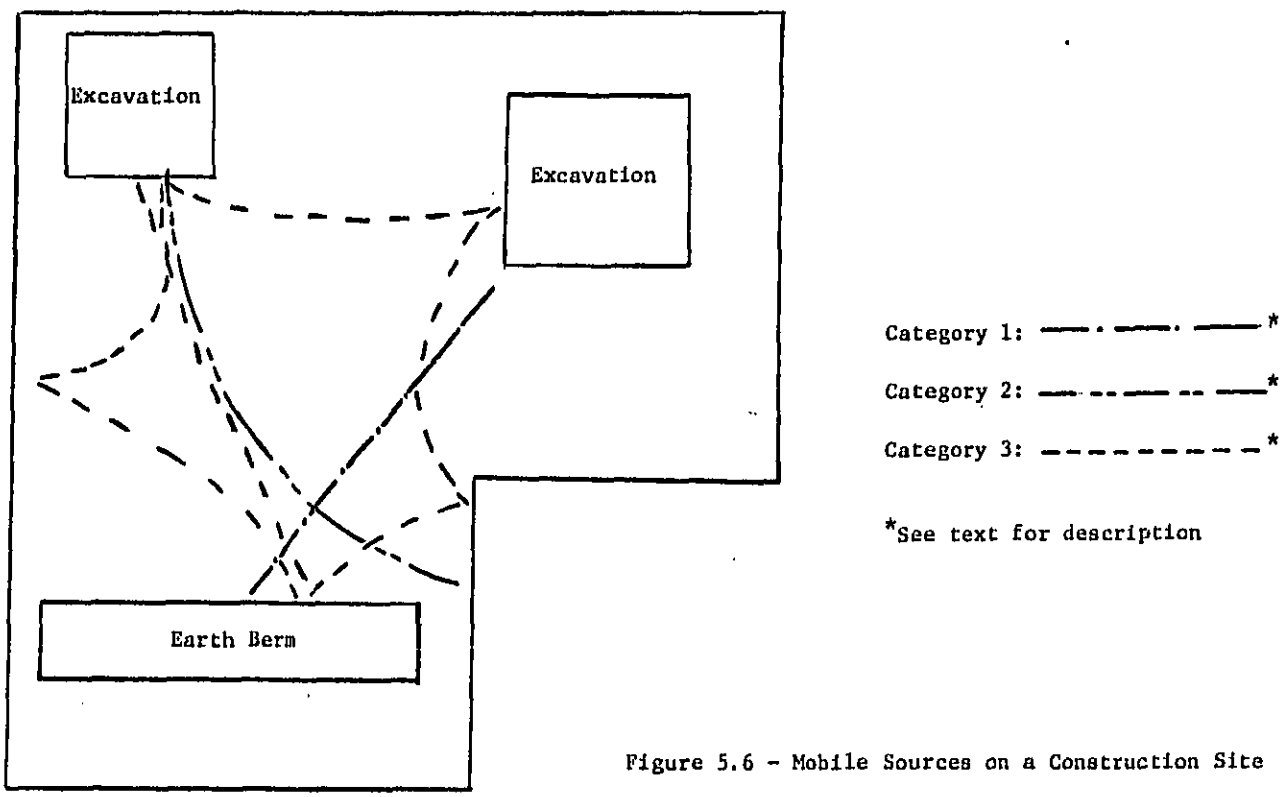


Figure 5.6 - Mobile Sources on a Construction Site

NOT TO SCALE

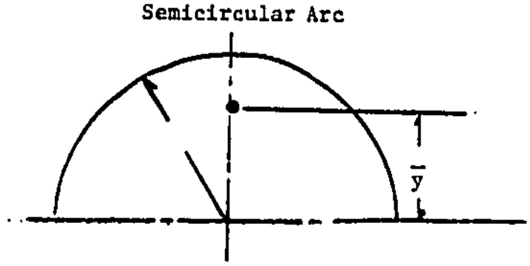
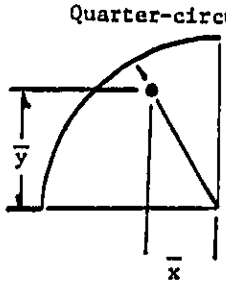
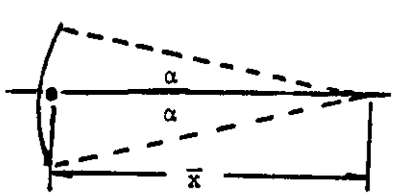
receiver must be at least three times the length of the path over which the equipment travels.* Equipment operations which meet this criterion may be treated as a stationary point source at the "acoustic center" of the path. Figure 5.7 presents the assumed "acoustic center" for a number of different typical paths. It is assumed that the equipment moves along the defined path at a relatively constant speed throughout its work cycle. With the "acoustic center" having been selected, the computation is accomplished in the same manner as for fixed sources.

Equipment operating throughout the site in a random manner is not common and therefore contributes little to site noise. Thus, for Category 3 mobile operations, assume the equipment noise emanates from the approximate geometric center of the construction activity. Consider the equipment as fixed, operating at this point, and use fixed source noise calculation methods.

5.3 Calculation of $L_{eq(24)}$ and L_{dn}

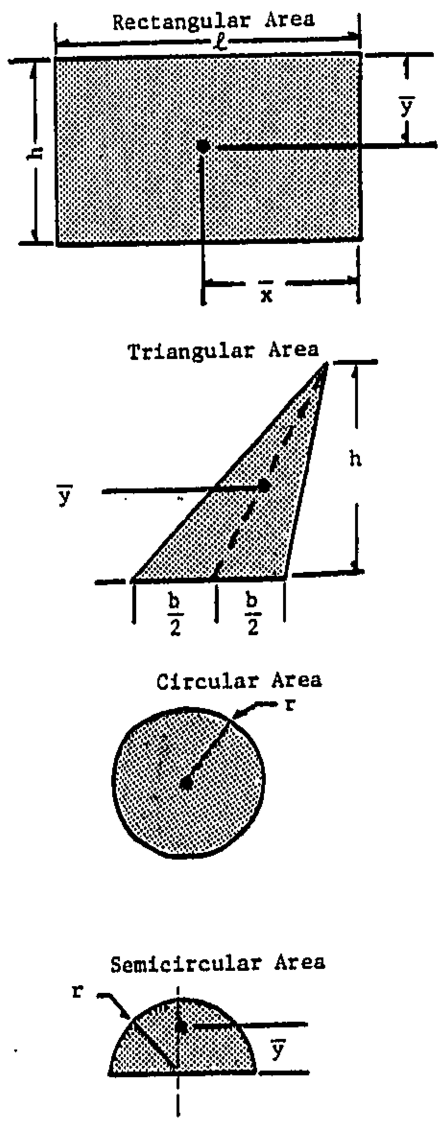
At each noise sensitive land use area, the average construction noise level contribution, Column (7) of Worksheet "C," is combined with the background ambient sound level, Column (8) of Worksheet "C," to estimate the community noise during construction. If the construction period is eight hours, then the combined noise level represents the average sound level for eight hours of the day. This is noted

*If the source moves in a complex path, then the longest straight line distance between two points on the path is used for this criterion.

	Location of "Acoustic Center"	
	$\bar{x}$	$\bar{y}$
Straight Line 	$\frac{\ell}{2}$	
Semicircular Arc 	Center	$\frac{2r}{\pi}$
Quarter-circular Arc 	$\frac{2r}{\pi}$	$\frac{2r}{\pi}$
Arc of Circle 	$\frac{r \sin \alpha}{\alpha}$	0

Note: If $\frac{\text{Source-Receiver Distance}}{\text{Path Length}} \leq 3$, break path into segments which meet the criteria and assume equipment is at centroid of each segment for fraction of time = $\frac{1}{N}$, where N = # of segments.

Figure 5.7a - "Acoustic Center" of Different Paths



	Location of "Acoustic Center"	
	$\bar{x}$	$\bar{y}$
Rectangular Area	$\frac{\ell}{2}$	$\frac{h}{2}$
Triangular Area		$\frac{h}{3}$
Circular Area	Center	Center
Semicircular Area	Center	$\frac{4r}{3\pi}$

Figure 5.7b - "Acoustic Center" of Areas. Use When Sources Are Known to Travel throughout Given Site Area

as $L_{eq(8)}$. Were the construction activity to occur from 0700 to 2200 with a one-hour break during lunch (1200-1300) and a one-hour break during dinner (2000-2100), then the Equivalent Sound Level would be noted as an $L_{eq(13)}$ for 13 hours of the day.

Two additional descriptors of environmental sound may be required to assess the noise impact. They are the 24-hour Equivalent Sound Level, $L_{eq(24)}$, and the Day/Night Sound Level, L_{dn}.

Calculation of $L_{eq(24)}$ requires the Equivalent Sound Level during construction activity, Column (9) of Worksheet "C," and the background ambient sound levels during periods other than construction (e.g., L_d - daytime and L_n - nighttime). A detailed background ambient sound level survey provides information of average sound levels for many different periods of the day. Assuming only two background ambient sound levels for daytime (0700-2200) and for nighttime (2200-0700) are available, a 24-hour Equivalent Sound Level is calculated from:

$$L_{eq(24)} = 10 \log_{10} \left[\frac{1}{24} \times \left(z \times 10^{L_{eq(z)}/10} + (15-z) \times 10^{L_d/10} + 9 \times 10^{L_n/10}\right)\right]$$

where z is the number of hours construction activity is carried out (during the daytime), and $L_{eq(z)}$ is the estimated average sound level during construction activity.

The Day/Night Sound Level, L_{dn}, can be calculated using the same method except that nighttime (2200-0700) sound levels are penalized 10 dB before incorporating them into the above equation for the $L_{eq(24)}$.

These calculations can be performed on a scientific calculator; however, as an alternative, the following technique using Worksheet "D" as shown in Figure 5.8, is suggested (detailed examples are given in Appendix D):

1) Determine the number of hours of construction activity during daytime (0700-2200) and its corresponding Equivalent Sound Level, L_{eq}. Enter the number of hours in Column B of Worksheet "D" (Figure 5.8) in the column corresponding to the L_{eq} value for the construction activity in Column A.

2) Enter the number of hours of daytime (15) minus the number of hours of construction activity in Column B next to the Day Sound Level, L_d, without construction activity, located in Column A.

3) Enter the number of nighttime hours (2200-0700, nine hours) in Column B next to the Night Sound Level, L_n, in Column A.

4) Multiply each number in Column B by its corresponding "relative sound energy" in Column C. Enter the result in Column D.

5) Add all the values in Column D to determine Sum D. Divide Sum D by 24.

6) Locate the value in Column C that is approximately equal to Sum D/24. The corresponding value in Column A is equal to the 24-hour Equivalent Sound Level, $L_{eq(24)}$.

The Day/Night Sound Level, L_{dn}, can be calculated using the above steps by including a 10 dB penalty for the nighttime sound levels in Step 4. Note that the procedure must be modified accordingly if any construction activity takes place between the hours of 10 p.m. and 7 a.m.

5.4 References

1. "Construction Noise Survey," Bureau of Noise Control, New York Department of Environmental Conservation, April 1974.

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

Sum D ________ Sum D/24 ________

$L_{eq(24)}$ ________ or L_{dn} ________

Figure 5.8 - Construction Activity Worksheet "D"

6.0 ASSESSING THE IMPACT OF CONSTRUCTION NOISE

6.1 Introduction

What levels of noise are acceptable? How much time and money should be spent to reduce noise? What justification is there to control construction site noise? These are important questions which must be considered when assessing noise impact. They are discussed in this chapter.

Assessing the impact of construction noise can be a simple process. There is a substantial body of information that relates human response to the noise environment. By utilizing the available information and considering the constraints on the specific situation, a good estimate of the acceptability of construction noise can be obtained.

In many instances, specific construction site noise regulations have been established by communities. Consideration of state and local standards is therefore the first step to be taken in assessing the impact of construction noise.

6.2 State and Local Regulations

The magnitude of construction site noise, estimated using the method discussed in Chapter 5.0, is used to evaluate potential non-compliance with state and local regulations and ordinances. Appendix E contains a summary of several current regulations adopted by local jurisdictions. The most common type of regulation establishes the maximum sound level permitted to cross a boundary line. For construction activities, this line is generally the boundary of the construction site.

Often it is the property line of a nearby noise sensitive land use. The permitted maximum sound level may be expressed in terms of octave band sound pressure levels (for steady sound), A-weighted sound levels, or the average A-weighted sound level as discussed in Chapters 3.0 and 5.0. The permissible noise levels generally vary with the land use, and may also vary with the time of the day and frequency content of the noise.

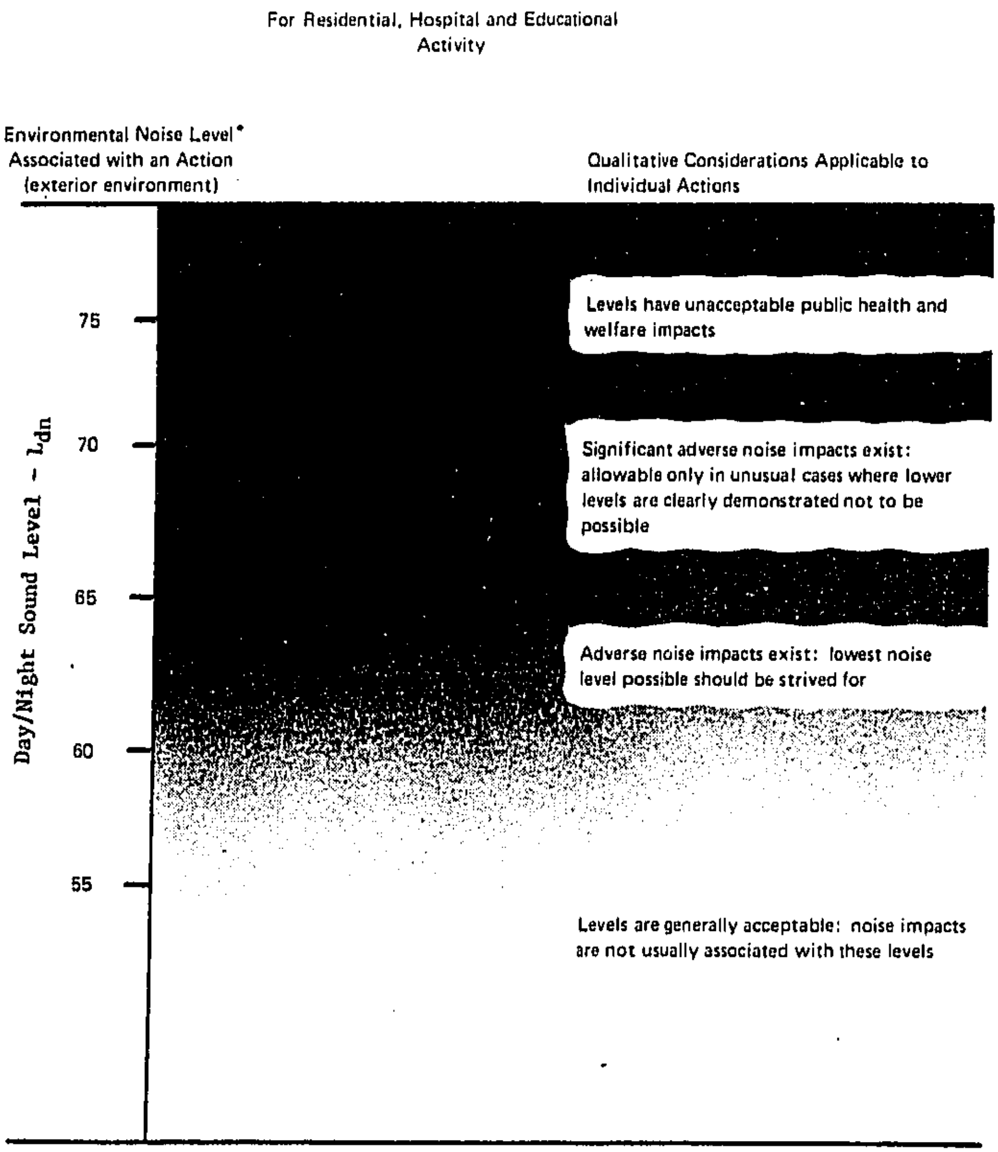
Another type of regulation which may be found at the local level is a curfew or restriction on the allowable hours of construction activity.

EPA has published a report[1] which presents the results of an EPA survey of state and municipal environmental noise control activities.

6.3 Federal Guidelines

In March 1974, EPA published a report entitled, "Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety."[2] This document identifies protective noise levels for a variety of activities and land uses. These levels are based only upon health and welfare effects and do not consider the cost or feasibility of achieving the levels. Consequently, they should not be viewed as standards, but as long-term goals.

Regardless of the feasibility of achieving these levels, they do serve as a basis for judging the impact of noise and the need to take abatement measures. Figure 6.1, which is based upon this report, illustrates the impact of



*Interior noise levels will depend on the building structure.

Figure 6.1. Anticipated Reaction of People to Varying Levels of Noise Exposure

environmental noise in certain areas. It is generally accepted that sound levels below an L_{dn} = 55 dB do not generally cause significant impact, while sound levels above an L_{dn} = 75 dB are unacceptable for sensitive land uses.

Figure 6.2 summarizes the results of several community attitudinal surveys dealing with noise effects, such as annoyance and community reaction. The magnitudes of the effect of noise on speech, community reaction, complaints, annoyance, and attitude towards community are presented in Table 6.1 for Day/Night Sound Levels of 55, 65, and 75 dB.

The Department of Housing and Urban Development (HUD) has established criteria[3] to discourage the building of new housing in areas where sound levels are high. These guidelines indicate that it is acceptable to build in areas where the ambient A-weighted sound levels do not exceed 45 dB more than 30 minutes per 24 hours, while it is normally acceptable to build in areas where the ambient A-weighted sound levels do not exceed 65 dB for more than 8 hours per 24 hours. Above this exposure level, the area is considered normally unacceptable.

The National Academy of Sciences' Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) has recently published guidelines for preparing the noise section of Environmental Impact Statements.[4] This report provides a technique which can be used to quantify the level of impact in terms of the magnitudes of the average sound levels and the number of people

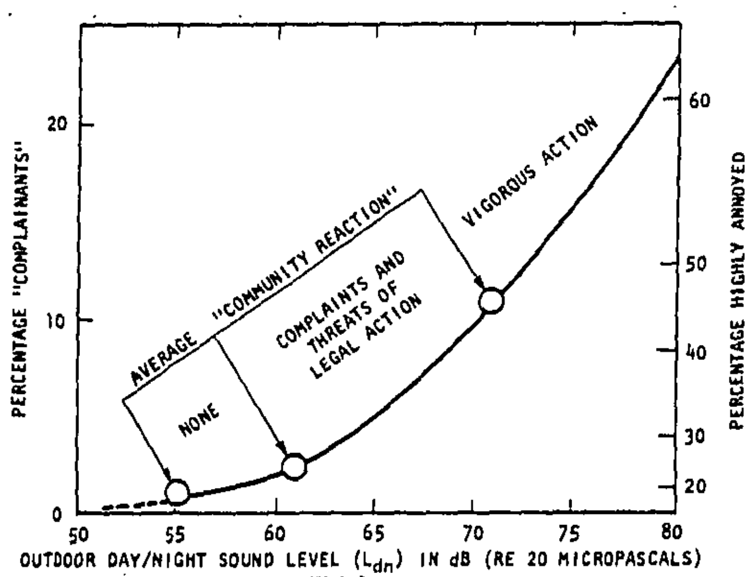


Figure 6.2. Summary of Annoyance Survey and Community Reaction Results[2]

TABLE 6.1 SUMMARY OF HUMAN EFFECTS FOR OUTDOOR DAY/NIGHT SOUND LEVEL OF 55 dB, 65 dB and 75 dB

Type of Effects	L_{dn} = 55 dB Magnitude of Effect	L_{dn} = 65 dB Magnitude of Effect	L_{dn} = 75 dB Magnitude of Effect
Speech - Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety	99% sentence intelligibility (average) with a 4 dB margin of safety	Sentence intelligibility (average) less than 99%
- Outdoors	100% sentence intelligibility (average) at 0.35 meter	100% sentence intelligibility (average) at 0.1 meter	100% sentence intelligibility not possible at any distance
	99% sentence intelligibility (average) at 1.0 meter	99% sentence intelligibility (average) at 0.35 meter	99% sentence intelligibility (average) at 0.1 meter
	95% sentence intelligibility (average) at 3.5 meters	95% sentence intelligibility (average) at 1.2 meters	95% sentence intelligibility (average) at 0.35 meter
Average Community Reaction	None; 7 dB below level of significant "Complaints and threats of legal action" and at least 16 dB below "vigorous action' (attitudes and other non-acoustical factors may modify this effect)	Significant; 3 dB above level of significant "complaints and threats of legal action" but at least 7 dB below "vigorous action" (attitudes and other non-acoustical factors may modify this effect)	Very severe; 11 dB above level of significant "complaints and threats of legal action" and at least 3 dB above "vigorous action" (attitudes and other non-acoustical factors may modify this effect)
Complaints	1%, depending on attitude and other non-acoustical factors	5%, depending on attitude and other non-acoustical factors	16%, depending on attitude and other non-acoustical factors
Annoyance	17%, depending on attitude and other non-acoustical factors	32%, depending on attitude and other non-acoustical factors	55%, depending on attitude and other non-acoustical factors
Attitudes Towards Area	Noise essentially the least important of various factors	Noise is one of the most important adverse aspects of the community	Noise is the most important of all factors

exposed to these sound levels. This impact descriptor is known as the Sound Level Weighted Population (LWP). Another useful concept proposed in this report is the Noise Impact Index (NII) which is used to compare the relative impact of one noise environment (alternatives) with that of another. It is defined as the sound level weighted population divided by the total population under consideration.

6.4 Assessing Construction Noise Impact

The assessment of construction noise impact requires good judgment and common sense. There are four factors which should be considered. These are:

1) The magnitude of the ambient sound existing without the construction activity;

2) The magnitude of the noise expected during construction;

3) The contribution of the construction activity to the total sound level; and

4) The characteristics of the construction noise irrespective of its magnitude.

The following example will illustrate these factors. Consider a construction site near a residential area where the Day/Night Sound Level is L_{dn} = 60 dB. The construction activity is expected to emit a sound level of L_{dn} = 65 dB. The resultant total sound level will then be L_{dn} = 66.3 dB (using the method in Appendix A-2.3).

In assessing this situation, we first see from Figure 6.1 that a Day/Night Sound Level of L_{dn} = 60 dB creates mild impact in residential areas. The construction noise contribution of L_{dn} = 65 dB itself will create significant adverse impact and, in fact, will dominate the combined Day/Night Sound Level of L_{dn} = 66.3 dB. From Figure 6.2 we see that over 30 percent of the people exposed will be highly annoyed and 5 percent can be expected to complain.

With a situation such as this, a significant amount of impact should be anticipated. The large change in the noise level from L_{dn} = 60 dB to L_{dn} = 66.3 dB will be very obvious. Since the construction activity is a primary contributor to the total noise, measures should be taken to abate the construction noise.

The duration of this construction activity should be strongly considered when deciding the level of effort to place on reducing the noise. For a one or two day job, perhaps no reduction measures would be necessary. For construction lasting a week or so, a portable barrier around the principal sound sources could be used. For longer jobs, other more comprehensive measures could be required (see Chapter 7.0).

As a general rule, the least expensive and least disruptive noise abatement measures should be applied first. As the severity of the noise impact increases, the complexity and cost of the noise abatement procedures will also increase. In particularly noise sensitive areas, noise reduction measures may be combined to achieve the desired noise levels.

To summarize, the questions that need to be considered are:

1) What is the current level of noise?

2) What level of construction noise is expected?

3) What portion of the total noise is construction noise?

4) How sensitive is the surrounding area to noise?

5) What will be the reaction of the exposed people to the noise?

6) What measures are available to reduce the construction noise?

7) What is the effectiveness of these measures and how will they impact the cost and duration of the construction activity?

The following chapter discusses a variety of the techniques used to reduce noise at construction sites.

6.5 References

1. "State and Municipal Noise Control Activities 1973-1974," EPA 550/9-76-006, January 1976.

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

3. "Noise Abatement and Control: Department Policy, Implementation, Responsibilities, and Standards," U.S. Department of Housing and Urban Development Circular 1390.2, August 1971.

4. "Guidelines for Preparing Environmental Impact Statements on Noise," Report of Working Group 69 on Evaluation of Environmental Impact of Noise, CHABA, National Academy of Sciences, 1977.

7.0 NOISE CONTROL METHODS

There exist various cost effective procedures which can be used to reduce the noise impact of construction activity. These techniques involve equipment noise control (actual machine modifications) and process noise control (changes in construction process, equipment and site configuration). Often, use of these techniques in combination can result in a significant decrease in construction site noise levels.

7.1 Equipment Noise Control

7.1.1 General Methods

A major noise source at the construction site is the internal combustion engine and its accessories. Most construction equipment is driven by gasoline or diesel engines. The major engine related noise sources are:

a) Exhaust
b) Intake
c) Panel vibration
d) Transmission
e) Cooling system

Exhaust mufflers are the principal means available to the construction contractor to reduce engine related noise. Mufflers provided as standard equipment, however, often do not reduce the noise enough for the specific construction site needs. More effective mufflers may be available and should be considered when the specific situation warrants a change.

Engine noise can be further reduced through the application of other techniques. For instance, reduction of engine vibration, and a corresponding reduction of noise, can be achieved by the use of better engine mountings. Enclosures and/or sound-absorptive material can be used on the engine housing, and damping materials can be applied to the sheet metal casings. For the most part, modifications such as these can only be carried out by the equipment manufacturer. However, some measures can be carried out by the owner after consultation with the manufacturer. These noise control techniques can also be applied to noisy components other than engines to produce a significant noise reduction.

Another general noise control technique is the use of substantially quieter equipment whenever possible. For example, electric motor driven equipment is usually significantly quieter than gasoline or diesel engine equipment.

7.1.2 Specific Measures

Various noise control techniques can be more clearly described in terms of the specific equipment to which they may be applied. However, noise control methods outlined for one type of equipment are often applicable to other similar equipment types. The purpose of this chapter is not to provide specific solutions, but to guide the reader to sources that describe these techniques in more detail.

- Crawler Tractor Noise

Intake and exhaust mufflers can be installed on the engine or existing mufflers improved. With optimal muffling, an A-weighted sound level reduction of 10 decibels in exhaust noise can be achieved. Cool air intakes can be shielded, enclosed, or fitted with silencers. This would result in a 10 decibel reduction in cool air intake noise.[1]

- Pile Driving

Steel or concrete piles are driven into the ground by impact pile drivers, which may be steam, pneumatic or diesel driven. Noise emitted from the driver can be reduced by using mufflers and enclosures. Although these methods are sometimes effective, substantial noise reduction is usually only possible when the pile is enclosed. A rubber apron, lined with sound absorbing material can be used for this purpose. Telescoping pipe is also often used as an enclosure. These measures often result in a 12 dB to 15 dB noise reduction.[2]

- Portable Air Compressors

Noise reduction can be achieved by using mufflers or enclosing the unit in a wooden shed or sheet metal skin. Large sheet metal panels should be treated with vibration damping material. Sound levels of new quieted versions of portable air compressors are 10 dB to 15 dB lower than older models and should be considered whenever possible.[2]

- Pneumatic Tools

Air exhausts on the tools should be properly muffled. The operator should also be aware that newer models are available which have sound levels approximately 10 decibels lower than those of older models.[1]

- Chain and Circular Saws

When possible, electric powered, as opposed to gasoline powered, saws should be used. Often damped circular saw blades can be purchased which emit less noise. If conditions allow, circular saws should be operated in enclosed areas. A simple wooden shed can reduce the sound level by 10 decibels.[1]

- Concrete Mixers

Electric motors are preferable to internal combustion engines. Friction wheels and V-belt drives are preferable to gear drives. The application of damping materials to the mixing drum and the motor housing can also reduce noise emissions of concrete mixers.[1]

- Blasting Operations

Blasting procedures are a source of high intensity noise often encountered during construction operations. Burying the primer cord, used to detonate the explosive, can reduce the sound levels 19 dB to 26 dB.[3] Blasting mats consist of heavy rubber and steel mesh sheets. They are used to reduce the noise and dust emitted from the blast. They also increase the effectiveness of the blasting operation and reduce the amount of flying debris.

7.2 Process Noise Control

7.2.1 Scheduling and Substitute Processes

It is often possible to reduce daily average noise levels during construction by conscientious scheduling. Equipment should be shut down between separate operations as long as this does not excessively interfere with the work progress. By scheduling various operations simultaneously, especially if one machine's noise emission predominates, quiet periods can often be achieved while noise levels during active periods are not changed significantly.

Whenever possible, alternate procedures and/or equipment should be investigated. One example has been previously mentioned, that is, the use of electric motor powered, as opposed to internal combustion engine powered, equipment. Equipment and procedure substitutions are more easily accomplished, by a contractor, than machine specific noise control techniques and therefore warrant careful consideration. Pile driving is a good example of how alternate equipment or processes may be used to achieve noise reductions. Possibilities include:

a) Vibrating pile drive method.[1] Instead of impact pile drivers, vibrating units are used. This possibility is limited since vibrating pile drivers can only be used in certain types of soil. Earth vibrations caused by vibrating pile drivers also may be undesirable.

b) The "English" pile driver method.[1] Steel piles are driven into the ground hydraulically.

c) The site "concrete" method. Deep, narrow ditches are dug, which are then filled with concrete, eliminating the need for piles. This method is limited to the proper structure of supporting rock and soil and bearing weight requirements.

d) The "Benoto" method.[1] Piles are hydraulically inserted into the ground using rotation.

Other processes and equipment substitutions provide noise reductions for specific construction phases.[1]

● <u>Demolition</u> - Front end loaders can be used for breaking up and removing asphalt roadways. Less equipment will be necessary, and since loaders are less noisy than pavement breakers, noise reductions will be achieved. Concrete buildings should be domolished using blasting instead of cranes and wrecking balls, when possible, since this will reduce average sound levels. Use of front end loaders instead of cranes and buckets for material removal is cheaper and quieter.

● <u>Clearing and Grading</u> - Use bulldozers and loaders instead of chain saws to clear trees, wherever possible. Use tractors equipped with ripper blades to break up rocky ground instead of blasting. Blasting requires noisy rock drilling equipment. Use scrapers instead of loaders for earth removal since scrapers have larger capacities and are quieter than loaders. Motor graders should be used in place of tractor-dozers or scrapers for grading.

● <u>Foundation Excavation</u> - The use of loaders and tractor-dozers for basement excavation instead of excavators is desirable in terms of speed and mobility. Backhoes are quieter than trenchers and are therefore preferable for slab laying. For hauling material, rubber tired vehicles are preferable to track types due to their lower sound levels and superior mobility.

● <u>Foundation</u> - Concrete trucks are less noisy than an on-site batch plant and should be used where economically feasible. Electric vibrators and trowels are preferable to gasoline engine operated units. For foundation fill and compacting, rollers are preferred over tampers; although they are more expensive, they are much less noisy.

- Erection - The use of off-site prefabrication should be considered whenever possible to decrease on-site activity and consequently noise emissions. Prefabricated structures are economically competitive to on-site fabrications and their erection produces much less noise. Nails, guns and staples should be used in place of hammers wherever possible.

- Landscaping - Use of motor graders instead of tractor-dozers will reduce noise.

These techniques are not applicable to all sites due to site-specific or project-specific features. In addition, smaller projects may not be able to support the cost of extra equipment necessary to accomplish some of the substitutions outlined above. The contractor should carefully examine all alternatives to minimize noise impact.

7.2.2 Site Noise Control Measures

In this category are included all those noise mitigation procedures which are not specific to equipment, but instead result in a potential noise reduction for all equipment. They include the operating of equipment as far from the impacted areas as possible; the rerouting of traffic to avoid sensitive areas; the use of barriers; and the use of natural site features as barriers. Barriers are often the most effective noise control measures which can be applied to many phases of the construction process.

Barriers can be constructed of boards, sheets of wood or metal, or masonry. If excavation is extensive, the excavated earth can be left on site and used as a shield until the noisy phase of construction is completed. Existing structures on or near the site can be used as effective barriers, as can equipment not in use or stockpiled materials. A properly built barrier should have a surface weight of 20 kg/m^2 as a minimum and should not have any acoustic leaks or open seams. If possible, a sound absorptive material should be applied to the side of the barrier facing the noise sources. This prevents increased sound levels in the direction opposite the sound-shield and also reduces amplification between the barrier and the machine.

A sound barrier functions in a similar manner as a barrier to light rays. "Acoustic" shadows, though, are not as clearly defined as light shadows due to their longer wavelength. Also, sound is not shielded equally at all frequencies. A barrier is more effective at high frequencies than low frequencies; the shorter the wavelength, the more the noise reduction. Care must be taken to have the barrier sufficiently long so that the noise traveling over it has the shortest path (Figure 7.1).[2] The efficiency of the barrier can be reduced if other machines or objects reflect sound "around" the barrier. This problem can be eliminated with proper barrier design (Figure 7.2).[2]

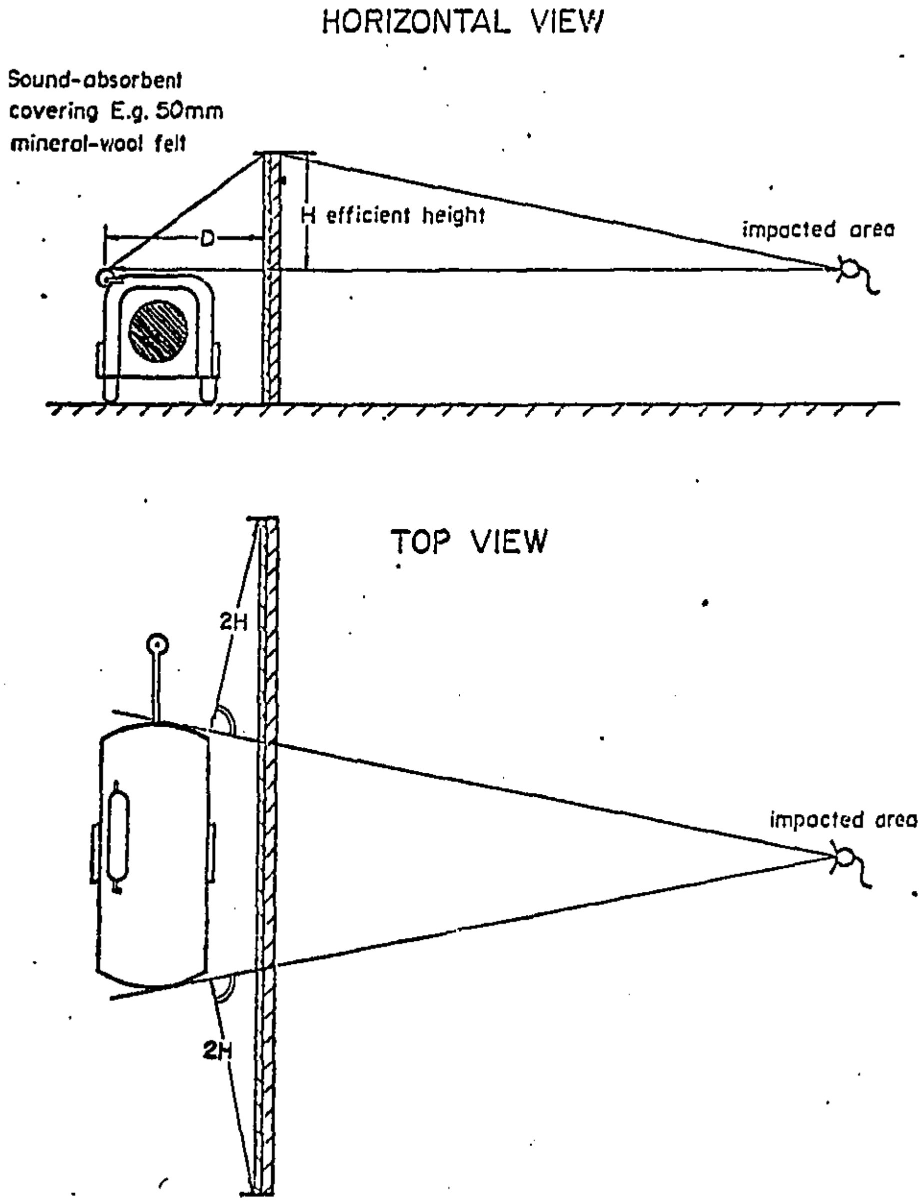


Figure 7.1 Barrier for Construction Noise Reduction

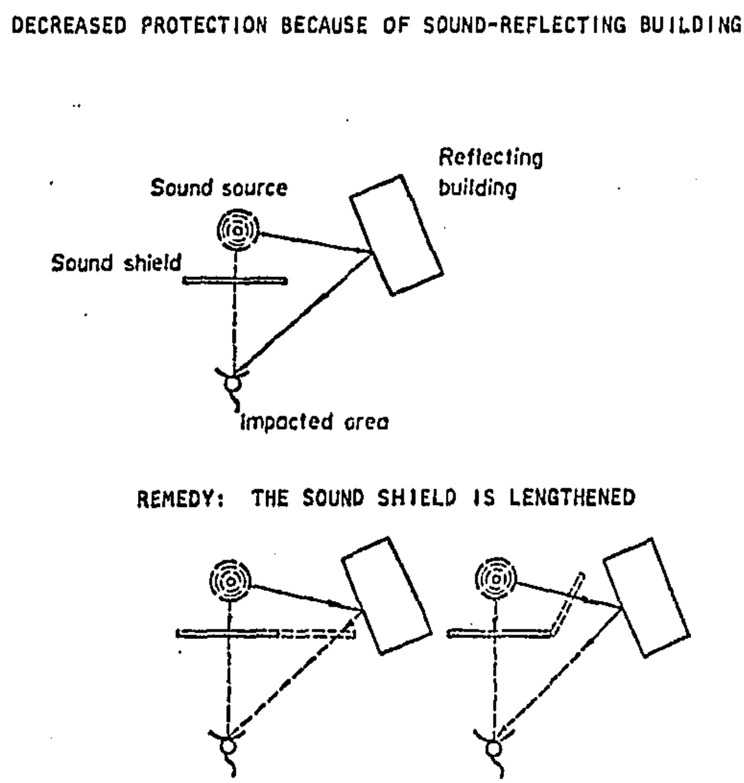


Figure 7.2 Solutions to Minimize Unwanted Reflections When Using a Barrier

When using a barrier to control noise at a construction site, it is useful to keep in mind that a barrier's effectiveness increases with increases in its height and its proximity to the noise source or to the receiver. A barrier's effectiveness is limited, in practical situations, by atmospheric effects to a noise reduction of 25 decibels.

For construction equipment noise, useful predictions of A-weighted sound level reduction due to the presence of a barrier can be made using the graph shown in Figure 7.3. An example of the use of this graph is presented in Appendix D.

Other measures which can be implemented include using the noisiest equipment at as great a distance as possible from the noise sensitive areas. Whenever possible, noisy tools should be used in an enclosure, possibly a trailer. Certain jobs, such as woodworking, can often be done inside.

7.3 References

1. "Construction Noise: Specification, Control, Measurement and Mitigation," Construction Engineering Research Laboratory Technical Report E-53/ADA 009668, April 1975.

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

3. Viskne, A., "Measurement and Reduction of Noise from Detonating Cord Used in Quarry Blasting," Bureau of Mines RI 7678, 1978.

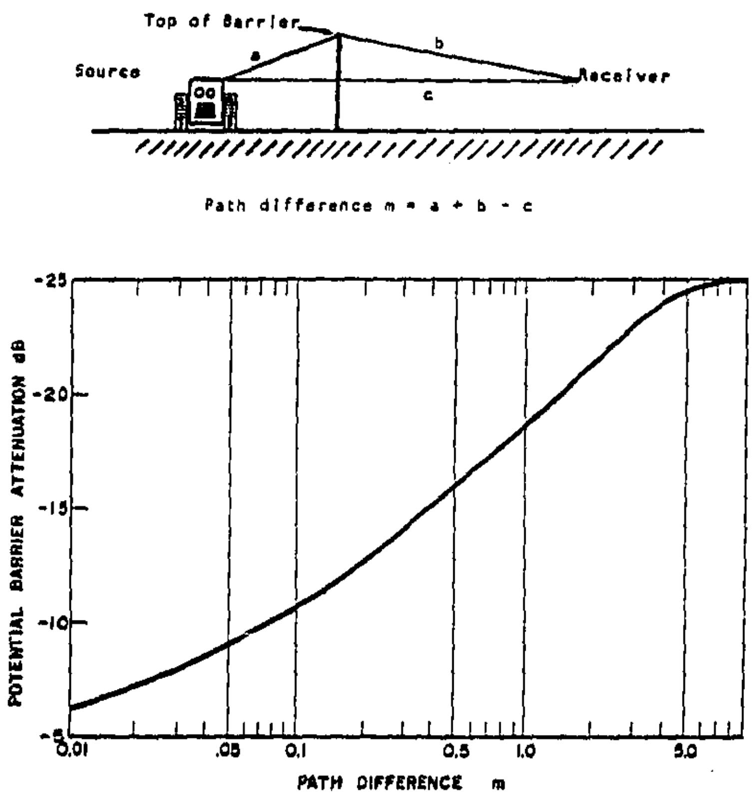


Figure 7.3 A-Weighted Noise Reduction Due to a Barrier As a Function of the Path Difference in Meters

APPENDICES

APPENDICES

A - ACOUSTICAL CONCEPTS, DECIBEL ADDITION AND BIBLIOGRAPHY

B - CONSTRUCTION EQUIPMENT NOISE LEVELS

C - CONSTRUCTION EQUIPMENT USAGE FACTORS

D - ILLUSTRATIVE EXAMPLES

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APPENDIX A

ACOUSTICAL CONCEPTS, DECIBEL ADDITION AND BIBLIOGRAPHY

A-1 The Nature of Sound

Sound, in its simplest terms, is a form of aerodynamic vibration which transmits energy from one point in space to another. It is a pressure fluctuation to which the ear responds. Sound waves behave like the ripples in a pond produced by throwing a stone into the water. Like the ripples, sound waves move away from the source at a constant speed.

The speed of sound in air varies slightly with temperature and humidity, but for most purposes may be regarded as having a constant value of 340 meters/sec (1120 ft/sec).

The two basic properties used to define sound are its frequency content (as indicated by its pitch) which is expressed in Hertz (one Hertz is equal to one cycle per second) and its amplitude (as indicated by its loudness). Since sound is a pressure phenomenon, the amplitude of a sound should be expressed in units of pressure, but to simplify matters, it is commonly expressed in decibels (discussed in Section A-2.1).

To develop a clearer idea of the magnitude of common sound signals, Figure A.1 is presented. Note that the range of sound pressure perceived by many is quite large, on the order of 1:1,000,000. However, the magnitude of the sound pressure variation relative to local atmospheric pressure is quite

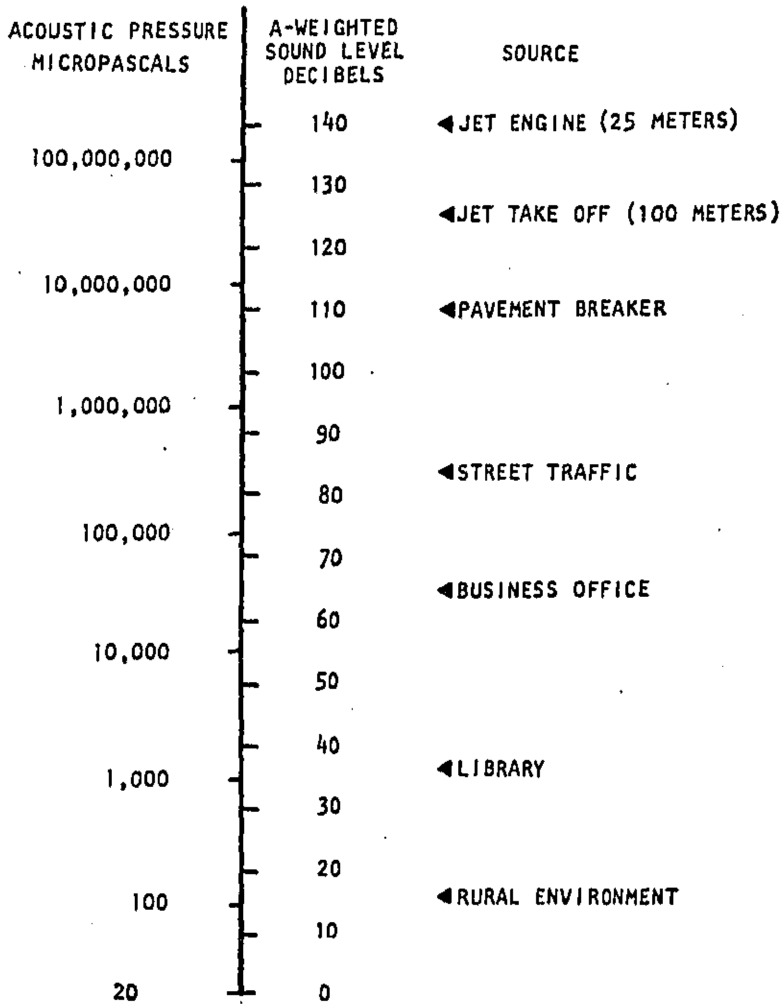


FIGURE A.1 MAGNITUDE OF SOME TYPICAL SOUNDS small. The loudest sound the ear can tolerate (140 dB re 20 microPascals) is a maximum pressure variation that is 1/500 of normal atmospheric pressure.

Most sounds are composed of a number of frequency components. Often sound is analyzed (using electronic instruments) in bands of frequencies. The preferred bands for acoustic measurements cover the audible range (nominally 20-20,000 Hz) and consist of ten octave bands. The range of frequencies in each band increases as the frequency increases. The upper frequency of each band is always twice the lower frequency. For example, the 1000 Hz octave band extends from 707 Hz to 1414 Hz. The preferred octave band center frequencies are 31.5 Hz, 63 Hz, 125 Hz, 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz and 16000 Hz. Note the doubling here as well.

For more detailed analysis of a sound's frequency content, still narrower bands, such as 1/3 or 1/10 octave bands, are used.

A-2 The Mathematics of Acoustics

A-2.1 The Decibel

The extent of the variation in pressure corresponding to an acoustic signal is commonly measured in terms of microPascals. A microPascal is approximately equal to one hundred thousandth of normal atmospheric pressure.

Due to the large range of sound pressures encountered (as seen in Figure A.1), it is more convenient to express the sound pressure on a logarithmic scale. This compression in scale to smaller numerical values is easier to use. The Sound Pressure Level, L_p, is defined mathematically as:

$$L_p = 10 \log_{10} \frac{p^2}{(p^2_{ref})} \text{ dB} = 20 \log_{10} \left(\frac{p}{p_{ref}}\right) \text{ dB}$$

(The symbol, dB, represents the unit of sound level, decibel.)

where p is the root mean square sound pressure, and p_{ref} is a reference pressure

The standard reference pressure is 20 microPascals which corresponds approximately to the faintest sound that an average young adult can hear in a quiet surrounding. The important point to remember is that the decibel is non-dimensional and is a ratio of two pressures.

A-2.2 Weighting Scales

The apparent loudness that we attribute to a sound varies not only with the sound pressure but also with the frequency of the sound. For instance, a low frequency sound will not seem as loud as a high frequency sound of "equal" sound pressure. To account for this variation in human perception, weighting criteria were developed many years ago. Three criteria are shown in Figure A.2. By far, the most common of these is the A-weighted criteria which attempts to reflect the human ear's decreased sensitivity to low frequencies at normal sound levels. Sound levels are measured with meters using electrical networks which automatically apply these weighting criteria. A sound measured with a device using such a network

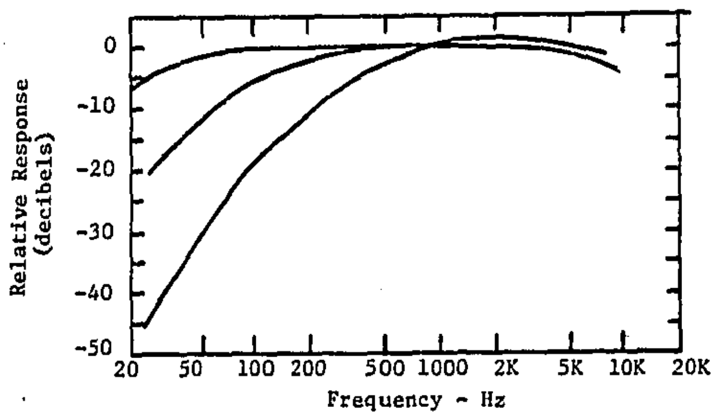


Figure A.2 - Frequency Response Characteristics[2] in the American National Standard Specification for Sound Level Meters ANSI S1.4-1971

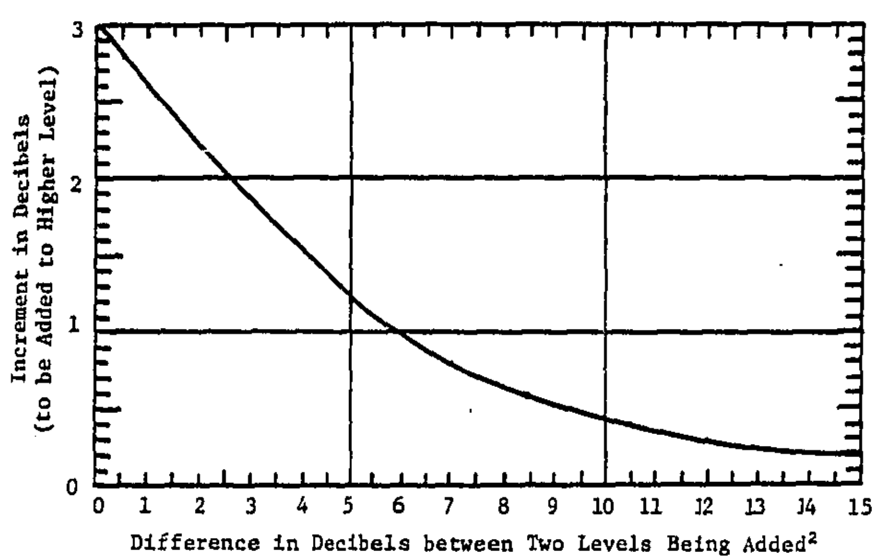


Figure A.3 - Chart for Combining Decibels providing a value referred to as an A- (or B-, or C-) weighted sound level.

A-2.3 Combining Decibels

Very often there are two independent sound sources radiating concurrently. To determine the combined effect of the two sources, we add their contribution on an energy basis (sound pressure levels are not added directly but instead are converted to pressure squared terms, which are added and then reconverted to decibels). In other words,

100 dB + 100 dB does not equal 200 dB

Instead,

100 dB + 100 dB = 103 dB

One method of combining decibels is the use of the graph in Figure A.3. By knowing the two levels and therefore the difference between the two, the increment to be added to the higher level is determined. This yields the resultant sound level.

A-2.4 Equivalent Sound Level, L_{eq}

Environmental noise is not steady but fluctuates considerably in level as a function of time. To fully characterize the exposure of an individual to time-varying sound levels, a history or cumulative distribution of the sound levels would be necessary. This requires a large number of samples. To simplify matters, noise from both individual events and quasi-steady state sources are averaged. This time weighted average is known as the Equivalent Sound Level, L_{eq}. The

Equivalent Sound Level is the steady noise level, which in a stated period of time, would contain the same acoustic energy as the actual time-varying sound. The mathematical definition of L_{eq} for an interval T is:

$$L_{eq} = 10 \log \left(\frac{1}{T} \int_0^T \frac{p^2(t)}{p_o^2} dt\right) \text{ dB}$$

where p(t) is the time-varying sound pressure, and
p_o is the reference pressure.

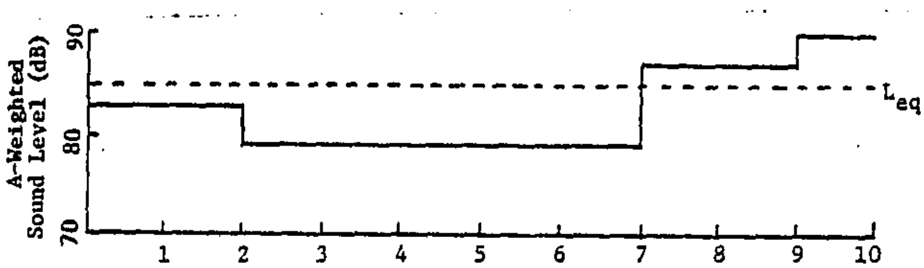
An approximation to this integral is:

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

where L_i is the A-weighted sound level for time interval i,
t_i is the length of time interval i, and
T is the period of interest $(\sum_{i=1}^{n} t_i)$.

The steps used to calculate L_{eq} are given in the following example:

Example: A backhoe has a 10-minute duty cycle.
For 2 minutes, it produces a steady sound level of 83 dB.
For 5 minutes, it produces a steady sound level of 79 dB.
For 1 minute, it produces a steady sound level of 87 dB.
For 2 minutes, it produces a steady sound level of 90 dB.



Time (minutes)
Duty Cycle of Backhoe

Determine the Equivalent Sound Level, L_{eq}, for the duty cycle.

Using the mathematical formula for L_{dn} and a scientific calculator, the calculation of L_{dn} for this example is performed:

$$L_{eq} = 10 \log_{10} [\frac{1}{10} \times (2x10^{83/10}+5x10^{79/10}+1x10^{87/10} +2x10^{90/10})] = 85 \text{ dB}$$

A-2.5 Day/Night Sound Level

The development of Equivalent Sound Level was followed by the development of the Day/Night Sound Level. This is the average A-weighted sound level during a 24-hour time period with a 10-decibel weighting (penalty) applied to the nighttime sound levels (10 p.m. to 7 a.m.). This may be expressed mathematically as

$$L_{dn} = 10 \log_{10} \frac{1}{24} [15(10^{L_d/10})+9(10^{L_n+10/10})]$$

where $L_d = L_{eq}$ for the daytime (0700-2200) hours, and
$L_n = L_{eq}$ for the nighttime (2200-0700) hours.

An example demonstrating the calculation of L_{dn} is presented below.

Example: Measurements made at a proposed construction site yield a Day Sound Level of 60 dB and a Night Sound Level of 55 dB. Determine the Day/Night Sound Level.

Using the mathematical formula for L_{dn} and a scientific calculator, the calculation of L_{dn} for this example is performed:

$$L_{dn} = 10 \log_{10} [\frac{1}{24}x(15x10^{60/10}+9x10^{65/10})] = 63 \text{ dB}$$

A-2.6 Distance Attenuation

Sound waves for many situations may be approximated by a free spherical progressive wave. The emitted sound power spreads out from the source with continuously increasing radii. Since the sound power must remain constant (conservation of energy), the intensity at a given distance from the source must be proportional to the inverse of the spherical surface area (radius squared). The sound level attenuation as a function of distance can easily be computed. The "inverse square law" of attenuation, as it is commonly called, predicts a six-decibel reduction for each doubling of distance from the sound source's origin. Figure A.4 can be used for determining the sound pressure level at different source-receiver distances.

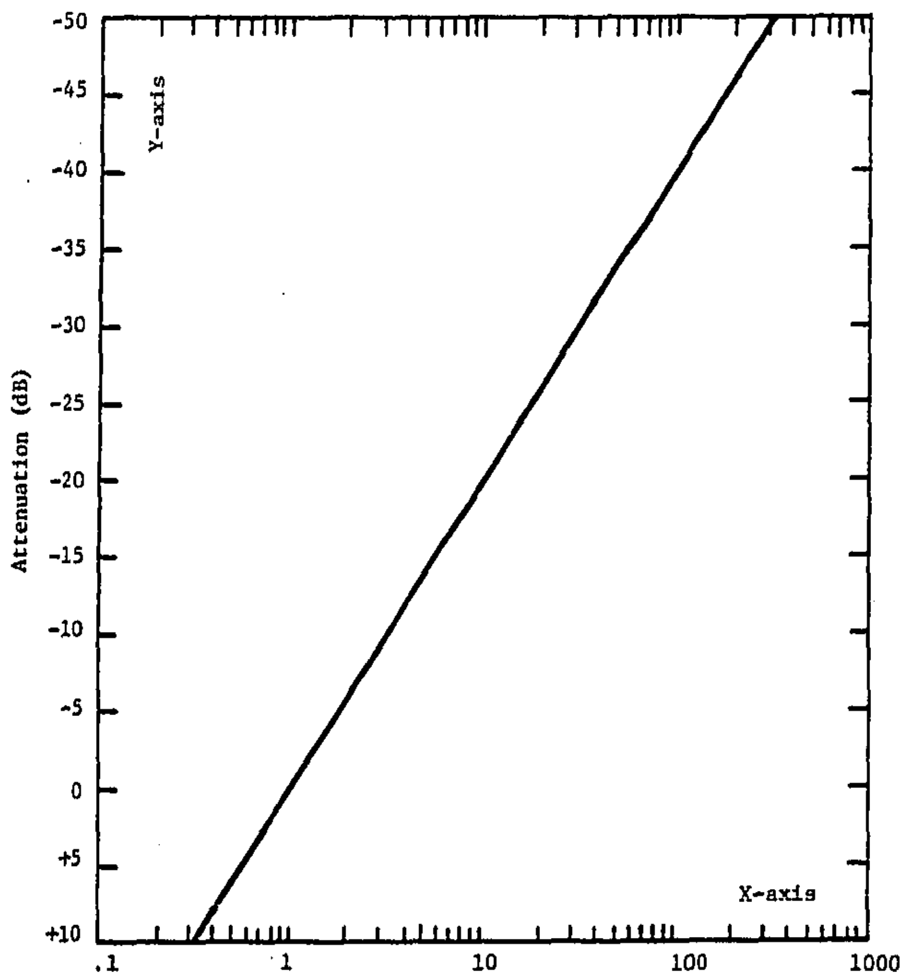
For example, if the sound level at 200 meters is 92 dB, the sound level at 950 meters is estimated by using the graph in Figure A.4. Enter the X-axis at a ratio of (950/200) = 4.75, and move upward to where this value intersects the curve. The corresponding Y-axis value is the distance attenuation, 13.5 dB. Subtracting 13.5 from 92 provides the sound level of 78.5 dB. Alternately, a calculator can be used for determining distance attenuation. The corresponding mathematical solution is presented below.

Example: An observer 200 meters from a noise source measures a sound level of 92 dB. What is the sound level at 950 meters?

$$\text{Attenuation} = 10 \log_{10} \left(\frac{950}{200}\right)^2 = 20 \log_{10} \left(\frac{950}{200}\right)$$

$$L_{p950} = L_{p200} - 20 \log_{10} \left(\frac{950}{200}\right) = 92 - 20 \log_{10} \left(\frac{950}{200}\right)$$

$$= 78.5 \text{ dB}$$



Distance from Source to Observer
Distance from Source to Location at Which Sound Level is Known

Figure A.4 - Distance Attenuation

Note: Applicable to point sources only, either small source or a large distance from a large source. Distance to source is at least three times typical dimension of source.

Note that this relationship only holds for small sources or for large distances (three times the major dimensions) from large sources.

Sound level attenuation calculated by this procedure does not include the attenuation due to air absorption and effects of ground cover, such as trees and brush.[3] Discussions of these additional attenuation effects which can be significant over very large distances are available in several references found in the Bibliography at the end of this Appendix.

A-3 References

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3. Wiener, F.M. and Keast, D.N., "Experimental Study of the Propatagion of Sound Over Ground," Journal of the Acoustical Society of America, Vol. 31 No. 6, 1959.

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"Handbook of Noise Ratings," Karl S. Pearsons, et al, NTIS Report N74-23275, April 1974.

"Regulation of Construction Activity Noise," Bolt Beranek and Newman Report 2887, November 1974.

APPENDIX B

CONSTRUCTION EQUIPMENT NOISE LEVELS

Included in Table B.1 is a list of typical construction equipment and their A-weighted sound levels. Also included is a brief description of the item, and the source for the data. Note that the sound levels presented are typical values. The range of values for actual equipment is quite large. Differences of 20 decibels between two equipment models with the same function are not unusual. Furthermore, as new noise control measures are instituted by manufacturers, the sound levels presented in the table can be expected to change.

It is therefore of great value to either directly measure, or obtain from the manufacturer, sound levels of the specific equipment to be used on the construction project. The levels provided in the table should only be used when specific noise measurements cannot be obtained. Measurements when performed should be made during the equipment's noisiest mode of typical operation and the sound levels measured should be only from the machine being studied (i.e., background ambient sound levels without the unit operating should be at least 10 decibels lower than the sound level of the machine being measured).

A major noise source not on this list, but which is often present at very large scale construction projects which require a considerable amount of concrete, is a concrete batch plant, which allows on-site preparation of concrete instead of requiring a large number of trucks to deliver the prepared concrete from off site. The sound level usually associated with an operating batch plant is 69 dB measured at 76 meters (250 ft). The noise results from plant operation and concrete trucks being loaded. The plant usually operates continuously during the workday (24 hours) when concrete is required.

<u>References</u>

1. "Regulation of Construction Activity Noise," Bolt Beranek and Newman, Inc. Report No. 2887, November 1974.

2. "Construction Site and Equipment Noise in New York City," Lewis S. Goodfriend and Associates Report prepared for Bureau of Noise Abatement, Department of Air Resources, City of New York, 1974.

TABLE B-1

A-WEIGHTED SOUND LEVELS OF TYPICAL CONSTRUCTION EQUIPMENT AT 15 METERS

Item	Description	Typical Sound Levels - dB
Air Compressor	Supplies power in the form of compressed air during all phases of construction	81
Backhoe	Earth moving devices used mainly at residential and public work sites. Commonly fitted with paving breakers, cranes, booms, and dozer blades	85
Explosives	Used for breaking up large concentrations of rock during clearing phase of construction	92*
Concrete Mixer	Supplies concrete for foundation and erection phases of building	85
Concrete Pumps	Used for concrete pouring operations	82
Concrete Vibrators	Used to remove entrained air bubbles and maintain homogeneity of concrete mixture	76
Crane, Derrick	Raising and movement of construction components	88
Crane, Mobile	Used for placement of materials and equipment	83
Dozer	Earth moving devices used primarily during the clearing and excavation phases of construction	87
Generators	Used to supply electric power to lighting and handtools during construction phases before utility lines are installed	78
Grader	Used primarily in highway construction	85
Pavement Breakers	Used for breaking up existing structures during excavation phase of construction	88
Loaders	Track or wheel mounted earth-moving machines	84
Paver	Spread and finish bituminous and concrete pavements	89
Pile Driver	Used to drive load bearing members during foundation phase	101
Pneumatic Tool	Hand operated tools (wrenches, chippers, grinders) used for finishing of structures	85
Pump	Used to remove water from excavations	76
Rock Drill	Used to drill holes in rock for fitting explosive charges.	98 Reference 2
Roller	Used to smooth foundation or pavements during finishing phase of public works projects	80
Saw	Used to cut wooden components	78
Scraper	Strip, transport and spread earth during excavation phase of project	88
Shovel	Used for excavation	82
Trucks	Used as haulers of earth, fill, and rubble as well as other applications during all phases of construction	88

*these levels result when proper precautions (mats) are taken to ensure that the blast energy goes into the rock, instead of the surrounding environment.

All sound levels are from Reference 1 unless otherwise noted.

APPENDIX C

CONSTRUCTION EQUIPMENT USAGE FACTORS

C-1 Description of Usage Factor

In the course of a typical work cycle, construction equipment spend part of their cycle idling or preparing to perform a task. During some part of its work cycle, the noise the machine emits is higher than it is at any other time. Since L_{eq} is an average value representing the total sound energy emitted during the period of interest, the maximum sound level, L_A,* and the duration of maximum noise as a fraction of the total period must be known to determine the equivalent (energy average) sound level emitted by the machine during a total work period: for example, a typical work day. The fraction of this period that the equipment operates in its noisiest mode is designated as the Usage Factor (UF). The usage factor is considered to consist of two component elements; an operating factor (F_1) and a utilization factor (F_2). $UF = F_1 \times F_2$. The operating factor is that portion of the typical work cycle that the equipment is emitting its maximum noise. This factor is illustrated in Figure C.1, where $F_1 = T_1/T_2$. Three possible time-varying modes of equipment noise emission are possible. They are listed below:

Mode 1: The equipment works cyclically; for example, a backhoe or front end loader may generate maximum sound while trenching but significantly less sound while using its loader.

*The maximum sound level, L_p, is the average sound level of the equipment in its noisiest mode. To better illustrate L_A, Figure B.1 shows a typical work cycle for a unit of construction equipment.

Mode 2: The equipment moves throughout the site.

Mode 3: An operation is performed sporadically, possibly only once during the observation period.

The utilization factor is that portion of the work period (e.g., 8-hour work day) that the equipment is on the site and is being used. Thus, the utilization factor considers the number of work cycles for the equipment during typical operations during the work period. Figure C.2 illustrates possible time histories applicable to each mode. The operating factor (F_1) is computed from the fraction of time the equipment is in its noisiest mode. The utilization factor is then multiplied by the operating factor to yield the usage factor.

Stationary equipment may not be operating, may be idling while other preparatory activities are in process, or may be operating at full load (and maximum noise level). These operations may be repeated often during a typical construction day. This activity is shown in Figure C.2 as Mode 1.

Mobile equipment may be operating at maximum noise levels for a short duration; for example, a front end loader while loading. The equipment (the loader) may travel a considerable distance to place this load. At a receiver, sound levels drop significantly as the loader leaves the scene even though the source noise level has not diminished. Mode 2 of Figure C.2 illustrates this activity.

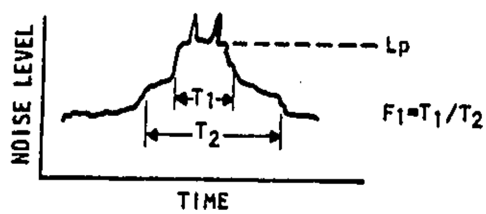
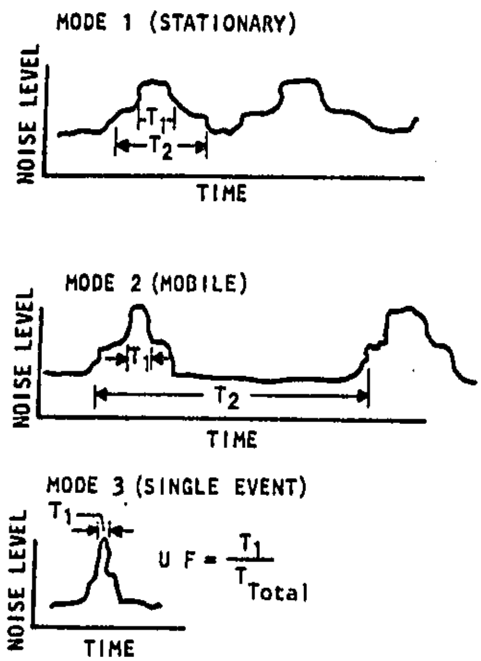


Figure C.1 Operating Factor - Time History Construction Equipment



Operating Factor $F_1 = T_1/T_2$
Utilization Factor $F_2 = T_2/T_{Total}$

T_{Total} might be construction duration (an 8-hour day)

Figure C.2 Usage Factor - Examples of Time Histories

A single event is illustrated by Mode 3 of Figure C.2. The total period T_2 is assumed to be the construction duration, perhaps an 8-hour day.

The maximum sound level of the equipment and its usage factor are used to evaluate L_{eq} as shown below:

$$L_{eq} = 10 \log_{10} (U.F. \times 10^{(L_p/10)})$$

Operating factors and utilization factors are best determined from measurements at a construction site where similar operations to the site under study are occurring.

The references listed below include discussion and tabulations of usage factors and may be used with caution in the absence of measured data.

- "Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing," CERL Interim Report N-3, July 1976.
- "Noise from Construction Equipment and Operations, Building Equipment, and Home Appliances," USEPA NTID 300.1, December 1971.
- "Background Document for Portable Air Compressors," USEPA 550/9-76-004, December 1975.
- "Technology Analysis - Noise Pavement Breakers and Rock Drills," Dames & Moore, 1976, EPA Contract No. 68-01-3288 (to be published).
- Report of Symposium, February 1-2, 1977, "Highway Construction Noise," Dames & Moore, FHWA Contract No. DOT-FH-11-9191 (to be published).

APPENDIX D

ILLUSTRATIVE EXAMPLES

D-1 Chapter 2.0 - Construction Phase Schedules

Any construction project can be described by a series of discrete phases of construction activity. Often these phases will coincide either totally or in part. Two examples of construction phase schedules are presented here to illustrate this concept, which is discussed in Chapter 2.0.

The first schedule presented is for construction of a large fossil fuel electric generating station located in a rural, densely forested area in the northeastern United States. The schedule is presented in Table D.1.

The second schedule is for a small drive-in banking facility. The schedule is presented in Table D.2. Note that only four of the possible seven construction phases are necessary for this small project.

TABLE D.1

CONSTRUCTION PHASE SCHEDULE FOR FOSSIL FUEL GENERATING PLANT

1st Year: J F M A M J J A S O N D; 2nd Year: J F M A M J J A S O N D; 3rd Year: J F M A M J

I	General Site Preparation Back Hoes, Clearing and Grading Trucks, Dozers, Scraper
II	Excavation and Backfill Back Hoes, Front-end Loaders, Dump Trucks, Scrapers, Dozers, Graders, Pile Drivers
III	Foundation Concrete Work Concrete Trucks, Concrete Vibrators
IV	Structural Steel Erection (Plant and Fuel Tanks) Cranes, Air Compressors, Impact Wrenches, Welders
V	Coal-Handling Facility (Alternate) Concrete Trucks, Cranes
VI	Railroad Construction Dozers, Graders, Railroad Equipment
VII	Truck Deliveries*

*General deliveries might average as low as two deliveries per day to 12 deliveries per day.

TABLE D.2

CONSTRUCTION PHASE SCHEDULE FOR DRIVE-IN BANKING FACILITY

Jan. Feb. March April May June July

Demolition (removal of existing concrete slab on site) Front end loaders, pavement breakers	1 month
Erection (Prefabricated building) Concrete truck, crane, compressor	3 months
Finishing	3 months
Landscaping Tractor	1 month

D-2 <u>Chapter 3.0 - Baseline Sound Level Survey Locations</u>

This example illustrates the selection of baseline measurement locations for an underground parking garage for a hospital located in a suburban residential area of New Jersey. The construction site and the locations surveyed are shown in Figure D.1. They are:

Location 1 - Private Residence
Location 2 - Private Residence
Location 3 - Small Park
Location 4 - Church
Location 5 - The Hospital

Although measurement locations around the construction site boundary were not selected in this example, they are recommended in order to establish a baseline for future reference. Note that each of the major categories of noise sensitive land use areas has been included in the survey.

Note: Existing hospital in crosshatch; Projected parking garage shaded.

Figure D.1 Baseline Sound Level Survey Locations for Suburban Hospital Parking Garage Construction Project

Chapter 5.0 - Estimating Construction Site Noise

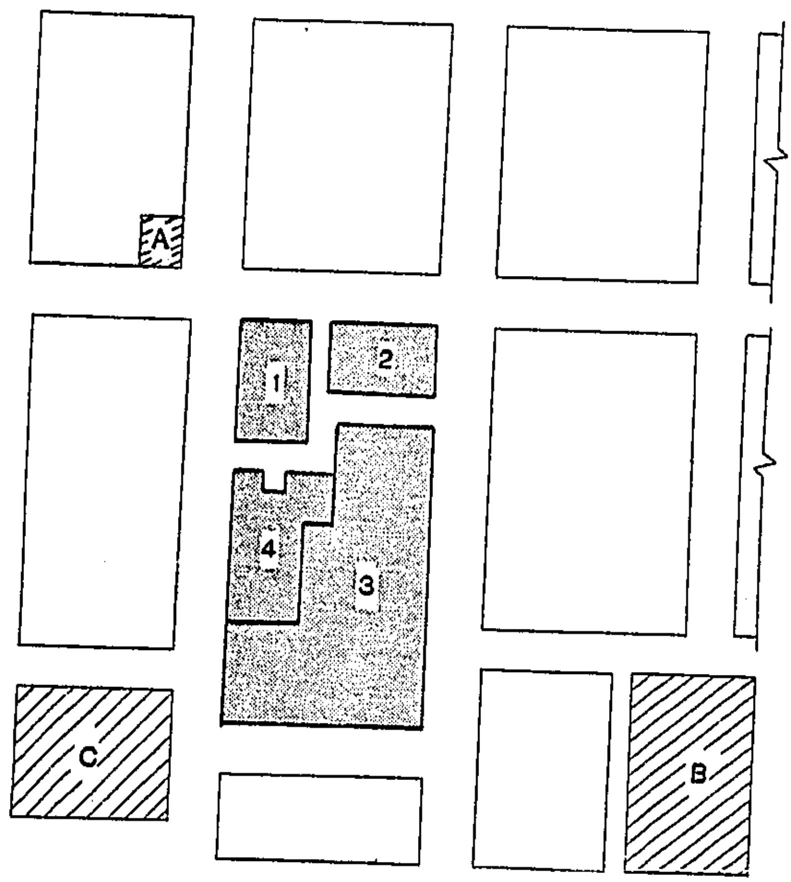
Examples illustrating the use of the four construction activity worksheets are presented below. They are provided as examples of how information may be organized to aid in estimating the noise emitted from a construction site. This information must be as detailed as possible to assure the accuracy of the estimated sound levels.

D-3 Section 5.2.1 - Worksheet "A" - Site Plan and Equipment List

A shopping plaza is to be built in an urban community. The project requires demolition of abandoned warehouses and the erection of a shopping mall, an office building, an on-grade parking lot and a three-story parking garage.

On the site plan, shown in Figure D.2, the areas of construction activity are indicated by solid shading with number designations, and nearby noise sensitive land use areas are indicated by crosshatching with letter designations.

A construction activity worksheet for the excavation phase for the multi-level parking garage was filled in and is shown as Figure D.3. A sketch is included on the worksheet showing the construction site and an area surrounding the site. A description and the amount of construction equipment used is listed.



Surrounding Noise Sensitive Land Use Areas

A - House of Worship
B - Hospital
C - Park

Major Plaza Features

1 - Office Building
2 - Parking Area
3 - Shopping Plaza
4 - Parking Garage

Figure D.2 - Urban Shopping Plaza Site Plan

Figure D.3 - Construction Activity Noise Worksheet "A" - An Example

Project Name Shopping Plaza

Construction Phase Excavation

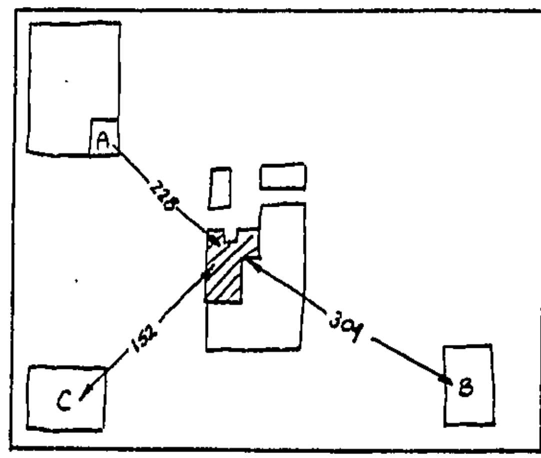
Construction Activity Parking Garage

Site Map Designation 4

Duration of Activity 8/1/76 - 9/10/76

Hours of Daily Activity 0700 - 1600 *

*Excludes mealtime



Sketch of Site Area

Equipment List

Type	Model	# of Units	L_A (db)	Distance (meters)	Usage Factor	Noise Sensitive Land Use	Location	Distance to Construction Activity (Meters)
Backhoe	John Deere JD310	1	85	15	.16	House of Worship	A	228
Dozer	Cat. D8H	1	87	15	.4			
Truck	Kenworth Brute	2	88	15	.4	Hospital	B	304
Compressor	I-R 1505	1	81	15	1.0	Park	C	152

D-4 Section 5.2.2 - Mobile Operation Categories

There are three types of mobile operation for construction equipment. In Category 1, equipment spends time at several different locations with very little time spent in transit. Category 2 equipment spends the major time moving from one spot to another in a simple operating pattern. In Category 3, the equipment spends part of the time in transit and part of the time stationary. Its movement is random or complex and is approximated by choosing a central point within the path to use as the equipment's location.

D-4.1 Mobile Operation Category 1: A crawler tractor with a front end loader is used to move earth from an excavation area to an earth berm. In doing so, it spends approximately 45 percent of its time at the excavation, 50 percent of its time building the berm and the remaining 5 percent of the time in motion. Figure D.4 shows the location of the excavation, the berm, and the noise sensitive land use area being considered.

The usage factor (per location) for this crawler tractor is calculated for each activity from:

Activity	Operating Factor		Utilization Factor	Usage Factor
Excavation	0.70	times	0.45	0.315
Berm	0.70	times	0.50	0.350

(Usage Factor determined as in Appendix C)

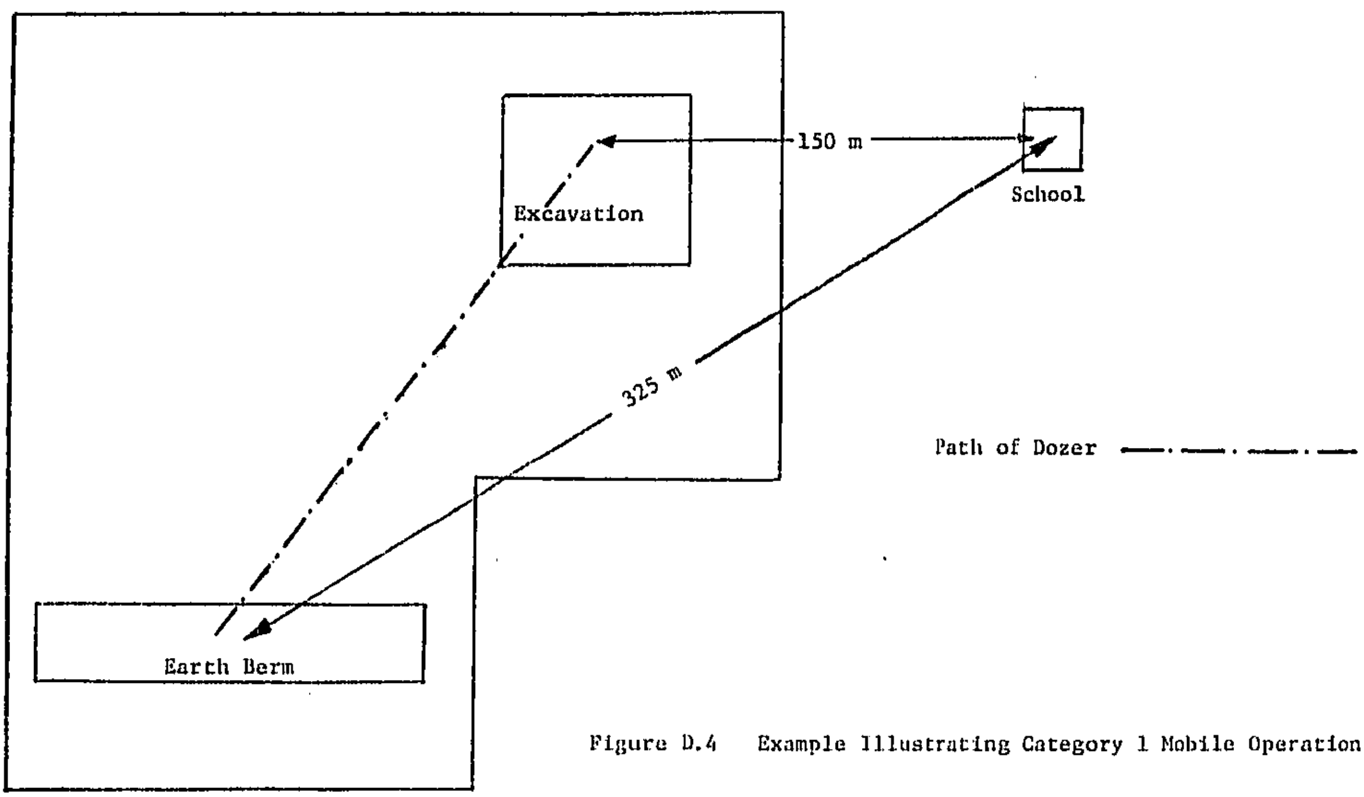


Figure D.4 Example Illustrating Category 1 Mobile Operation

NOT TO SCALE

D-4.2 Mobile Operation Category 2: A grader is used to prepare a parking lot for paving. It moves back and forth on the site covering the area shown in Figure D.5. To calculate the noise exposure at the noise sensitive land use area, the grader is assumed to be located at the center of the parking lot area at all times. Note that the "acoustic center" of the grader's path, in this case, is equal to the geometric center of the area it travels across. The distance from source to the noise sensitive land use area is 300 meters, as indicated in Figure D.5.

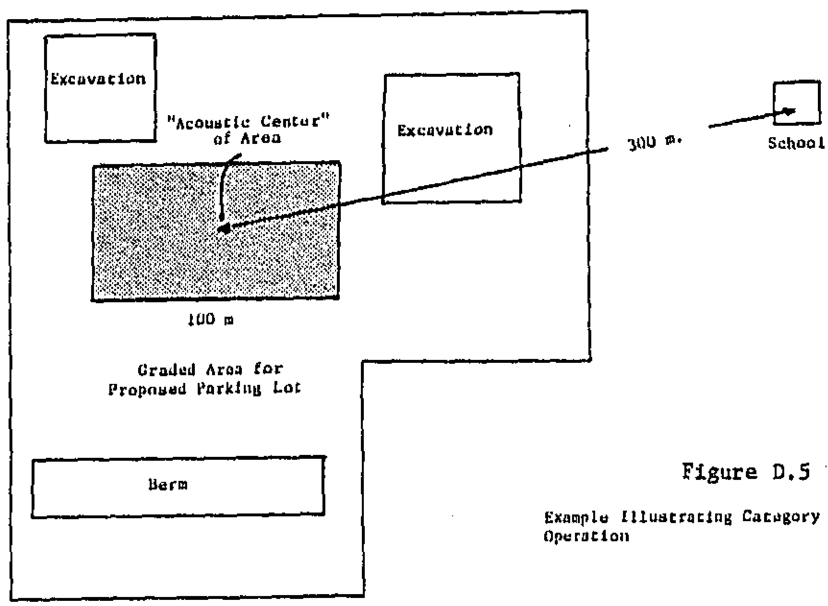


Figure D.5

Example Illustrating Category 2 Mobile Source Operation

NOT TO SCALE

D-5 Construction Activity Worksheets "B" and "C"

Entries for the crawler tractor in Example D-4.1 are made on Construction Activity Worksheets "B" and "C" as shown in Figures D.6 and D.7. The usage factor was calculated in the above example D-4.1.

Figure D.6 Construction Activity Worksheet "B" - An Example

Project G— S— Offices Phase Excavation Construction Period 8/76-9/76 Hours of Construction 8

(1) Activity Description	(2) Equipment Type	(3) L_A (dB)	(4) Dist. (M)	(5) L_A @ 15m (dB)	(6) # of Units	(7) Unit Adjustment	(8) Usage Factor	(9) Usage Factor Adjustment	(10) L_{eq} @ 15 m (dB)	(11) Total L_{eq} @ 15 m (dB)
① Excavation of Building Found.	Dozer	87	15	87	1	0	.315	-5	82	82
② Construction of Berm	Dozer	87	15	87	1	0	.35	-4	83	83

Figure D.7 Construction Acitity Noise Worksheet "C" - An Example

Project G—— S—— Offices Phase Excavation Construction Period 8/76 - 9/76

(1) Noise Sensitive Land Use Area	(2) Construction Activity	(3) Distance	(4) Activity L_{eq} @ 15m (dB)	(5) Distance Adjustment	(6) Const. L_{eq} (dB)	(7) Total Const. Contribution L_{eq} (dB)	(8) Background Ambient L_{eq} (dB)	(9) Est. Total Ambient Noise Level L_{eq} (dB)
School	Excavation of Building Found.	150	82	- 20	62			
	Berm Construction	325	83	- 26.7	56.3	63	54	63.3

D-6 Section 5.3 - Computation of the 24-Hour Average Sound Level, $L_{eq(24)}$, and the Day/Night Average Sound Level, L_{dn}

Illustrative examples of the computation of $L_{eq(24)}$ and L_{dn} are presented below. The basic equations and a scientific calculator or the Construction Worksheet "D" (Figure D.8) and graphs may be used to complete the calculation. Table D.3 gives the results of hourly measurements of the preconstruction ambient sound levels and the estimated noise levels emitted from a construction site used in the examples.

D-6.1 Computation of $L_{eq(24)}$ and L_{dn} Using the Equations

If hourly measurements, such as those in Table D.3, are available, the following equation may be used:

$$L_{eq(24)} = 10 \log_{10} [\frac{1}{24} \times \sum_{i=1}^{24} 10^{L(i)/10}]$$

where $L_{(i)}$ is the L_{eq} for each of the 24 hours of a day.

Inserting the values from Table D.3 into the equation:

$$L_{eq(24)} = 10 \log_{10} [1/24 \times (10^{6.8}+10^{6.8}...10^{4.8}+10^{4.9})]$$

$$= 10 \log_{10} [1/24 \times 6.3 \times 10^{7}]$$

$$= 10 \log_{10} [2.6 \times 10^{6}] = \underline{64 \text{ dB}}$$

Adding 10 dB to the nighttime (2200-0700) hourly sound level measurements before insertion into the above equation permits the calculation of the Day/Night Sound Level, L_{dn}.

If hourly measurements are not available, and instead the daytime (0700-2200) and nighttime (2200-0700) average sound levels, L_d and L_n, and the estimated equivalent sound level for construction activity, are available, another equation is used. The equation as presented in Section 5.3 is:

$$L_{eq(24)} = 10 \log_{10} [\frac{1}{24} \times (z \times 10^{L_{eq(z)}/10} + (15-z) \times 10^{L_d/10} + 9 \times 10^{L_n/10})]$$

where z is the number of hours of construction activity, and

$L_{eq(z)}$ is the estimated equivalent sound level during construction activity.

If L_d = 62 dB, L_n = 51 dB and the construction activity L_{eq} = 68 dB for eight hours, the equation can be solved in the following steps:

$$L_{eq(24)} = 10 \log_{10} [1/24 \times (8 \times 10^{6.8} + 7 \times 10^{6.2} + 9 \times 10^{5.1})]$$

$$= 10 \log_{10} [1/24 \times (5.1 \times 10^7 + 1.1 \times 10^7 + 0.1 \times 10^7)]$$

$$= 10 \log_{10} [1/24 \times (6.3 \times 10^7)]$$

$$= 10 \log_{10} (2.6 \times 10^6) = \underline{64 \text{ dB}}$$

D-6.2 Computation of $L_{eq(24)}$ and L_{dn} Using Worksheet "D"

The 24-hour Avergage Sound Level can be calculated with the Construction Worksheet "D" given in Figure D.8 using the following steps:

1) Count the number of hours at each sound level. Enter these values, the counts, in Column B next to its corresponding sound level located in Column A.

2) Multiply the counts in Column B by the corresponding "Relative Sound Energy" in Column C and enter the results in Column D.

3) Add all values in Column D to determine Sum D, and divide Sum D by 24.

4) Locate the value in Column C that is approximately equal to Sum D/24. The corresponding value in Column A is equal to the average sound level, $L_{eq(24)}$ for this period.

Figure D.9 is a sample worksheet using the hourly sound level measurements in Table D.3.

Calculation of the Day/Night Average Sound Level using Construction Worksheet "D," Figure D.8, is very similar to the method for calculating the 24-hour equivalent sound level. The only difference is that sound levels for the nighttime hours (2200-0700) are penalized by adding 10 dB to them before counting the values. A sample worksheet for the computation of L_{dn} using the hourly sound level measurements in Table D.3 is presented in Figure D.10.

TABLE D.3 EXAMPLES OF HOURLY SOUND LEVELS FOR A CONSTRUCTION SITE

Time of Day	Hourly Average Sound Levels dB
0700-0800	*68*
0800-0900	*68*
0900-1000	*68*
1000-1100	*68*
1100-1200	58
1200-1300	*68*
1300-1400	*68*
1400-1500	*68*
1500-1600	*68*
1600-1700	65
1700-1800	66
1800-1900	62
1900-2000	60
2000-2100	58
2100-2200	55*
2200-2300	54*
2300-2400	52*
2400-0100	52*
0100-0200	50*
0200-0300	48*
0300-0400	48*
0400-0500	48*
0500-0600	48*
0600-0700	49*

NOTE: Italics indicate construction sound levels.

*10-decibel penalties are added to these nighttime values for the computation of L_{dn}.

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

Sum D ________ Sum D/24 ________

$L_{eq(24)}$ ________ or L_{dn} ________

Figure D.8 Construction Worksheet "D"

A SOUND LEVEL dB	B COUNT		C RELATIVE SOUND ENERGY		D RELATIVE TOTAL SOUND ENERGY
100		x	100,000	=	
99		x	79,400	=	
98		x	63,100	=	
97		x	50,100	=	
96		x	39,800	=	
95		x	31,600	=	
94		x	25,100	=	
93		x	20,000	=	
92		x	15,900	=	
91		x	12,600	=	
90		x	10,000	=	
89		x	7,940	=	
88		x	6,310	=	
87		x	5,010	=	
86		x	3,980	=	
85		x	3,160	=	
84		x	2,510	=	
83		x	2,000	=	
82		x	1,590	=	
81		x	1,260	=	
80		x	1,000	=	
79		x	794	=	
78		x	631	=	
77		x	501	=	
76		x	398	=	
75		x	316	=	
74		x	251	=	
73		x	200	=	
72		x	159	=	
71		x	126	=	
70		x	100	=	
69		x	79.4	=	
68	8	x	63.1	=	504.8
67		x	50.1	=	
66	1	x	39.8	=	39.8
65	1	x	31.6	=	31.6
64		x	25.1	=	
63		x	20.0	=	
62	1	x	15.9	=	15.9
61		x	12.6	=	
60	1	x	10.0	=	10.0
59		x	7.94	=	
58	2	x	6.31	=	
57		x	5.01	=	
56		x	3.98	=	
55	1	x	3.16	=	3.16
54	1	x	2.51	=	2.51
53		x	2.00	=	
52	2	x	1.59	=	3.18
51		x	1.26	=	
50	1	x	1.00	=	1.00
49	1	x	.794	=	.79
48	4	x	.631	=	2.52
47		x	.501	=	
46		x	.398	=	
45		x	.316	=	
44		x	.251	=	
43		x	.200	=	
42		x	.159	=	
41		x	.126	=	
40		x	.100	=	
39		x	.079	=	
38		x	.063	=	
37		x	.050	=	
36		x	.040	=	
35		x	.032	=	

Sum D 627.9   Sum D/24 26.2

$L_{eq(24)}$ 64   or L_{dn} ______

Figure D.9 Sample Worksheet "D" for Calculation of $L_{eq(24)}$

A SOUND LEVEL dB	B COUNT		C RELATIVE SOUND ENERGY		D RELATIVE TOTAL SOUND ENERGY
100		x	100,000	=	
99		x	79,400	=	
98		x	63,100	=	
97		x	50,100	=	
96		x	39,800	=	
95		x	31,600	=	
94		x	25,100	=	
93		x	20,000	=	
92		x	15,900	=	
91		x	12,600	=	
90		x	10,000	=	
89		x	7,940	=	
88		x	6,310	=	
87		x	5,010	=	
86		x	3,980	=	
85		x	3,160	=	
84		x	2,510	=	
83		x	2,000	=	
82		x	1,590	=	
81		x	1,260	=	
80		x	1,000	=	
79		x	794	=	
78		x	631	=	
77		x	501	=	
76		x	398	=	
75		x	316	=	
74		x	251	=	
73		x	200	=	
72		x	159	=	
71		x	126	=	
70		x	100	=	
69		x	79.4	=	
68	8	x	63.1	=	504.8
67		x	50.1	=	
66	1	x	39.8	=	39.8
65	2	x	31.6	=	63.2
64	1	x	25.1	=	25.1
63		x	20.0	=	
62	3	x	15.9	=	15.9
61		x	12.6	=	
60	2	x	10.0	=	20.0
59		x	7.94	=	
58	6	x	6.31	=	37.86
57		x	5.01	=	
56		x	3.98	=	
55	1	x	3.16	=	
54		x	2.51	=	
53		x	2.00	=	
52		x	1.59	=	
51		x	1.26	=	
50		x	1.00	=	
49		x	.794	=	
48		x	.631	=	
47		x	.501	=	
46		x	.398	=	
45		x	.316	=	
44		x	.251	=	
43		x	.200	=	
42		x	.159	=	
41		x	.126	=	
40		x	.100	=	
39		x	.079	=	
38		x	.063	=	
37		x	.050	=	
36		x	.040	=	
35		x	.032	=	

Sum D 740.9 Sum D/24 30.9

$L_{eq(24)}$ ________ or L_{dn} 65

Figure D.10 Sample Worksheet "D" for Calculation of L_{dn}

D-7 Chapter 7.0 - Noise Reduction Due to a Barrier

This example illustrates the method used to predict the reduction in sound level due to a barrier as described in Section 7.3.

A crawler tractor produces an A-weighted sound level of 75 dB at a receiver 15 meters (50 ft) away. A barrier is to be erected between the crawler tractor and the receiver as shown in Figure D.11a. The barrier is 10.5 meters (35 ft) from the receiver and extends 1.5 meters (5 ft) above the crawler tractor.

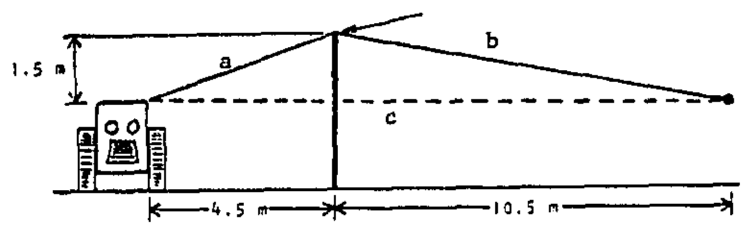
The A-weighted sound level reduction is determined as follows:

1) Determine the path length difference (i.e., the difference between the straight line path from the tractor to the receiver and the path from the tractor to the top of the barrier, then to the receiver).

2) Locate this path difference, .35 meter (1 ft) on the horizontal axis of the graph in Figure D.11b.

3) Draw a vertical line from this location to the curve.

4) Draw a horizontal line from the curve to the vertical axis. The intersection of this horizontal line and the vertical axis indicates the value of the reduction in sound level due to the barrier, about 14 dB.



a = 4.75 meters
b = 10.6 meters
c = 15.0 meters
Path difference m = 4.75 + 10.6 - 15.0 = 0.35 meters

Figure D.11a Position of Barrier, Noise Source and Receiver

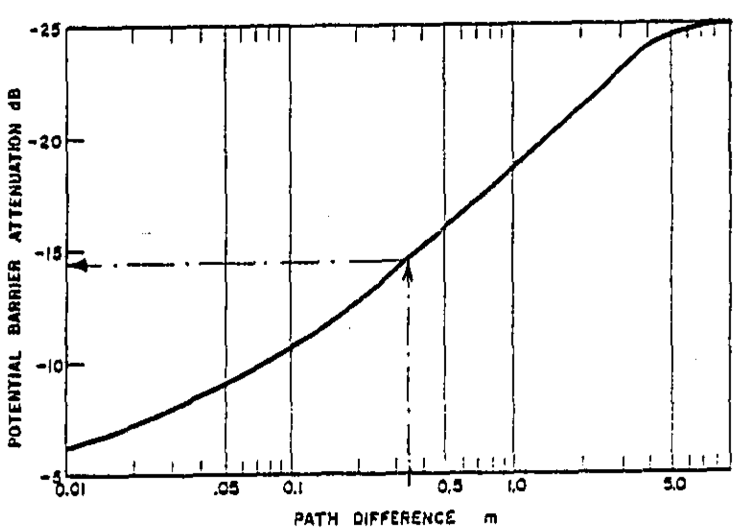


Figure D.11b A-Weighted Noise Reduction Due to a Barrier as a Function of the Path Difference in Meters

APPENDIX E

CURRENT STATE AND LOCAL NOISE REGULATIONS

The reader should be aware of the numerous state and local ordinances which must be considered in assessing impact or compliance. The EPA report, "Noise Source Regulation in State and Local Noise Ordinances," 550/9-75-020, 1975, lists land use noise regulations for over 54 local jurisdictions, and lists approximately 100 more with enabling legislation permitting the development of noise regulations. A summary of the type of regulation and the sound level limits are provided in tables contained in this Appendix.

The user of this manual is strongly encouraged to obtain noise regulations for the local jurisdiction in which the proposed project is to be constructed and to determine how they apply to the proposed project. A careful review of these documents will provide the proper nomenclature, measurement procedure, and other information necessary to assess compliance with local criteria.

TABLE E.1

STATE LAND USE NOISE REGULATIONS

(All levels in A-weighted dB unless noted otherwise)

Criteria / State	Land Usage	Effective Date	Maximum Continuous Noise L_d	L_n	Max. Noise Level L max	Max. Impulse Noise	Comment
1. California	Large Airports	B 1-1-76			80		Existing
		A 1-1-76			75		Existing
		A 1-1-81			70		Existing
		A 1-1-86			65		Existing
	Small Airports	B 1-1-76			70		Existing
		A 1-1-76			65		Existing
	New Airports				65 CNEL		
2. Colorado			7am/7pm	7pm/7am			
	Residential	N/S	55	50			Exempts A/C
			L_{25} 65	N/A			Exempts A/C
	Commercial	N/S	60	55			Exempts A/C
			L_{25} 70	N/A			Exempts A/C
	Light Indust.	N/S	70	65			Exempts A/C
			L_{25} 80	N/A			Exempts A/C
	Industrial	N/S	80	75			Includes rail-road right-of-ways.
			L_{25} 90	N/A			
3. Illinois			7am/10pm	10pm/7am		7am/10pm 10pm/7am	
	Class A (Resident)	8-9-73	*55	*45		50 45	From Class A
			*55	*45		50	From Class B
			*61	*51		57	From Class C
	Class B (Commercial)	8-9-73	*55	N/S		50 45	From Class A
			*61	N/S		57	From Class B
			*66	N/S		57	From Class C

A/C – Aircraft; RR – Railroad; N/A – Not Applicable;
A/P – Airports; N/S – Not Specified; A – After; B – Before

*Estimated from Octave Band SPL (dB) data

TABLE E.1 (continued)

STATE LAND USE NOISE REGULATIONS
(All levels in A-weighted dB unless noted otherwise)

Criteria / State	Land Usage	Effective Date	Maximum Continuous Noise Ld	Maximum Continuous Noise Ln	Max. Noise Level L max	Max. Impluse Noise		Comment
3. Illinois (Cont.)			7am/10pm	10pm/7am		7am/10pm	10pm/7am	
	Class C (Industrial)	8-9-73	*61	N/S		56	46	From Class A
			*61	N/S		61		From Class B
			*70	N/S		65		From Class C
4. New Jersey			7am/10pm	10pm/7am				
	Residential	1-18-74	65	55		80		Also Octave
		1-1-76		50		80		Band Levels
	Commercial				65	80		Also Octave Band Levels
5. Oregon			7am/10pm	10pm/7am				Includes operation of all motor vehicles.
	All Private Property		60	55				

A/C – Aircraft; RR – Railroad;
A/P – Airports; N/S – Not Specified; A – After; B – Before
*Estimated from Octave Band SPL (dB) data

TABLE E.2

SUMMARY OF LOCAL JURISDICTIONS WITH CONSTRUCTION NOISE REGULATIONS

Community	Construction Site Regulation	Construction Equipment		Notes
		Operation	Sale	
Baltimore, Md.	X			exempts emergency work
Boston, Mass.			X	includes agricultural and commercial equipment
Broward Co., Fla.	X			
Chicago, Ill.			X	includes agricultural and commercial equipment
Cleveland, Ohio	X	X		
Colorado Springs, Col.			X	excludes pile drivers
Cook Co., Ill.			X	includes agricultural and commercial equipment
Des Plaines, Ill.			X	includes agricultural and commercial equipment
Fort Collins, Col.	X			
Framington, Conn.	X	X		
Grand Rapids, Mich.			X	includes agricultural and commercial equipment
Helena, Mont.	X			
Kalamazoo, Mich.	X			

TABLE E.2 (continued)

Community	Construction Site Regulation	Construction Equipment Operation	Construction Equipment Sale	Notes
King Co., Wash.		X		includes agricultural and commercial equipment
Lakewood, Calif.	X			uses industrial zoning levels
Louisville, Ky.			X	
Madison, Wis.		X		includes farm tractors
Minneapolis, Minn.	X			
Montgomery Co., Md.	X			
New York, N.Y.		X	X	includes air compressors and pavement breakers
Newark, N.J.		X		air compressors and pavement breakers only
Palo Alto, Calif.	X	X		
Pasadena, Calif.	X			
Rochester, Minn.	X			
Saint Paul, Minn.	X			
Salt Lake City, Utah			X	includes agricultural and commercial equipment
San Diego, Calif.	X			

TABLE E.2 (continued)

Community	Construction Site Regulation	Construction Equipment Operation	Construction Equipment Sale	Notes
San Francisco, Calif.	X	X		exempts impact tools and emergency construction
Savannah, Ga.		X		exempts impact tools
Seattle, Wash.	X			
Toledo, Ohio		X		exempts emergency construction
Colorado, State of	X			uses industrial zoning sound levels
New York, State of		X		only near multiple dwellings

TABLE E.3

SUMMARY OF LOCAL JURISDICTIONS WITH LAND USE REGULATIONS

Community	dB*	Octave Band	Other	Notes
Amarillo, Tex.		X		old octave band frequencies
Anaheim, Calif.	X			general regulation- not by zones
Baltimore, Md.	X			corrections for time duration
Bellevue, Wash.	X			
Boston, Mass.		X		
Broward Co., Fla.	X			
Colorado Springs, Colo.	X			
Columbia, S.C.		X		old octave band frequencies
Cook Co., Ill.	X	X		
Coral Gables, Fla.		X		
Chicago, Ill.	X	X		
Dayton, Ohio		X		
Fremont, Calif.			X	maximum levels in (20-300Hz, 300-2400, > 2400)
Grand Rapids, Mich.	X	X		
Honolulu, Hawaii		X		old octave band frequencies
Inglewood, Calif.	X			
Kansas City, Mo.		X		old octave band frequencies
Kalamazoo, Mich.	X			includes railroad right-of-way
Lakewood, Colo.			X	maximum levels in dB
Los Angeles, Calif.	X			
Las Vegas, Nev.			X	maximum levels in dB
Madison, Wisc.			X	maximum levels in dB
Mason Co., Wash.			X	maximum levels in dB
Miami, Fla.		X		old octave band frequencies

* A-Weighted Sound Level

Table E.3 (continued)

SUMMARY OF LOCAL JUISDICTIONS WITH LAND USE REGULATIONS

Community	dB*	Octave Band	Other	Notes
Milwaukee, Wisc.	X			
Minneapolis, Minn.	X			
New Orleans, La.		X		old octave band frequencies
Niskayuna, N.Y.			X	maximum level in dB
Oakland, Calif.	X			
Pawtucket, R.I.	X			
Pasadena, Calif.			X	maximum levels in dB; time corrections
Pontiac, Mich.			X	maximum levels in dB
Orlando, Fla.		X		old octave band frequencies
Racine, Wisc.			X	maximum levels in dB
Richland, Wash.		X		old octave band frequencies
Salt Lake City, Utah	X			corrections for time duration
San Diego, Calif.	X			
San Francisco Calif.	X			
Silverton, Ore.		X		old octave band frequencies
Springfield, Mass.		X		old octave band frequencies
Tacoma, Wash.		X		old octave band frequencies
Torrance, Calif.			X	maximum levels in dB
Warwick, R.I.		X		old octave band frequencies
Westland, Mich.			X	maximum levels in dB
Winston Salem, N.C.		X		old octave band frequencies
Virginia Beach, Va.		X		old octave band frequencies

*A-Weighted Sound Level

TABLE E.4

SUMMARY OF LOCAL JURISDICTION
INTRUSIVE NOISE SOURCE REGULATIONS
(All levels in A-weighted dB unless noted otherwise)

Criteria / Jurisdiction	Noise Source Description	Operations Max. Level	Operations Meas. Dist.	New Sales Eff/Mfg Date	New Sales Accept. Level	Comments
1. Arizona, Tucson	H,W,C	70dBC	50 ft.			
2. California, a) Burbank	M/E	50 60 70 75				Residential–10 pm-7 am Residential–7 am-10 pm Commercial–anytime All Other–anytime
b) Downey	Outdoor E/E	< 5	P/L			Above Ambient
c) Inglewood	H,W,C, M/E	<90 <5	300 ft. P/L			 Above Ambient
d) San Diego	Outdoor E/E H, W,C Refuse Vehicle Refuse Vehicle Power Model Vehicle	<90 89 86 80 < 5	50 ft. 300 ft. 50 ft 50 ft.			10 sec. duration/10 min. A 12-31-73 A 12-31-77 Above Zoning Ambient
e) San Francisco	Refuse Vehicle Power Model Vehicle H,W,C	80 75 85 80 <75	50 ft. 50 ft. 50 ft. 50 ft. P/L			A 3-18-73 A 3-18-78 A 3-18-73 A 3-18-76
f) Torrance	H,W,C E/E; M/E	<90 < 5	300 ft. P/L			 Above Ambient
3. Colorado, Lakewood	L/R/E	80	25 ft.			
4. Florida, a) Broward Co.	Outdoor E/E	80 75	25 ft. 25 ft.			Industrial Area Business/Commercial Prohibited Residential

H–Horns; W–Whistles; C–Claxons; M/E–Fans, Air Conditioners, Etc.; P/L–Property Line; E/E–Electronic Equipment; L/R/E–Light Residential Equipment

TABLE E.4 (continued)

SUMMARY OF LOCAL JURISDICTION INTRUSIVE NOISE SOURCE REGULATIONS

(All levels in A-weighted dB unless noted otherwise)

Criteria / Jurisdiction	Noise Source Description	Operations		New Sales		Comments
		Max. Level	Meas. Dist.	Eff/Mfg Date	Accept. Level	
4. Florida (Cont.) b) Coral Gables	M/E	<60	15 ft.			Or 15 ft. from P/L
c) Hollywood	M/E	<60	P/L or 15 ft.			Whichever is greater
5. Illinois, a) Chicago	L/R/E		50 ft. 50 ft. 50 ft.	A 1-1-72 A 1-1-75 A 1-1-78	74 70 65	
b) Cook County	L/R/E		50 ft. 50 ft. 50 ft.	B 1-1-75 A 1-1-75 A 1-1-78	74 70 65	
c) Marengo	M/E M/E H E/E	< 5 < 5dB <89 <15 <50	 300 ft. P/L			Above Ambient Any Octave Band re Amb. Above Ambient Radio/TV in Residential Z.
6. Indiana, Indianapolis	E/E	<100 dBC				
7. Massachusetts, Boston	L/R/E		50 ft.	A 1-1-72 A 1-1-75 A 1-1-78	74 70 65	
8. Michigan, Grand Rapids	L/R/E		50 ft. 50 ft. 50 ft.	A 7-1-73 A 1-1-75 A 1-1-80	88 86 80	

H–Horns; M/E–Fans, Air Conditioners, Etc.; P/L–Property Line; E/E–Electronic Equipment; L/R/E–Light Residential Equipment

TABLE E.4 (continued)

SUMMARY OF LOCAL JURISDICTION INTRUSIVE NOISE SOURCE REGULATIONS
(All levels in A-weighted dB unless noted otherwise)

Criteria / Jurisdiction	Noise Source Description	Operations Max. Level	Operations Meas. Dist.	New Sales Eff/Mfg Date	New Sales Accept. Level	Comments
9. New York, New York City	H,W,C	75	25 ft.	1974	75	
	Emerg. Vehicles	90	50 ft.			
	M/E	45	3 ft.			Inside nearest open window of dwelling affected
	Refuse Vehicle		10 ft.	A 12-31-74	70	
10. Utah, Salt Lake City	L/R/E		50 ft.	A 1-1-73	74	
			50 ft.	A 1-1-75	70	
			50 ft.	A 1-1-78	65	
	H,W,C	<90	50 ft.			Unless danger signal
11. Wisconsin, a) Madison	L/R/E <5hp	70	50 ft.			
	L/R/E – 5-20hp	78	50 ft.			
	L/R/E >20hp	88	50 ft.			
b) Milwaukee	M/E (Air Cond. in Residential Area)	D 60.5 N 60.5				Specified in octave bands Violation if >5dB any band
c) Racine	Air Conditioning Residential Area	< 5				Over ambient in sleeping room of adjacent dwelling.
	E/E	< 5				Above ambient in any adjacent dwelling

H–Horns; W–Whistles; C–Claxons; M/E–Fans, Air Conditioners, Etc.; E/E–Electronic Equipment; L/R/E–Light Residential Equipment; D–Day, N–Night

TABLE E.5

MISCELLANEOUS NOISE REGULATIONS

Aspen, Colorado Boulder, Colorado }	Specifies a limit of 80 dB, A-weighted, at 25 ft from noise source or 25 ft from the property line on which the noise source is located.
Clifton, New Jersey	Any source of sound is in violation if it is more than 10 dB above the ambient in daytime (7 am to 10 pm) and 5 dB above the nighttime (10 pm to 7 am) ambient.
Glenville, New York	A source cannot exceed 70 dB at the property line.
Indianapolis, Indiana	General limit of 115 dB, C-weighted.
Marengo, Illinois	Less than 70 dB, A-weighted, or 70 dB in any octave band within 200 ft of a school, hospital, or church.
Pocatello, Idaho	General regulation - less than 92 dB, A-weighted, at 20 ft.

Enclosed Places of Entertainment

	A-Weighted Sound Levels	
Lakewood, California	8 hrs - 90 dB	2 hrs - 100 dB
	6 hrs - 92 dB	1 hr - 105 dB
	4 hrs - 95 dB	30 min - 110 dB
	3 hrs - 97 dB	15 min - 115 dB
Salt Lake City, Utah	Less than 100 dB, A-weighted, or provide a warning sign.	