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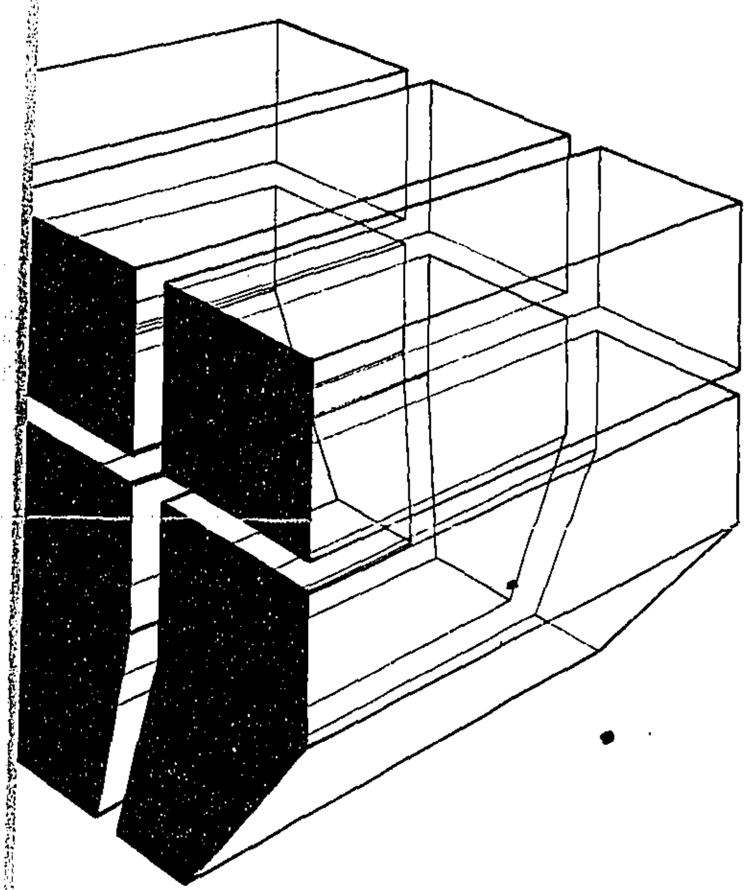
INTERIM REPORT N-3
July 1976
Construction Site Noise: Specification and Control

COST EFFECTIVENESS OF ALTERNATIVE NOISE REDUCTION METHODS FOR CONSTRUCTION OF FAMILY HOUSING



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The objective of this work was to obtain the cost/benefit relationships associated with new, quieter construction equipment and/or construction process modification. A workable cost/benefit model was developed for this purpose,* but a significantly

*P. Schomer and B. Homans, *Construction Noise: Specification, Control, Measurement, and Mitigation*, Technical Report E-53/ADA009668 (Construction Engineering Research Laboratory [CERL], April 1975).

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larger data base must be acquired to apply this model. This initial work effort concentrated on one type of construction—multifamily housing construction. Significant findings included:

(1) Construction site boundary noise can be significantly reduced by a number of currently available techniques; (2) the use of two quieter machines of lower capacity in lieu of one standard machine not only costs more but is of questionable noise control value, since the total noise exposure is sometimes greater from two machines than from one larger machine; (3) cost/benefit relationships for estimating purposes can be provided only after a significantly larger data base is obtained.

EXECUTIVE SUMMARY

This report is the second of a series of construction noise programs whose principal objectives are to develop and evaluate equipment usage, operational methods, or physical means to attenuate the noise of construction sites to acceptable levels and to describe quantitatively the cost associated with these reductions. The first report, *Construction Noise: Specification, Control, Measurement, and Mitigation*, generally described the problem, as well as a number of accepted measurement techniques and current state-of-the-art mitigative measures.

Construction noise reduction is generally expensive. New, quieter equipment will cost a contractor more to purchase or rent. Mitigative measures are also costly, because they increase equipment installation costs (in the case of barriers) or slow the construction process and raise labor and operating costs.

The objective of this phase of the continuing research was to obtain the cost/benefit relationships associated with new, quieter equipment or construction process modification.

Cost/benefit analysis is a feasible estimating tool for construction cost estimators, but significant further investigation is required before definitive, non-site-specific relationships are available. A significantly larger data base must be acquired that will relate the cost to quieted equipment usage and construction processes for broad construction areas and phases. It is desirable to provide Army construction estimators with tables, nomograms, and equations that describe the cost/sound-level relationships for construction phases: for example, ground clearing for family housing or landscaping for barracks construction. Currently, data are not available to provide this information definitively.

To determine the feasibility of developing cost/benefit relationships, the Construction Engineering Research Laboratory (CERL) designed a program to measure family housing construction noise levels, determine feasible construction equipment noise reduction levels and associated costs, and study feasible construction process modification and associated costs. The Fort Hood, Texas, 1000-unit residential housing construction site was chosen for this study; family housing was chosen because it comprises most of the construction performed by the military.

Construction site noise models were compared with measured noise data and used to estimate the effect on off-site noise of equipment and process changes on-site. Manufacturers of construction equipment used at Fort Hood were questioned about present noise levels of their equipment, feasible future quieted noise levels, and associated costs. Corps of Engineers representatives and Fort Hood construction contractors provided details about the manpower, equipment, construction methods, and costs for the Fort Hood residential housing construction.

The principal conclusions drawn from the results of this study are:

1. Construction sound levels can be reduced off-site by using quieter construction equipment or process noise control, such as barriers.

2. The cost at Fort Hood for quieter equipment would be approximately $800 per decibel per piece of equipment. To achieve desirable levels at a particular location at Fort Hood during ground clearing, approximately $10,000 would have to have been added to equipment cost.

3. Use of two quieter machines of lower capacity in lieu of one standard machine not only costs more, but is of questionable noise control value. The total noise exposure may be significantly longer, thus negating the somewhat lower noise levels.

4. Cost/benefit relationships can be provided for construction cost estimating purposes only after a significantly larger data base is obtained. Noise level versus engine power, costs versus noise level, process costs versus noise level, and off-site noise level predictive models can be refined and provided in a useful format for field use by Corps of Engineers and contractor personnel.

FOREWORD

The U.S. Army Construction Engineering Research Laboratory (CERL) conducted this study for the Directorate of Military Construction, Office of the Chief of Engineers, under Project 4A762720A896, "Pollution Control Technology"; Task 02, "Environmental Quality Technology for Operation and Construction of Military Facilities"; Work Unit 002, "Construction Site Noise: Specification and Control."

The OCE Technical Monitor was Mr. D. Spivey.

The report is the result of a joint effort by Dr. Fred Kessler of Dames and Moore, Dr. Robert Chanaud of Engineering Dynamics Inc., and Dr. P. Schomer, Mr. B. Homans and Mr. J. McBryan of CERL. Dr. Kessler produced a major portion of the draft and Dr. Schomer performed most of the coordination and editing.

Dr. R. K. Jain is Acting Chief of the CERL Environmental Division (EN), and Dr. P. Schomer is Leader of the EN Acoustics Team.

COL M. D. Remus is Commander and Director of CERL, and Dr. L. R. Shaffer is Deputy Director.

CONTENTS

TABLES

TABLES (cont.)

TABLES (cont.)

TABLES (cont.)

FIGURES

COST EFFECTIVENESS OF ALTERNATIVE NOISE REDUCTION METHODS FOR CONSTRUCTION OF FAMILY HOUSING

1 INTRODUCTION

Background

Noise produced by the construction of various U.S. Army facilities has caused private complaints, and it can be assumed that the number of complaints received is indicative that many other people, both on-post and off-post, are annoyed by the noise.[1]

The U.S. Environmental Protection Agency (EPA) is investigating community noise, its sources, and responses to it. Since equipment used in construction has been identified as a principal community noise source having the potential to degrade the public health and welfare,[2,3] the EPA has initiated a program to develop regulations limiting noise from equipment identified as a major noise source.

Regulating equipment noise at the equipment's initial point of sale is one of a few effective means to control construction site noise. Other methods include modifying the construction process and activity at the site, and using a curfew to restrict the time during which construction can be accomplished. However, these noise control methods may result in an added expense to the owner (in this case, the U.S. Army). The Corps of Engineers, as one of the world's largest construction contractors, is interested in feasible methods of construction site noise control and associated costs.

The Corps' Military Construction Division is charged with supporting the Districts and Divisions which act as the contracting bodies for the construction of permanent facilities. To support these construction activities, the Corps of Engineers sponsors development research programs in the area of pollution prevention, abatement, and control. Part of this pollution research concerns construction noise and its control. CERL Technical Report E-53[4] tells Districts how to limit construction noise via specification, and includes information on: 1) measurements which verify compliance with contract regulations; 2) methods to mitigate noise; and 3) background of various laws, regulations, and case histories. One factor not covered in E-53, however, is means of determining the cost to the Corps of Engineers of the various noise reduction programs.

Purpose

The purpose of this report is to quantify the costs associated with noise reduction at construction sites in order to create cost vs. benefit construction site noise control. This study is a first attempt at such a quantification and, as such, concentrates on the maximum element currently constructed by the military—family housing. Other areas to be studied in the future include hospital additions, new hospitals, and barracks construction, areas that are programmed to be major parts of military construction over the next 5 years. Of lower priority are such areas as field shops, which usually are not located near noise-sensitive areas.

Approach

In presenting some of the cost/benefit relationships associated with construction equipment noise control, this report discusses in detail feasible changes in construction processes and activities that have high potential for noise control. For these discussions, the construction site is considered to be a noise source made up of numerous individual contributors to construction site noise. Construction activities may be grouped into four major categories:[5,6]

1. Residential
2. Nonresidential (office and commercial)
3. Industrial
4. Public works (including road building).

At a given time during the construction process, an individual activity or group of activities called

[1] P. Schomer and B. Homans, *Construction Noise: Specification, Control, Measurement, and Mitigation*, Technical Report E-53/ADA009668 (Construction Engineering Research Laboratory [CERL], April 1975).

[2] *Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare With an Adequate Margin of Safety*, 550/9-74-004 (U.S. Environmental Protection Agency [USEPA], March 1974).

[3] "Identification of Products of Major Sources of Noise," *Federal Register*, Vol 39, No. 121 (June 21, 1974).

[4] P. Schomer and B. Homans.

[5] *Noise From Construction Equipment and Operations, Building Equipment, and Home Appliances*, NTID 300.1 (USEPA, December 31, 1971).

[6] *Background Document for Proposed Portable Air Compressor Noise Emission Regulations*, 550/9-74-016 (USEPA, October 1974).

phases may be taking place. These include:

1. Demolition
2. Rough ground clearing
3. Utilities
4. Excavation
5. Foundation
6. Above grade
7. Landscaping.

Each of the above contains noise-producing elements. A discussion of the general construction site noise control problem is very complex and beyond the scope of this study. Instead, residential housing as an element of the total problem has been investigated and the results are reported here. As additional investigations (by the U.S. Army, the federal EPA, the construction industry, and others) are conducted and results promulgated, the cost benefit of construction noise control (in general) will become known.

To keep within budgetary and time constraints, residential housing at Fort Hood, Texas, was used for the cost/benefit model. Fort Hood was selected due to the large number of construction activities being conducted simultaneously at this large site.

Five phases of construction were in progress at Fort Hood: clearing, excavation, foundation, framing, and landscaping. Numerous types of construction equipment, discussed in subsequent sections, were being used.

The study consisted of four major segments.

1. Noise Survey. A site visit and noise survey were conducted at the Fort Hood construction site. Locations simulating site boundary points (residential neighbors) were selected. Noise levels were recorded both manually and on tape and were later analyzed in a laboratory. The noise of individual construction equipment was measured while it was being used. Usage factors and the fraction of time during which equipment was noisiest were determined.

2. Construction Process Noise Control. Methodology modifications were considered for the various construction phases. Each operation was studied separately and methods were tabulated and compared. The cost of each operation or method and its estimated sound levels were obtained. Construction phases were considered in terms of noise level, cost, noise reduction techniques, and noise reduction costs.

3. Noise Control. A construction site noise model was adapted for use and was evaluated by using actual field noise data. The model required individual equipment sound levels and usage factors to compute site noise levels. Information relating to future equipment sound levels and processes was used in the model to estimate construction site noise reductions, a benefit which was then compared to the cost of achieving equipment and process noise reduction.

4. Cost-Benefit Analysis. Site noise reductions resulting from equipment noise and process noise controls were quantified when possible and compared with the costs of respective abatement techniques.

2 FORT HOOD SOUND LEVEL DATA ACQUISITION AND ANALYSIS

The site selected for this cost/benefit analysis study was the ongoing construction of 1000 family housing units at Fort Hood, Texas. The construction at this base is carried out in five major phases which are summarized together with the equipment used in Table 1. Sound level measurements at Fort Hood were performed by the CERL acoustics staff. The locations for these measurements were chosen to minimize the number of measurements required while maximizing the information obtained. Each measurement location was at the boundary of a work area in which a particular construction phase was in progress. Thus, the construction noise measured was that of a specific construction phase. Figure 1 provides the locations at which sound level measurements were made. Table 2 summarizes the locations and the construction activity relating to each.

The energy equivalent sound level, L_{eq}, for each site boundary location was calculated from measurements made either manually or by tape recording. Appendix A describes the equipment used by CERL personnel and specific details for the construction noise measurements.

Data Acquisition Methods

Manual Method

The Society of Automotive Engineers (SAE) recommended procedure for measurement of construction site boundary sound level (see Appendix B) provides an estimate of the equivalent sound level,

Table 1

Phases of Construction and Equipment Present at the Fort Hood Family Housing Construction Site

Phase of Construction	Equipment
1. Finishing, Road Preparation (final), Landscaping	Flat Roller Air Compressor Grader Forklift
2. Erection of House Frames, Road Preparation	Circular Saws (2) Supply Truck (4½ Ton) Air Compressor Forklift Backhoes (2) Scraper Grader Mobile Crane
3. Foundation	Front End Loaders (2) Hydraulic Hammer
4. Excavation, Grading Site Preparation	Compactor Graders (2) Dump Trucks (2) Bulldozers (2) Scraper
5. Clearing, Initial Excavation, Utilities Installation	Bulldozers (4) Scraper Backhoe Front End Loaders (2)

NOTE: Numbers in parentheses denote that more than one piece of this equipment was observed.

L_{eq}. This estimate is obtained from the arithmetic average of a special group of the sampled data. One must sample the A-weighted sound level for a 10-sec period each 30 sec and note (Figure 2) the maximum sound level that occurs during that time. The total measurement period may be 30 min in duration. Samples within 6 dBA of the maximum noted value are arithmetically averaged. One would prefer "energy" averaging all samples,* but this may prove cumbersome. It can be shown that the special averaging technique provides a result within 1 dB of the "energy" average.

A durational correction must be used to obtain the construction site equivalent sound level, L_{eq}. The durational correction relates to the fraction of time during which the site is in its noisiest mode. This fraction is obtained by dividing the number of data samples (n) within 6 dBA of the maximum value by

*Energy average is defined as $10 \text{ Log}_{10} \Sigma 10^{n_i/10}$, where n_i are the individual values in dB to be averaged.

Table 2

Description of Measurement Locations at Fort Hood Construction Site

Location	Activity
1.1	Interior Finishing on Houses, Rolling Roadbed in Preparation for Paving
2.1	Roofing of Houses, Ditching
2.2	Roofing and Sheathing
2.3	Erection of House Frames and Road Grading
2.4	Erection of Houses and Digging
4.1	Grading and Site Preparation
4.2	Fill and Grade for House Foundation, Grading and Compaction of Road
5.1	Clearing and Removal of Dirt (taken to Location 4.1)

the total number of samples noted on the data sheet (N). The level (dB) correction is ten times the logarithm of the fraction n/N. Expressed as an equation:

$$\text{correction (dB)} = 10 \text{ Log}_{10} (n/N) \quad \text{[Eq 1]}$$

Alternatively, one may use the correction table shown below:

n/N	*Correction dB*
0.1	−10
0.1 to 0.2	− 7
0.2 to 0.3	− 5
0.3 to 0.4	− 4
0.4 to 0.5	− 3
0.5 to 0.6	− 2
0.6 to 0.8	− 1
0.8 to 0.9	− 0.5
0.9 to 1.0	0

Tape Recording and Analysis Method

An alternate sound level measurement and analysis procedure consists of recording the sound on magnetic tape simultaneously with the acquisition of manual data. The 30-min sample of construction sound is acquired by using a 1-in. (24 mm) condenser microphone with windscreen, a precision sound level meter used as a linear pre-amplifier, and an instrument-quality magnetic tape recorder. Laboratory analysis of the recorded tape is accomplished by a system consisting of an instrument-quality tape recorder and a computer-controlled data reduction system developed by CERL. The

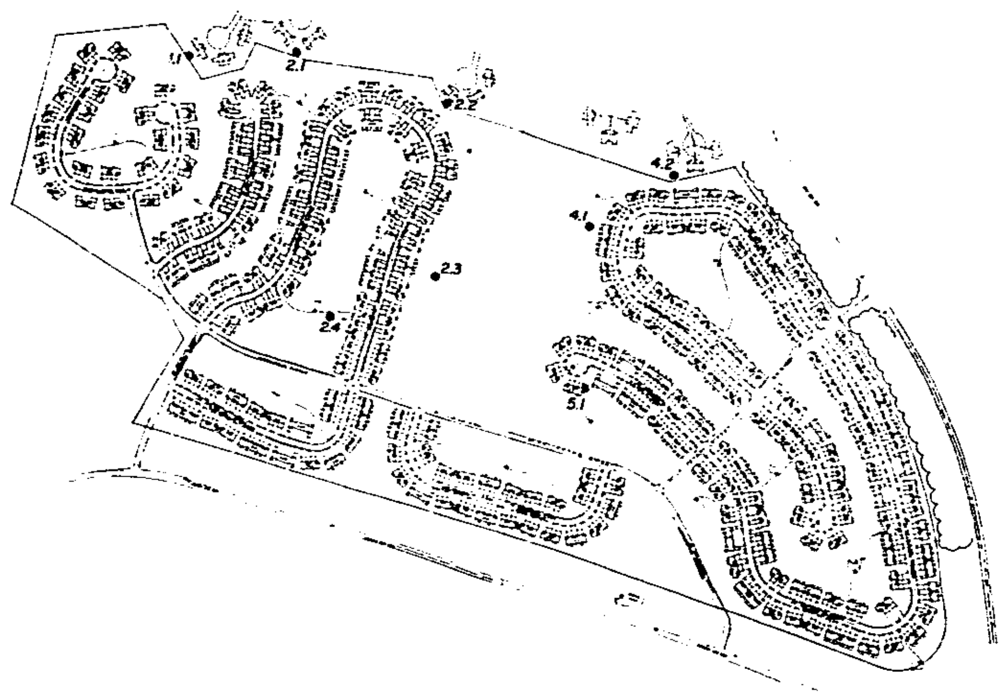

Figure 1. Fort Hood SAE measurement locations.

CONSTRUCTION NOISE EXPOSURE DATA SHEET

Instructions:

1. Calibrate sound-level meter using acoustic calibrator.
2. Install windscreen, select A-weighting network, select "slow" response.
3. Observe for 10 ± 2 seconds at the start of each minute and ½ minute for 30 minutes.
4. Tabulate maximum reading L_a.

Construction: ☐ Activity ☐ No Activity

Determine Arithmetic Average $\bar{L}_A$

L_A(dBA)

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

SUM:* ______

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

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

Construction Site______ Date______ Time ______

Wind Velocity______ mph. Temperature______ °F. Engineer ______

Remarks ______

______

Figure 2. Typical site data sheet.

analysis system contains an edit feature for deletion of intrusive sounds which are not characteristic of the construction noise (people talking nearby, overloads induced by wind gusts). Figure 3 shows typical analysis printout. The analysis contains A-weighted sound level cumulative distributions L_{99} (the sound level exceeded 99 percent of the measurement time) to L_0. Also included are the standard deviation, the energy equivalent sound level (L_{eq}), and other parameters relating to the federal EPA day/night equivalent sound level (L_{dn}). (L_{dn} is not used for this study.)

During measurement by the procedures described above, all manufacturer specifications for the measuring and recording equipment were followed. The two measurement systems were calibrated using calibrators supplied with the equipment. Meteorological parameters were also noted. If high wind speed (greater than 10 knots) or excessive relative humidity (greater than 90 percent) occurred during the measurement period, the recording session was terminated.

.0	J	Number of blocks skipped
911.1400	H	Month, day, hour and minute
10.	C	Samples per second
120.	B	Full scale dB level
107228.	A	Total number of samples
0.	A	Number of wind samples
0.	A	Number of overscale samples
55.3698	L	L_h
55.5905	L	L_d
47.1911	L	L_n
56.3178	L	L_{dn}
47.0000	L	L_{99}
48.0000	L	L_{90}
51.0000	L	L_{50}
56.0000	L	L_{10}
67.0000	L	L_1
72.0000	L	$L_{.1}$
76.0000	L	$L_{.01}$
77.0000	L	L_0
5.3077	D	Standard deviation

Figure 3. Typical statistical analysis of tape-recorded construction sound levels.

Discussion of Results

Table 3 summarizes the equivalent sound level, L_{eq}, for each property line measurement location, obtained from the manual and tape-recorded measurements. Generally, the L_{eq} values obtained by both methods agree to within ±5 dB. The discrepancies between the equivalent sound levels from the two methods are greatest when the construction activity is impulsive in nature, such as hammering and sawing. The agreement between the L_{eq} evaluated by the SAE procedure and the computer-controlled analysis procedures is best when the construction activities produce relatively constant sound levels, such as grading or earth removal.

Appendix A summarizes all data obtained during this phase of the study. Included are the data samples recorded during the manual measurements at each location and the cumulative distribution and L_{eq} values obtained from the tape recording and analysis method.

Table 3

Summary of Equivalent Sound Levels Calculated From Measured Sound Data at Representative Site Boundary Locations—Fort Hood, Texas

	CALCULATED L_{eq}	
Location	From SAE Procedure	From Computer-Controlled Analysis Procedure
1.1	65	66
2.1	64	60
2.2	72	67
2.3	72	69
2.4	61	63
4.1	68	70
4.2	70	70
5.1	73	73

Construction Site Noise Model

It is desirable to formulate an analytical model of construction site noise to quickly and economically evaluate numerous construction scenarios. With this model, one may estimate construction site noise due to various arrangements of (1) present construction equipment, and (2) future quieted construction equipment.

The model used in this study is similar to one developed for the federal Environmental Protection

Agency (EPA).[7] It is simple and reasonably accurate. Use of the model results in an estimation of the equivalent (energy average) sound level, L_{eq}, emitted from the site during an 8-hr day.

The model basically consists of two components: the equipment maximum* (A-weighted) sound level and the fraction of time the equipment is in its noisiest mode.

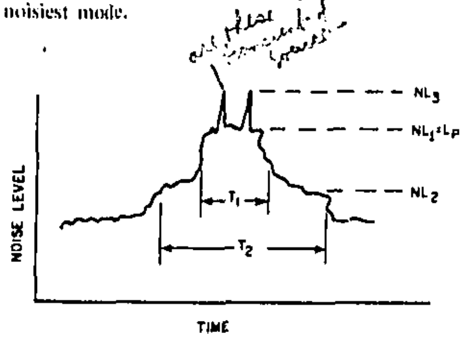

Figure 4. Explanation of L_p, the average sound level of a backhoe in its noisiest mode.

Equipment Sound Levels

In the course of a typical work cycle, a unit of equipment spends part of the cycle idling or preparing to perform a task. During some part of its work cycle, in which the machine performs a task, the noise it emits is higher than it is at any other time. Combining the maximum sound level, L_p, emitted by the machine with the fraction of total cycle time that this maximum sound level occurs provides an estimate of the equivalent (energy average) sound level emitted by the machine during its total work cycle. The fraction of total cycle time that the equipment is in its noisiest mode is designated as the usage factor (U.F.). The usage factor depends on the type of machine and the task it performs. Generally, Fort Hood construction equipment emitted noise in three time-varying modes:

Mode 1: The equipment is stationary but works cyclically; for example, a backhoe may generate maximum sound while trenching but significantly less sound while employing the bucket.

Mode 2: The equipment moves throughout the site; for example, a front-end loader moves earth from an excavation to a pile or truck.

Mode 3: An operation is performed sporadically, possibly only once during the period of observation. (This mode is a special case of Mode 1.)

Figure 5 illustrates the possible time histories applicable to each mode. The usage factor, U.F., is computed from the fraction of time the equipment is in its noisiest mode.

Equipment operating at a site may not operate in its noisiest mode continuously. In fact, the portion of time an item of construction equipment is in its noisiest mode may be quite short. Figure 5 illustrates the three modes discussed above.

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 5 as Mode 1.

Mobile equipment may operate 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 5 illustrates this activity.

A single event is illustrated by Mode 3 of Figure 5. The total period T_2 is assumed to be the construction duration, perhaps an 8-hr day.

The equivalent sound level for a machine in its work cycle is evaluated from:

$$L_{eq} = 10 \log_{10} (U.F. \times 10^{(L_p/10)}) \quad \text{[Eq 2]}$$

The maximum sound levels and usage factors are used to evaluate an L_{eq} for each item of equipment.

[7] *Background Document for Proposed Portable Air Compressor Noise Emission Regulations*, 550/9-74-016 (USEPA, October 1974).

*Maximum sound level, L_p, is the average sound level of the equipment in its noisiest mode. To better illustrate L_p, Figure 4 shows a typical work cycle for a backhoe at Fort Hood. NL_1 is the noise level during trenching and is the maximum sound level (L_p) for the cycle. NL_2 is the noise level occurring when the bucket is used. The baseline noise level occurs while the equipment is idling between jobs and is a very low level compared to L_p. Various transients in the level above the average maximum sound level that occur from time to time are indicated as NL_3.

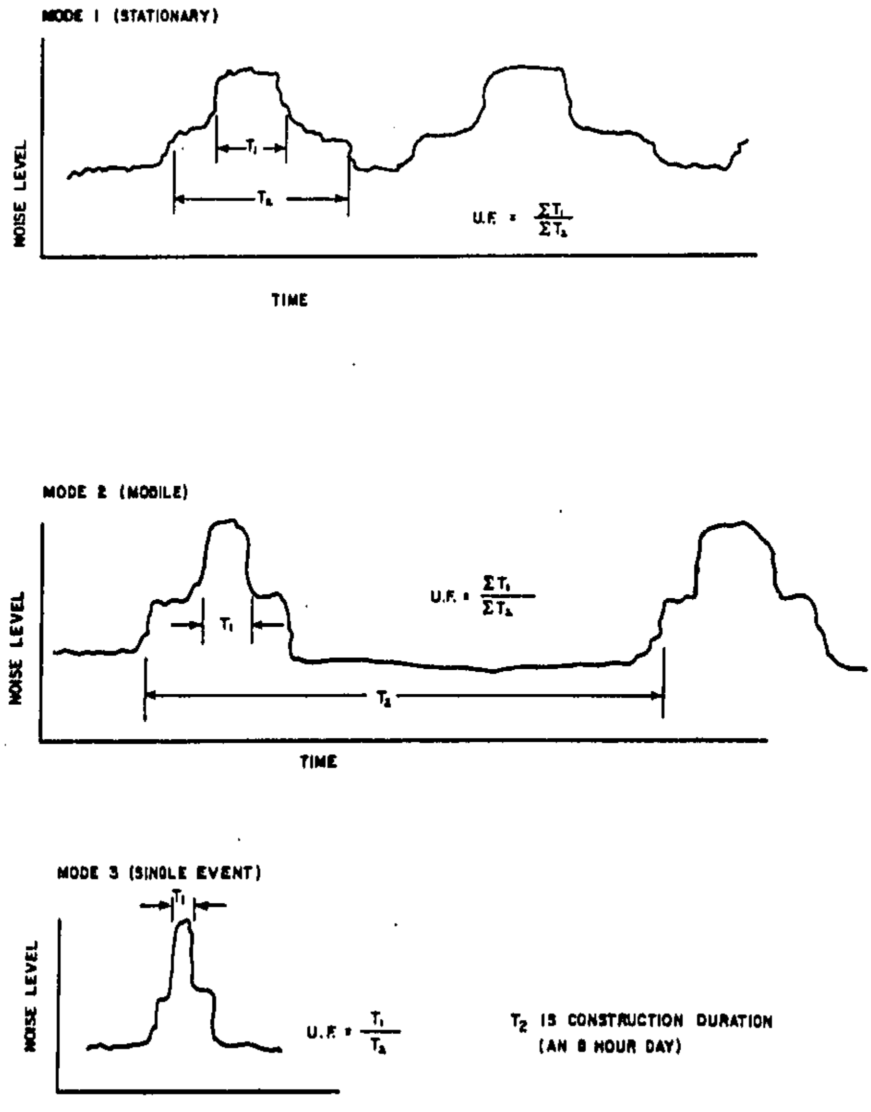

Figure 5. Evaluation of usage factor (U.F.).

These individual contributions are extrapolated from the equipment work area to a property line location and are added on an energy basis to obtain the equivalent sound level resulting from the simultaneous use of all construction equipment at the site. Table 4 illustrates this technique, based on data gathered at the Fort Hood property line measurement location 4.2. The construction activity nearest this location is fill and grade for housing foundations, road grading, and compaction. Table 4 contains the maximum sound level, L_p, 50 ft (15 m) from each piece of equipment and the observed usage factor. The sound is extrapolated to the observer location, assuming hemispherical sound propagation to estimate the contribution at the observer. Individual contributions are then added to compute the total equivalent sound level, L_{eq}, at the observer.

Table 4

Estimated Energy Equivalent Sound Level Data at Location 4.2* of CERL Survey—Fort Hood, Texas

Equipment	Maximum Sound Level (dBA at 50 ft [15 m])	U.F.**	Distance From Equipment to Observer (feet)	Equivalent Sound Level L_{eq} (dB) (at Observer)
Compactor (Roller)	82	.80	185 (56 m)	70
Grader	82	.80	210 (64 m)	69
Grader	87	.48	400 (122 m)	66
Dozer	82	1.00	400 (122 m)	64
Tractor	83	.60	400 (122 m)	63
Dump Truck	86	.30	400 (122 m)	63

L_{eq} at observation point (dB) = 75

*Activity—fill and grade of housing foundations, road grading and compaction.

**Fraction of time in noisiest operating mode—based on CERL measurements.

Estimated Site Boundary Equivalent Sound Levels

Equipment location and equipment operation data were collected during the site boundary sound level measurement sessions. These data were used to estimate usage factors needed for the construction noise model. In addition, maximum equipment sound levels were also measured, usually at 50 ft (15 m). Where maximum sound levels were not measured at the Fort Hood site, supplemental data were obtained from manufacturers or from the literature. The equivalent sound levels, L_{eq}, at each measurement location (Figure 1) were computed using the noise model. Table 5 provides these results. The estimated equivalent sound levels in Table 5 may be compared with the equivalent sound levels obtained from measurements. The equipment maximum sound levels, usage factors, and equivalent sound levels for all measurement locations are summarized in Appendix B.

Table 5

Summary of Equivalent Sound Levels at Boundary Line Measurement Locations of Fort Hood Construction Site

	CALCULATED L_{eq} (dB)		
Location	SAE Procedure	Computer Analysis of Tape-Recorded Data	Construction Noise Model
1.1	65	66	66
2.1	64	60	61
2.2	72	67	67
2.3	72	69	71
2.4	61	63	63
4.1	68	70	68
4.2	70	70	75
5.1	73	73	72

The equivalent sound levels calculated using the model agree to within ±5 dB with the L_{eq} values calculated from manually observed data and within ±2 dB with the L_{eq} calculated from computer-controlled analysis.

The data base used to confirm the model is unfortunately small. While the equipment sound levels are fairly well documented, the usage factor information is sparse. It has been found that the usage factors obtained during this study differ significantly from those tabulated in the EPA publication referenced below.[a] As an example, the usage factor presented in this publication for a bulldozer during the excavation phase of residential construction is 0.1. This value differs significantly from the usage factor for a bulldozer observed during the excavation phase at Fort Hood. The Fort Hood observed usage factor is 1.0. The usage factor for a tractor loader, which at Fort Hood was found to be 0.6, is listed at 0.1 in the EPA data. The usage factors listed by EPA are based

[a]*Background Document for Proposed Portable Air Compressor Noise Emission Regulations*, 550/9-74-016 (USEPA, October 1974).

on an average of numerous residential construction sites. The approach discrepancy between the EPA data and Fort Hood data must be rectified, since the construction site model depends not only on accurate equipment maximum sound level data, but also on valid estimates of the usage factors.

3 TECHNOLOGY AND COST (GENERAL)

General Site Noise Control Methods

CERL Report E-53 describes means to lessen the noise of construction sites.[9]

This study is concerned with the cost of various operational alternatives. To this end, a large amount of basic data has been gathered and tabulated for use in estimating costs of various noise reduction alternatives. In Section 5 of this report these data are used to develop various site-specific examples.

Basically, four general categories are considered for operational noise reduction methods:

1. Shielding
2. Time controls
3. Site masking noise
4. Fixed equipment height.

Shielding

One general method of controlling the noise emission from a construction site is to block and redirect the sound in a direction which is less sensitive to noise. Another alternative is to block and absorb the sound. The former might be called a "barrier," while the latter may be called an "enclosure." Appendix C discusses these methods specifically with regard to the means of creating them.

Blocking a noise source can be a simple and effective means of reducing noise emissions if the specific direction of the sound is known. Barriers can do many things on a construction site to reduce noise and do not necessarily require additional building or construction of units specifically for the purpose. Barriers or enclosures are not considered part of any specific piece of machinery, but rather part of the construction site. Barriers can be any object which interferes with sound transmission.

[9] P. Schomer and B. Homans, *Construction Noise: Specification, Control, Measurement, and Mitigation*, Technical Report E-53/ADA009668 (CERL, April 1975).

The use of barriers or enclosures on a construction site to reduce noise emission to noise-sensitive areas appears to have merit. Depending on the configuration of the land and the specific construction technique, significant noise reduction can be obtained. For the situations where only small reductions occur, that small reduction can be used to supplement other reductions, such as time controls or machinery noise reduction.

There are several situations where effective barriers can be installed and there are several where a barrier can do no good. In general, barriers are good for both stationary and moving equipment. Fences on the order of 10 ft (3 m) may be useful in confined construction sites where source and receiver are close together. Berms, either in conjunction with a fence or not, material stockpiles, existing or newly constructed buildings or other equipment may be used as shields. Appendix D provides the costs of such structures.

Enclosures, either as a barrier, or a partial or complete enclosure, are perhaps the most effective site noise control method for stationary equipment or almost stationary operations.

Within this group, the following are explicit methods:

1. Fences	5. Enclosures
2. Earth berms	6. Machine location
3. Stockpiles	7. Blankets
4. Buildings	8. Unused equipment

These methods are discussed in detail in Appendix C.

Time Controls

The regulation of operations time by the contractor can be a valuable tool in noise control. By knowing how long a given operation will take and the factors that will influence its expected emissions, the contractor is more able to regulate his scheduling and procedures to keep noise at low levels. Factors influencing noise control and time relations are discussed below.

There are several effective time (or scheduling) controls, particularly time of day and those which affect the level vs. duration curve. Data available to date do not make it clear whether it is preferable from the receiver's viewpoint to have high, short-duration noise, or low, long-duration noise. Complaints are generally based on exposure to high-level sources over a certain time period. Since a main construction industry criterion is work to be performed in the shortest time period, any attempt to go toward low-level, long-duration operations will be strongly resisted.

Until more positive criteria are developed, the advantage of time controls is not clear. This comment applies during the normal working hours; nighttime restrictions are definitely required.

Within this group of time controls, the following are explicit methods:

1. Time of day
2. Day of week
3. Season
4. Duration of operation
5. Multiple vs. single operation
6. Operator efficiency.

These are discussed in detail in Appendix C.

Site Masking Noise

Noise from the site can be masked by taking advantage of natural sounds emanating from the surrounding areas. By creating an ambient level on the site, noisy operations can be masked and their impact reduced.

Taking advantage of naturally occurring noise can be a feasible noise abatement technique. Natural sounds have the disadvantage of not always being predeterminable, but have the advantage of costing nothing. (See Appendix C.)

Fixed Equipment Height

Fixed equipment can be shielded more easily than mobile equipment, but in addition the elevation of equipment also presents a problem. Height is the only explicit control in this group (see Appendix C).

Itemized Noise Control Methods

Based on the specific noise reduction methods discussed in the General Site Noise Control Methods section, the following list of feasible general site noise control methods is presented.

1. Fences
2. Earth berms
3. Stockpiles
4. Buildings
5. Enclosures
6. Machine location
7. Blankets
8. Unused equipment
9. Time of day
10. Day of week
11. Season
12. Duration of operation
13. Multiple vs. single use
14. Operator efficiency
15. Natural sounds
16. Height
17. Ground.

General and Specific Site Noise Control by Task

The noise due to any specific operation can be controlled by the general methods listed in the previous section. For example, the noise of a backhoe used for clearing and grading of trees and brush can be controlled by fences, earthberms, enclosures, duration of operation, operator efficiency, and natural sound.

For any given operation, a number of alternatives usually exist. Following is a list of operations for which alternative methods, and methods of noise control for each alternative are presented (see Appendix E).

1. Demolition
   a. Roadways
   b. Buildings
   c. Material removal

2. Clearing and Grading
   a. Trees and brush
   b. Rock removal
   c. Earth removal
   d. Grading

3. Utilities installation
   a. Excavation
   b. Draining
   c. Placement
   d. Backfilling
   e. Compaction

4. Foundation excavation and backfilling
   a. Earth removal
   b. Rock removal
   c. Backfilling
   d. Compaction
   e. Additional equipment

5. Foundation—forming and placing
   a. Forming
   b. Pile driving

Table 6

Illustrative Example for Site Noise Control Clearing and Grading—Rock Removal

METHODS	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Mach. Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Oper.	Multi vs. Single	Operator Efficiency	Natural Sounds	Height
Bulldozer	X	X				X			X	X	X	X		X	X	
Rock Drill and Blasting	X	X			X	X	X	X	X	X		X		X	X	
Rock Drill and Splitters	X	X			X	X		X	X	X		X		X	X	
Rippers	X	X				X			X	X	X	X		X	X	
Loaders	X	X				X			X	X	X	X		X	X	
Dump Trucks	X	X				X			X	X	X	X		X	X	

c. Concrete supply
d. Concrete handling
e. Placing and finishing

6. Erection—framing and exterior-interior work
   a. Material supply
   b. Material movement to building
   c. Construction
   d. Exterior work
   e. Interior work

7. Landscaping
   a. Grounds preparation
   b. Roads

Table 6 is an example of data contained in Appendix E, for clearing and grading—rock removal (Item 2b). The various rock removal methods are listed in the table, along with appropriate noise control alternatives.

Noise Levels and Cost by Specific Method

Each specific construction site operation (as listed in the previous section) and alternative methods for accomplishing them (as listed in Appendix E) are presented in Appendix D with sound levels and associated costs. These values were difficult to obtain. No sound levels could be obtained for many of the alternative methods, which produces a weakness in the final result, since what is desired is the trade-off between sound and cost. Further study is required to obtain these data.

Another weakness is the lack of data on operational time of these alternative methods in order to determine total equivalent noise level vs. cost. The cost data were based on the hourly rates for the rental of the equipment used, which appears to be the method preferred by contractors themselves.

Equipment Noise Control

For construction activities in residential areas and in areas sensitive to high noise levels, noise from construction activities is to be kept at as low a level as possible. The previous sections discussed the reduction of construction site noise by employing alternate construction methods. This section presents various noise control techniques available for reducing construction equipment noise. A summary of the cost of quieting construction equipment noise is presented in Table 7.

Enclosures

Sound radiation can be reduced considerably by either enclosing the entire item of construction equipment or its individual components, e.g., engine. The publication referenced below describes the use and design of enclosures to reduce construction equipment noise.[10] With a properly designed

[10] *Regulation of Construction Activity Noise*, BBN Report 2887 (Bolt, Beranek, and Newman, November 1974).

Table 7

EPA Basic Information on Construction Equipment (1974)*

Equipment Types	Present		Quiet Products Level 1		Best Technology Level 2		
	Sound Level (a)	Average Unit Price	Sound Level (a)	Average Unit Price	Sound Level (a)	Average Unit Price	Units Produced Per Year (b)
Air Compressor	81	$ 8,500	71	$ 9,500	65	$ 12,000	12,000
Backhoe	85	18,000	80	18,500	76	19,800	18,000
Concrete Mixer	85	25,000	83	25,400	75	27,500	7,000
Concrete Pump	82	50,000	80	50,650	75	55,000	500
Concrete Vibrator	76	2,000	70	2,060	66	2,200	6,000
Crane, Derrick	88	110,000	80	111,000	76	113,000	2,200
Crane, Mobile	83	50,000	80	51,000	76	53,000	4,300
Dozer	87	28,000	83	28,800	78	30,800	18,000
Generator	78	1,000	71	1,100	65	1,400	70,000
Grader	85	22,000	80	22,600	76	24,200	7,000
Jackhammer (P.B.)	88	800	80	850	75	950	(20,000)(c)
Loader	84	20,000	80	20,600	76	22,000	30,000
Paver	89	42,000	80	43,000	76	44,200	800
Pile Driver	101	33,000	90	33,500	80	37,000	350
Pneumatic Tool	85	300	75	320	65	400	(100,000)
Pump	76	430	71	450	65	580	50,000
Rock Drill	98	35,000	90	36,000	80	39,000	(1,000)
Roller	80	11,000	75	11,330	70	12,100	6,000
Saw	78	100	70	110	65	150	(500,000)
Scraper	88	70,000	83	71,500	78	75,000	5,000
Shovel	82	71,000	80	72,000	76	74,000	3,000
Truck	88	18,000	83	18,250	75	19,500	75,000

a. Sound level refers to average level during operation in dBA at 50 ft (15 m).
b. Estimated from Department of Commerce published data and industry sources (sales may include other industries).
c. Parentheses enclose preliminary estimate.
*From *Regulation of Construction Activity Noise*, BBN Report 2887 (Bolt, Beranek, and Newman, November 1974).

enclosure and vibration isolation system, construction equipment noise can be reduced by about 25 dB. This can be achieved by: (1) reducing vibrations at resonance frequencies by using special material such as lead foil bonded to metal; (2) increasing absorption by covering the inner walls with high sound absorptive material such as mineral wool sheets or porous artificial foams; (3) isolating the enclosure from equipment vibrations; and (4) avoiding openings or acoustical leaks.

Partial Enclosure

For construction equipment where the use of enclosures will interfere with the functioning of its components, servicing, or air circulation, a partial enclosure can be used. Partial enclosures can be constructed from boards, sheets of wood, or metal, and are effective in reducing excess sound emission in specific directions. A well-designed partial enclosure with vibration isolation can provide approximately a 10-dB reduction in equipment noise.

Mufflers

For earth-moving equipment where the major noise source is the diesel engine, such as bulldozers and scrapers, an improved muffler will be effective in reducing the equipment noise. With an optimal muffler design at the engine exhaust and cool-air intake, the construction equipment noise can be reduced by as much as 10 dB.

Altered Cooling System

Fan cooling noise is a major source of noise in traction vehicles. An improved cooling system can reduce the fan noise by about 10 dB. This can be achieved by using thermatic fans and improved fan/shroud assemblies to provide efficient air pumping with attendant fan speed reduction.

Isolators

Noise radiation due to the transmission of vibration to exterior surfaces can be reduced by resilient isolators. When resilient isolators are used in place of rigid mountings, a 10-dB reduction in vibration often is achieved.

Damping

A 5-dB reduction at the resonance frequency (or frequencies) can be achieved when viscoelastic or constrained-layer coatings are applied to noise-radiating surfaces which are vibrating in a resonant mode.

4 TECHNOLOGY AND COST (FORT HOOD)

Estimated Feasible Quieted Fort Hood Equipment Sound Levels

To estimate feasible site boundary sound level reductions due to equipment noise control, future quieted equipment sound levels are required. One source for these sound levels is the manufacturers. The manufacturers of equipment used at the Fort Hood site were contacted by letter (Figure 6 is a sample letter), and requested to indicate the present sound levels emitted by their equipment, achievable future equipment sound levels, and the cost to the renter or buyer of this quieted equipment. For uniformity, it was requested that the sound levels be those obtained in accordance with SAE J88 procedures (Appendix B). A list of manufacturers contacted by letter is shown in Figure 7. In some instances, it was necessary to follow up the letter contact with phone calls to the manufacturers. Where estimates of quieted sound levels were not available from manufacturers, best estimates of future levels were based on sources such as EPA surveys or general manufacturers data.[11,12] In some instances, equipment sound levels were very low and no further noise control was planned by the manufacturer. Table 8 summarizes the construction equipment in use at the Fort Hood site, the present sound levels, anticipated future quieted sound levels, and the estimated increase in list price due to noise control.

Typical estimates from equipment manufacturers indicate that a noise reduction of 4 to 8 dBA is considered feasible, at an increase in list price of between 3 and 5 percent. Table 9 is a summary of noise control methods indicated by manufacturers.

Table 8

Summary of Sound Level and Cost Estimates From Available Data

Equipment	Present Measured Level L(dBA) at 50 ft (15 m)	Anticipated Future Level L(dBA) at 50 ft (15 m)	Increase in Cost to Buy, %
A1	81 (Stationary)	73 (Stationary)	5
		91 (Drive-By)	5
A2	87	86 (3)	6
A3	78 (Stationary)	73 (Stationary)	6
		88 (Drive-By)	6
A4	88	82 (3)	6
A5	77	74	6
A6	82	82 (3)	6
A7	87	82 (3)	6
A8		84 (3)	6
A9	83	73	6
B1	86	82	3
B2	72	None Planned	
C1	76	None Planned	
D1	76	71	(Kit) $56.00
E1	86	80	4 (Special Order)
F1	75-85 (Est.)	Model Discontinued—None Available	
F2	82-87 (High idle—depends on engine) 84-90 (Engine loaded)	Special Order 4-8 dB Reduction	10
G1	82	80	3
G2	84	80	3
G3	81	80	3
G4	85	80	3
G5	86	80	3
G6	81	80	3
H1	83.0	77	2-5
H2	77.3	74.0	3-5
H3	No sound level data available—noise suppression kit can be retrofitted—same as on other machines		$185.00
H4	80.0	78.0	2-3
I1	73.5-77.0	None Planned	
J1	78		
K1	82	76 (9)	6
L1	75-77	73	
M1			
M2			
N1	82	79	5
O1	74	64	33

[11] W. N. Patterson and T. Freeze, *Traction Vehicles—Noise and Cost of Abatement*, Report 2655b (USEPA, 1974).

[12] Statement by J. B. Codlin of Fiat-Allis at USEPA public hearing, July 8-9, 1971.

February 13, 1975

Mr. John W. Barnett, Vice President
Ingram Manufacturing Company
P. O. Box 2020
San Antonio, Texas 78297

Dear Mr. Barnett:

Dames & Moore has been retained by the U.S. Army Corps of Engineers Construction Engineering Research Laboratory (CERL) to study the cost-benefit of construction equipment noise control as it relates to construction site noise. We have developed a model of construction site noise which utilizes construction equipment sound levels and usage factors. Our desire, at the end of the study, is to obtain information on the cost of reducing site sound levels by

a) reducing equipment sound levels,
b) changes in the construction process.

We are directing our efforts to family housing construction being undertaken at Fort Hood, Texas. Field measurements are being made there and compared with engineering analysis.

The following Ingram equipment is operated at the Fort Hood construction site: Flat Roller (Metal); Pneumatic Roller (Tires). We would appreciate any information you could forward us on present sound levels (J88), feasible future quieted sound levels, and the estimated added cost to the purchaser or leaser of this quieted equipment.

Your earliest assistance in this matter would be greatly appreciated.

Very truly yours,

DAMES & MOORE

FMKessler

Frederick M. Kessler, Ph.D.
Associate

FMK/ht

cc Dr. P. Schomer - CERL

Figure 6. Sample letter sent to manufacturers.

1. F.M.C. Corporation
2. Ingersoll-Rand
3. Poclain
4. J. I. Case
5. Vibramax Corporation, Division of J. I. Case
6. Clarke Equipment Company
7. Wacker Corporation
8. Ingram Manufacturing Company
9. Komotsu-American Corporation
10. John Deere & Company
11. Fiat-Allis
12. Koehring Company
13. Euclid, Inc.
14. Caterpillar Tractor Company
15. Power Tool Manufacturers (Various)

Figure 7. List of manufacturers contacted whose equipment is used at Fort Hood.

It was found that some equipment in use at Fort Hood meets operator noise level acceptability criteria (OSHA). Some manufacturers are not involved in ongoing spectator (community) noise control efforts; however, several of these manufacturers indicated that they could provide technical assistance for noise control on a "per piece" basis. It is estimated that "special" noise control efforts could reduce spectator sound levels about 4 to 8 dBA, at an increase in list price of between 4 and 10 percent.

The data in Table 8 are summarized in Figure 8, where the maximum sound level (stationary operation) is plotted against flywheel horsepower, for present earthmoving equipment and for future quieted earthmoving equipment. Many numerical techniques are available which provide "trends" or empirical relationships. The equipment parameters and noise levels provided by the construction equipment manufacturers do not initially appear to be related. A *least-squares* curve-fitting computer program was used with the manufacturer-supplied equipment horsepower values and sound levels to provide the equations shown below. Six relationships were evaluated by summing the square of differences between these relationship estimates and the actual data. The relationships used are:

$$Y = A + BX \quad \text{[Eq 3]}$$

$$Y = A\,\mathrm{Exp}\,(BX) \quad \text{[Eq 4]}$$

$$Y = AX^B \quad \text{[Eq 5]}$$

$$Y = A + (B/X) \quad \text{[Eq 6]}$$

$$Y = 1/(A + BX) \quad \text{[Eq 7]}$$

Table 9

Summary of Noise Control Methods Indicated by Manufacturers

Equipment Type	Noise Control Method
Bulldozers Scrapers Front-end loaders Backhoes Graders Roller-compactors	Side panels and other engine enclosures, improved mufflers, use of absorptive materials, baffles on fan intake, vibration isolation of engine mounts, noise-suppression fan, baffles in hydraulic system.
Dump truck	engine enclosure, thermatic fan.
Hand tamper	Add-on silencer kit available from manufacturer; new equipment includes kit as standard.

$$Y = X/(A + BX) \quad \text{[Eq 8]}$$

The best "fit" is Y = A + BX, where X is the logarithm of horsepower/100, and Y is the sound level (dB) at 50 ft (15 m). Again it should be noted that the data base was sparse and that these relationships should only be considered "trends" until a sufficiently large sample is available to provide improved confidence. A least squares "best fit" through the data indicates that the *present* maximum sound level at 50 ft (15 m) for earthmoving equipment used at Fort Hood may be related to flywheel horsepower by:

$$L_{p1}\ (\text{at 50 ft [15 m]}) = 82 + 7.0 \log_{10}(HP/100) \quad \text{[Eq 9]}$$

where L_{p1} is the present sound level in dBA.

By contrast, the *future* maximum sound level for the same equipment after noise control efforts is related to flywheel horsepower by:

$$L_{p2}\ (\text{at 50 ft [15 m]}) = 77.6 + 6.3 \log_{10}(HP/100) \quad \text{[Eq 10]}$$

where L_{p2} is the quieted sound level in dBA.

Cost of Equipment Noise Control

Present Equipment "Cost to Buy"

Estimates of "cost to buy" of present equipment were obtained from the manufacturers and from

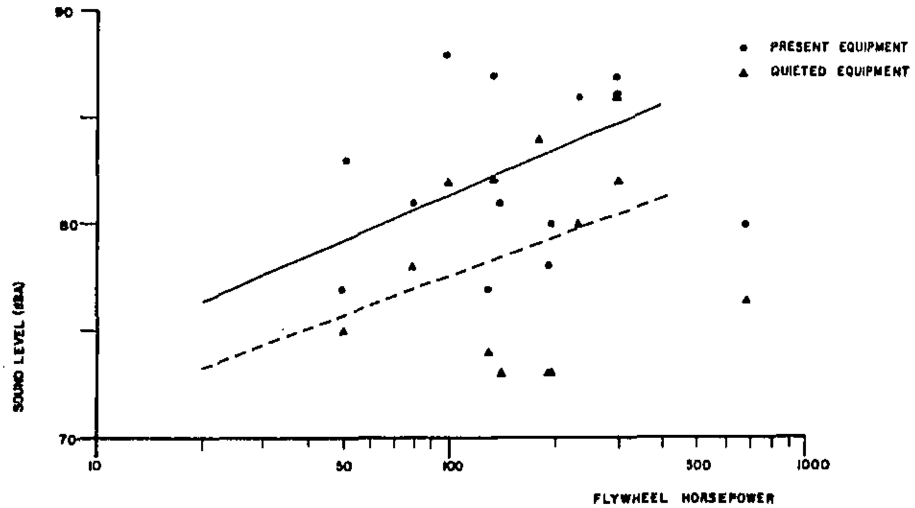

Figure 8. Equipment sound level (dBA at 50 ft [15 m]) as a function of flywheel horsepower for construction equipment at Fort Hood.

surveys of equipment vendors. Although equipment costs vary throughout the country and depend on the individual equipment dealer, the cost estimates obtained are representative of the overall equipment cost to the contractor. The "cost to buy" of present machinery is plotted against flywheel horsepower in Figure 9. A least squares "best fit" through the data indicates a linear relationship defined by

$$C_1 = 452 \times HP \qquad \text{[Eq 11]}$$

where C_1 is present cost to buy in dollars.

Future Quieted Equipment "Cost to Buy"

The estimated increase in list price shown in Table 8 for equipment noise control is combined with the present "cost to buy," and plotted against horsepower, as shown in Figure 9. A least squares "best fit" through these data indicates that the "cost to buy" future quieted equipment is also linearly related to flywheel horsepower by:

$$C_2 = 468 \times HP \qquad \text{[Eq 12]}$$

where C_2 is future (quieted) cost to buy in dollars.

As seen from these two curves, an average overall increase in list price of quieted equipment of 3.5 percent is indicated.

Cost to Operate Present Equipment

The operating cost (including maintenance) of construction equipment varies throughout the country, depending on the availability of parts and service. However, average overall maintenance costs have been compiled from sources such as manufacturers' handbooks[13,14] and previous surveys.[15,16]

The hourly cost to operate the construction machinery includes: (1) fixed costs, such as depreciation, insurance, interest, and taxes; and (2) operating costs, such as fuel, lubricants, filters, tires, repairs, and labor. The operating cost does not include the operator's wage.

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[13] *Caterpillar Performance Handbook*, Ed. 5 (Caterpillar Corporation, January 1975).

[14] *Basic Estimating*, Ed. 3 (International Harvester Company, 1972).

[15] *Equipment Ownership and Operating Expense Manual* (U.S. Army Corps of Engineers, North Pacific Division, April 1974).

[16] *A Study to Determine the Economic Impact of Noise Emission Standards in the Construction Equipment Industry—Portable Air Compressor Report* (USEPA-ONAC, June 1974).

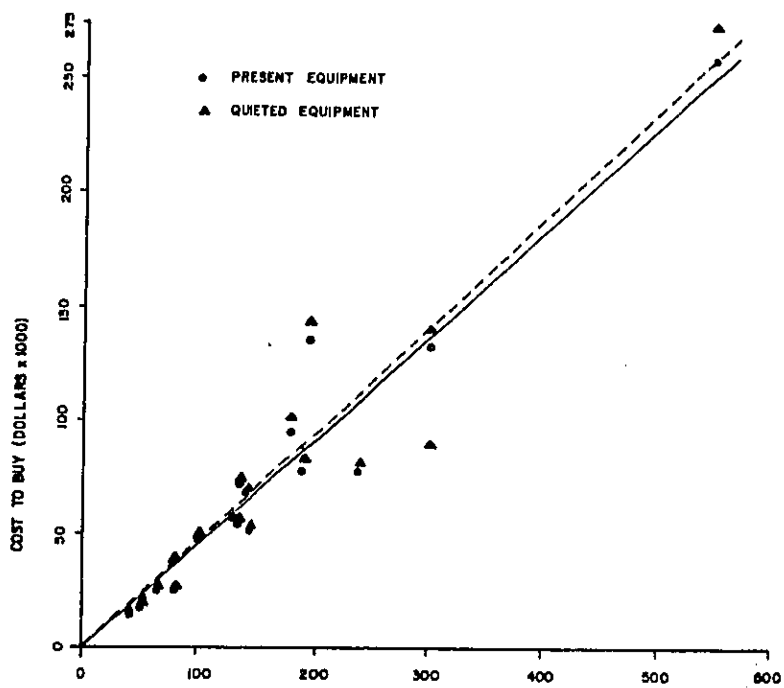

Figure 9. Purchase price as a function of flywheel horsepower for construction equipment used at Fort Hood.

Available data on the cost per hour to operate the Fort Hood construction equipment are summarized and plotted against flywheel horsepower in Figure 10. A least squares "best fit" through these data indicate that the hourly cost to operate is related to the flywheel horsepower by:

$$CR_1 = 0.096 \times HP \qquad \text{[Eq 13]}$$

where CR_1 is present operating cost rate in dollars per hour.

Comparing the cost to operate for 1 hour to the cost to buy present equipment indicates that the hourly operating cost is, on the average, 0.021 percent of the purchase price.

Cost to Operate Future Quieted Equipment

An adequate assessment of the cost to operate future quieted equipment is hindered by lack of available information on the continuing cost of construction equipment noise control. Increased operating costs could result from increased power demands on heavier equipment or equipment required to run harder due to noise control accessories. Also, since enclosures, baffles, and vibration isolators may be fabricated from materials whose efficiency is degraded in time by the harsh environment of construction sites, frequent replacement could result in increased maintenance costs.

The uncertainty of noise control on operating and/or maintenance cost gives rise to considerable variation in the estimates of the cost of operation of quieted construction equipment. One estimate, by a manufacturer of earthmoving equipment, is that noise control will increase the cost to operate by 6 percent for machines in the 100 to 200 horsepower range, and by 5 percent for larger machines. Alternatively, results of previous surveys on the costs of air compressor and diesel truck noise control indicate a negligible increase in the operating cost.[17]

[17] *Background Document for Proposed Portable Air Compressor Noise Emission Regulations*, 550/9-74-016 (USEPA, October 1974).

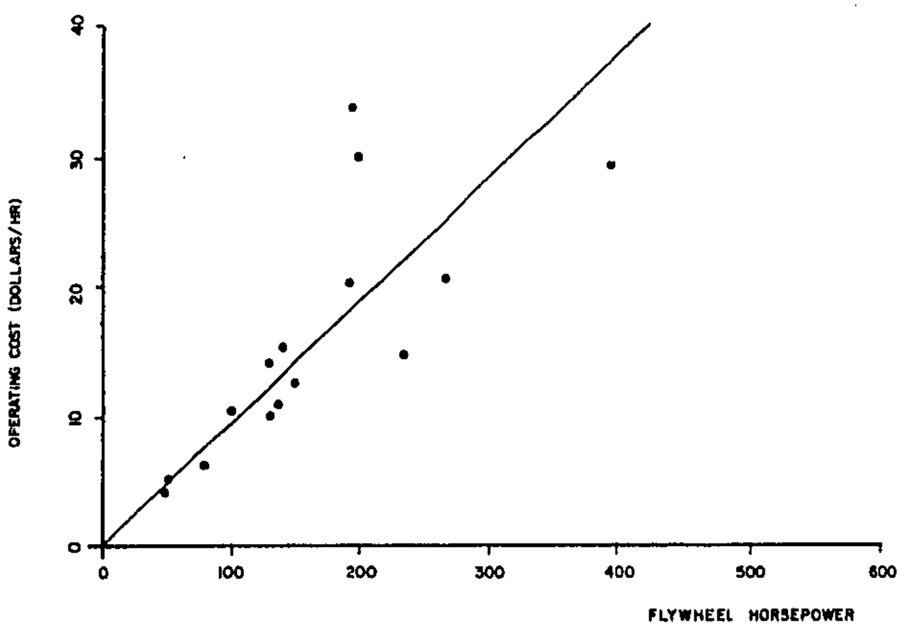

Figure 10. Machine operating cost/hour as a function of flywheel horsepower for construction equipment used at Fort Hood.

5 COST/BENEFIT ANALYSIS

To assess the noise level reduction (benefit) achievable at Fort Hood, four technology approaches are considered. Analyses of feasible construction site boundary noise reduction and associated costs were made for equipment noise control and process changes for noise control.

Equipment Noise Control

Estimate of Sound Level Reduction vs. "Cost to Buy"

The estimated quieted equipment sound levels and increases in "cost to buy" supplied by manufacturers (as seen in Table 8) were used to estimate a generalized relationship between change in operating sound level and change in equipment cost.

Numerous relationships between equipment sound and list price were investigated to locate the most representative relationship. The data, such as change in sound level as a ratio of intensities or change in sound level as a function of flywheel horsepower, were analyzed by computer, using various curvefitting programs as discussed earlier. The equations, representing linear, exponential, or other relationships, were compared on the basis of "best fit." In Figure 11, a decrease in operating sound level (in dBA) is plotted against the change in list price (in dollars). It was found that the relationship shown in Figure 11 was valid for machines such as dozers, loaders, etc. Smaller construction machinery, such as portable air compressors (160 cu ft/min), forklifts, and flatbed trucks, were considered separately as special noise control problems for which the cost of noise reduction was estimated to require approximately a 1 percent increase in list price per decibel. The cost of reduction of radial power saw noise was estimated at 33 percent increase for a 10-dB reduction.

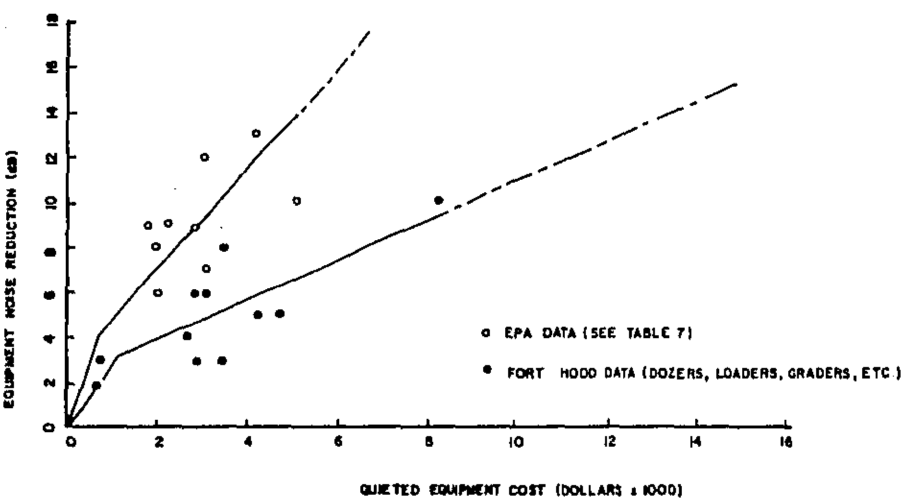

Figure 11. Equipment noise reduction vs. cost for manufacturer supplied Fort Hood equipment and EPA data.

Similar cost for construction equipment noise control data were collected for the federal EPA.[18] These data and a best fit relationship are shown in Figure 11. It is seen from this figure that the benefit to cost relationship (22 dBA/$1000) reported in the publication referenced below is considerably greater than for similar types of equipment used at Fort Hood (0.9 dBA/$1000).

Construction Site Cost-Benefit

Estimated equivalent sound levels, L_{eq}, based on future quieted equipment (Table 8) were computed at boundary locations. The property line sound levels (quieted equipment) were computed using the model discussed in Chapter 2. Usage factors and distances to operating machines were kept constant while the equipment sound levels were reduced by amounts considered feasible. Estimates of the increases in "cost to buy" the quieter equipment were also made. These estimates were made by comparing the total increased list price (present list price plus percent cost increase, in dollars) for all equipment at each construction site to the total present value of all equipment at each site. Appendix D contains a sample calculation and supplemental cost information.

The results of the calculations are summarized in Table 10, which contains the equivalent sound levels at each measurement location calculated by using present and future quieted equipment sound levels. The estimated increases in present equipment cost (cost to buy) to achieve these reductions are also shown in this table. It can be seen from Table 10 that the largest noise reduction (benefit) for the least cost occurs at location 4.1, where a decrease in L_{eq} of 7 dB is estimated with the accompanying increase in equipment cost of 4.3 percent. The construction activity contributing most to this location's noise level is grading and site preparation, which requires earthmoving equipment such as dozers and scrapers. The smallest cost/benefit relationship occurs at location 2.1, where the noise is affected by roofing of houses and ditching operations. These tasks require smaller machines such as forklifts and backhoes.

Site Noise Level Criterion vs. Cost

Use of the aforementioned cost/benefit relationships to estimate the increase in equipment cost required to reduce property line sound levels to a desired criterion level is illustrated in the following example for measurement location 5.1. The phase of activity at this location is clearing and initial excavation.

The minimum distance from the observer to the predominant work area is 170 feet (52 m). The

[18] *Regulation of Construction Activity Noise*, BBN Report 2887 (Bolt, Beranek, and Newman, November 1974).

Table 10

Estimated Equivalent Sound Levels and Percentage Increase In List Price of Quieted Equipment at Site Boundary Locations—Fort Hood Construction Site

Location (See Figure 1)	Estimated Equivalent Sound Level (dB): Present Equipment	Estimated Equivalent Sound Level (dB): Future Quieted Equipment	Estimated % Increase in List Price—Future Quieted Equipment (Overall)
1.1	66	62	5.1
2.1	61	59	5.3
2.2	67	67	0
2.3	71	69	2.6
2.4	63	61	5.4
4.1	68	61	4.3
4.2	75	72	5.1
5.1	72	67	4.4

equivalent sound level estimated by the construction noise model for present equipment is 72 dB.

A recent document[19] recommends permissible sound levels in residential areas near construction sites. CERL recommends that the sound level during the excavation phase of construction should not exceed 57 dB in a residential area 150 m from the predominant work area. For this example, where the work area is only 52 m from the residential boundary, the equivalent sound level at measurement location 5.1 should not exceed 66 dB. But at location 5.1 the sound level with present equipment is 72 dB, indicating that a reduction of 6 dB is required.

Two front end loaders are operating at this site. Unit No. 1 has a maximum sound level of 89 dBA at 50 ft (15 m) while Unit No. 2 has a maximum sound level of 88 dBA at the same distance. Each has a usage factor of 0.15. At this site, the distance to observer is about 170 ft (52 m). After a few trial assumptions, it can be calculated that if each front end loader emitted 82 dBA at 50 ft (15 m), the site L_{eq} would be reduced to 66 dB. To achieve this, Unit No. 1 must be reduced 7 dB while Unit No. 2 must be reduced 6 dB.

[19] P. Schomer and B. Homans, *Construction Noise: Specification, Control, Measurement, and Mitigation*, Technical Report E-53/ADA009668 (CERL, April 1975).

Use of Figure 11 shows that these noise reductions would require an increased purchase price of $5500 and $4300 for Units No. 1 and No. 2, respectively, or a total of $9800. These data are summarized in Table 11.

Estimated Feasible Sound Level Reductions by Process Changes

To estimate feasible site boundary sound level reductions due to changes in the way a particular operation is conducted, two example situations from the Fort Hood construction site have been chosen. The first example is the rough grading operation near location 4.1 shown in Figure 1, and the second is a trenching operation. The first operation gains little from barrier attenuation and the second gains a significant amount. The costs associated with each change are also estimated so that the cost-benefit analysis can be made in terms of dollars/dB.

Example 1—Grading-Site Preparation

During the period of observation at Fort Hood, the primary noise sources contributing to the levels measured at locations 4.1 and 4.2 (see Figure 1) were: (1) Case 450 bulldozer; (2) Caterpillar D6 bulldozer; (3) Allis-Chalmers 260B scraper; and (4) Caterpillar D9H bulldozer. Each of these vehicles were closely tracked for one day so that their position with respect to location 4.1 and their noise output were known as a function of time.

Table 11

Sample Computation (Fort Hood Location 5.1) Criterion Property Line Sound Level 66 dB (L_{eq})

Equipment	Present Sound Level dB 50 ft (15 m)	Quieted Sound Level dB 50 ft (15 m)	Original Cost to Buy $	Increased Cost to Buy $	Increase %
Front End Loader #1	89	82	51,000	5500	10.8
Front End Loader #2	88	82	47,000	4300	9.1
	L_{eq} = 72 dB	L_{eq} = 66 dB	98,000	9800	10.0

From these data, it was possible to obtain actual usage factors, as well as the sound levels caused by both moving and fixed noise sources. The bulldozers moved only distances near 30 ft (9 m) and so could be considered as fixed sources, while the scraper traveled nearly 4000 ft (1219 m) in one cycle, since it scraped dirt and carried it offsite.

To measure the effect of each operation, a computer program was written which accepted position and sound power data for small increments of time and for each noise source. L_{eq} was then computed over some specified time greater than the longest cycle time of the equipment; distances for L_{eq} 55 were determined; and contours of constant L_{eq} were plotted. Three of the computer printouts are shown in Figures 12, 13, and 14. Figure 12 shows the Case 450 bulldozer (source 1) and its associated L_{eq} 65, L_{eq} 55 contours. The maximum sound power level L_W was 120 dB, the effective radius of source motion 15 ft (5 m) compared with the radius of 675 ft (206 m) for the L_{eq} 55 contour, so the source is acoustically "compact" in that the ratio of the source motion radius to the L_{eq} 55 radius is much less than one. Figure 13, with a different scale, shows the L_{eq} contours for the sum of the Case 450 and the Caterpillar D6 bulldozers (L_W = 120 dB). The L_{eq} 55 contour is virtually a circle, indicating that the source is still acoustically "compact." Figure 14 shows the influence of adding source 3, the 260 B scraper. The scraper spent considerable time (53 percent) at low speed collecting dirt with an L_W = 120, and also at high speed (45 percent), delivering the dirt offsite with an L_W = 123. This is an example of two maximum sound levels, each associated with a different speed and a very high usage factor. It is clear that the total source is no longer acoustically "compact," but the L_{eq} 55 contour is still nearly circular.

The important result of the preliminary calculations is that the construction site can be treated as acoustically "compact" if the L_{eq} 55 contour is considered. This has important bearing on the accuracy of the equation given in the equipment sound levels. The actual equation for a sum of continuous noise sources is

$$L_{eq} = 10\,\mathrm{Log}_{10}\left[\sum_{n} U.F._n \frac{10^{(L_W)_n/10}}{\sqrt{n}}\right] \qquad \text{[Eq 14]}$$

which for an acoustically compact source becomes

$$L_{eq} = 10\,\mathrm{Log}_{10}\left[\frac{1}{r^2}\sum_{n} U.F._n\, 10^{(L_W)_n/10}\right] \qquad \text{[Eq 15]}$$

For the present example, L_p and r are known for the exact situation, so an effective U.F. or operation U.F. as

$$\overline{U.F.} = \frac{\sum_{n} U.F._n\, 10^{(L_W)_n/10}}{\sum_{n} 10^{(L_W)_n/10}} \qquad \text{[Eq 16]}$$

can be determined where L_{W_n} is interpreted as the *maximum* sound power of the *nth* source. That is, $\overline{U.F.}$ is a composite usage factor containing the U.F. for each source and accounting for sound powers other than the maximum for each of the sources. The three equations yield:

	U.F.
Source 1 only	.46
Sources 1 + 2	.82
Sources 1 + 2 + 3	.72

With these data the change in radius of L_{eq} 55 can be estimated through the following equation.

$$L_{eq} = 10\,\mathrm{Log}_{10}\left[\frac{\overline{U.F.}}{r^2}\sum_{n} 10^{(Lw_n/10)}\right] \qquad \text{[Eq 17]}$$

or

$$r = \left[\frac{\overline{U.F.}\sum_{n} 10^{(Lw_n/10)}}{10^{5.5}}\right] \qquad \text{[Eq 18]}$$

The results of using alternative equipment for the job are shown in Table 12. Case I (Table 12a) applies to only one bulldozer operating, Case II (Table 12a) applies to two bulldozers operating, and Case III (Table 12b) applies to two bulldozers plus a scraper. Operating cost data for Caterpillar products were available, along with performance data and estimates of maximum sound power level. Cost estimates must be based on the amount of work performed, rather than the cost per day or hour, so the reference work was set to 13,000 cu yd (9939 m³), the

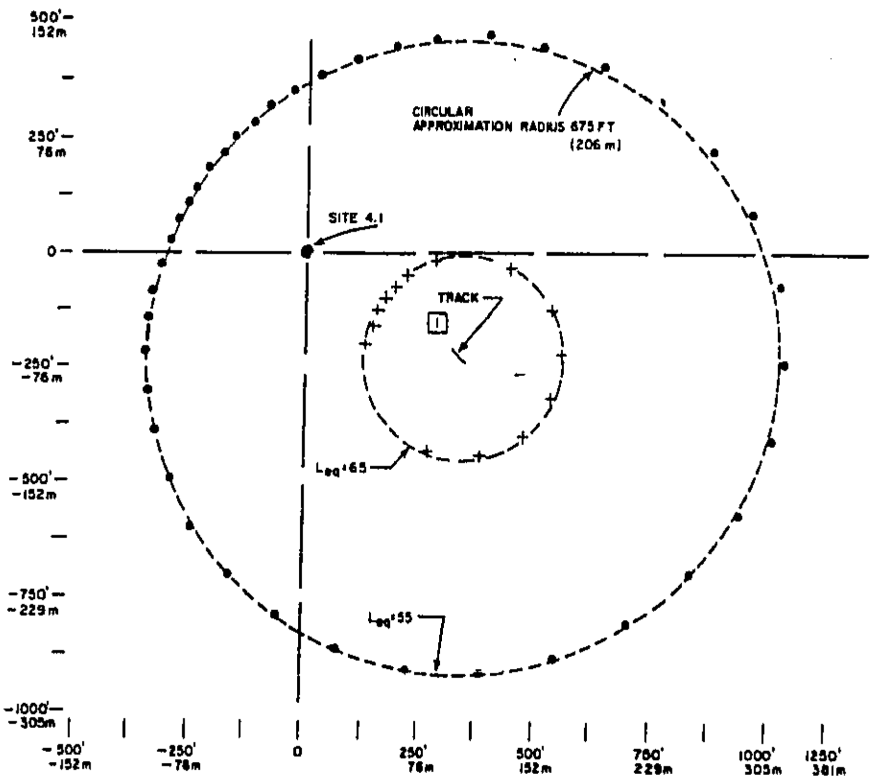

Figure 12. Noise level contours—source 1 only.

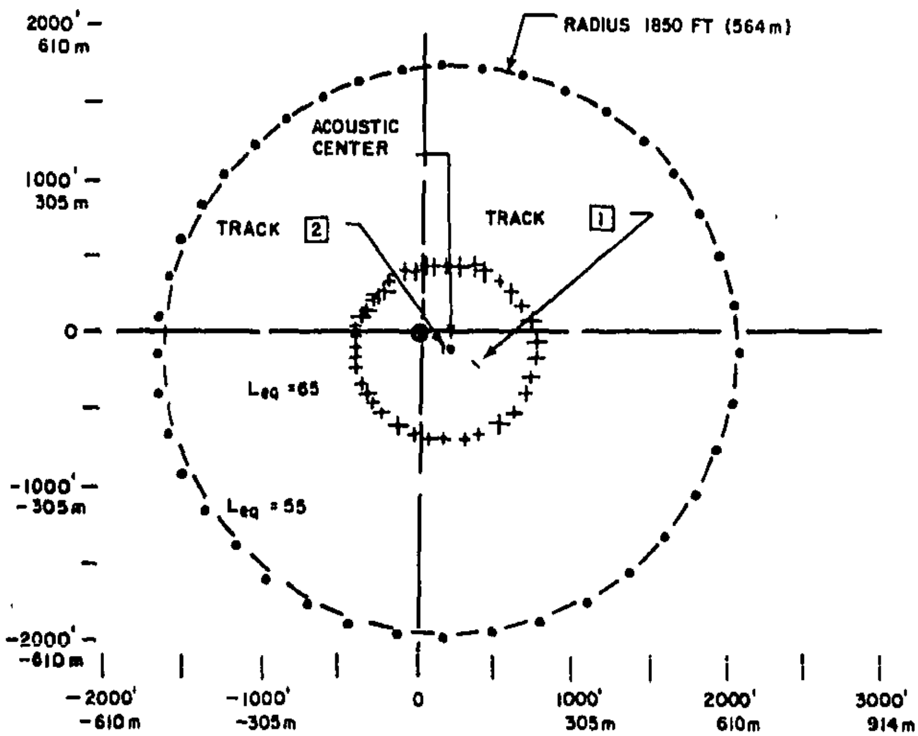

Figure 13. Noise level contours—sources 1 and 2.

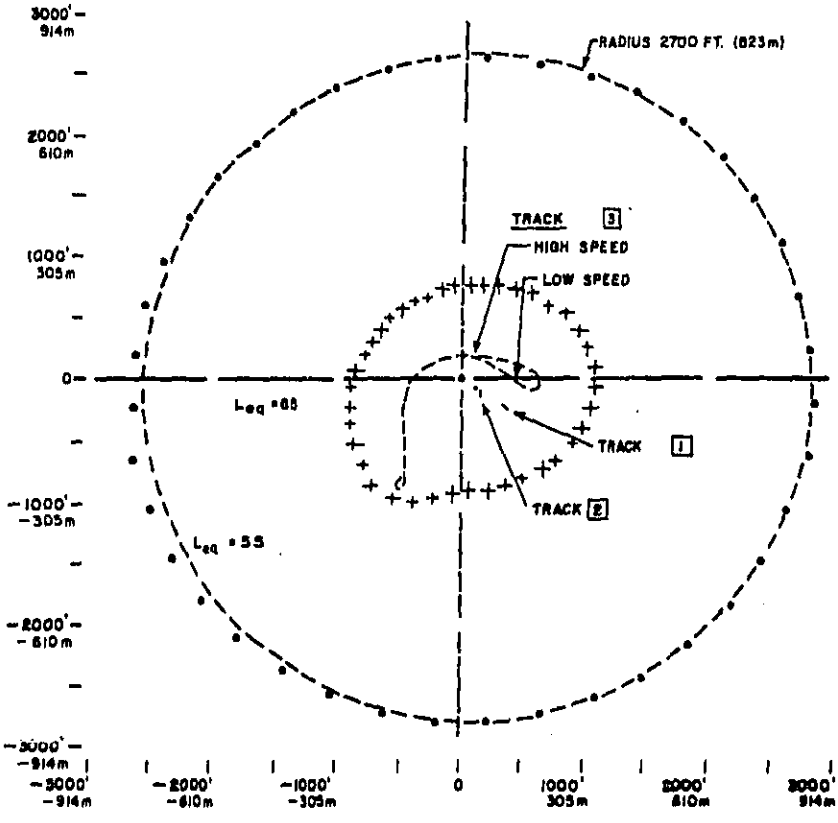

Figure 14. Noise level contours—sources 1, 2, and 3.

amount of dirt that can be moved by a D9H in an 8-hr shift with a 50 ft (15 m) dozing distance. Two significant results occur: (1) as the flywheel horsepower decreases, the noise decreases and the cost increases (such a job requires more than $40/dB of reduction or over $3.10 per 1000 cu yd for each decibel of reduction); (2) associated with the noise reduction is the increased time to accomplish the task. For the example given, a sixfold increase in time is required (7.8 dB) for a 5-dB reduction in noise. Thus, if a measurement scale is used in which duration of exposure is weighted equally with intensity of exposure, the *larger machine is both cheaper and causes less total exposure*. Because the larger machines cause a larger radius for the L_{eq} 55 contour, more people would be exposed to noise above this threshold. The following measurement scale can be used.

$$P_{eq} - \text{Days} = \frac{TD\,(\pi r^2 - A_{site})}{6.69 \times 10^8} \qquad \text{[Eq 19]}$$

where P_{eq} is the population exposed over L_{eq} 55
T is the time of exposure (hours)
D is the population density (pop/sq mi)
r is the L_{eq} 55 radius (ft)
A_{site} is the area of the site (sq ft).

Using 200 ft (61 m) as the radius of the site and using 100 people/sq mi as the population density (other densities can be corrected for by a multiplier) leads to the results for Case I shown in the last column of Table 12a. *The above conclusion is still the same.*

The result of Case I is that *replacement of equipment by smaller, less noisy equipment does not result in less total noise exposure.*

The results for Case II must also be the same, since two bulldozers are operating simultaneously.

Table 12b provides the results for Case III, in which various sizes of scraper were used, including a very large one requiring a D9H pusher bulldozer. Again, the very largest pieces of equipment are the most cost-effective, and the smaller vehicles cost approximately $30 to $40 per dB of reduction, or between $2.30 and $3.07 per 1000 cu yd (765 m³) for each decibel reduction. The smaller vehicles also require longer times, so if a measurement scale is used in which duration of exposure is weighted equally with intensity of exposure, the larger machines cause less exposure. Including the number of people exposed as a criterion, such as P_{eq} – days, the table shows that the larger machines cause less total exposure even though they are lower. The result for Case III is that *replacement of equipment by smaller, less noisy equipment does not provide less total noise exposure.*

Example 2—Trenching Operation

The following describes one ditching operation that was not directly measured at the sites noted in Figure 1. In this operation, an excavator was digging a utility trench across open ground. Two process changes could be utilized: (1) the equipment could be made smaller and (2) barriers could be erected.

Table 13 presents data resulting from the analysis. Case I is reduction in excavator size using duration and intensity of exposure equally as criteria for total noise exposure; in this case, the increase in time required to perform a task is offset by the reduction in machine noise. Because these machines are large, the cost per decibel of reduction is high—being in the hundreds of dollars per dB. If the number of people exposed to the noise is also incorporated, as it was in the previous section, there is an optimum size which is not the largest machine as before. If more data were available a better estimate could be made.

Case II deals with the erection of a plywood barrier ⅝ in. (1.6 cm) thick in 8 ft (2.4 m) sections for portability. Four subcases were examined:

1. 8 ft (2.4 m) high, 10 ft (3.0 m) from source
2. 8 ft (2.4 m) high, 20 ft (6.1 m) from source
3. 16 ft (4.9 m) high, 10 ft (3.0 m) from source
4. 16 ft (4.9 m) high, 20 ft (6.1 m) from source.

The source was estimated to be 6 ft (1.8 m) high and the observer to be 7 ft (2.1 m) high. Because of the large angle change associated with the line-of-sight in this geometry, the effective shadow zone extends to very large distances as shown in Figure C1. The sound attenuation of each octave band of an internal combustion engine source was computed and summed into a sound level reduction. The engine noise spectrum is an important aspect of barrier noise reduction.

Table 13 indicates that an 8 ft (2.4 m) fence is equivalent to reduction in equipment size, in that reductions on the order of 5 dB are obtained. A 16-ft (4.9 m) high barrier increases the noise reduction by nearly 20 dB, which is now well worth considering. Material cost estimates were based on the construc-

Table 12

Noise-Cost Trade-offs—Rough Grading

a. Bulldozer Size Change

Tractor Type	Flywheel HP	Capacity BCY/hr	Time for 13,000 BCY	Cost Per Hour	Total Cost $	Est. L_w	Radius of L_{eq} = 55	Average $/dB	P_{eq}-Days Exposure
D4D	75	270	48 hr	$12.00	$576	117	853 ft	57	15.5
D5	105	405	32	14.10	451	118	958	40	13.2
D6C	140	495	26.2	17.60	461	119	1075	57	13.7
D7G	200	900	14.4	21.20	305	120	1206	8	9.6
D8K	300	1260	10.3	28.90	297	121	1353	8	8.7
D9H	410	1620	8	36.20	289	122	1518	0	8.5

b. Scraper Size Change

Scraper Type	Flywheel HP	Capacity CY	Time for 13,000 BCY	Cost Per Hour	Total Cost $	Est. L_w	Radius of L_{eq} = 55	Average $/dB	P_{eq}-Days Exposure
C621B	330	20	32.5	28.83	937	119	1345 ft	32	27
C631C	415	30	21.7	39.60	859	120	1509	23	22.8
C641B	550	38	17.1	53.13	908	121	1693	41	22.7
C B	550	44	14.7	54.89	807	121	1693	16	19.5
C660B*	550	54	8.0	93.04	744	125	2683	0	26.9
AC260B	300	20	32.5	27.44	892	119	1345	25	26.9
AC261B	300	23	28.5	32.18	917	119	1345	29	23.6
AC460C	422	33	19.7	41.94	826	120	1509	16	20.6
TEREX S11E	144	11	59.1	16.27	961	117	1068	27	30.5
IH E-200	130	9	72.2	14.59	1053	117	1068	39	37.3

*with D9H pusher

Table 13

Noise-Cost Trade-offs—Trenching

Case I

Excavation Type	Flywheel HP	Capacity BCY	Cycle Time	Time for 13,000 BCY	dB Log of Time	Cost Per Hour	Total Cost	Est. L_w	Radius L_{eq} 55	Ave. $/dB	P_{eq}-Days Exposure
C225	125	.87	22	91.3 hr	+3	40.00	3652	117	1194	$425	59.4
C235	195	1.38	25	65.4	+1.3	45.00	2943	118	1340	283	53.9
C245	325	2.38	32	48.5	0	49.00	2376	120	1687	0	63.9

Case II*

Height ft	Distance from Excavation ft	Noise Reduction dBA	Material Cost	Cost Per Hour	Total Cost	$/dB**	Radius L_{eq} 55	P_{eq}-Days Exposure***
8	10	7	$324	$40	$ 764	109(63)	753	38(12)
8	20	45	324	40	764	170(98)	1005	43(22)
16	10	20.5	651	50	1200	59(27)	159	32(0)
16	20	18	651	50	1200	67(31)	212	32(0)
0	0	0	0	0	0	0	1687	63.9

*Using C245 Excavator
**Parentheses are for reuse of barriers
***Based on 180° zone of protection

tion of a fence whose transmission loss is of sufficient magnitude so that these attenuation estimates may be reasonably achieved. The cost per decibel of reduction was based on the assumption that the materials were purchased specifically for the job and not used elsewhere, which will not always be the case. The 16-ft (4.9 m) high barrier appears to provide reasonable value. The numbers in parentheses represent the costs associated only with moving the barriers, presuming they are revised.

Barriers do not change the duration of noise exposure. Based on these criteria, there is no duration-intensity trade-off. Practical barriers can only be erected on one side, because the excavated soil must be unloaded on the other. Using the number of people exposed as an additional criterion, the P_{eq} – days exposure index as shown in Table 13 is obtained. The numbers in this table are based on the barrier protecting only a 180-degree zone. If, in fact, the excavated soil is stored as an earth berm on the other side, the exposure indices in parentheses are applicable.

The results from this example suggest that little is to be gained by using larger, faster equipment in trenching but that *significant reductions can be obtained by the use of plywood barriers and/or earth berms.*

6 CONCLUSIONS AND RECOMMENDATIONS

The results discussed earlier and the conclusions and recommendations discussed in this section provide additional information towards the desired construction (noise) cost-estimating guidelines. Much work is still to be accomplished.

Conclusions

1. Cost/benefit relationships for site noise control may be derived from construction equipment manufacturer data and from records of the U.S. Army Corps of Engineers and its contractors. The relationships and examples presented in this report are of questionable accuracy due to the sparseness of the data collected. They should only be considered trends. More data will be gathered during subsequent years to improve accuracy.

2. Construction site noise can be modeled, and the models used to evaluate construction equipment and construction process noise level scenarios.

3. The construction model, if used with care, provides estimates of off-site noise levels which agree within 5 dB with noise measurement and analysis accomplished by tape recording/computer analysis or by manual SAE procedures.

4. Construction equipment manufacturers were most cooperative in providing noise and cost data. They are an excellent source of data needed for refinement of the equipment noise control/cost relationships.

5. The U.S. Army Corps of Engineers has well-documented files containing manpower, material, and equipment usage records of construction activity. The Fort Hood family housing construction records contained this information for each day and will be analyzed in further studies to provide a baseline from which additional noise control costs could be extrapolated.

6. A significant discrepancy exists between usage factor (fraction of time equipment is in its noisiest mode) information obtained at Fort Hood and that reported by the EPA.[20,21] This discrepancy may be due to the method of investigation used at Fort Hood, the possible atypical nature of Fort Hood construction, the averaging methods used by EPA, or some other unexplained reasons.

7. It is possible to relate cost to noise reduction in a general manner. Since this study considered only Fort Hood equipment and construction methods, this was very difficult because:

   a. Each site is different. The offsite acoustical environment varies significantly from site to site.

   b. The mix of equipment types and the site-specific nature of their use introduces variability.

   c. Many day-to-day options are available to the contractor with very few days being typical.

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[20] *Background Document for Proposed Portable Air Compressor Noise Emission Regulations*, 550/9-74-016 (USEPA, October 1974).

[21] *Regulation of Construction Activity Noise*, BBN Report 2887 (Bolt, Beranek, and Newman, November 1974).

Recommendations

Since a great deal of data describing noise levels, feasible noise control methods for equipment and sites, and associated costs are required to successfully develop cost/benefit (noise reduction) relationships, the following recommendations for additional pragmatic studies are suggested.

1. Construction site sound levels should be obtained at additional family housing construction sites during each construction activity listed in the Background section of Chapter 1. These data should be obtained in a manner similar to those for Fort Hood but for a sufficient period to insure that the data are representative of the site activity. The site sound levels, usage factors, and equipment sound levels should be analyzed statistically to determine means, standard deviations, or distributions. This requires a large body of data. The analysis should be accomplished by construction activity prior to grouping in a manner reported by EPA.

2. Construction site noise level studies, including equipment noise and usage factors, should be obtained at more Corps construction sites. Construction activity groupings should be maintained. Also, future requirements for noise sections of Environmental Impact Statements for projects can be fulfilled using information gathered during these programs.

3. An in-depth inquiry into construction equipment manufacturers' programs for noise control should be made. All major equipment should be included and more specific data than gathered during this program should be obtained. Cooperation between CERL and the EPA in this area, for products designated as major noise sources, should produce optimum results.

4. Individual methods for site noise control should be investigated, perhaps site by site, until a sufficient data base is available for development of trends or empirical relationships. The variation in site construction methods is very broad, requiring that the program be carefully planned and examples selected for maximum effect.

5. As the data are gathered and analyzed, tables, graphs, nomographs, equations, etc., should be forwarded to U.S. Army Corps of Engineers construction activities for inclusion into the estimation guidelines. Contractors should be required to meet site noise criteria.[22] Estimators should be provided with a means of evaluating added construction costs as early as possible. As changes in relationships are uncovered by additional data gathering and analysis, notices of modifications should be forwarded to appropriate personnel for their use.

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[22] P. Schomer and B. Homans, *Construction Noise: Specification, Control, Measurement, and Mitigation*, Technical Report E-53/ADA009668 (CERL, April 1975).

APPENDIX A:

EQUIPMENT USED FOR DATA ACQUISITION AND SUBSEQUENT ANALYSIS AT FORT HOOD, TEXAS

Data Acquisition

Instrumentation was used at Fort Hood to gather data for the SAE Construction Site Noise Procedure (described in Appendix B) and for the sound levels of individual equipment. The readouts from computer analysis of the tape-recorded data, including cumulative distribution (percentage of exceedance) and equivalent sound level, L_{eq}, are summarized in Table A1. Table A2 gives the individual equipment sound levels. Both of these procedures used a B&K 2209 Type 1 sound level meter and a B&K 4144 1-in. (24 mm) condenser microphone connected by a B&K AO 0028 10-m extension cable. The microphone was supported by a 4 ft (1.2 m) camera tripod, protected by a B&K 0207 polyurethane windscreen and calibrated by B&K 4220 pistonphone. Magnetic linear tape recordings were made from the sound level meter by a Nagra DJ full track recorder with the Nagra QCJA step attenuator. The system was monitored with a set of headphones.

Meteorological data were gathered by using a sling psychrometer to measure temperature and relative humidity, and a simple anemometer and compass to note wind speed and direction. In addition, the SAE Construction Site Noise Procedure used two sets of microphones, windscreens, extension cables, tripods, and sound level meters to facilitate infrequent

Table A1

Summary of Cumulative Distribution and Equivalent Sound Level From Analysis of Tape-Recorded Data—Fort Hood, Texas

Measurement Location*	Cumulative Distribution		Measurement Location*	Cumulative Distribution	
	Percent Exceeded	Sound Level (dBA)		Percent Exceeded	Sound Level (dBA)
1.1	99	53	2.4	99	50
	90	55		90	53
	50	61		50	57
	10	69		10	62
	1	76		1	71
	0	79		0	87
	L_{eq} = 66			L_{eq} = 63	
2.1	99	54	4.1	99	57
	90	55		90	60
	50	57		50	67
	10	63		10	74
	1	69		1	75
	0	74		0	89
	L_{eq} = 60			L_{eq} = 70	
2.2	99	53	4.2	99	62
	90	54		90	65
	50	57		50	69
	10	72		10	72
	1	80		1	74
	0	83		0	84
	L_{eq} = 67			L_{eq} = 70	
2.3	99	57	5.1	99	62
	90	59		90	65
	50	66		50	69
	10	72		10	78
	1	79		1	80
	0	89		0	83
	L_{eq} = 69			L_{eq} = 73	

*See Table 2 for description of activities at measurement locations.

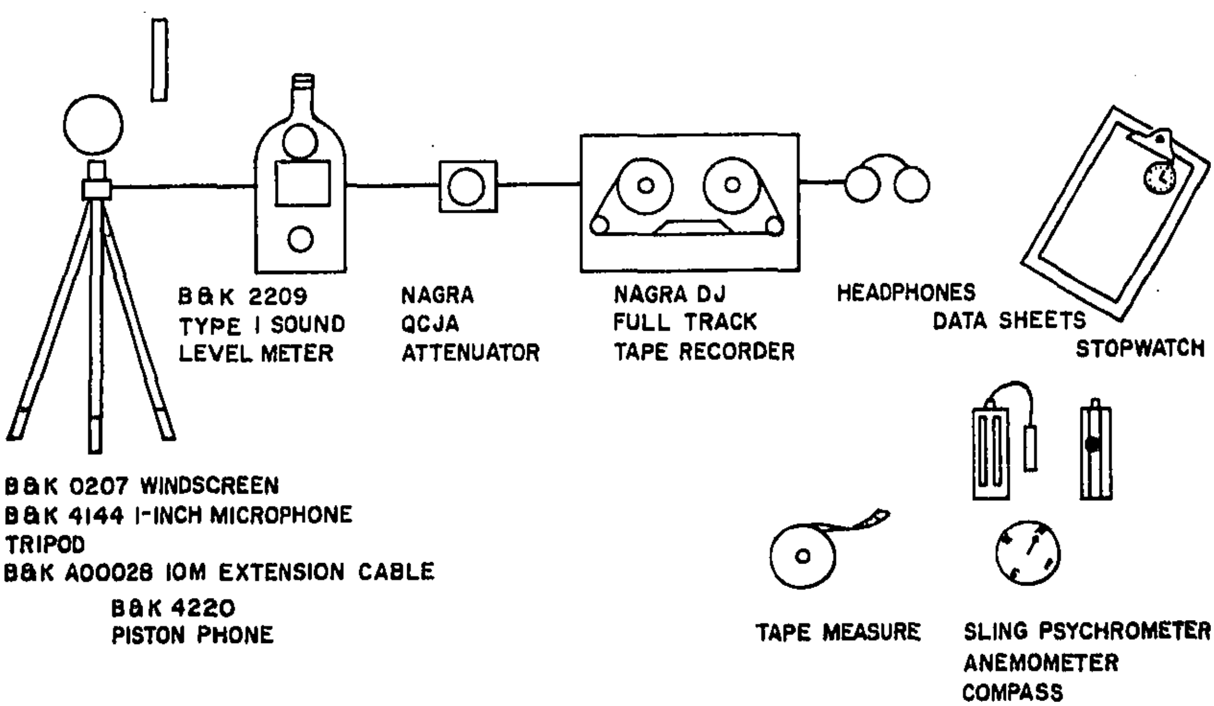

Figure A1. Equipment used for data acquisition at Fort Hood, Texas.

Table A2

Sound Levels of Individual Equipment at Fort Hood, Texas

	Sound Level at 50 ft (15 m)		Operation Performed
Bulldozers			
Case 450	89 dBC	80 dBA	Finishing site preparation (moving light sand)
	80 dBC	68 dBA - Idle	
	82 dBC	74 dBA - Backing	
Caterpillar D6	98 dBC	88 dBA - Forward & Backing	Rough site preparation (leveling mounds of dirt)
Caterpillar D6C	94 dBC	84 dBA	Backing
	94 dBC	85 dBA	Forward scraping
Caterpillar D8K	88 dBC	79 dBA	Passby (moderate load)
Caterpillar D8K	94 dBC	88 dBA	Digging furrows
	94 dBC	89 dBA	Backing up (fast)
Caterpillar D6	96 dBC	87 dBA	
	92 dBC	84 dBA - Average	Passby with moderate load (forward & reverse)
John Deere 350B	90 dBC	81 dBA - Forward	Filling in trench (10 ft below microphone)
	90 dBC	81 dBA - Forward	
	89 dBC	79 dBA - Forward	
	86 dBC	78 dBA - Backing	
Compactors			
Caterpillar DW20	90 dBC	81 dBA	Road preparation
	88 dBC	82 dBA	
Graders			
Caterpillar 12G	89 dBC	75 dBA - Forward	Site preparation (leveling sandy soil)
	96 dBC	86 dBA - Backing	
		67-74 dBA - Idle	
Caterpillar 12F	100 dBC	85 dBA	Road preparation (grading)
Caterpillar 12F	97-95 dBC	80-82 dBA	Road grading (moderate load)
	95-96 dBC	79-81 dBA - Backing	
Caterpillar 14E	86 dBC	73 dBA	Site preparation (leveling sandy soil)
	92 dBC	80 dBA	
	82 dBC	65 dBA	
Caterpillar 12G	85 dBC	82 dBA	Road grading (finishing sand)
Allis-Chalmers M65	79 dBC	71 dBA - Forward	Road grading (finishing sand)
	81 dBC	70-75 dBA - Backing	
	79-80 dBC	71 dBA - Forward	
	83 dBC	73-76 dBA - Backing	
	83 dBC	72 dBA - Forward	
Caterpillar 12F	91 dBC	81 dBA - Backing	
	89 dBC	81 dBA - Forward	
Caterpillar 14E	95 dBC	80 dBA	Grading roadway (making 4 in. cut)
	94 dBC	79 dBA - Slower	
	88 dBC	78 dBA - Idle	
Front End Loaders			
Caterpillar 930	93 dBC	87 dBA	Removing piles of hard dirt
	92 dBC	88 dBA - Forward	
	85 dBC	83 dBA - Leaving site	
	87 dBC	79 dBA - Forward	

Table A2 (cont'd)

	Sound Level at 50 ft (15 m)		Operation Performed
John Deere 644-B	96 dBC	89 dBA - Lifting	Removing piles of hard dirt
	93 dBC	85 dBA - Lifting	
	96 dBC	89 dBA - Backwards while scraping	
	92 dBC	82 dBA - Backwards while scraping	
	83 dBC	73 dBA - Leaving site	
Caterpillar 930	95 dBC	84 dBA - Near idle	Scooping dirt from pile
	93 dBC	82 dBA	
Caterpillar 930C	93 dBC	82 dBA	Picking up dirt
	83 dBC	73 dBA	
	90 dBC	81 dBA	
Caterpillar 950	87 dBC	78 dBA	Hauling 4-ft tile sections
	85 dBC	80 dBA - Backing (no load)	
	92 dBC	82 dBA - Picking up tile	
	81 dBC	74 dBA - Backing	
Caterpillar 930	95 dBC	81 dBA	Scooping dirt from pile, then leaving
	90 dBC	79 dBA - Backing	
Caterpillar 930	90 dBC	81 dBA	Scooping dirt
	94 dBC	81 dBA	
	93 dBC	82 dBA	
	95 dBC	81 dBA	Dumping dirt into dump truck
	90 dBC	81 dBA	
	92 dBC	82 dBA	Backing
	93 dBC	83 dBC	
	91 dBC	82 dBA	
Clarke M610	84-87 dBC	73-75 dBA	Picking up sand
	83 dBC	74 dBA	
	88 dBC	73 dBA	Forward
	88 dBC	72 dBA	Passby
Hydraulic Hammers			
BMC	102 dB peak		Tamping fill over sewer line
	99-105 dB peak (1/sec)		
Scrapers			
Allis-Chalmers 260B	89 dBC	83 dBA	Fully loaded, traveling down 10° slope
Allis-Chalmers 260B	92 dBC	89 dBA	Unloaded, traveling up 10° slope
Allis-Chalmers 260B	87 dBC	78 dBA	Backing
	82 dBC	72 dBA	Idle
	93 dBC	87 dBA	Starting up
Allis-Chalmers 260B	91 dBC	87 dBA	Dumping dirt for road bed
Hand Tampers			
Wacker 51005		76 dBA	Shielded by operator
		85 dBA	Unshielded
	87 dBC	87 dBA	Side
	90 dBC	88 dBA	Facing
	86 dBC	85 dBA	Shielded
Cranes			
Skyhook - 5-section telescopic	81-83 dBC	75-78 dBA	Raising framed trusses to second story

Table A2 (cont'd)

	Sound Level at 50 ft (15 m)		Operation Performed
Backhoes			
Case 580B	71 dBC	59 dBA	Idle
	80 dBC	68 dBA	Setting up in sandy soil
	77 dBC	66-67 dBA	Idle
	80 dBC	69-71 dBA	Ditching and emptying shovel
	78-79 dBC	69-70 dBA	Idle
	79-81 dBC	72-74 dBA	Ditching with faster idle
Case 580B	78-80 dBC	66 dBA	Filling in plumbing trench using front loader
John Deere 410	88 dBC	82 dBA	Digging trench for sewer line
	85-87 dBC	81-82 dBA	
Case 530	86 dBC		Filling in telephone trench (Backhoe used as trencher
Hy Hoes			
Caterpillar 235	85 dBC		Digging 10 ft w x 20 ft D trench in hard clay
	80 dBC	76 dBA	Steady
	86 dBC	81 dBA	Digging, clanking
	74 dBC	65 dBA	Idle
John Deere 690A	82 dBC	73 dBA (Scooping)	Digging plumbing trench
	89 dBC	87 dBA - Impulsive	
John Deere 690A	88 dBC		
	89 dBC	79 dBA - Moving	
	89 dBC	85 dBA - Scraping	
Self-Propelled Rollers			
Vibramay	82-83 dBC	84-85 dBA	Rolling sandy soil
Ingram Flat	92 dBC	86 dBA	Passby up grade
	78 dBA		Passby down grade
Ingram Pneumatic	83 dBC	80 dBA	Passby
		80 dBA	
Ingram Pneumatic	79 dBC	75 dBA	Downhill 5° grade
	79 dBC	71 dBA	Uphill
	85 dBC	81 dBA	Uphill revving engine
	81 dBC	78 dBA	Downhill
	86 dBC	80 dBA	Uphill full speed
Ingram Flat	87 dBC	77 dBA	Finishing road bed (slow)
	90 dBC	84 dBA	
Compressors			
Ingersoll Rand DRAF 160CFM	91 dBC	82 dBA - right side	Testing plumbing for leaks
Unidentified	68 dBC	69-70 dBA - Idle	Plastering
	84 dBC	75-86 dBA	Rear operating
	77-78 dBC	67-68 dBA	Right side operating
Trenchers			
Ditchwitch R65	86 dBC	81 dBA - left side	Trenching for telephone cable 8 in. wide
	86-86 dBC	81-83 dBA - right side	
	86-88	81-83 dBA - hard clay subsoil	
Ditchwitch R65	89 dBC	81 dBA - continuous	Trenching
	91 dBC	85 dBA	
	91 dBC	83 dBA - rock	

Table A2 (cont'd)

	Sound Level at 50 ft (15 m)		Operation Performed
Forklifts			
John Deere 480	89 dBC 86 dBC	81 dBA 79 dBA	Passby - no load
Small Cement Mixer			
Unidentified	79-78 dBC	67-68 dBA	Mortar mixing for brick facade
Cement Truck			
Unidentified	88-90 dBC	69 dBA 79 dBA	

attenuator setting changes for the A-weighted readings. Figure A1 illustrates the equipment used in block diagram format.

Measurement and recording equipment were operated and calibrated according to manufacturer's specifications and instructions, and all applicable standards were followed. Meteorological parameters were noted. If high wind speed (greater than 10 knots) or excessive relative humidity (greater than 90 percent) occurred during the measurement period, the recording session was terminated.

Analysis of SAE Construction Site Noise Tape-Recorded Data

All SAE tapes were analyzed in the laboratory using the CERL analysis system. (See Tape Recording and Analysis Method section.)

The CERL system is an extension of the monitoring systems assembled for use at EPA regional offices. Basically, data are played back from a Nagra tape recorder, A-weighted, digitized, and then classified at a rate of 10 Hz by a Wang 600 computing calculator. Statistical calculations are performed by the calculator and these data are output onto digital cassette tape for further analysis. Intrusive noise (wind gusts, conversations near the microphone, etc.) may be edited so that they are ignored by the system.

A comparison of the equivalent sound levels for the SAE procedure and computer analysis of this procedure is shown in Table 3.

APPENDIX B:

TEST METHODS AND RESULTS

Draft No. 6 (15 January 1975)

SAE Recommended Practice: Measurement Procedure for Determining a Representative Sound Level at a Construction Site Boundary Location*

1. Scope

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

2. Introduction

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

3. Definitions

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

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

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

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

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

4. Instrumentation

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

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

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

4.4 A windscreen (see Paragraph 7.3).

4.5 An anemometer with ±10 percent accuracy.

5. Site Determination

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

*From *SAE Recommended Practice: Measurement Procedure for Determining a Representative Sound Level at a Construction Site Boundary Location*, Draft 6 (Society of Automotive Engineers, 1975).

____
(Construction Site)

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

2. Construction Site ____________________ Type ____________________

3. Sound-Level Meter: Manuf. ____________________ Model ____________ S/N ____________

4. Weather Conditions ____________________

5. Remarks ____________________

Figure 1. Sample sketch format.

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

6. Measurement

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

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

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

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

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

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

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

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

Arithmetic average of L_A values.

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

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

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

7. General Comments

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

7.2 It is recommended that persons technically

CONSTRUCTION NOISE EXPOSURE DATA SHEET

Instructions:

1. Calibrate sound-level meter using acoustic calibrator.
2. Install windscreen, select A-weighting network, select "slow" response.
3. Observe for 10 ± 2 seconds at the start of each minute and ½ minute for 30 minutes.
4. Tabulate maximum reading L_n.

Construction: ☐ Activity ☐ No Activity

Determine Arithmetic Average $\bar{L}_A$

L_A (dBA)

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

SUM:* ________

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

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

Construction Site____________ Date________ Time________

Wind Velocity________ mph. Temperature________ °F. Engineer ________

Remarks ________________________

____

Figure 2. Sample construction noise exposure data sheet.

trained and experienced in the current techniques of sound measurements select the equipment and conduct the tests.

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

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

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

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

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

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

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

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

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

REFERENCES

1. Companion Document (Unpublished SAE Report).

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

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

4. SAE J184 Sound Level Acquisition System.

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

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

TABLE 1

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

Fort Hood Results

Table B1 is a summary of equipment sound level and usage factor data for measurement locations at Fort Hood, Texas.

Table B1

Summary of Equipment Sound Level and Usage Factor Data for Measurement Locations—Fort Hood, Texas

Equipment	Peak Sound Level (dBA at 50 ft (15 m))	Usage Factor**	Distance to Observer (feet (m))		L_{eq} (dB)
Location * 1.1					
Roller	77	.37	1000	(305)	47
Air Compressor	82	.08	240	(73)	57
Grader	87	.03	1000	(305)	46
Forklift	85	.38	350	(107)	64
Saw (Radial)	80	.30	300	(91)	59
Equivalent Sound Level at Observer (dB) = 66					
Location 2.1					
Backhoe	77	.07	240	(73)	52
Backhoe	77	.036	350	(107)	56
Forklift	85	.004	150	(46)	51
Saw (Radial)	80	.10	320	(98)	57
Equivalent Sound Level at Observer (dB) = 61					
Location 2.2					
Truck—4½ Ton	73	.70	150	(46)	62
Saw (Radial)	80	.23	130	(40)	65
Equivalent Sound Level at Observer (dB) = 67					
Location 2.3					
Scraper	87	.17	160	(49)	69
Grader	82	.33	160	(49)	67
Crane (Mobile)	78	.05	100	(30)	59
Forklift	86	.004	160	(49)	52
Equivalent Sound Level at Observer (dB) = 71					
Location 2.4					
Backhoe	77	.43	220	(67)	60
Backhoe	77	.43	270	(67)	58
Air Compressor	82	.08	300	(91)	55
Forklift	85	.01	280	(85)	50
Equivalent Sound Level at Observer (dB) = 63					
Location 4.1					
Scraper	87	.18	354	(108)	63
Dozer	82	.17	200	(61)	70
Dozer	82	.17	300	(91)	66
Tractor	83	.53	400	(122)	62
Equivalent Sound Level at Observer (dB) = 68					
Location 4.2					
Roller Compactor	82	.80	185	(56)	70
Grader	82	.80	210	(64)	69
Grader	87	.48	400	(122)	66
Dozer	82	1.00	400	(122)	64
Tractor	83	.60	400	(122)	63
Dump Truck	86	.30	400	(122)	63
Equivalent Sound Level at Observer (dB) = 75					
Location 5.1					
Front End Loader	88	.15	170	(52)	69
Front End Loader	89	.15	170	(52)	70
Equivalent Sound Level at Observer (dB) = 72					

*For construction activity near measurement location see Table 2.
**Usage factor—fraction of time in noisiest mode—based on data collected on site by CERL personnel.

APPENDIX C:

CONSTRUCTION SITE NOISE CONTROL

Shielding

Fences

Fences of one type or another usually surround a construction site. The primary purpose of fencing is not to keep noise in but to keep people out. To construct an entire soundproof or sound-reducing fence around a construction site of any kind would be quite expensive. However, if properly constructed, fences can be effective barriers to sound as well as people. The basic principle of sound attenuation by a barrier is to place the potential sound receiver in as much of the shadow zone of the barrier as possible. The angle formed between a line from the source to the top of the barrier and the line from the receiver to the top of the barrier should be as great as possible, as shown in Figure C1. When it is zero or less, no shielding occurs. Thus, there are certain cases when a barrier can be quite effective. Some of these are:

1. When the source is at ground level or in an excavation

2. When the barrier is high

3. When the source is close to the barrier

4. When the receiver is at ground level or down a slope

5. When the receiver is close to the barrier

6. When the frequency of the sound is high.

The shadowing of a source is poor at low frequencies (because the sound can diffract around the barrier), whereas at high frequencies, a larger shadow is cast.

These advantages can be applied to certain specific circumstances:

1. In populous areas where the distance between source and receiver is short

2. Where one-story residential homes are predominant

3. When clearing, grading, or other ground operations are being conducted

4. When stockpiles are available on the site boundary

5. When buildings are constructed starting at the noise-sensitive area and moving away, leaving the new buildings as barriers.

Barriers are valueless in the following circumstances:

1. When the major noise source is predominantly low frequency

2. When the noise source is elevated from the site boundary such as upslope or on a building

3. When the receivers are in multistory structures.

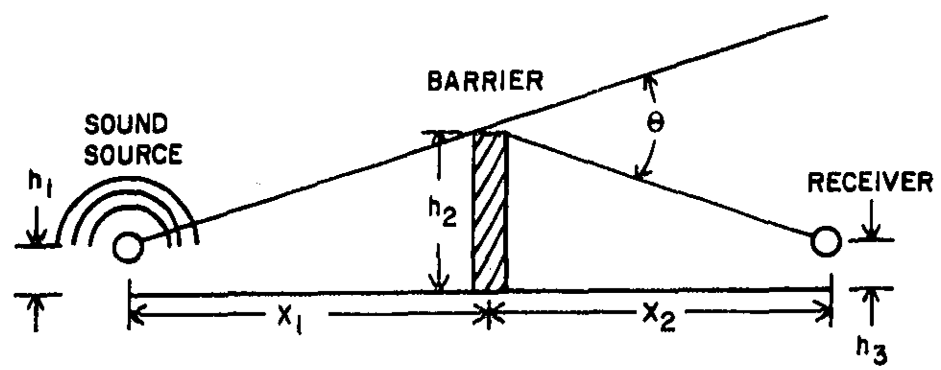

Figure C1. Basic principle of barrier attenuation.

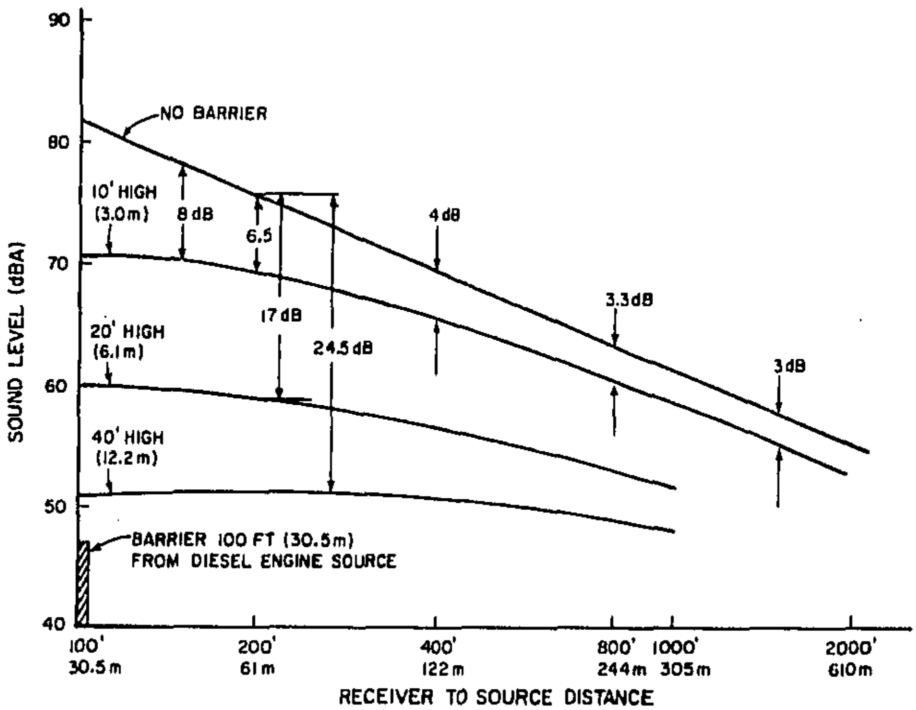

Figure C2. Shielding caused by barriers for diesel engine source 100 ft (30.5 m) from barrier.

When barriers can be used, their effectiveness depends upon both the distance between source and receiver and the height of the barrier. Figure C2 gives some example situations of that effectiveness for a diesel engine source (a bulldozer) operating 100 ft (30 m) from various height barriers on flat ground. A 10-ft (3.0 m) high barrier provides measurable reduction for the receiver if he is within 100 ft (30 m) of the barrier. When the barrier is 20 ft (6.1 m) high, a valuable reduction of 10 dB will extend out to 1000 ft (305 m). It is not recommended that a 20-ft (6.1 m) high fence be built, but rather that lumber stockpiles be set to act as a sound barrier. The Occupational Safety and Health Act limits such stockpiles to 20 ft (6.1 m). When the barrier is 40 ft (12.2 m) high, very high levels of reduction occur. Such heights are typical of two-story construction. Neither stockpiles nor homes are continuous barriers, so these large reductions cannot be realized in practice.

Simplicity, mobility, and effectiveness are the keys to keeping costs down in noise reduction. As a barrier, fences can be constructed of wood planking, plywood, or any other sturdy material and may be hung with rubber or canvas matting. These materials can be used repeatedly as needed and setup and takedown times are minimal.

As a structural support, the fence is ideal since it must be sturdy to prevent unwanted entrance. As mentioned previously, the fence can be hung with matting backed by plywood. Since leaks are a problem, overlapping is essential to improve sound reduction. Plywood gives added reflectivity and the matting aids in absorption.

Many materials can be found onsite or can be used for other purposes. As examples, chain link fencing (an excellent structural support) may already be in use to prevent unwanted entry. Plywood is usually found on a construction site, so its cost as additional material is nominal. Matting would be an added cost, but its use in other areas, such as protective covering for materials or shielding from flying debris in other operations would make it more an asset than a liability onsite.

Sections of fence, or the entire fence, depending on the length and height, can be made into a sound shield either entirely or in localized sections. A fence can be considered as the sound enclosure for the entire site; however, since some noise sources within the site will be mobile, it does not necessarily have to be a sound shield at all points at all times. Factors from both inside and outside the site will determine which sections of fence will become shields at different times. Used in conjunction with other methods of noise reduction, which are discussed later, the fence enclosure can be effective in a wide variety of situations, either as a primary or secondary noise reduction technique.

Earth Berms

On most home construction sites, earth is moved, the site is physically changed, and the ground is redistributed. Often, large amounts of earth are loaded into trucks, hauled away, and dumped. This material can be used onsite to form an earth fence or earth berm which can reduce noise emissions from the site. Earth from road excavation, foundation excavation, or high-spot excavation can be dumped on the perimeter of the site or between impacted areas and those areas where construction activity will take place. The earth should be piled as high or higher than a fence or other site enclosure—10 to 15 ft (3.0 to 4.6 m), if possible. Earth berms can be used as a base for a fence, raising the effective height, provided the soil is available before the fence is needed. Planning beforehand is important.

If it is known that a great deal of earth is to be removed but that backfilling around foundations will be needed at a later date, piling excavated earth in the form of an earth berm around the site can be a benefit, both in terms of noise reduction during construction and stocking for later use. The cost of creating a temporary earth berm would be comparable to immediate removal, the only difference being that removal would take place at a later date. No additional material is involved since the soil is readily available. In this way the material can be utilized more effectively on-site than off-site.

Earth berms are not practical to use around small areas where operations will be completed in a short period of time (since the earth will have to be moved too much), but they can be of great benefit to the site as a whole.

Stockpiles

Material stockpiles on a construction site can be used as shielding either by proper placement of materials around noise sources or by placing machinery behind material piles. According to OSHA regulations, material cannot be piled higher than 20 ft (6.1 m) (this height should be more than adequate for shielding in most cases). Any material can be used and can, if needed, be covered or draped with sound-absorbing material (matting) to reduce reflectivity and increase sound absorption. Bundles of lumber can be placed to provide shielding for a great distance, if necessary, or can be used to plug gaps in other types of shielding. This method is simple, mobile, effective, and the cost is nominal, since the material will be eventually used on-site in the process of construction.

A primary basis for minimizing noise reduction costs is to effectively use the materials on hand. In some instances, stocks of straw in bales for use in muddy conditions can be used as sound shields until they are needed at another time for another use. By maximizing the use potential of material on-site, it becomes more versatile and valuable as an investment and can substitute for or replace additional material which would otherwise be required. As a particular operation progresses, the material can be moved with it or can be used in the following operation. For example, if stockpiled bundles of lumber were shielding a basement excavation and foundation pouring sequence, the material would be available for the next operation (flooring and framing). Planning material placement is a key to smooth sequential operation transition and, in this case, also reduces the noise emitted from the site.

Buildings

Buildings can be effective sound-shielding devices, as noted earlier. On home construction sites, building operations should proceed away from the impacted areas to create a noise barrier for later operations. If the site is surrounded by areas of impact, building should proceed toward the center of the site, using the existing homes as surrounding shields.

Stationary machinery should be placed behind buildings for use as barriers. If the wall surfaces are covered with sound absorbing material, their absorption characteristics can be increased, depending on material and thickness.

As mentioned earlier, planning is important. By determining the direction of building operations, the newly built structures can act as shields; and there is no cost involved, since they are to be built anyway. They can act in place of shielding devices which would have had to be used had the operations been directed toward the impacted area. Existing buildings should be used to their maximum extent, but the direction of actual construction can be even more beneficial on larger sites.

Enclosures

Machinery sound enclosures can effectively reduce noise emissions if the machinery is stationary. Enclosures can be built of plywood and two by four's and covered inside with an absorbing material. Tent enclosures can be made of heavy fabric, rubber, or a similar heavy material, faced inside with a sound-absorptive material. Tent enclosures are not as physically strong as rigid enclosures, but they can be used when protected by other structures. Tent enclosures also do not provide as much sound absorption as rigid structures.

Enclosures can be used to quiet various types of stationary machinery (compressors, generators, pumps, engines) and to shield noise emissions from manual operations (drilling, sawing, hammering), if it is possible to perform these operations within the enclosure. One problem of enclosing machinery is heat buildup inside. The enclosure must be ventilated to minimize overheating and reduction of machinery performance. Partial enclosures overcome the heat problem and should use existing structures as part of their structure. Bales of straw can be very useful for this purpose. Enclosures can be built and taken down rapidly and moved where needed and should use available site material as much as possible.

Location of Machinery

Noisy machinery on a construction site should be located as far away from the impacted areas as possible. If this is not possible, the machinery should be located behind structures, shields, or enclosures. Stationary machinery should be located so that it can be used over as large an area as possible and thus avoid relocation. Compressors and generators running different tools on the site should have as great an effective operating radius as possible. This reduces the takedown and setup time for sound shields and related materials, but it may degrade the performance of hydraulic and pneumatic tools. If the construction site is planned beforehand, stationary equipment can be located and building can proceed within their effective operating radius. Using the stationary equipment as a focal point for operations and extending the working radius of the equipment can mean more efficient noise control, since the sources will be less mobile and easier to contain.

Blankets for Concrete

In the demolition of concrete, reflected sound can be reduced 5 dBA by using matting or fabric blankets to absorb the sound. This method will be most effective if the space is enclosed. The matting or blankets can be of the same type hung on fences or buildings at other areas on the site. Canvas filled with mineral wool, or thick cotton fiber or foam can make suitable sound-absorbing blankets which can be used for various operations.

Unused Equipment

Many times on a construction site, equipment not in use can be used as a sound shield if it is parked at points where shielding is required. Idle machinery is unproductive and is a cost; if the machinery can be put to use in reducing noise, it becomes productive. The parked machinery can be used as a structural mechanism for sound-reflection or sound-absorbing material which can be leaned against or hung on it. Machinery and equipment then become mobile supporting mechanisms for other noise-reducing materials. Bulldozer blades, loader buckets, and scrapers set lengthwise to noise sources can provide shielding and reduce the costs involved in constructing other types of shielding. This minimizes additional costs incurred in constructing shield support structures.

Time Controls

Time of Day

Noise impact can be reduced by regulating and scheduling operations on a site throughout the day to coincide with ambient noise levels of the surrounding area, although this may prove difficult at times. The noisiest operations should be performed while ambient levels are highest in the impacted areas; for example, times of day when traffic flow is the greatest are well suited for conducting noisy operations. Such times are morning rush hour—7:30 to 9:00 a.m.; noon hour—11:30 a.m. to 1:30 p.m.; and evening rush hour—3:30 p.m. to 6:00 p.m. Other relatively quiet times such as early in the morning, should be reserved for quieter operations. Daily scheduling of activities with reference to surrounding ambient levels should be considered when planning operations on the site. Evenings are preferable in business districts.

Day of Week

Most construction operations are performed on a 5-day work week basis, but in some areas, weekend work is advisable. If impacted areas surrounding the site are heavily occupied during the week, excessively noisy operations can be conducted on weekends when the impacted areas are less occupied. In business districts, weekends are preferable, while in residential areas, weekdays are preferable.

Season

The season of the year will affect noise from a construction site. In dry weather, machinery will get better traction and ground conditions will cause less slippage and thus less high engine noise; however, dry weather also means more noise reflection from hardened ground surfaces. In addition, people open windows and increase the impact of transmitted noise during warmer, drier weather. In wet seasons, ground conditions make operations more difficult and add time to operations. Traction levels are reduced and higher engine rewing is required to perform vehicle operations; however, the moisture reduces sound levels. Thus, seasonal work can become a trade-off between operational efficiency and noise levels. Operations should be carried out when ground conditions are dry and stable since these conditions make other control measures easier to implement.

In general, colder weather is preferable to warmer weather for conducting operations, since most people are then indoors.

Duration of Operation

By controlling the length of time an operation takes, the duration of noise is controlled. Using the most efficient methods can reduce the time an operation takes, but the most efficient method is not always the quietest. However, if the scheduling is such that the operation coincides with high ambient levels, the effect of a short noisy operation can be reduced. By determining the quickest way to complete an operation, the duration of the noise is reduced and the operation can create a higher noise level than can one having a long duration. The best choice is to reduce both duration and noise by efficient operations and other suitable methods discussed in this section. Controlling duration is only one way to reduce noise and should be used in conjunction with other methods to maximize its noise reduction potential.

Multiple vs. Single Operations

Since noise levels are not appreciably increased during multiple operations of approximately equal sources (i.e., two operations at 90 dB each generate only 93 dB combined), scheduling multiple operations on a site can be beneficial in noise reduction. Since single operations can extend total duration time on a site, multiple operations can reduce noise duration time. Again it is a matter of scheduling operations both in relation to time and to spatial characteristics to achieve reduction in either noise level or noise duration. Multiple scheduling can achieve efficiency in both total operations time and in noise-level reduction. For example, if two or three of the noisiest operations are conducted at the same time and scheduled at times of the day when ambient levels are highest, the impact of the emission may be felt less than if the operations were conducted singly throughout the day. Multiple operations are then preferable to single operations if planned carefully.

From the regulatory viewpoint, if one uses the Day-Night Average Noise Level (L_{dn}),* there is no advantage in multiple operations since that measure is based on a total sound energy concept (the total energy emitted as sound remains unchanged). However, there may be some advantage in multiple operations if percentile levels are used.

Operator Efficiency

The efficient operation of machinery by proficient operators can cause increased noise levels over those

*L_{dn} is the energy-averaged A-weighted noise level integrated over a 24-hr period with a penalty applied for noise levels occurring in the nighttime.

caused by less proficient operators. Highly trained and experienced operators, in order to gain maximum efficiency from the equipment, will bring their machines to their operating limit consistently and for long periods. Operating in this manner will reduce the cycle time of an operation and will bring about job completion in a shorter period. Less trained operators are of two types: (1) the cautious learner who is slower but operates his machine within its limit (he will cause less noise but increase the cycle time of the operation), and (2) the hot-rodder who is careless with his equipment and overdrives his machine (he will cause more noise but will decrease the operation cycle time).

Thus it can be concluded that highly trained drivers, in general, are likely to cause more noise than less proficient operators and are not an effective means for site noise control.

Site Masking Noise—Natural Sounds

Naturally occurring noise in areas surrounding the site (ambient levels) can be used to mask noise from the site. Scheduling daily operations to coincide with times of high ambient levels will then be necessary but may prove difficult at times. Scheduling can be achieved if ambient levels can be determined and occur regularly, but in some cases this may be a hit-and-miss system.

Site Absorption

The site itself will absorb sound to a degree; however, it is not considered feasible to increase site absorption by deliberate use of absorbing materials except within specific enclosures or in exceptional cases where adverse reflections are present.

There are two broad areas of absorption on a site.

The Ground

Hardened ground or rocky conditions on-site will reflect sound more than absorb it. Moist or loose ground conditions will have the opposite effect. If possible, noisy equipment should be kept away from areas having characteristics that will increase their noise levels and should be placed in areas having higher absorptive characteristics. Covering areas with absorptive material is also possible but is more expensive. Ground conditions can be changed in localized areas, however, to increase absorption and reduce noise.

Buildings

Buildings can be covered with absorptive matting or draping material to reduce sound levels. This would entail additional costs but the material could be re-used for sound reduction and could be used to protect equipment and materials on-site.

Fixed Equipment Height

Noisy machinery should be kept at ground level, if possible, to more easily attain shielding or absorption.

At ground level, fencing, buildings, machinery, construction shields or enclosures, and any of the other methods previously discussed can be used as noise shields. By locating machinery on the ground, the noise dispersal area is reduced and sound can be more easily contained. Noise equipment should be placed on low spots at the site in order to use the surrounding higher areas as shields.

APPENDIX D:

NOISE LEVELS AND COSTS FOR EQUIPMENT AND PROCESS NOISE CONTROL

Noise Levels and Costs—Equipment Control

This section contains a sample calculation of the increase in equipment list price and the decrease in equivalent sound level, L_{eq}, for a fill and grade construction activity at Fort Hood, Texas. Location 4.2 is used for this example.

The equivalent sound level at location 4.2 is computed from maximum equipment sound levels, their usage factors, and the distance of the center of equipment operation from location 4.2.

$$L_{eq} - (dB) = 10 \log_{10} \left(\sum_i U.F._i \left[10^{[(L_p)_i/10 - 20 \log_{10} D_i)]}\right]\right) \qquad \text{[Eq D1]}$$

where L_{eq} is the equivalent sound level at the observer (site boundary)

$U.F._i$ is the usage factor. Usage factors were obtained from on-site measurements of equipment operating cycles or from federal EPA data.[11]

$(L_p)_i$ is the equipment operating sound level as measured at 50 ft (15 m) in dBA

D_i is the distance in feet from the center of equipment operation to the observer.

[11] *Regulation of Construction Activity Noise*, BBN Report 2887 (Bolt, Beranek, and Newman, November 1974).

Table D1a summarizes the equipment observed on site during this construction phase, the present equipment operating sound levels, the distances and usage factors for each unit of equipment, and the present list price of the equipment. Table D1b summarizes the equipment sound level and cost based on manufacturers' estimates of feasible future results. It is seen from the equivalent sound levels and total equipment costs that the equivalent sound level with future quieted equipment at location 4.2 is estimated to be 3 dB less than the present level, at an estimated increase of 5.1 percent in total equipment list price.

Noise Levels and Costs—Process Control

Each specific construction site operation and alternative methods for accomplishing it are tabulated in Tables D2 through D36, along with sound levels and associated costs. Sound levels could not be obtained for many of the alternative methods, nor could operational time be determined.

The cost data were based on the hourly rates for the rental of used equipment, which appears to be the method preferred by contractors themselves. Equipment entries marked with an asterisk (Tables D2 through D36) are generally preferred methods.

Table D1a

Current Sound Level and Cost Data—Present Equipment at Location 4.2* of CERL Survey—Fort Hood, Texas

Equipment	Present Sound Level (dBA at 50 ft (15 m))	Usage Factor**	Distance from Equipment to Observer (ft)	Equivalent Sound Level L_{eq} (dB) (at Observer)	List Price (Dollars x 10^3)
Compactor (Roller)	82	.80	185 (56.4 m)	70	67.8
Grader	82	.80	210 (64.0 m)	69	61.0
Grader	87	.48	400 (121.9 m)	66	71.0
Dozer	82	1.00	400 (121.9 m)	64	69.0
Tractor	83	.60	400 (121.9 m)	63	20.3
Truck	86	.30	400 (121.9 m)	63	76.8
	L_{eq} At Observation Point (dB) = 75		Total Equipment List Price (Dollars x 10^3) = 365.9		

*Activity—Fill and Grade of Housing Foundations, Road Grading, and Compaction.
**Fraction of Time in Noisiest Operating Mode.

Table D1b

Estimated Sound Level and Cost Data—Future Quieted Equipment at Location 4.2* of CERL Survey—Fort Hood, Texas

Equipment	Future Quieted Sound Level (dBA at 50 ft (15 m))	Usage Factor**	Distance from Equipment to Observer (ft)	Equivalent Sound Level L_{eq} (dB) (at Observer)	Future List Price (present) Plus % Increase (Dollars x 10^3)
Compacter (Roller)	78	.80	185 (56.4 m)	66	71.9
Grader	82	.80	210 (64.0 m)	69	64.6
Grader	82	.48	400 (121.9 m)	61	75.3
Dozer	73	1.00	400 (121.9 m)	55	72.5
Tractor	77	.60	400 (121.9 m)	57	21.3
Truck	80	.30	400 (121.9 m)	57	79.9
		L_{eq} at Observation Point (dB) = 72		Total Equipment List Price (Dollars x 10^3) = 385.5	

*Activity—Fill and Grade of Housing Foundations—Road Grading and Compaction
**Fraction of Time in Noisiest Operating Mode

Table D2

Asphalt Roadway

Methods	dBA at 15 m	Cost/hr
Asphalt Saw (18 HP) (13.4 kW)	78	$2.50 + Blade + Operator
Jackhammer (30 to 55 lb) (13.6 to 24.9 kg)	88	$1.80 + Compressor + Operator
Breaker Tool		$1.60 + Compressor + Operator
*Rubber-Tired Loader	83	½ yd (0.38 m³) – $12.50 3 to 4 yd (2.3-3.1 m³) – $30.25 5 to 6 yd (3.8-4.6 m³) – $46.75 8 to 10 yd (6.1-7.6 m³) – $73.25
*Track Loader	86	3 yd (2.3 m³) – $35.75 4 yd (3.1 m³) – $46.75 2 yd (1.5 m³) – $16.00 2½ yd (1.9 m³) – $22.00
Compressor (Gas) 160 cu ft/min (4.5 m³/min)		$4.70
Compressor (Diesel) 160 cu ft/min (4.5 m³/min)		$5.25
Compressor (Electric) 160 cu ft/min (4.5 m³/min)		$3.25

Table D3

Concrete Roadway

Methods	dBA at 15 m	Cost/hr
Oxylance	·	$35.00 + Operator
Concrete Saw (18 HP) (13.4 kW)	80	$3.75 + Blade + Operator Gas $37.00 (Complete) Electric $40.00 (Complete)
Jackhammer (30 to 50 lb) (13.6 to 22.7 kg)	88	$1.80 + Compressor + Operator
Breaker Tool		$1.60 + Compressor + Operator
Rock Drill	98	$1.30 + Compressor + Operator $15.60 + Compressor + Operator
Concrete Splitter	62	
• Mobile Crane + Headache Ball	88	14 ton (12700 kg) – $30.50 + Ball 15 ton (1360 kg) – $34.50 + Ball 22 ton (19958 kg) – $39.50 + Ball
Compressor Gas		$4.70
160 cfm Diesel		$5.25
(4.3 m³/min) Elect		$3.25

Table D4

Wood Frame Buildings

Methods	dBA at 15 m	Cost/hr
Mobile Crane + Headache Ball	88	14 ton (12700 kg) – $30.50 + Ball 15 ton (13608 kg) – $34.50 + Ball 22 ton (19958 kg) – $39.50 + Ball
Mobile Crane + Clamshell Bucket	88	14 ton (12700 kg) – $30.50 + Bucket 15 ton (13608 kg) – $34.50 + Bucket 22 ton (19958 kg) – $39.50 + Bucket
Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
*Track Loader	86	3 yd (2.3 m³) – $35.75 4 yd (3.1 m³) – $46.75 2 yd (1.5 m³) – $16.00 2½ yd (1.9 m³) – $22.00
*Rubber-Tired Loader	83	½ yd (0.4 m³) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.25

Table D5

Reinforced Concrete Buildings (Upper Structure)

Methods	dBA at 15 m	Cost/hr
Mobile Crane + Headache Ball	88	14 ton (12700 kg) – $30.50 + Ball 15 ton (13608 kg) – $34.50 + Ball 22 ton (19958 kg) – $29.50 + Ball
*Blasting		$35.00 + Material (0.40/lb)

No alternative to use of headache ball.

Table D6

Reinforced Concrete Buildings (Foundation)

Methods	dBA at 15 m	Cost/hr
Blasting		$35.00 + Material (.40/lb) (.88/kg)
Jackhammer	88	$1.80 + Compressor and Operator
Rock Drill	98	$1.30 + Compressor and Operator
Concrete Splitter	62	$15.60 + Compressor and Operator
Breaker Tool		$1.60 + Compressor and Operator
Concrete Saw 18 HP (13.4 kW)	80	$3.75 + Blade and Operator
Oxylance		$35.00 + Operator
*Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
*Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
Compressors 160 cu ft/min gas diesel ($4.5 m^3$) electric		$4.70 $5.25 $3.25

Table D7

Removal of Material From Site

Methods	dBA at 15 m	Cost/hr
*Track Loader	86	3 yd (2.3 m³) – $35.75 4 yd (3.1 m³) – $46.75
*Rubber-Tired Loader	83	½ yd (0.4 m³) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.25
Mobile crane + Clamshell Bucket	88	14 ton (12700 kg) – $30.50 + Bucket 15 ton (13608 kg) – $34.50 + Bucket 22 ton (19958 kg) – $39.50 + Bucket
Dump Trucks	91	6 yd (4.6 m³) – $15.00 12 yd (9.2 m³) – $18.00 20 yd (15.3 m³) – $27.50

Table D8

Clearing and Grading Trees and Brush

Methods	dBA at 15 m	Cost/hr
*Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
*Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
*Track Loader	86	3 yd (2.3 m³) – $35.75 4 yd (3.1 m³) – $46.75 2 yd (1.5 m³) – $16.00 2½ yd (1.9 m³) – $22.00
*Rubber-Tired Loader	83	½ yd (0.4 m³) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.25
Backhoe	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.50 18 ft (5.5 m) – $32.50
Blasting		$35.00 + material (.40/lb) (.88/kg)
Chain Saws	111	18-20 in. (0.46 to 0.51 m) – $2.50 + operator
Dump Trucks	91	6 yd (4.6 m³) – $15.00 12 yd (9.2 m³) – $18.00 20 yd (15.3 m³) – $27.50

*Use bulldozers in conjunction with loaders.

Table D9

Clearing and Grading Rock Removal

Methods	dBA at 15 m	Cost/hr
*Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
*Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
*Track Loader	86	3 yd (2.3 m^3) – $35.75 4 yd (3.1 m^3) – $46.75 2 yd (1.5 m^3) – $16.00 2½ yd (1.9 m^3) – $22.00
*Rubber-Tired Loader	83	½ yd (0.4 m^3) – $12.50 3 to 4 yd (2.3 to 3.1 m^3) – $30.25 5 to 6 yd (3.8 to 4.6 m^3) – $46.75 8 to 10 yd (6.1 to 7.6 m^3) – $73.25
Rippers	86	Track Loader – $42.50 (4 yd) (3.1 m^3) Track Dozer – $60.50 (14 ft) (4.3 m)
Rock Drill and Blasting	98	$1.30 + Compressor + Operator $15.60 + Compressor + Operator
Dump Trucks	91	6 yd (4.6 m^3) – $15.00 12 yd (9.2 m^3) – $18.00 20 yd (15.3 m^3) – $27.50
Compressor		
gas		$4.70
160 cu ft/min diesel		$5.25
(4.5 m^3/min) electric		$3.25

Use bulldozers or loaders with ripping blades to loosen rock. The same machine is to be used for removal.

Table D10

Earth Removal

Methods	dBA at 15 m	Cost/hr
Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
Track Loader	86	3 yd (2.3 m^3) – $35.75 4 yd (3.1 m^3) – $46.75 2 yd (1.5 m^3) – $16.00 2½ yd (1.9 m^3) – $22.00
Rubber-Tired Loader	83	½ yd (0.4 m^3) – $12.50 3 to 4 yd (2.3 to 3.1 m^3) – $30.25 5 to 6 yd (3.8 to 4.6 m^3) – $46.75 8 to 10 yd (6.1 to 7.6 m^3) – $73.25
*Scraper	85	23 yd (17.6 m^3) – $57.50 15 yd (11.5 m^3) – $43.75 9 yd (6.9 m^3) – $32.50
Dump Trucks	91	6 yd (4.6 m^3) – $15.00 12 yd (9.2 m^3) – $18.00 20 yd (15.3 m^3) – $27.50

Table D11

Grading

Methods	dBA at 15 m	Cost/hr
Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
Track Loader	86	3 yd (2.3 m^3) – $35.75 4 yd (3.1 m^3) – $46.75 2 yd (1.5 m^3) – $16.00 2½ yd (1.9 m^3) – $22.00
Rubber-Tired Loader	83	½ yd (0.4 m^3) – $12.50 3 to 4 yd (2.3 to 3.1 m^3) – $30.25 5 to 6 yd (3.8 to 4.6 m^3) – $46.75 8 to 10 yd (6.1 to 7.6 m^3) – $73.25
Scraper	85	23 yd (17.6 m^3) – $57.50 15 yd (11.5 m^3) – $43.75 9 yd (6.9 m^3) – $32.50
*Motor Grader	81	13-ft (4 m) blade – $34.25 13-ft (4 m) blade – $36.25 (6 wheel drive) 13-ft (4 m) blade – $39.50

Table D12

Excavation and Draining

Methods	dBA at 15 m	Cost/hr
*Trencher	85	6 in. (0.15 m) wide – $12.50 + Operator 60 in. (1.52 m) deep
*Backhoe	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.50 18 ft (5.5 m) – $32.50
Excavator	82	35,400 lb (16057 kg) – $30.00 37,000 lb (16783 kg) – $35.00 44,160 lb (20031 kg) – $39.00
*Electric Pump and	74	$1.90
Generator (5 kW)	76	$1.90
Gas Pump 3 in. (7.6 cm) (Centrifugal)	78	$1.80

Use trencher for straight stretches and backhoe for irregular spots.

Table D13

Utilities Placement

Method	dBA at 15 m	Cost/hr
Mobile Crane	88	14 ton (12700 kg) – $30.50 15 ton (13608 kg) – $34.50 22 ton (19958 kg) – $39.50
Excavator and Hook	82	35,400 lb (16057 kg) – $30.00 37,000 lb (16783 kg) – $35.00 44,160 lb (20031 kg) – $39.00
Loader and Hook	83	½ yd (0.4 m³) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.25
*Backhoe and Hook	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.50 18 ft (5.5 m) – $32.50
Flatbed Trucks	91	16 ft (4.9 m) Trailer $4.50 + Operator

Other methods do not apply to residential construction.

Table D14

Backfilling

Methods	dBA at 15 m	Cost/hr
Track Bulldozer	86	11 ft (3.4 m) blade – $28.50 12 ft (3.7 m) blade – $36.50 13 ft (4.0 m) blade – $48.50
Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
Track Loader	83	3 yd (2.3 m³) – $35.75 4 yd (3.1 m³) – $46.75 2 yd (1.5 m³) – $16.00 2½ yd (1.9 m³) – $22.50
Rubber-Tired Loader	83	½ yd (0.4 m³) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.75
*Backhoe	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.50 18 ft (5.5 m) – $32.50

Table D15

Compacting

Methods	dBA at 15 m	Cost/hr
Jumping Jack - Hand Tampers	101	$3.75 + Operator
Machine-Mounted Tampers	102	$23.50 + Operator
Sheepsfoot Compactors	81	$7.50 (28 in.)(0.71 m) + Operator
*Flat Rollers	78	$8.45 (26 in.)(0.66 m) + Operator

Table D16

Basement

Methods	dBA at 15 m	Cost/hr
Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
Track Loader	86	3 yd (2.3 m^3) – $35.75 4 yd (3.1 m^3) – $46.75 2 yd (1.5 m^3) – $16.00 2½ yd (1.9 m^3) – $22.00
Rubber-Tired Loader	83	½ yd (0.4 m^3) – $12.50 3 to 4 yd (2.3 to 3.1 m^3) – $30.25 5 to 6 yd (3.8 to 4.6 m^3) – $46.75 8 to 10 yd (6.1 to 7.6 m^3) – $73.25
Excavator	82	35,400 lb (16057 kg) – $30.00 37,000 lb (16783 kg) – $35.00 44,160 lb (20031 kg) – $39.00
Backhoe	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.50 18 ft (5.5 m) – $32.50

Use of track bulldozer, rubber-tired bulldozer, track loader, or rubber-tired loader is recommended.

Table D17

Slabs on Soil

Method	dBA at 15 m	Cost/hr
Trencher	85	6 in. (0.15 m) wide – $12.50 + Operator
*Backhoe	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.50 18 ft (5.5 m) – $32.50

Table D18

Rock

Method	dBA at 15 m	Cost/hr
Rock Drill and Blasting	98	$1.30 + Compressor + Operator $35.00 + Material (.40/lb) ($.88/kg)
*Rock Drill and Splitter	98 62	$1.30 + Compressor + Operator $15.60 + Compressor + Operator
Jackhammer (30 to 55 lb) (13.6-24.9 kg)	88	$1.80 + Compressor + Operator
Breaker Tool		$1.60 + Compressor + Operator
Compressor 160 cu ft/min (4.5 m³/min) gas		$4.70
Compressor 160 cu ft/min (4.5 m³/min) diesel		$5.25
Compressor 160 cu ft/min (4.5 m³/min) electric		$3.25

Table D19

Foundation Excavation Hauling

Methods	dBA at 15 m	Cost/hr
Track Loader	86	3 yd (2.3 m³) – $35.75 4 yd (3.1 m³) – $46.75 2 yd (1.5 m³) – $16.00 2½ yd (1.9 m³) – $22.00
*Rubber-Tired Loader	83	½ yd (0.4 m³) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.25
Dump Truck	91	6 yd (4.6 m³) – $15.00 12 yd (9.2 m³) – $18.00 20 yd (15.3 m³) – $27.50

Table D20

Pile Driving and Caisson

Methods	dBA at 15 m	Cost/hr
Drill Auger		$60.00
Diesel		$120.00
Air		$120.00
Drop Weight		$80.00
Sonic		$150.00 to $200.00
Water Jet		$120.00
Hydraulic	69	$140.00
Benoto Method		N/A

Table D21

Foundation Forming
(In-Place Steel, Wood, and Prebuilt)

Methods	dBA at 15 m	Cost/hr
Power Saws		$1.25 (10-in. Skill) (0.25-m) + Operator
Hammers	71	$7.00 (Carpenter's hourly rate)
Mobile Crane	88	14 ton (12700 kg) - $30.50 15 ton (13608 kg) - $34.50 22 ton (19958 kg) - $39.50
Loader and Hook	83	½ yd (0.4 m³) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.25
*Backhoe and Hook	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.50 18 ft (5.5 m) – $32.50

Table D22

Concrete Supply

Methods	dBA at 15 m	Cost/hr
*Concrete Truck	83	$25.00 (6.5 yd) (5.0 m³)
Gas or Electric Site Mixer (3½ cu ft) (0.10 m³)	89	$1.50 + Operator

Table D23

Concrete Transfer

Methods	dBA at 15 m	Cost/hr
Concrete Pumps	82	$75.00
*Concrete Trucks	83	$25.00 (6.5 yd) (5.0 m³)
Mobile Hoist Crane and Bucket	88	14 ton (12700 kg) – $30.50 + bucket 15 ton (13608 kg) – $34.50 + bucket 22 ton (19958 kg) – $39.50 + bucket
Power Buggies (Mechanical)		$3.75 + Operator

Other methods do not apply to residential construction.

Table D24

Pouring and Finishing

Methods	dBA at 15 m	Cost/hr
*Electric Vibrator		$1.30 + Operator
Gas Vibrator		$1.50 + Operator
Vibrating Screed (Gas)		$2.25 + Operator
Mechanical Trowel (Gas)		36 in. (0.91 m) – $2.50 + Operator 48 in. (1.22 m) – $3.00 + Operator
*Electric Trowel		36 in. (0.91 m) – $2.50 + Operator 48 in. (1.22 m) – $3.00 + Operator

Table D25

Backfilling

Methods	dBA at 15 m	Cost/hr
Track Bulldozer	86	11-ft (3.4 m) blade – $28.50 12-ft (3.7 m) blade – $36.50 13-ft (4.0 m) blade – $48.50
Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade – $50.50 16-ft (4.9 m) blade – $70.50
Track Loader	86	2 yd (1.5 m³) $16.00 2½ yd (1.9 m³) – $22.00 3 yd (2.3 m³) – $35.75 4 yd (3.1 m³) – $46.75
Rubber-Tired Loader	83	½ yd (0.4 m) – $12.50 3 to 4 yd (2.3 to 3.1 m³) – $30.25 5 to 6 yd (3.8 to 4.6 m³) – $46.75 8 to 10 yd (6.1 to 7.6 m³) – $73.25
*Backhoe	82	12 ft (3.7 m) – $21.00 14 ft (4.3 m) – $24.00 18 ft (5.5 m) – $32.50

Table D26

Material Supply

Methods	dBA at 15 m	Cost/hr
Flatbed Trucks	91	16-ft (4.9 m) trailer $4.50 + Operator
Forklifts (gas)	83	6000-lb (2722 kg) pneumatic 15-ft (4.6 m) lift – $10.30 + Operator

No alternative to using trucks and forklifts.

Table D27

Material on Building

Methods	dBA at 15 m	Cost/hr
Mobile Crane	83	14 ton (12700 kg) – $30.50 15 ton (13608 kg) – $34.50 22 ton (19958 kg) – $39.50
Forklift (gas)	83	6000-lb (2722 kg) pneumatic 15-ft (4.6 m) – $10.30 + Operator
*Conveyor (electric)		16 to 26 ft (4.9 to 7.8 m) – $4.00
Conveyor (gas)		40 ft (12.2 m) – $8.00

Table D28

Construction

Methods	dBA at 15 m	Cost/hr
Power Saws	78	$1.25 (10-in. Skill) (0.25 m) + Operator
Hand Hammers	71	$7.00 (Carpenter's hourly rate)
Nail Gun and Compressor	65	$1.00 + Operator $2.00 (6 to 8 cu ft/min) (0.17 to 0.23 m^3) gas/electric
*Pre-fabs off-site	0	
Mobile Crane	88	14 ton (12700 kg) – $30.50 15 ton (13608 kg) – $34.50 22 ton (19958 kg) – $39.50

Strong recommendation given for prefabrication off-site.

Table D29

Exterior Work Masonry

Methods	dBA at 15 m	Cost/hr
Gas or Electric Site Mixer	89	3½ cu ft (0.10 m³) – $1.50 + Operator

No alternative except to refrain from using brick at all.

Table D30

Roofing

Method	dBA at 15 m	Cost/hr
*Nail Gun and Compressor	65	$1.00 + Operator
Hand Hammer	71	$2.00 (6 to 8 cu ft/min) (0.17 to 0.23 m³/min) gas or electric
Staple Gun and Compressor		$1.00 + Operator $2.00 (6 to 8 cu ft/min) (0.17 to 0.23 m³/min) gas or electric
Tarring	85	$30.00
Roll Roofing		$20.00
Wood Shakes		$25.00
Aluminum Shingles		$18.00

Table D31

Exterior Siding

Methods	dBA at 15 m	Cost/hr
*Nail Gun	65	$1.00 + Operator + Compressor
Hand Hammer	71	$7.00 (Hourly Rate)
Compressor gas (6 to 8 cu ft/min) (0.17 to 0.23 m³/min) electric		$2.00

Table D32

Interior

Methods	dBA at 15 m	Cost/hr
Insulation Blowing		N/A
*Insulation by Hand Staplers		$7.00 (Hourly rate)
Welders		Gas 300 Amp - $3.00 + Operator Electric 300 Amp $1.90 + Operator
Pipe Threaders		$3.00 + Operator
Power Drills		$0.50 + Bits + Operators
Power Saws		$1.25 (10-in. Skill) (0.25 m) + Blade + Operator
Steel Saws		$1.75 + Blade + Operator

Table D33

Grounds Preparation and Sprinkler System

Methods	dBA at 15 m	Cost/hr
Track Bulldozer	86	11-ft (3.4 m) blade $28.50 12-ft (3.7 m) blade - $36.50 13-ft (4.0 m) blade - $48.50
Rubber-Tired Bulldozer	83	13-ft (4.0 m) blade $50.50 16-ft (4.9 m) blade - $70.50
*Motor Grader	81	13-ft (4.0 m) blade - $34.25 13-ft (4.0 m) blade - $36.25 (6-wheel drive) 13-ft (4.0 m) blade - $39.50
*Rollers	78	$8.45 (26 in.) (0.66 m) + Operator
*Ditcher	85	4 in. wide, 18 in. deep (0.10 m/0.46 m) - $4.50 + Operator 6 in. wide, 36 in. deep (0.15 m/0.91 m) $5.75 + Operator 6 in. wide, 60 in. deep (0.15 m/1.52 m) - $12.50 + Operator

Use motor grader for fine grading.
To install sprinklers, a ditcher is best.

Table D34

Planting

Methods	dBA at 15 m	Cost/hr
*Seeding		$.02 to .04/sq ft ($.21 to $.43/m²)
Sodding (Forklifts)		$.09 to .10/sq ft ($.91 to $1.08/m²)
*Backhoe (Trees)	82	12-ft (3.7 m) - $21.00 14-ft (4.3 m) - $24.50 18-ft (5.5 m) - $32.50
Spade Shovel		$60.00
Hand Digging		$4.00
*Trucks	91	16-ft (4.9-m) trailer $4.50 + Operator

Table D35

Curbing

Methods	dBA at 15 m	Cost/hr
Hand Hammers	71	$7.00 (Hourly Rate) + Material
*Concrete Trucks	83	$25.00 (6.5 cu yd) (5.0 m³)
Gas or Electric Site Mixer (3½ cu ft) (0.1 m³)	89	$1.50 + Operator
*Curb Paver		$20.00 + Operator

Table D36

Roads

Methods	dBA at 15 m	Cost/hr
*Motor Grader	81	13-ft (4.0 m) blade - $34.25 13-ft (4.0 m) blade - $36.25 (6-wheel drive) 13-ft (4.0 m) blade - $39.50
Concrete Paver		$35.00 + Operator
Asphalt Paver		$33.00 + Operator
Roller	78	$8.45 (26 in.) (0.66 m) + Operator

APPENDIX E:

RECOMMENDED NOISE REDUCTION METHODS

Asphalt Roadway (Table E1)

Use front end loaders for demolition of asphalt roadways. Since loaders can be used for both breaking up and loading out, less equipment will be necessary, and therefore costs will be reduced. Loaders are less noisy than jackhammers and faster than asphalt saws. The noise can be reduced by timing the operation to coincide with high ambient levels in the surrounding area.

Concrete Roadways (Table E2)

Use the mobile crane and ball for demolition of concrete roadways. It is faster than other methods and requires less equipment and manpower.

Wood Frame Buildings (Table E3)

Use front end loaders to push or pull down wood buildings. It is the cheapest and quietest method, since the same machine can both demolish and load out the material. See corresponding table for noise-reduction methods.

Reinforced Concrete Buildings (Upper Structure) (Table E4)

Blasting is the cheaper and less noisy of the two methods, but may not do the job adequately due to the presence of reinforcing material. In such cases, a crane and headache ball is the only alternative.

Reinforced Concrete Buildings (Foundation) (Table E5)

Use bulldozers to remove the remaining portions of buildings; they are the cheapest and quietest method. If reinforcing material prohibits the use of bulldozers, impact tools, splitters, and torches may have to be used.

Removal of Material from Site (Table E6)

Use front end loaders instead of crane and bucket; they are cheaper and quieter.

Clearing and Grading Trees and Brush (Table E7)

Use bulldozers and loaders for clearing trees and brush. If trees are too large, chain saws will have to be used. Shielding can be used to reduce saw noise. Roots can be cut and stumps pulled out with bulldozers or loaders.

Rock Removal (Table E8)

Loose rocky ground area should be broken up with ripper blades attached to loaders or bulldozers; the same vehicle can remove the loosened material.

Blasting should be considered only in solid rocky areas or in areas where gravity can aid the work process. Since loaders and a dozer will be required after blasting in some cases, they may also be used to do the work of blasting. Blasting requires drilling and is therefore louder than the loaders and dozers.

For large boulders, drills and splitters should be used for breakup instead of blasting. They both require drilling but splitters are cheaper and quieter.

Earth Removal (Table E9)

Use scrapers as much as possible for earth removal. They have larger capacities than loaders and are quieter than loaders and hauling trucks. In some cases, combinations of equipment such as bulldozers to push material to loaders (which load material to waiting trucks) are necessary. For shorter distances to the dump site, scrapers are less expensive and noisy than loaders and hauling trucks.

Grading (Table E10)

Motor graders should be used, since they are the cheapest and quietest equipment. For rough grading, however, dozers, loaders, or scrapers may have to be used but are not the best choice. Some six-wheeled drive graders can handle heavier loads and may be able to handle rough grading on some sites. See corresponding table for noise reduction methods.

Utilities Installation Excavation and Draining (Table E11)

Use a trencher for long, straight distances and a backhoe for short, irregular distances. Backhoes are versatile and can also place pipe after excavation. Distance and depth are important factors and must be considered when estimating specific job requirements. Backhoes should be adequate for most residential utilities excavation. Pumps should be electric, since they are quieter and not prohibitively more expensive.

Utilities Placement (Table E12)

Use a backhoe and hook to place utility pipes. They are quieter than cranes and less expensive since they can also dig the necessary trenches; thus, less equipment will be required on-site. Their versatility is a factor which must be considered when planning the operation. Flatbed trucks are not a feasible alternative.

Backfilling (Table E13)

Use backhoes for backfilling, since they are cheaper and quieter than either dozers or loaders and can also excavate trenches and place utility pipes. Of all the equipment, they are the most versatile, and are cheaper and quieter by comparison.

Compacting (Table E14)

Use rollers to compact earth over residential utilities. They are the least noisy and the cost is not prohibitive. Hand tampers are much cheaper per hour but their noise emission is much louder.

Foundation Excavation Basement (Table E15)

Use loaders or dozers for basement excavation. They are cheaper and faster than excavations and the rubber-tired types are not appreciably noisier. They can handle more load than backhoes and move front-loaded earth faster. Rubber-tired loaders or dozers are recommended over track-type because of increased speed and mobility.

Slabs on Soil (Table E16)

Use a backhoe over a trencher since it is more mobile and can move more quickly around the site for each slab. It is also quieter, but costs appreciably more.

Rock (Table E17)

Use rock drills and splitters instead of blasting, although in some cases, blasting may be the only method possible. Splitters are quieter and less expensive. Paving breakers would take longer, extend noise duration, and may in the long run be more expensive. Electric compressors should be used where possible instead of gas or diesel.

Hauling (Table E19)

Use rubber-tired loaders rather than track-type, since they are more mobile, can carry heavier loads, are quieter, and the cost difference is not prohibitive.

Hauling trucks offer no alternatives over use of other equipment except by manufacturers design of a quieter model.

Foundation Forming (Table E19)

Forming done on-site with saws and hammers can be shielded to an extent or, if the forms are large enough, they can be built in enclosures and set in place with backhoes and hook attachments. The sections must still be nailed together at the site, however, and should be shielded where possible.

Backhoes are quieter and less expensive than loaders or cranes, and should be used if the forms are not too large.

Concrete Supply (Table E20)

Use the concrete truck to supply concrete for foundations. It is less costly and less noisy than mixing on-site. Mobility of trucks is also an advantage.

Concrete Transfer (Table E21)

Use concrete trucks for concrete transfer. They are less costly than pumping or buggies and would already be on-site to deliver concrete. Pumps, buggies, and hoists are special-purpose methods and do not apply to residential foundations.

Pouring and Finishing (Table E22)

Use an electric vibrator and trowel rather than gas-operated types. The only alternative to a vibrating screed is hand-screeding with a two by four.

Backfilling (Table E23)

Use a backhoe for backfilling. They are cheaper and quieter than either dozers or loaders.

Compacting (Table E24)

Use rollers for foundation compacting. They are the least noisy equipment for this purpose and their cost is not prohibitive when compared with other methods. Hand tampers are much cheaper, but much louder.

Framing, Material Supply (Table E25)

Flatbed trucks and forklifts are the only feasible methods of material supply (framing).

Material on Building (Table E26)

Use electric conveyors to transport materials to upper floors of buildings. They are the cheapest method and can be shielded if excessively noisy.

Construction (Table E27)

Power saws should be shielded or enclosed to decrease noise emissions. Nail guns are less noisy than hand-hammering and are faster in the long run. Nail guns should be used where possible.

The use of off-site prefabricated structures is quieter, faster, and cheaper than on-site construction. The following are some characteristics of prefabricated structures.

- All preliminary site work is the same as for conventionally built homes
- Townhouses and condominiums can be prefabricated
- All brickwork is done on-site (e.g., fireplace)
- Structure is bolted to the foundation
- Structure is ready for utility hookups
- Module units are bolted together
- Subfloors are glued and nailed in factory
- 1000 sq ft (93 m^2) homes require 17 working days in the factory and 2 days on-site (brickwork may require more or less work). Building a conventional home of equal size may take 5 to 7 weeks, depending on weather conditions
- The cost of prefabricated housing is about $20/ sq ft ($215/m^2) not including foundation cost ($1700 to $3500). The cost of conventional housing is about $26/sq ft ($280/m^2), but this price includes foundation costs
- The cost will be a function of site location and material used
- $1.90/mile is the estimated interstate rate for transportation
- Prefabricated structures are delivered by flatbed truck, and crane-set or slid onto the foundation.

Prefabricated structures require the use of a crane and truck to set the building on the foundation. In the long run, prefabricated structures would produce less noise at competitive costs. They are recommended and should be seriously considered.

Masonry (Table E28)

There is no feasible alternative to mixing mortar, except to refrain from using brick.

Roofing (Table E29)

Use nail guns or staple guns instead of hand-hammering or tarring. Tarring requires a heating kettle which is loud and difficult to enclose because of the heat.

Siding (Table E30)

Use nail guns instead of hand hammers. They are quieter, faster, and cheaper in the long run. Use an electric or gas compressor for the nail gun.

Interior (Table E31)

Use hand staplers for insulating.

Use electric instead of gas-powered welders.

For all other interior work, no alternative methods exist except use of prefabricated structures.

Landscaping, Grounds Preparation and Sprinkler System (Table E32)

Use a motor grader for fine grading on sites. It is quieter and costs only slightly more than bulldozers.

Rollers and ditches are the most feasible means for installing sprinkler systems.

Planting (Table E33)

Use seeding instead of sodding; it is cheaper and requires less equipment. Use a backhoe for tree planting; it is cheaper and can dig and transport the trees in the same manner as a spade shovel. Hand digging would cost more in the long run and a machine would be necessary to transport the trees. There is no alternative to use of trucks.

Curbing (Table E34)

Use concrete trucks instead of on-site mixing, because of mobility, cost, and noise advantages.

Use curb pavers over hand-built forms. In the long run, they will be cheaper and faster.

Roads (Table E35)

There is no feasible alternative to motor graders for fine road grading.

Asphalt paving is cheaper than concrete paving, but is less durable. There are no feasible alternatives to the paving methods.

Table E1

Asphalt Roadway

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Asphalt Saw	X	X	X	X	X			X	X	X		X		X	X		
Jackhammer & Compressor	X	X	X	X	X			X	X	X		X		X	X		
Loader	X	X							X	X	X	X		X	X		

Table E2

Concrete Roadway

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Oxylance	X	X	X	X	X			X	X	X		X	X	X	X		
Concrete Saw	X	X	X	X	X			X	X	X		X	X	X	X		
Jackhammer & Compressor	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	
Rock Drill Concrete Splitter & Compressor	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	
Crane & Headache Ball	X	X		X					X	X		X	X	X	X		

Table E3

Wood Frame Buildings

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Crane & Headache Ball	X	X		X		X			X	X		X		X	X		
Bulldozer	X	X		X		X			X	X	X	X		X	X		
Crane & Clamshell Bucket	X	X		X		X			X	X	X	X		X	X		
Loader	X	X		X		X			X	X	X	X		X	X		

Table E4

Reinforced Concrete Buildings (Upper Structure)

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Crane & Headache Ball	X	X		X		X			X	X		X		X	X		
Blasting	X	X		X			X		X	X		X		X	X		

Table E5

Reinforced Concrete Buildings (Foundation)

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Blasting	X	X					X		X	X		X		X	X		
Jackhammer & Compressor	X	X	X	X	X	X	X	X	X			X		X	X	X	
Rock Drill Concrete Splitter & Compressor	X	X	X	X	X	X	X	X	X			X		X	X	X	
Oxylance	X	X	X	X	X			X	X			X		X	X		
Concrete Saw	X	X	X	X	X		X	X	X			X		X	X		
Bulldozer	X	X		X					X			X		X	X		
Steel Saw	X	X	X	X	X			X	X			X		X	X		

Table E6

Removal of Material From Site

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Loaders	X	X				X			X	X	X	X		X	X		
Clamshell Bucket	X	X				X			X	X		X		X	X		
Dump Trucks	X	X				X			X	X	X	X		X	X		

Table E7

Trees and Brush

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Bulldozer	X	X				X			X	X	X	X		X	X		
Chain Saws	X	X	X	X	X	X		X	X	X		X		X	X		
Blasting	X	X					X		X	X	X			X	X		
Backhoe	X	X				X			X	X	X	X		X	X		
Loaders	X	X				X			X	X	X	X		X	X		
Dump Trucks	X	X				X			X	X	X	X		X	X		

Table E8

Rock Removal

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Bulldozer	X	X				X			X	X	X	X		X	X		
Rock Drill & Blasting	X	X			X	X	X	X	X	X		X		X	X		
Rock Drill & Splitters	X	X			X	X		X	X	X		X		X	X		
Rippers	X	X				X			X	X	X	X		X	X		
Loaders	X	X				X			X	X	X	X		X	X		
Dump Trucks	X	X				X			X	X	X	X		X	X		

Table E9

Earth Removal

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Bulldozers	X	X				X			X	X	X	X	X	X	X		
Loaders	X	X				X			X	X	X	X	X	X	X		
Scrapers	X	X				X			X	X	X	X	X	X	X		
Dump Trucks	X	X				X			X	X	X	X		X	X		

Table E10

Grading

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Scraper	X	X				X			X	X	X	X	X	X	X		
Bulldozer	X	X				X			X	X	X	X	X	X	X		
Loader	X	X				X			X	X	X	X	X	X	X		
Motor Grader	X	X				X			X	X	X	X	X	X	X		

Table E11

Excavation and Draining

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Trencher	X	X	X			X			X	X	X	X		X	X		
Backhoe	X	X	X			X			X	X	X	X		X	X		
Excavator	X	X	X			X			X	X	X	X		X	X		
Electric Pump & Generator	X	X	X	X	X	X		X	X	X	X				X	X	X
Gas Pump	X	X	X	X	X	X		X	X	X	X				X	X	X

Table E12

Utilities Placement (Includes Material Delivery)

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Mobile Crane	X	X	X	X		X			X	X	X	X		X	X		
Excavator & Hook	X	X	X	X		X			X	X	X	X	X	X	X		
Loader & Hook	X	X	X	X		X			X	X	X	X	X	X	X		
Backhoe & Hook	X	X	X	X		X			X	X	X	X	X	X	X		
Flatbed Trucks	X	X	X	X		X			X	X	X	X		X	X		

Table E13

Backfilling

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Bulldozer	X	X	X	X		X			X	X	X	X		X	X		
Loader	X	X	X	X		X			X	X	X	X	X	X	X		
Backhoe	X	X	X	X		X			X	X	X	X	X	X	X		

Table E14

Compacting

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Jumping Jack Hand Tamper	X	X	X	X		X			X	X	X	X		X	X		
Flat Roller	X	X	X	X		X			X	X	X	X		X	X		
Sheepsfoot Compactor	X	X	X	X		X			X	X	X	X		X	X		
Machine Mounted Tamper	X	X	X	X		X			X	X	X	X		X	X		

Table E15

Basement

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Backhoe	X	X	X	X		X			X	X	X	X		X	X		
Excavator	X	X	X	X		X			X	X	X	X		X	X		
Bulldozer	X	X	X	X		X			X	X	X	X		X	X		
Loader	X	X	X	X		X			X	X	X	X		X	X		

Table E16

Slabs on Soil

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Trencher	X	X	X	X		X			X	X	X	X		X	X		
Backhoe	X	X	X	X		X			X	X	X	X	X	X	X		

Table E17

Rock

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Rock Drill, Compressor & Blasting	X	X	X	X	X	X		X	X	X		X		X	X		
Rock Drill, Compressor & Splitter	X	X	X	X	X	X		X	X	X		X		X	X		
Jackhammer & Compressor	X	X	X	X	X	X		X	X	X		X		X	X		

Table E18

Hauling

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Loaders	X	X	X	X		X			X	X	X	X	X	X	X		
Dump Trucks	X	X	X	X		X			X	X	X	X		X	X		

Table E19

Foundation (In-Place Steel, Wood, and Prebuilt)

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Power Saws	X	X	X		X	X		X	X	X		X		X	X		
Hammers	X	X	X		X			X	X	X		X		X	X		
Crane	X	X	X	X		X			X	X	X	X		X	X		
Loader & Hook	X	X	X	X		X			X	X	X	X		X	X		
Backhoe & Hook	X	X	X	X		X			X	X	X	X		X	X		

Table E20

Concrete Supply

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Concrete Truck	X	X	X	X		X			X	X	X	X		X	X		
Mix on Site	X	X	X	X	X	X		X	X	X		X		X	X	X	

Table E21

Concrete Transfer

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Concrete Pumps	X	X	X	X	X	X		X	X	X		X		X	X	X	
Concrete Trucks	X	X	X	X		X			X	X	X	X		X	X		
Hoist Crane & Bucket	X	X	X	X		X			X	X	X	X		X	X		
Mechanical Wheel Barrow	X	X	X	X					X	X	X	X		X	X		

Table E22

Pouring and Finishing

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Hand (Elec.) Vibrator	X	X	X	X				X	X	X				X	X		
Mechanical (Gas) Vibrator	X	X	X	X				X	X	X				X	X		
Vibrating Screed	X	X	X	X	X			X	X	X				X	X		
Mechanical Trowel (Gas)	X	X	X	X	X			X	X	X				X	X		
Electric Trowel	X	X	X	X	X			X	X	X				X	X		

Table E23

Backfilling

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Bulldozer	X	X	X	X					X	X	X	X		X	X		
Loader	X	X	X	X					X	X	X	X		X	X		
Backhoe	X	X	X	X					X	X	X	X	X	X	X		

Table E24

Compacting

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Jumping Jack Hand Tampers	X	X	X	X				X	X	X	X	X		X	X		
Machine Mounted Tampers	X	X	X	X					X	X	X	X		X	X		
Rollers	X	X	X	X					X	X	X	X		X	X		
Sheepsfoot Compactor	X	X	X	X					X	X	X	X		X	X		

Table E25

Material Supply

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Flatbed Trucks	X	X	X	X		X			X	X	X	X		X	X		
Forklifts	X	X	X	X		X			X	X	X	X		X	X		

Table E26

Material on Building

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Mobile Crane	X	X	X	X					X	X	X	X		X	X		
Conveyor	X	X	X	X	X	X		X	X	X	X	X		X	X	X	
Forklift	X	X	X	X					X	X	X	X		X	X		

Table E27

Contruction

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Power Saws	X	X	X	X	X			X	X	X	X	X		X	X		
Hand Hammers	X	X	X	X	X			X	X	X	X	X		X	X		
Nail Guns & Compressors	X	X	X	X	X	X		X	X	X	X	X		X	X		
Prefab Off Site											X	X					
Mobile Crane	X	X	X	X		X			X	X	X	X		X	X		

Table E28

Exterior Work Masonry

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Mix On Site	X	X	X	X	X	X		X	X	X	X	X		X	X	X	

Table E29

Exterior Work—Roofing (Roll and Single)

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Compressor & Nailing	X	X	X	X	X	X		X	X	X	X	X		X	X	X	
Compressor & Stapling	X	X	X	X	X	X		X	X	X	X	X		X	X	X	
Tarring	X	X	X	X	X	X		X	X	X	X	X		X	X	X	

Table E30

Exterior Siding

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs. Single	Operator Efficiency	Natural Sounds	Height	Ground
Hand Hammers	X	X	X	X					X	X	X	X		X	X		
Nail Gun & Compressor	X	X	X	X	X	X		X	X	X	X	X		X	X	X	

Table E31

Interior

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs Single	Operator Efficiency	Natural Sounds	Height	Ground
Insulation Blowing	X	X	X	X	X	X			X	X	X	X		X	X		
Insulation Hand Application	X	X	X	X	X				X	X	X	X		X	X		
Welders	X	X	X	X	X	X		X	X	X	X	X		X	X		
Pipe Threader	X	X	X	X	X	X		X	X	X	X	X		X	X		
Drills	X	X	X	X	X	X		X	X	X	X	X		X	X		
Steel Saws	X	X	X	X	X	X		X	X	X	X	X		X	X		
Power Saws	X	X	X	X	X	X		X	X	X	X	X		X	X		

Table E32

Grounds Preparation and Sprinkler System

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs. Single	Operator Efficiency	Natural Sounds	Height	Ground
Bulldozer	X	X	X	X					X	X	X	X		X	X		
Grader	X	X	X	X					X	X	X	X		X	X		
Roller	X	X	X	X					X	X	X	X		X	X		
Ditcher	X	X	X	X					X	X	X	X		X	X		

Table E33

Planting

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs. Single	Operator Efficiency	Natural Sounds	Height	Ground
Seeding	X	X		X					X	X	X	X		X	X		
Sodding (Forklifts)	X	X		X		X			X	X	X	X		X	X		
Backhoe (Trees)	X	X		X		X			X	X	X	X		X	X		
Spade Shovel	X	X		X		X			X	X	X	X		X	X		
Hand Digging	X	X		X		X			X	X	X	X		X	X		
Trucks	X	X		X		X			X	X	X	X		X	X		

Table 34

Curbing (Forming and Pouring)

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs. Single	Operator Efficiency	Natural Sounds	Height	Ground
Hand Hammers	X	X		X				X	X	X	X	X		X	X		
Concrete Trucks	X	X		X		X			X	X	X	X		X	X		
Mix On Site	X	X		X	X	X		X	X	X	X	X		X	X		
Curb Paver	X	X		X		X			X	X	X	X		X	X		

Table E35

Roads

Methods	Fences	Earth Berms	Stockpiles	Buildings	Enclosures	Machine Location	Blankets	Unused Equipment	Time of Day	Day of Week	Season	Duration of Operation	Multi. vs. Single	Operator Efficiency	Natural Sounds	Height	Ground
Motor Grader	X	X		X		X			X	X	X	X		X	X		
Concrete Paver	X	X		X		X			X	X	X	X		X	X		
Asphalt Paver	X	X		X		X			X	X	X	X		X	X		
Roller	X	X		X		X			X	X	X	X		X	X		

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