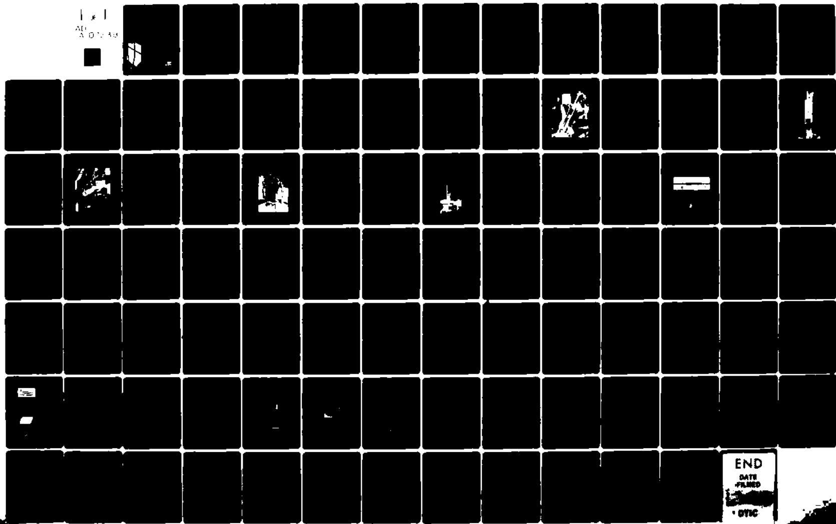
AD-A107 239 DAMES AND MOORE CRANFORD NJ F/G 13/2
NOISE CONTROL: PILE DRIVER DEMONSTRATION PROJECT, WATERLOO, IOW--ETC(U)
JUL 81 F M KESSLER, P D SCHOMER CERL-08684-004-10
UNCLASSIFIED CERL-TR-N-111 NL



1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0 4.5 5.0

MICROCOPY RESOLUTION TEST CHART

construction
engineering
research
laboratory

United States Army
Corps of Engineers
...Serving the Army
...Serving the Nation

Technical Report N-111
July 1981

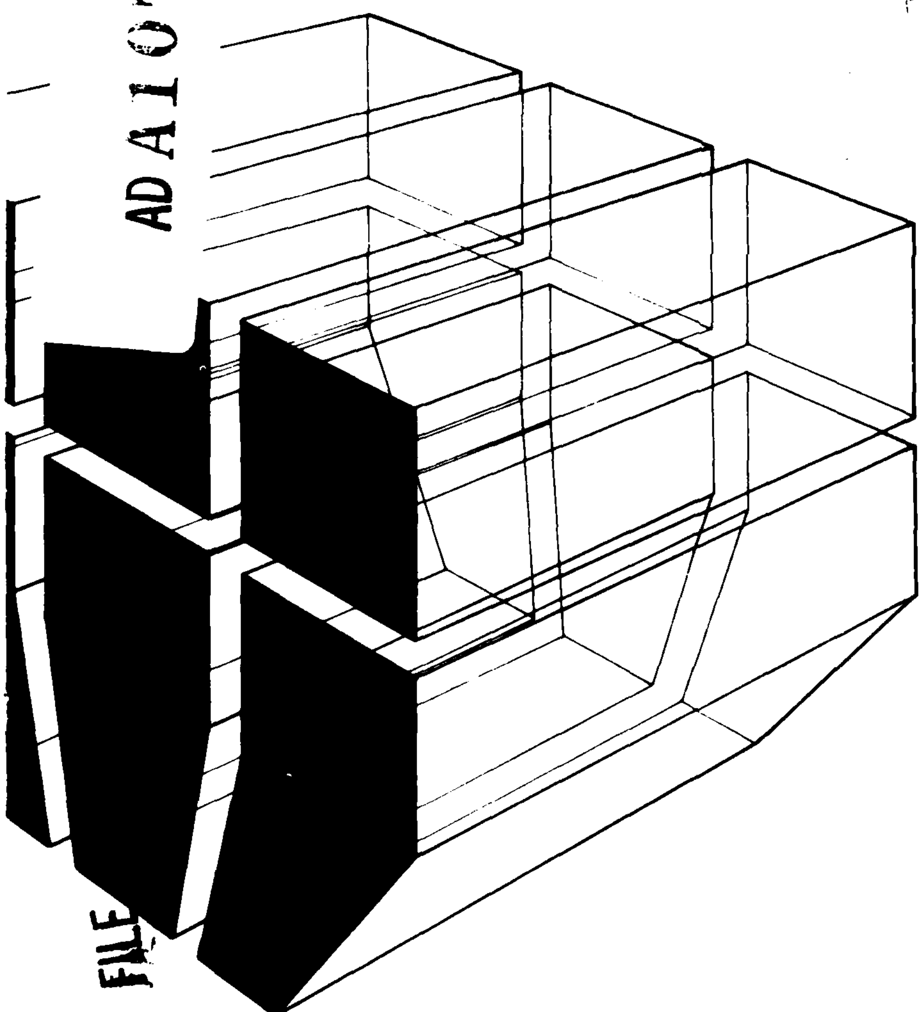
NOISE CONTROL: PILE DRIVER DEMONSTRATION PROJECT, WATERLOO, IOWA

LEVEL

12

AD A107239

1981



by
Fred Kessler
Paul Schomer

CERL

DTIC FILE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CERL-TR-N-111	2. GOVT ACCESSION NO. AD-A107	3. RECIPIENT'S CATALOG NUMBER 239
4. TITLE (and Subtitle) NOISE CONTROL: PILE DRIVER DEMONSTRATION PROJECT, WATERLOO, IOWA		5. TYPE OF REPORT & PERIOD COVERED FINAL
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Fred Kessler Paul Schomer		8. CONTRACT OR GRANT NUMBER(s) 08684-004-10
9. PERFORMING ORGANIZATION NAME AND ADDRESS Dames & Moore 6 Commerce Drive Cranford, N.J. 07016		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. ARMY CONSTRUCTION ENGINEERING RESEARCH LABORATORY P.O. BOX 4005, Champaign, IL 61820		12. REPORT DATE July 1981
		13. NUMBER OF PAGES 91
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Copies are obtainable from the National Technical Information Service
Springfield, VA 22151

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

noise pollution
pile drivers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A project jointly sponsored by the Environmental Protection Agency (EPA), Office of Noise Abatement and Control; the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL); and the Directorate of Civil Works was undertaken to demonstrate in a construction project the availability of retrofit control technology for pile drivers. The

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block 20 cont'd).

demonstration took place in Waterloo, Iowa, at a Corps of Engineers flood control project on the Cedar River.

Various in-use retrofit noise control measures for reducing the noise of pile drivers were investigated: alternative pile driving techniques, mufflers, noise enclosures, impact cushions, and vibration damping of piles. Costs and productivity impacts associated with the noise control measures were also examined. Costs were developed in units of dollars per pile. Productivity was identified in terms of the time to set up and drive a pile. The ability of a general construction contractor to bid on a noise specification, and then obtain and implement the noise control measures during the construction project were a part of the demonstration.

Retrofit of the standard impact pile driver with a noise enclosure and muffler provided a noise reduction of 10 dB. An alternative pile driver to the standard impact pile driver, the vibratory hammer, provided a 17-dB noise reduction. Both of these noise reductions were limited by other construction activity noise. Total weekly costs of the various test configurations were developed. There is some uncertainty, however, with the results for productivity, that is, the time to set up and drive a pile. This uncertainty is a result of a number of factors, the principal one of which is the lack of sufficient data for statistical confidence limits. The added total weekly costs associated with the noise control retrofit measures, enclosure and muffler, were very small. The vibratory pile driver took the longest time to drive a pile. The noise enclosure and muffler had no significant impact on the time to drive a pile. The enclosure did require a longer set up time, but a longer duration test is required to substantiate these productivity data. The Corps of Engineers' use of a detailed contract bid document specifying noise control requirements was successful. Based solely on the bid specification, the contractor bid the job, fabricated, and implemented the noise control measures receiving no assistance from the acoustical consultant. The flood control site was also used to demonstrate that a slight shift in a material trucking route can result in a significant reduction in offsite noise impact. By re-routing trucks to and from the site, only five homes were exposed to the truck noise compared to a total of 42 homes on the primary route.

FOREWORD

This project was a joint effort of the Environmental Protection Agency (EPA) Office of Noise Abatement and Control (under Interagency Agreement EPA-78-D-H0234), and the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory (CERL), Environmental Division.

The Corps of Engineers, Directorate of Civil Works, participated by providing the site for study and allowing the noise demonstration program to take place as a part of the flood control project at Waterloo, Iowa. Many individuals in the Civil Works Directorate in Washington, in Rock Island District, and the area office at Waterloo, Iowa, aided in the design and execution of this study. Without the expert assistance of these individuals and groups, the study would not have been possible.

This report was prepared by Dames & Moore under CERL contract number 08684-004-10. Dr. Paul Schomer was the CERL principal investigator and contract monitor. Dr. L. R. Shaffer is Technical Director of CERL and Colonel Louis J. Circeo is Commander and Director. Dr. R. K. Jain is Chief of the Environmental Division.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Program Objectives

The Noise Control Act of 1972 as amended by the Quiet Communities Act of 1978 specifically cites construction equipment as an area of concern with respect to noise. The U.S. Environmental Protection Agency's Office of Noise Abatement and Control (EPA/ONAC), in addition to its regulatory activities, has sponsored studies on construction equipment noise emissions and control, as well as research on the effects of noise on public health and welfare.

Executive Order 12196, dated February 26, 1980, requires Federal agencies to take the lead in environmental protection. As a result, the U.S. Army Corps of Engineers' Construction Engineering Research Laboratory has supported a research program on construction noise control as it relates to U.S. Army operations. Such research has included establishing specifications to be used in construction contracts to limit the permissible noise, methods to test compliance with specifications, assembly of methods to attenuate site noise, and assembly of other background information, such as expected noise levels and costs.[1,2,3*]

The findings of these earlier studies led to the undertaking of a demonstration program designed to identify techniques for noise attenuation of pile driver operations and materials transportation and to evaluate these techniques using a cost-effectiveness framework.[4] CERL and EPA/ONAC through an interagency agreement then developed a work plan to demonstrate that pile driver and material transportation noise control can be accomplished through retrofit controls with minimal outside assistance to the contractor for only a small percentage of the total project cost. Dames & Moore was selected to serve as a consultant to CERL, and Corps of Engineers/Civil Works Directorate (CW) cooperation was solicited for the use of a site for the demonstration. The Cedar River flood control site in Waterloo, Iowa, was selected. Various noise mitigation methods and attendant costs were evaluated, and a contractor bid document was prepared.

---

*Superscript numbers refer to reference list beginning on page 56.

The contract was bid and Shappert Engineering Company was selected as prime contractor.* Shappert was the low bidder on the total flood control project with a bid of $2,898,992.50. This compared to the CW estimate of $2,960,697. Shappert's estimate for the demonstration project was $22,000 for performing the test. The CERL estimate for the demonstration project was $18,500. Four other bids for the noise control demonstration project ranged from $22,000 to $30,000.[5]

Shappert Engineering, without soliciting or requiring any outside expert acoustical assistance, designed the noise control equipment to retrofit a standard pile driver from suggested designs provided in the bid document. Shappert also selected an alternative pile driver and equipment from a suggested list.

The demonstration of pile driver noise control was conducted August 22-29, 1979 at a flood control site on the Cedar River in Waterloo, Iowa. All noise measurements were made by CERL. Cost data, progress, and operational constraints were observed and noted during the test duration.

This report presents the results of a collaborative effort between EPA/ONAC and CERL to demonstrate available retrofit controls for reducing construction site noise associated with pile driving operations in a manner that is both practicable and cost-effective. The problems of pile driver noise and appropriate mitigative measures have been examined, as it has been determined that pile drivers are one of the louder sources of noise on a construction site (see Table 1).

*Names and addresses of manufacturers and products referred to in this report are listed in Appendix D.

Note: Nomenclature used in this report is defined in Appendix E.

Table 1. Typical Construction Site Equipment
A-weighted Sound Levels (dB)

	Construction Equipment	Typical Sound Level at 15 Meters
1.	Dump truck	88
2.	Portable air compressors	81
3.	Concrete mixer (Truck)	85
4.	Paving breaker	88
5.	Scraper	88
6.	Dozer	87
7.	Paver	89
8.	Generator	76
9.	Pile driver	101
10.	Rock drill	98
11.	Pump	76
12.	Pneumatic tools	85
13.	Backhoe	85

Source: Reference 6

Four specific objectives have been realized through this noise control demonstration. They are:

- to demonstrate that pile driver noise can be reduced through retrofit controls incorporated at the construction site,
- to show that the bid document can be effectively utilized to effect noise control,
- to affirm that a construction contractor is capable of a realistic noise control bid estimate which will closely approximate his actual costs, and
- to give evidence that a construction contractor can effectively minimize construction site noise without extensive instructions or outside technical assistance.

This demonstration program also quantified the costs and noise reductions of the noise mitigation procedures selected. It also considered alternate trucking routes to and from the site as a means to mitigate other site noise impacts.

1.2 Planning the Demonstration

1.2.1 Work plan development

A work plan was developed which outlined the approaches to be taken to test the pile driver noise mitigation methods. Manufacturers and users of pile drivers were identified and contacted for information, literature was reviewed for further data on means of mitigating construction site noise, and noise sources were identified and analyzed. From this, a combination of techniques for existing retrofit noise control were selected for use in the demonstration project. An estimation was made of the pile driver noise reduction that could be achieved by implementing the proposed methods of noise control, and costs of the different control methods were compared.

1.2.2 Selection of demonstration site

Various sites across the country were evaluated for their suitability for this demonstration. A Corps of Engineers civil works (CW) construction site in Waterloo, Iowa, was chosen as the most acceptable of the available sites. Joint meetings were held between EPA/ONAC, CW, and CERL to secure the final commitment of CW to participate in the demonstration and to include the noise demonstration program in the bid specifications at the Waterloo, Iowa, construction site.[7]

1.2.3 Various noise mitigation methods and costs

The available measures for noise control are typically divided into three categories: attenuation of noise at its source, reduction of the sound traveling along its path, and minimization of the amount of noise received by the listener. The contractor is faced with a wide range of noise control techniques. He can apply existing technology to retrofit his equipment, he can substitute quieter equipment, he can put up barriers, he can issue protective devices to workers, and more. The challenge is to implement effective practicable means to control noise at reasonable cost.

Substitution of quieter equipment can be a feasible solution, although it may be the most expensive. For example, an earlier CERL report concluded that 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. The total noise exposure may be significantly longer, thus negating the somewhat lower noise levels.[2]

Supplying workers with protective devices for their ears is also a possibility, and certainly an economical one, but here the tradeoffs are inadequate protection for nearby noise-sensitive areas.

Retrofitting equipment can be a feasible solution, but again, it may be expensive. As with any noise control technique, there are the capital costs to retrofit (materials, design, construction, and installation) and there may be increased operating costs which result from higher maintenance expenses, lower worker productivity, etc.

In this report, the feasibility and costs of two mitigative measures were examined: the retrofitting of a standard pile driver and the substitution of a quieter vibratory pile driver. The alternative pile driver chosen for the demonstration was a MKT V-20 vibratory pile driver manufactured by McKiernan-Terry. Performance data and costs for this unit were compared to the costs and performance of retrofitting a standard Vulcan hammer with noise control devices including an exhaust muffler, an impact cushion, a hammer impact area enclosure, and damping for the piles. Data were also obtained for a pneumatic, air-cushioned Bolt hammer unit (Chelminski pile driver) which was demonstrated by Bolt Associates at their plant and not as a part of the demonstration project.

Cost elements included were such items as the contractor's materials, design, construction and installation costs (i.e., the capital costs), and some of the operating costs. Because of the relatively short duration of this demonstration, such factors as worker productivity and maintenance differentials could not be assessed. Driving time was assessed in terms of blows per unit time. The selection of alternate routes for the transportation of materials to and from the construction site was also studied.

1.2.4 Contractor bid document

Draft specifications were developed and incorporated into the CW bid documents as a separate bid item. These specifications were such that all of the five contractors who bid on the project were able to provide realistic dollar bids and none found it necessary to require additional information from either CERL or CW.[7] The CW bid specifications are included as Appendix A. The cost of developing the bid specifications is not included in the analysis of this demonstration.

2.0 DEMONSTRATION SITE

2.1 Description

The U.S. Army Corps of Engineers flood protection project at the confluence of Virden Creek and Cedar River in Waterloo, Iowa, was selected as the demonstration site. A pumping station was to be constructed on Virden Creek; piles were required for both a gravity outlet structure and the pumping station itself. The piles, concrete, and other construction materials had to be transported from an offsite concrete batch plant onto the construction site. A sketch of the construction site is shown in Figure 1.[4]

2.2 Nearby Noise-Sensitive Areas

Since the construction site is bounded by the Cedar River and the Iowa Public Service power plant, no noise-sensitive areas bound the construction site. The nearest residences are along Lafayette Street east of Utica Street. There are no noise-sensitive areas to the west of Utica Street. A public boat launching facility and a park are located up-river (west) of the site.

The Lafayette Street residences are affected by trucks bringing materials to the site. Truck traffic noise control is discussed in Section 5.0.

2.3 Flood Control Project

The CW flood control project is a $40,000,000 effort involving 20 miles of levees and floodwalls, a pumping station, and a gravity outlet for water flowing into Cedar River from Virden Creek, among other structures. Under normal conditions the gravity outlet, which is basically a culvert with a gate, is open to allow Virden Creek water to flow by gravity into Cedar River. However, when the Cedar River floods, the gravity outlet gate is closed so that Cedar River water will not back up into and flood Virden Creek. With the gate closed, however, Virden Creek water can no longer flow into Cedar River, resulting in the flooding of Virden Creek. Therefore a pump station is also being built to house three large pumps which have been designed

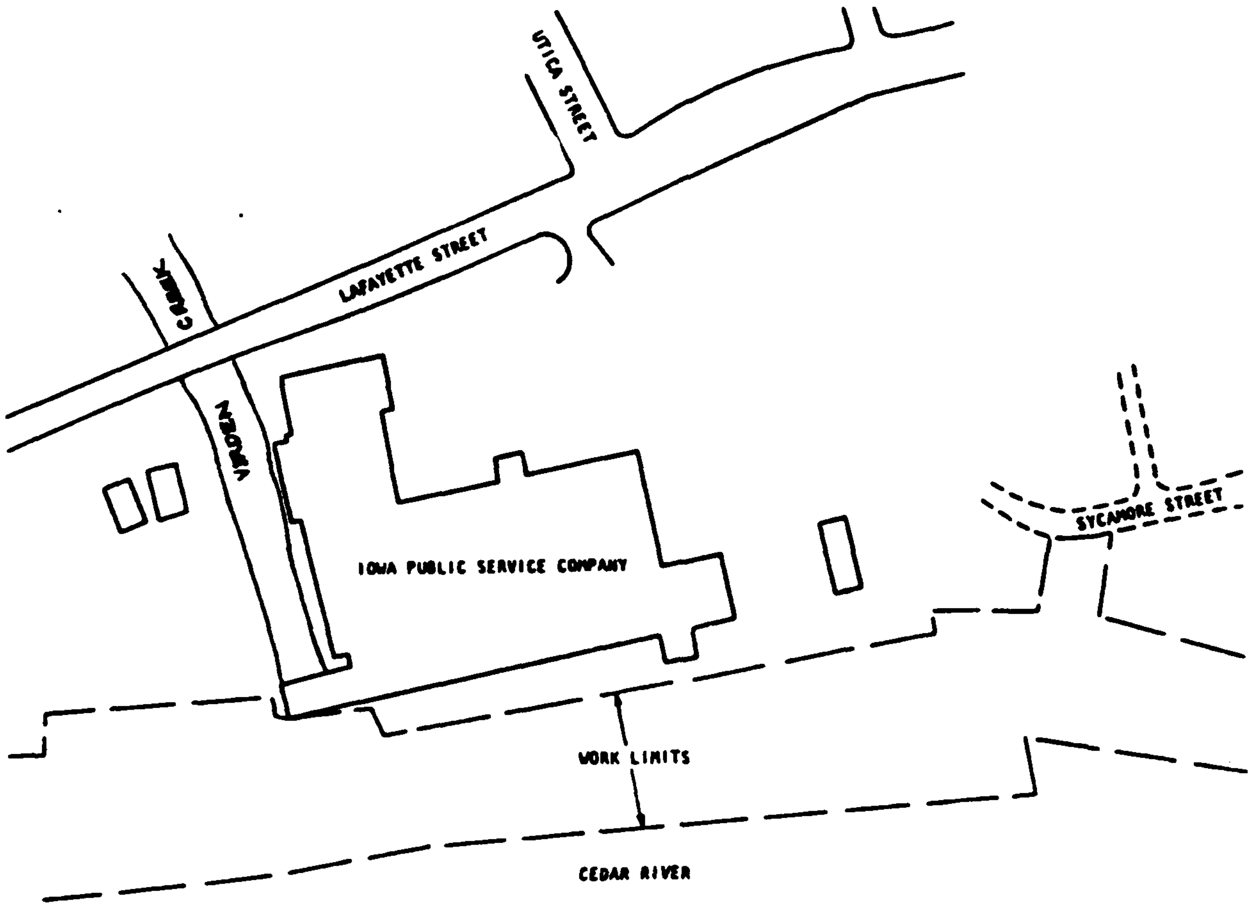


Figure 1. Flood Control Site

to handle Virden Creek water capacity under flood conditions by actively pumping water out of Virden Creek downstream into Cedar River, bypassing the gate altogether.[8]

2.4 Types and Numbers of Piles Used

The 17 piles used in the demonstration project were driven as part of 36 piles used in the construction of the gravity outlet structure as shown in Figure 2. The piles were .46 m (18 in.) round pipes which were later filled with concrete.

Note in Figure 2 that the piles are numbered from 3 to 17. No sound level measurements were obtained when the first two piles were driven. The piles were numbered by CERL as they were driven; these numbers do not necessarily agree with Shappert Engineering's numbering of the piles.

2.5 Standard Pile Driver

A Vulcan single-acting pile driver (hammer) size 010 was selected by Shappert Engineering Company as the standard unit. The "Decelflo" muffler was an off-the-shelf unit made by Vulcan and the enclosure was designed by Shappert to fit the Vulcan hammer. The performance specifications for the Vulcan 010 are presented below.

VULCAN SINGLE-ACTING PILE
HAMMER SIZE 010 SPECIFICATIONS[9]

Rated Striking Energy	32,500 ft. lb.	4,495 kgm
Blows per Minute @ Rated Pressure	50	50
Nominal Stroke	3.25 ft.	990 mm
Striking Velocity @ Impact	14.51 FPS	4.42 m/sec
Air Consumption (Adiabatic Compression)	1,002 CFM	28.36 cu m/min
Diameter of Piston	16.5 in.	419 mm
Weight of Striking Parts	10,000 lbs.	4,545 kg

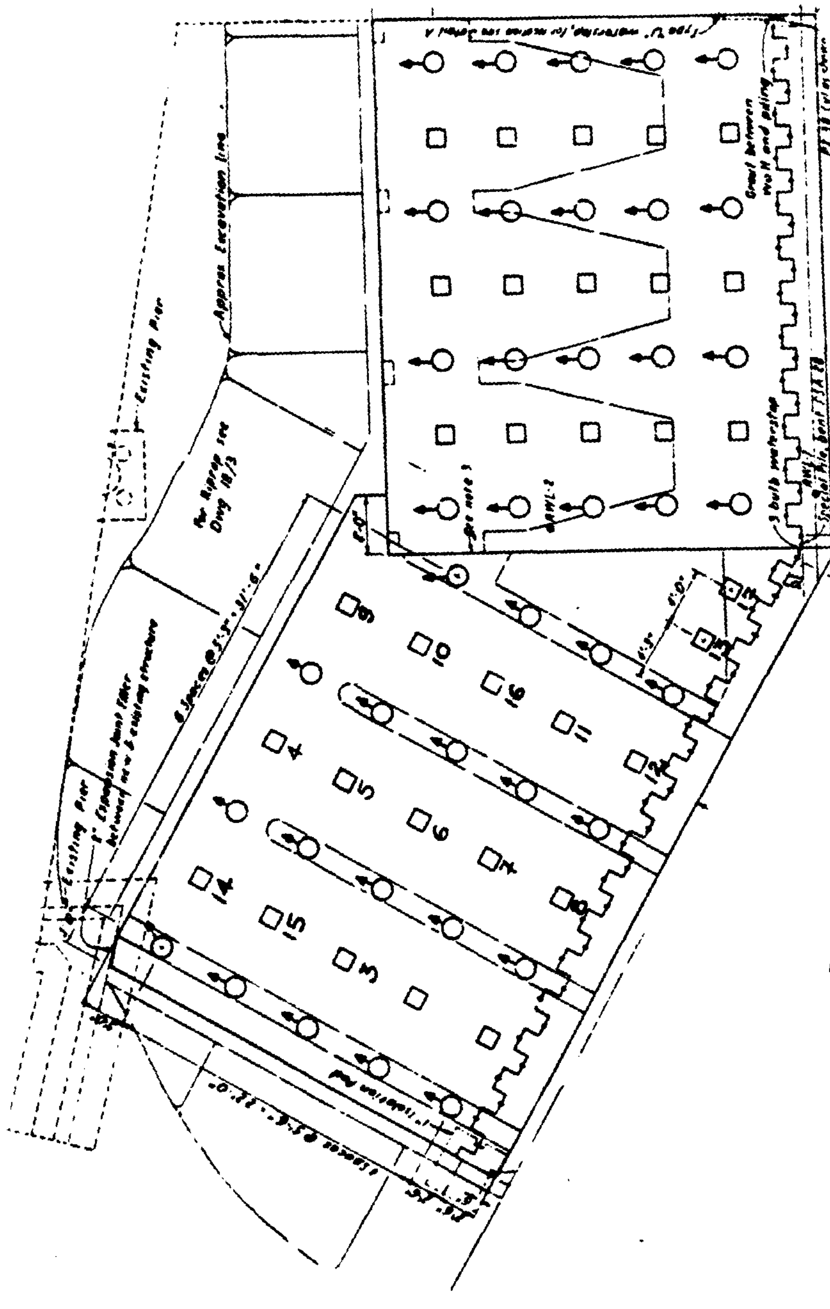


Figure 2. Pile Array With Pile Numbers

Source: Reference 10

2.6 Normal Haul Truck Transportation Route

The primary route for the transportation of materials from the nearby concrete plant to the site is along Lafayette Street, East/West First Street, and East/West Mullan Avenue, as displayed in Figure 3. This primary route passes by a number of homes on Lafayette Street. An alternate route utilizing Sycamore Street parallel to Lafayette Street can be used, which does not pass by a major residential area. The alternate route is also shown in Figure 3.

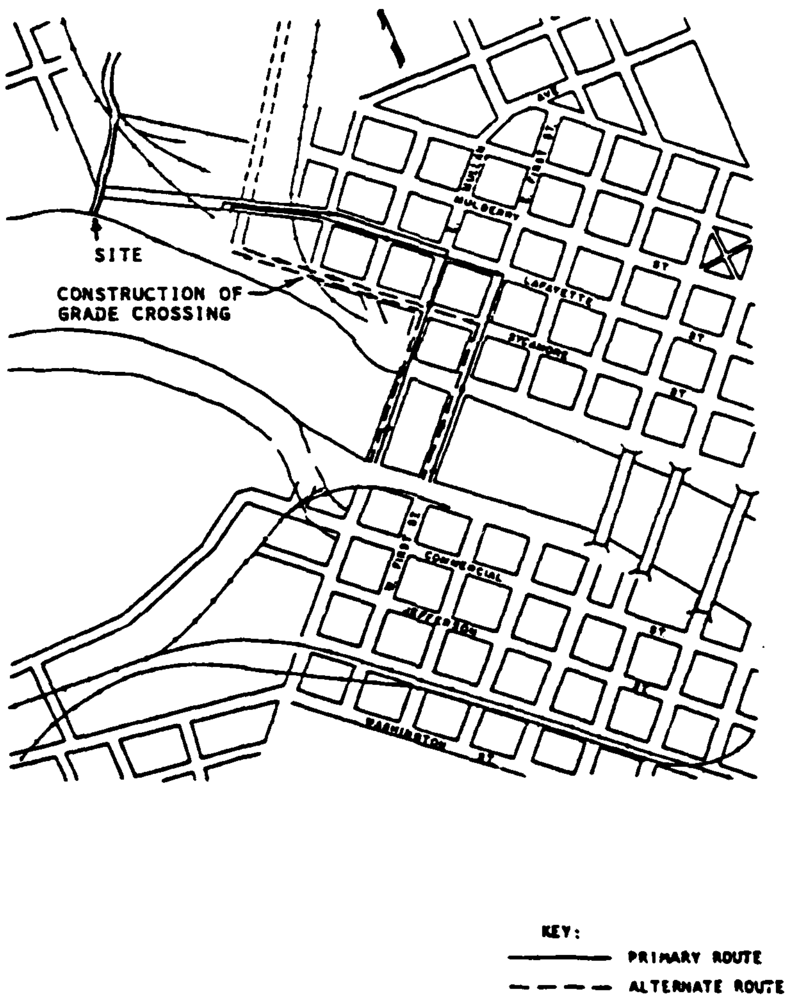


Figure 3. Primary and Alternate Trucking Routes

3.0 PILE DRIVER NOISE CONTROL

3.1 Pile Driver Description

3.1.1 Operating mechanisms

A pile driver is commonly a mechanism with a large weight (hammer) for driving piles* into the ground to support a bridge, building, or other structure. Originally hammers were simply dropped from the top of the leads** onto an anvil or base surface to transmit a blow to the pile underneath it; hence the name "drop hammer" is sometimes used. Most impact hammers today, however, are of the air pressure, steam, or diesel type. Figure 4 is a photo of the standard pile driver used in the demonstration.

Air and steam hammers contain a piston or ram lifted by steam pressure or compressed air which is then allowed to free-fall onto the anvil. Figure 5 shows a sketch of a single-acting air/steam unit. The ram of a diesel hammer is lifted by the energy released from fuel and gas combustion in a chamber between the bottom of the ram and the anvil. Thus on each impact, fuel injected into the chamber ignites and raises the hammer again. Figure 5 also shows a sketch of diesel hammers. The hammers of the air, steam, and diesel-driven pile drivers are called "single-acting" when the hammer fall is due to gravity alone. If on the down cycle the hammer is assisted by steam or air pressure, the hammer is called "double-acting," "compound," or "differential" according to its specific construction.[11]

3.1.2 Noise-producing mechanisms

The three primary sources of noise from pile drivers are the steam or air exhaust just as the hammer is about to fall, the hammer striking the anvil,

*Piles can be timbers, beams, pipes filled with concrete or other similarly shaped materials.

**Leads are the guides running parallel to the hammer which are suspended from the top of the lifting crane and hold the pile driver mechanism.

Figure 4. Photograph of Standard Unit
(Vulcan)

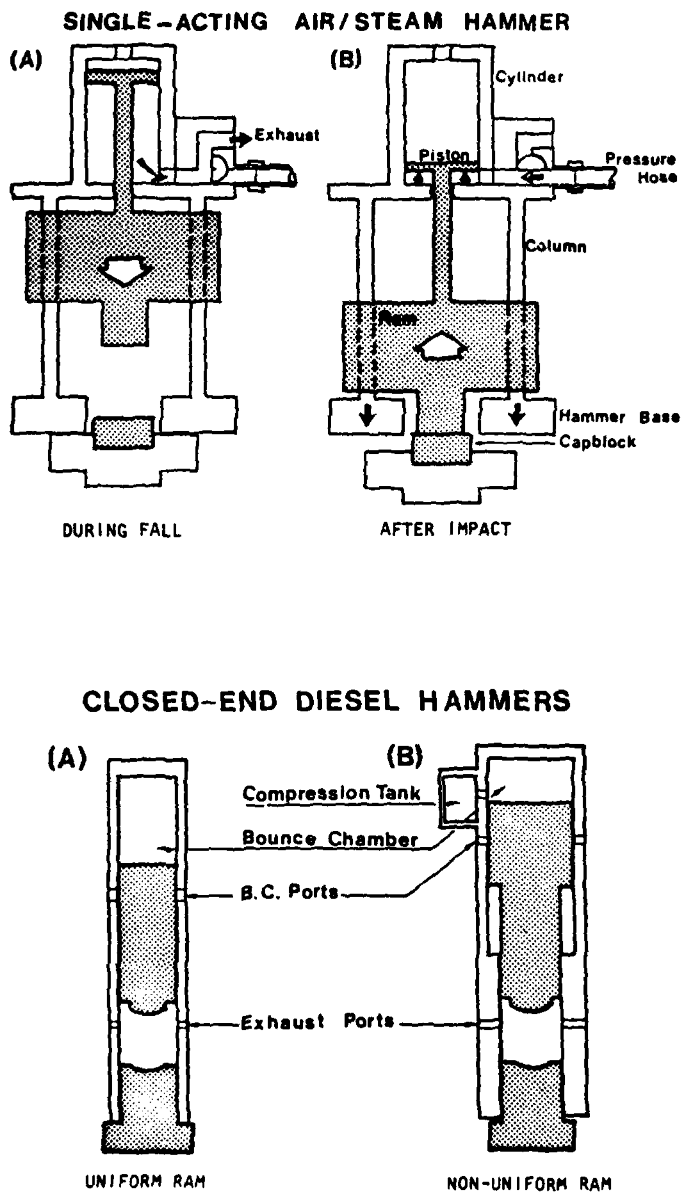


Figure 5. Sketches of Pile Driver Operation

Source: Reference 10

and the ringing sound characteristic of vibrating metal piles. The level of these noises (i.e., their A-weighted sound levels) varies with the types of hammer and pile being driven as well as with the character of the underlying soil and the construction site layout.[12] The exhaust and impact noise are about equal in level. The noises produced are of short duration (less than one second), but because of their level and character, these noise emissions are often quite annoying and at times even painful to the listener if they are not muffled in some way.

3.1.3 Annoyance characteristics

Pile driver noise is a major irritant because the sound is impulsive and because the high levels typically rise far above the ambient. As many studies and reports by individuals have shown, impulsive sounds may be judged more annoying than non-impulse sounds and sounds far above the ambient are more easily detected (by people).[13]

3.2 Noise Control Techniques

3.2.1 Retrofit

The retrofitting of pile drivers with noise control devices is one of three previously mentioned means of reducing noise. Several techniques are available which involve retrofitting existing pile hammers with mufflers or other acoustical treatment in order to attenuate the noise from the impact, the exhaust, the pile ringing, or all three. In this demonstration program, four different retrofit devices were added to a standard pile driver unit. The particular characteristics of each of the retrofit devices are outlined below:

3.2.1.1 Enclosure

This device is basically a long, acoustically-treated metal box, which is attached to the hammer and shields the impact area when the hammer/anvil strikes the pile (see Figures 6 and 7). The enclosure, designed and built

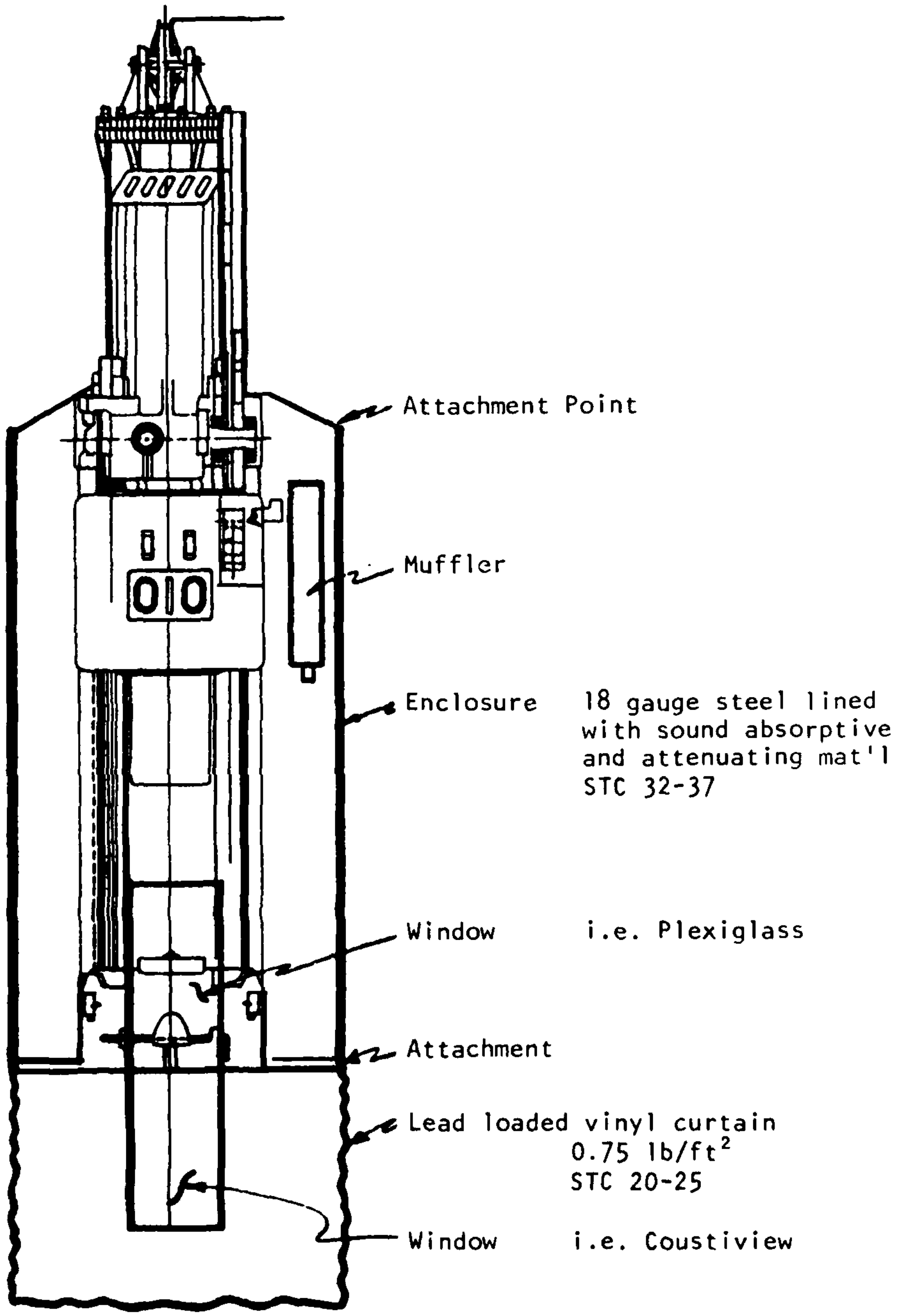


Figure 6. Schematics of Enclosure and Muffler

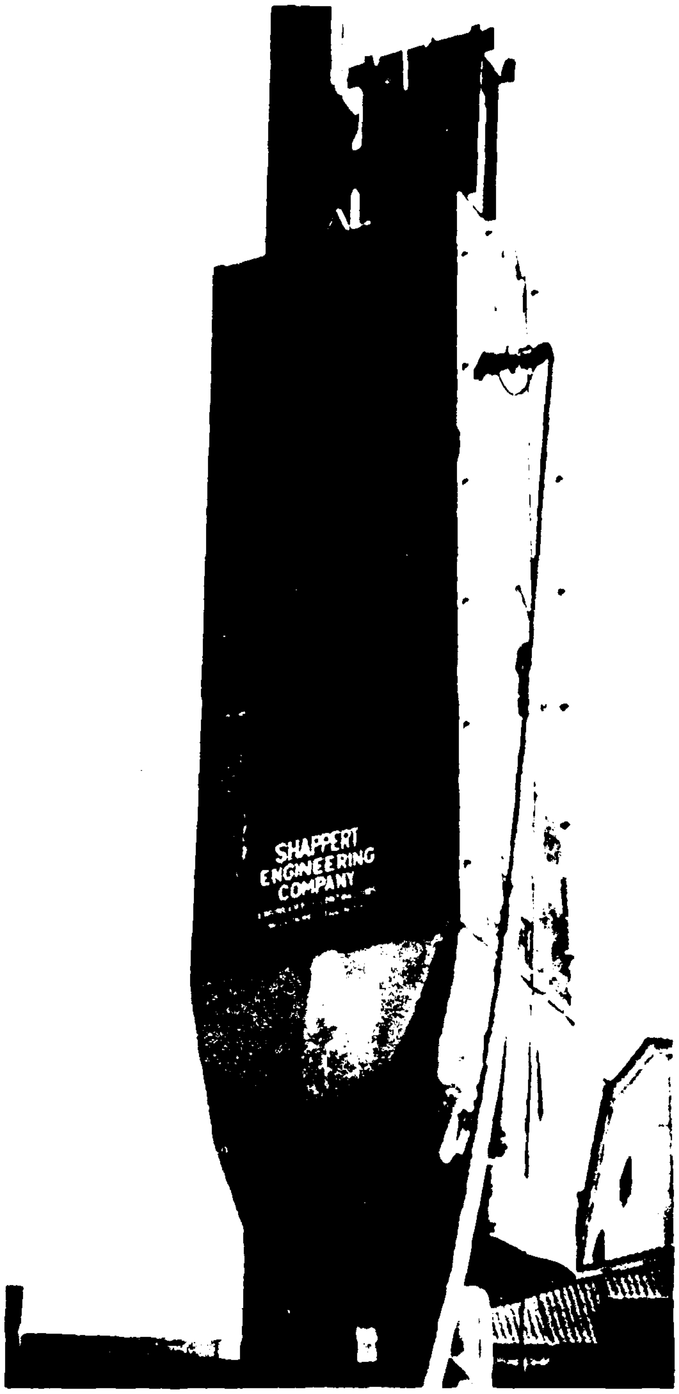


Figure 7. Photograph of Enclosure

by the contractor, was made of 18-gauge steel sheet metal, and enclosed both the hammer and hammer guides for a total length of 3.55 m (11 ft. 10 in.). It was lined on the inside with acoustic (sound-absorbing) foam to reduce the build-up of sound within the enclosure due to reverberation.*

A 1.2-m (4-ft.) vinyl skirt was attached to the bottom of the enclosure. Thus, it extended from the bottom of the enclosure so as to completely enclose the impact area. A .25-m (10-in.) Plexiglass window was installed in the enclosure and a flexible plastic window of similar size was installed in the skirt so that the hammer impact action could be observed by the workers.

Appendix B contains some information provided by Shappert Engineering Company on design details of the enclosure. The noise reduction capability of the enclosure, predicted from analysis, is given below:

Octave Band Center Frequency-Hz	31.5	63	125	250	500	1K	2K	4K	8K
Enclosure Noise Reduction-dB	3	6	10	17	22	27	32	37	41

3.2.1.2 Muffler

The ram of the Vulcan pile driver is raised by compressed air, and then using the force of gravity, is dropped onto an anvil which transmits a downward force onto the pile (see Figure 5). Associated with the free-fall of the ram is the sudden discharge of this air through an exhaust port. The noise produced by this large air pressure pulsation can be attenuated by installing a muffler on the exhaust port.

An "off-the-shelf" muffler that provides at least 15 dB (A-weighted) of noise attenuation was available from Vulcan Iron Works, Inc. The muffler was specifically designed for use on the exhaust ports of the Vulcan air and steam-driven pile hammers (see photo, Figure 8). These "Decelflo" mufflers are available at a cost of approximately $3,457.00 (9/11/78). Relatively few have been manufactured and they are thus not available for rental. One of the main advantages to the Vulcan muffler is that it is designed to attach conveniently

*The sound level increase due to reverberation may be as high as 12 dB; the acoustic treatment may reduce this by as much as 10 dB.

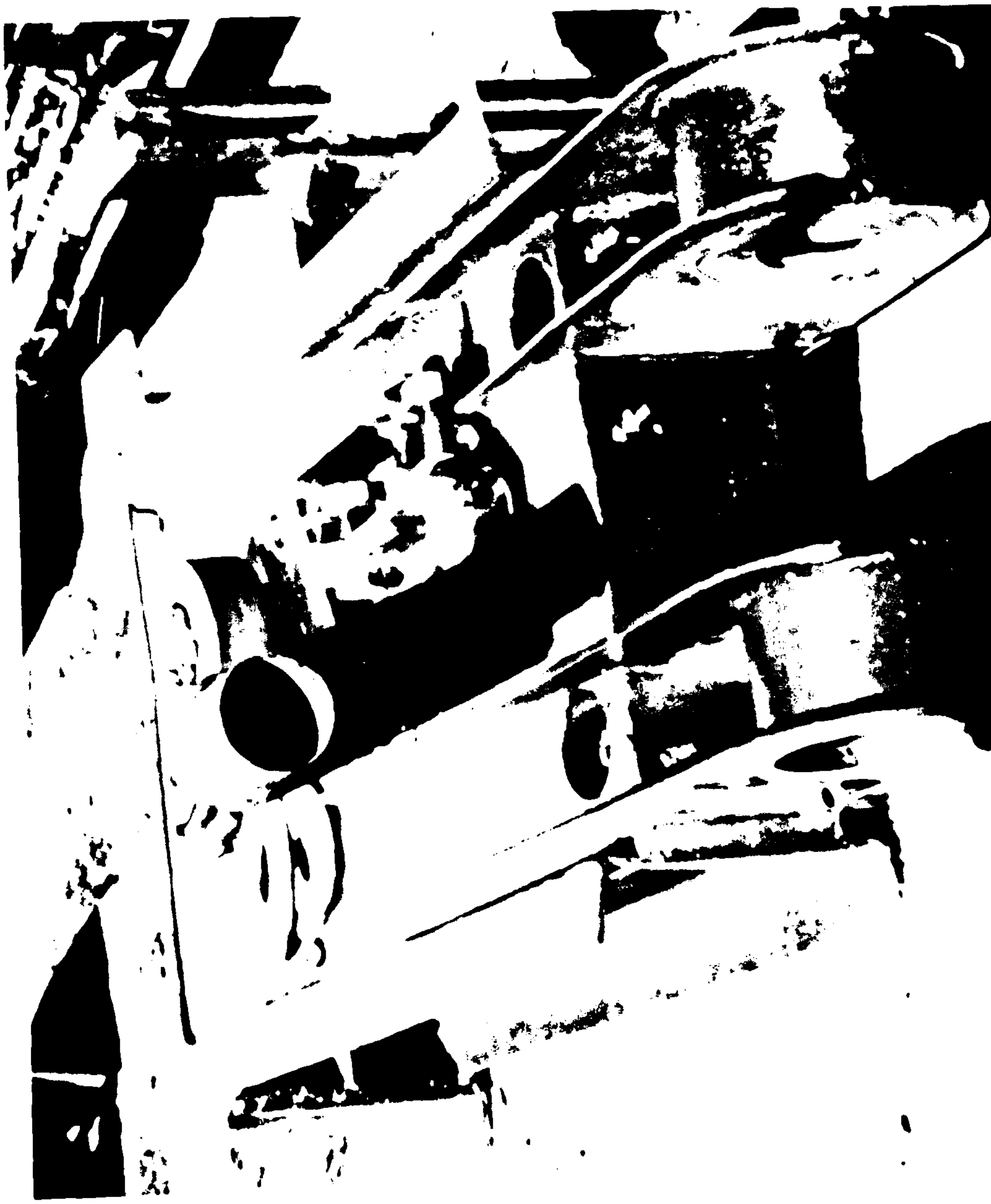


Figure 8. Photograph of Vulcan Muffler

to the hammer and be guided by the leads in the same manner as the hammer. Other mufflers at lower costs are available from independent muffler manufacturers such as the Donaldson Company, Burgess Manning, and others. However, many of these models may require extensive and costly rig modifications to accommodate the muffler to the pile driver such that the muffler is able to withstand the severe mechanical shocks.

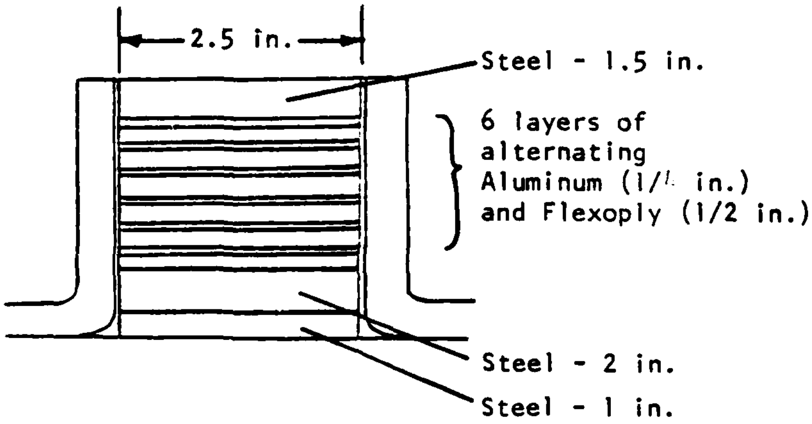
3.2.1.3 Pile damping

Noise reduction may also be achieved by applying energy-absorbing materials to the piles to mitigate the ringing noises associated with vibrating steel piles. In this demonstration, a water-based damping compound was applied in an unconstrained form in rings about 0.025 m (1 in.) thick at 2.4-m (8-ft.) intervals on the piles. As discussed in a later section, the application of damping material of this form proved to be time-consuming and therefore very expensive.

An alternative procedure to reducing the pile vibration has been suggested but not examined in this demonstration, principally due to the limitation of funds. It consists of strapping worn-out rubber tire tubes to the pile at 2.4-m (8-ft.) intervals. These are cut off as the pile reaches ground level and may then be reused.

3.2.1.4 Impact cushion

An impact cushion acts as a vibration isolator to reduce vibration transmitted to other parts of the pile driver, thereby reducing noise. At one time, this cushion was a 0.05 to .10-m (2-4-in.) wooden block developed to prolong anvil life and the pile head by placing it between the anvil and the pile head. Over the years it has been modified and improved. Currently the impact cushion is constructed of 0.1 to 0.3-m (4 to 12-in.) alternating layers of .006-m (.25-in.) sheet aluminum and .0127-m (1/2-in.) sheets of phenolic material which must be cut to the proper dimensions to fit the bonnet (see sketch). These pads require occasional replacement. In this study, the standard phenolic material was replaced with 1-in. (0.025-m) elastomeric material obtained from Peabody Noise Control, Inc.



Cross-Section of Bonnet
For VULCAN 10 Pile Driver

There were many uncertainties surrounding the use of elastomeric materials in the impact cushion. These concerns include the effect on driving time, durability, and costs. These concerns were to a small degree addressed in the demonstration. This is discussed further in section 4.3 of the body of the report.

3.2.2 Alternative pile drivers

Various alternatives to the conventional steam, air, or diesel-driven pile drivers were assessed. Pre-drilled concrete piles, vibratory pile drivers, air-cushioned pile drivers, hydraulic ("English") pile drivers and "Benoto" (rotation technique) pile drivers were all acceptable alternatives. Shappert selected a vibratory pile driver manufactured by McKiernan-Terry (MKT V-20) for use in the demonstration (see Figure 9) from a suggested list of equipment. The selection was based primarily on equipment availability, costs of rental and shipping, and the contractor's previous experience in using this type of equipment.

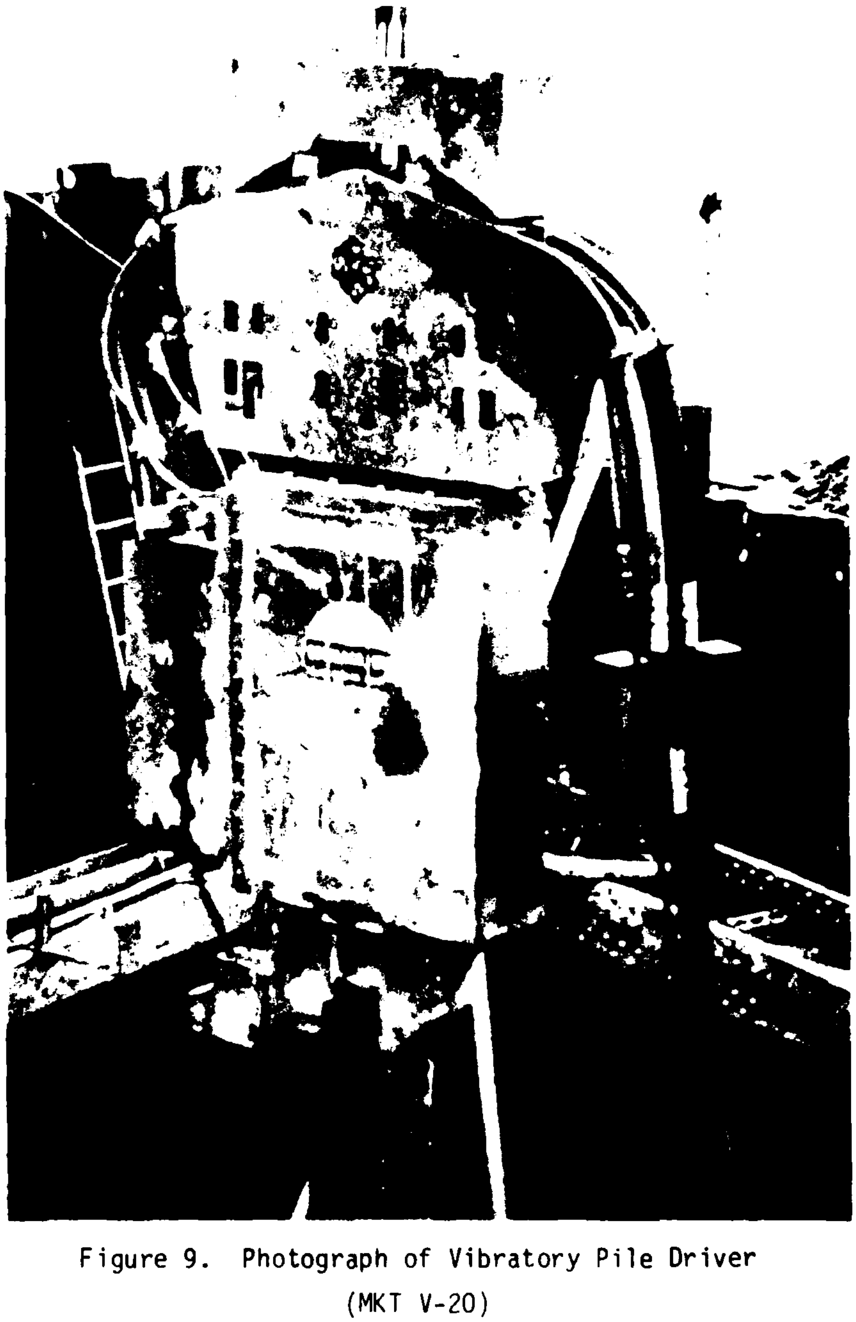


Figure 9. Photograph of Vibratory Pile Driver
(MKT V-20)

3.2.2.1 Vibratory pile driver

As an alternative to driving piles with a hammer, a vibratory force generator powered by an electric or hydraulic motor is occasionally used. The advantages to this method are primarily lower noise levels and rapid rates of soil penetration. In one demonstration comparing its performance to that of a standard single-acting steam hammer, the steam hammer sank a pile 20.4 m (67 ft.) in 90 minutes versus 21.6 m (71 ft.) in 42 seconds for the vibratory unit.[14] This is possible because the vibratory force generator provides a much higher frequency of thrusts to the pile than the conventional hammer. This more rapid thrust motion keeps the soil in an agitated state, thereby reducing frictional force and making the pile easier to drive. In addition, vibratory drivers are very effective pile extractors for use in any type of soil.

The main disadvantage to vibratory units is that their effectiveness depends very much on soil conditions, as they are unreliable in cohesive soils such as heavy clays, and are thus not suitable for all pile driving applications. In addition, extreme care is needed when using vibratory drivers in built-up areas to prevent the excessive surface settlements around existing structures due to soil agitation which are associated with using these pile drivers in granular soils.

3.2.2.2 Bolt unit/Chelminski design

Conventional hammers are less than optimally energy-efficient in that much of the impact energy is often dissipated through the cushion blocks and driving heads on impact. The Bolt unit has been designed to minimize this loss of energy through the use of a cushion of compressed air or steam. Rather than coming in contact with an impact cushion as with conventional pile drivers, the hammer rebounds from this cushion of air or steam. More energy is thus redirected to assist in raising the hammer again and less energy is dissipated as noise. Invented by Chelminski and developed by Bolt Associates, Inc., of Norwalk, Connecticut, this pile driver has undergone extensive redesigning to reach its present efficiency. Its main advantages are: decreased noise levels due to no metal-to-metal contact on hammer impact; no pile cushions and helmets (and their attendant extra costs) necessary; higher energy efficiency than the standard unit;* and the simplicity of design with very few moving parts (see Figures 10 and 11). In addition, this unit has the unique quality of having four separate driving modes which adjust to accommodate varying soil conditions during driving operations as well as being automatically self-regulating according to encountered soil resistance.

The main disadvantage of the Bolt unit is its relatively high capital cost. Its purchase price was $85,000 as of May 1979 with rental costs of 15% of the selling costs per month for short-term usage and 10% of the selling cost per month for long-term usage. The Bolt unit was not used in the demonstration. This unit was, however, available for recording noise measurements at the Bolt plant in Connecticut. Data from the Connecticut demonstration are included in this report.

3.2.2.3 Hush unit

A British firm, Sheet Piling Contractors, Ltd., has developed a diesel-driven hammer incorporated inside a very long "Hush Rig" enclosure which reduces sound emissions. This enclosure extends the full length of the pile being driven. Results of 68 dB at 15 m (50 ft.) have been reported. The sound insulating box is fixed at the top to the crane jib by a universal joint which keeps the hammer and the pile perfectly aligned. This ensures that the energy from the hammer is used to force the pile deeper and there is no dissipation of energy by lateral movement of the pile head, thereby ensuring successful pile driving under any soil conditions unlike most other silenced pile drivers. Further information may be obtained from S.P. Civil Engineering, Ltd., at the address provided in Appendix D.

*The prolonged downward push resulting from the compressed air-cushioned bouncing action is a more energy-efficient force than the conventional, irregular, sharp hammer blow resulting from the impact of one solid mass against the other.[15]

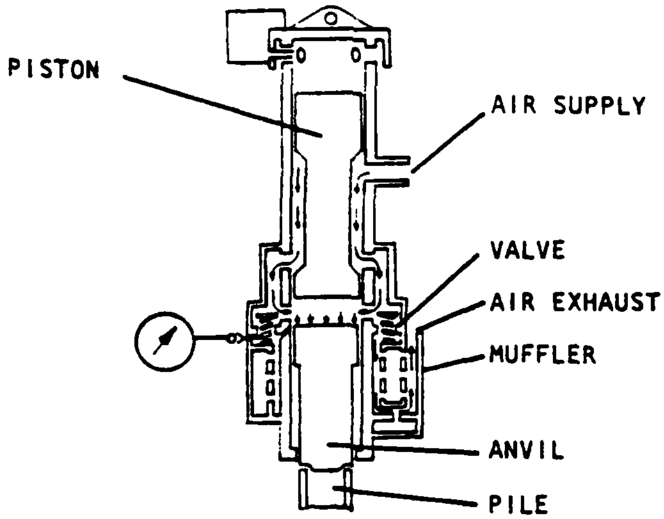


Figure 10. Schematic of Bolt Unit

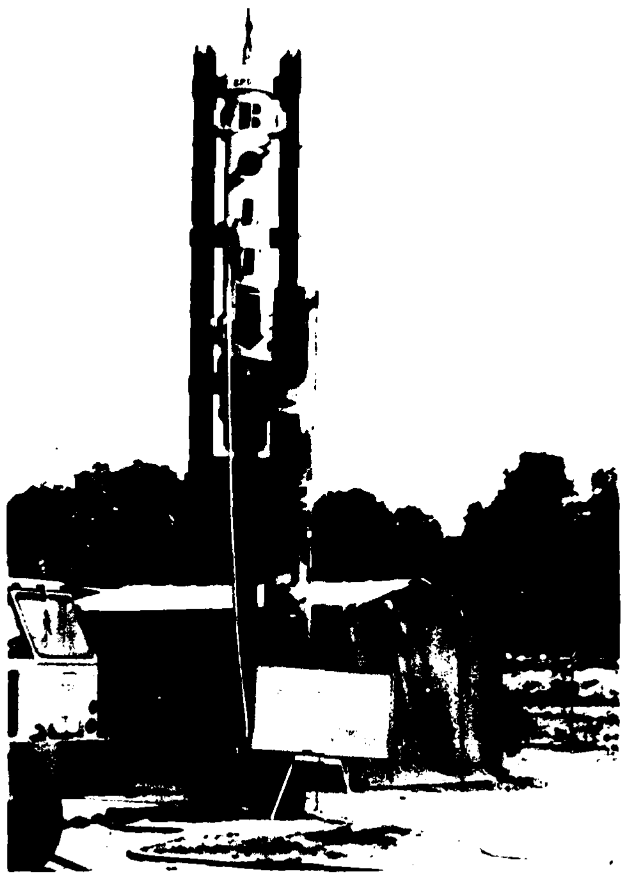


Figure 11. Photograph of Bolt Unit

4.0 RESULTS OF PILE DRIVING DEMONSTRATION

4.1 Operating Conditions During the Demonstration

During the testing of the pile drivers and their associated retrofit noise control accessories, a number of field operating conditions affected work efficiency and noise control.

As discussed below, the first ten of the seventeen piles involved in this demonstration were driven using the standard pile driver incorporating a variety of retrofit techniques. Many operational difficulties were encountered and these are discussed in detail. As a result, the first ten piles were driven at a rate of about four per day, whereas the last four piles were driven by the standard unit in half a day. Although this would initially seem to indicate that the use of the retrofitted unit decreases productivity by increasing the time required to set up and drive the piles, the number of piles involved is far too small to make a reliable conclusion.

By way of comparison, the same crew was used prior to the testing of the standard pile driver and the retrofitted pile driver to set up and align treated and untreated wooden piles for driving. This set-up and alignment period initially took up to 80 minutes. As the workers became more familiar with the procedures, this maximum time of 80 minutes diminished to approximately 17 minutes. As with the same crew with the wooden piles, much or all of the apparent productivity decrease with the retrofitted pile driver may really be a result of the crew getting used to driving the piles and not a result of the retrofit equipment.

The following table details the combinations of pile drivers and retrofit techniques used for the driving of piles 3 to 17. Sound level measurements were not obtained during the driving of piles 1 and 2.

Table 2. Summary of Combinations of Noise Control Technology Used at the Pile Driver Demonstration at Waterloo, Iowa

Pile No.	Muffler	Enclosure	Cushioned Pads	Damping Material	Vibratory	Standard
3	X	X		X		
4	X	X	X			
5	X	X	X	X		
6	X	X	X	X		
7	X	X	X	X		
8	X	X	X			
9	X	X		X		
10		X				
11					X	
12					X	
13					X	
14						X
15						X
16						X
17						X

A number of problems occurred during the set-up and work phases. These involved the fitting of the pile in the bonnet, the attachment of leads and chains, the positioning of the pile to the vertical beam and the placement of the noise control curtain on the retrofitted pile driver. These problems are discussed below.

4.1.1 Placement of the pile into the bonnet

The set-up and alignment of the pile required that the pile be moved by crane from the barge and placed within the bonnet of the hammer. This bonnet was specially made to fit 16-inch piles. The bonnet was snug and did not fit properly, resulting in each pile having to be cut free with a torch once the driving was completed. This procedure of cutting the pile free took 16-20 minutes which in no way was a result of using the retrofit equipment. Pile 15 was the only pile that did not need to be cut free by torch.

4.1.2 Lead and chain attachment

While driving the piles that were treated with damping material, the chains and leads attached to the pile driver caught on the exposed damping material. The chains had to be manually pulled while the pile was driven. A resulting loss of efficiency occurred. Additional noise was also generated due to the banging of the chains against the pile during driving.

4.1.3 Positioning of the pile to the vertical beam

The vertical H-beam which was used as a guide for the driving of the pile tended to be stiff and unyielding and therefore difficult to work around. When they were being moved, the piles often hit the beam, the driver, and the cross beam, causing additional noise. Part of the difficulty may have been the result of the crane having 20 more feet of boom length than required for this job. The standard pile driver used a formal guide system rather than the H-beam.

4.1.4 Attaching the curtain

The pile driver crew was unfamiliar with the noise control curtain which often got in the way of the leads. Care had to be taken in tying the curtain at the bottom so that it closed completely, but did catch on the piles coated with damping material. The curtain, when properly attached, should have had the flap overlapping. After driving several piles, the curtain ripped slightly. During the driving of piles 2 and 3, the flap opened about .3 m (1 ft.) resulting in a V-shaped pattern at the bottom which leaked sound. Figure 12 shows the ripped curtain. Improved fastening would alleviate this problem.

4.1.5 Damping material

A number of problems occurred with the water-based damping compound. The damping material on some piles had been applied too thickly and tended to flake off. The material had been applied in rings, eight rings per pile at 2.4-m (8-ft.) intervals. On pile 7 the damping material had flaked off considerably and there were only two complete rings of damping material left, and the rest were half rings or less. During driving of pile 7, a ringing sound was prominent, probably related to the missing damping material. On some of the other piles, small amounts of damping material were also missing.

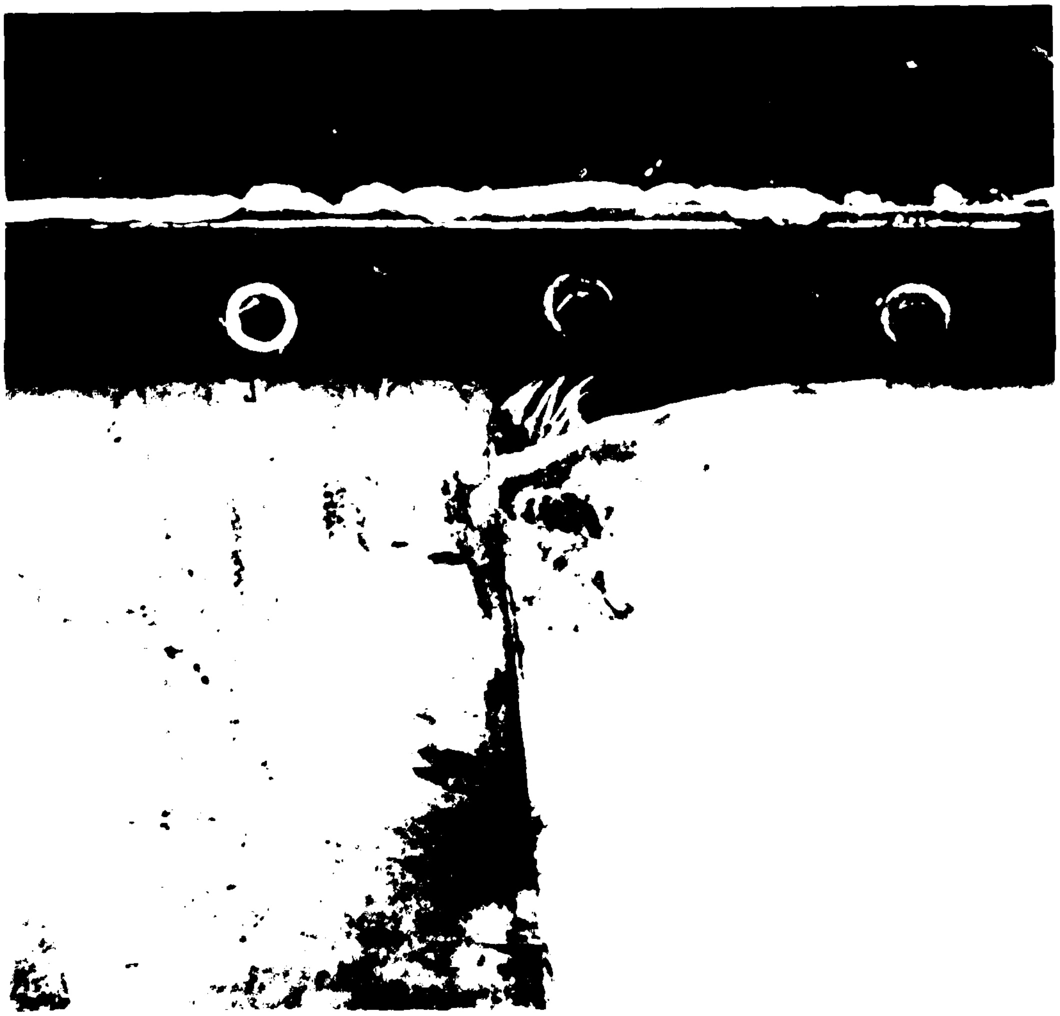


Figure 12. Photograph of Ripped Curtain

4.1.6 Cushion pads

In addition to the retrofit testing of damped piles, cushion pads were substituted for the standard phenolic pads and placed within the bonnet along with round aluminum plates in alternating layers of plates and pads. The pads were replaced after driving piles 4, 5 and 6. This replacement was found to be an overcautious procedure because the pads were not that noticeably worn, but this could not be determined without disassembling the bonnet. While changing the pads, the curtain had to be raised, which resulted in it tearing about .3 m (1 ft.). The pads were removed after driving pile 8. On the two occasions when the pads had sustained over 1400 blows, it was observed that the wear was not substantial and the pad could possibly withstand twice that number of blows or more.

4.1.7 Vibratory pile driver

A number of observations were made during the testing of the vibratory pile driver. During this testing, personnel were setting up the succeeding pile and the cranes used for this operation were clearly heard over the vibratory hammer noise. When the pile driver with the vibratory hammer became level with the cofferdam, a low frequency excitation (130 Hz - 90 dB) was observed. Piles 11, 12 and 13 were driven with the vibratory hammer which had a chain ring with three leads attached at the bottom. This held the pile vertical while driving, but the chains rattled against the pile. During the driving of a pile using the vibratory unit a rock layer was encountered. The vibratory pile driver was removed and the pile was driven to its proper level using a standard pile driver.

4.1.8 Other noise sources

In addition to the noise emanating directly from the driving operation, other noise sources were present and observed by field personnel. These noise sources had no impact on the overall measurement program except as noted in Appendix C. There was portable air compressor noise. There were also various sounds from the equipment being used such as the cranes.

Unusually heavy rains caused serious flooding during this demonstration program. To keep water out of the pile driving area, pumps had to be used. Pump noise increased the ambient sound levels, particularly during the driving of pile 7, so much so that the sound data for pile 7 were not used.

The standard pile driver had an exhaust chamber which allowed exhaust air (and its noise) to escape during pile driver operation. The exhaust was aimed in the direction of the land measurement team.

4.2 Sound Level Measurement Program

4.2.1 Instrumentation

The Construction Engineering Research Laboratory recorded pile driver noise at two locations: a land location to the northwest of the gravity outlet and a river location to the southeast. The river location is shown in the following sketch, Figure 13.

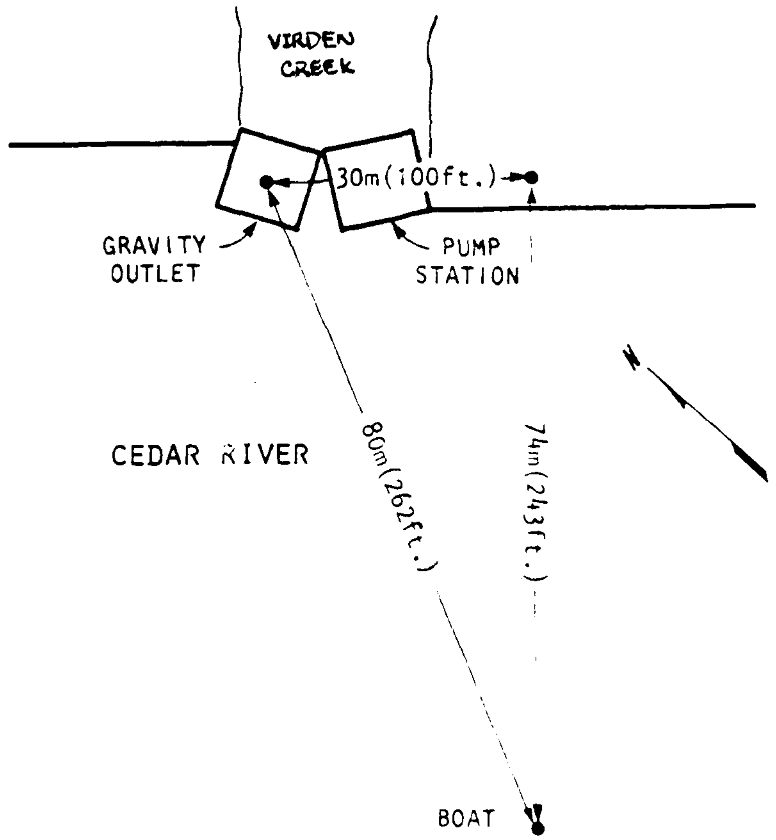


Figure 13. Sound Measurement Location (Cedar River)

The pile driver sound levels were recorded with a Bruel and Kjar Model 4921 outdoor microphone system and a Nagra DJ magnetic tape recorder at both the land and river locations. Tape recordings began prior to the start of pile driving to obtain the background sound levels, and ended when the pile was driven to refusal.* The magnetic tapes were analyzed using a Nagra DJ tape recorder, a GenRad Model 1921 Real Time Analyzer controlled by a Digital Equipment Corporation PDP 8/e computer.

4.2.2 Data analysis and results

Due to the time-varying nature of pile driver noise (i.e., impulsive-like sounds), the tape recordings were analyzed to produce:

a) Equivalent Sound Levels: L_{eq}

b) Exceedance levels: L_1, L_{10}, etc.

c) Time History of A-Weighted Sound Levels.

Octave band statistical sound levels, A-weighted sound level histograms, and cumulative distributions of A-weighted sounds were obtained for data recorded at both measurement locations for the standard, vibratory, and retrofitted pile driver operations. These data are on file with CERL.[16]

An analysis of sound level data obtained from the recordings made aboard a boat in the Cedar River is reported below to demonstrate the effects of pile driver substitution and retrofitting on noise levels. While data obtained on land are available, these data were subjected to higher background sound levels, reflections from nearby buildings and equipment, and some calibration problems. The river location provided more accurate and consistent results.

*"Refusal" is the point at which the pile is seated and no additional impact forces move it further.

Table 3 is a summary of the analyzed data. Although other statistical sound level descriptors were determined, only L_1 and L_{eq} are tabulated. L_1 is considered most representative of the impulsive type source present during pile driving operations. L_{eq} represents the acoustical energy level of the pile driver noise emissions.

The use of the muffler and enclosure reduced the noise by about 10 dB. However, inspection of the enclosure disclosed that with a comprehensive design and development effort, the enclosure/muffler performance can be improved.

The vibratory unit's noise levels are much lower than the standard unit (by 17 dB) and also lower than the retrofitted unit (by 6 dB), as expected. However, the vibratory unit requires a large, diesel engine-driven hydraulic pump which was not silenced. For vibratory pile driver sound level measurements, the unit was located 50 ft. from the land measurement location (see Figure 14). Thus, sound levels in the vicinity of the hydraulic unit were excessive; the sound levels measured at the land station are higher for the vibratory pile driver (L_{eq} = 86.9 dB) than for the standard unit (L_{eq} = 79.8 dB).

It is of interest to plot out the A-weighted sound level versus time. Figure 15 shows the impulsive nature of the sound excluding the vibratory unit. There are two impulsive components: the hammer impact and the air exhaust. Use of the muffler and enclosure eliminates air exhaust noise and significantly reduces impact noise. The Bolt unit's noise is included in the figure; only the impact noise is evident. The noise of the vibratory unit is relatively low with no impulsive characteristics.

Figure 15 indicates that the background sound levels during the time the piles were driven with the standard unit were generally higher than those existing during the operations of the other test units.

Table 3. Summary of Pile Driver Demonstration (Boat) Data

a. Individual Piles

Pile Driven	Description	A-wt Sound Level, dB at 80 m (264 ft.)	
		L_1	L_{eq}
3	Silenced[1] with damping	76	70.0
4	Silenced with pad	77	70.6
5	Silenced with pad and damping	76	70.3
6	Silenced with pad and damping	76	70.4
7	Silenced with pad and damping[2]	--	--
8	Silenced with pad	81	72.7
9	Silenced with damping	75	69.2
10	Enclosure, no muffler[3]	80	72.3
11	Vibratory	70	67.5
12	Vibratory	71	68.7
13	Vibratory	70	68.1
14	Unsilenced	87	78.9
15	Unsilenced	87	82.1
16	Unsilenced	86	78.5
17	Unsilenced	89	83.7

b. Averages

	A-wt Sound Level, dB at 80 m (264 ft.)	
	L_1	L_{eq}
a. Unsilenced	87	80.7
b. Silenced	76[4]	70.4[4]
c. Enclosure, no muffler	80	72.3
d. Vibratory	70.3	68.1
e. Bolt (separate factory demonstration)	80[5]	70.8[5]

---

[1] "Silenced" means enclosure plus muffler.
[2] Pile #7 data are omitted because the noise from pumps used to empty the cofferdam interfered with noise measurement.
[3] The exhaust air was directed inside the enclosure so that some attenuation was provided.
[4] Excluding pile #7.
[5] Extrapolated to 80 m.

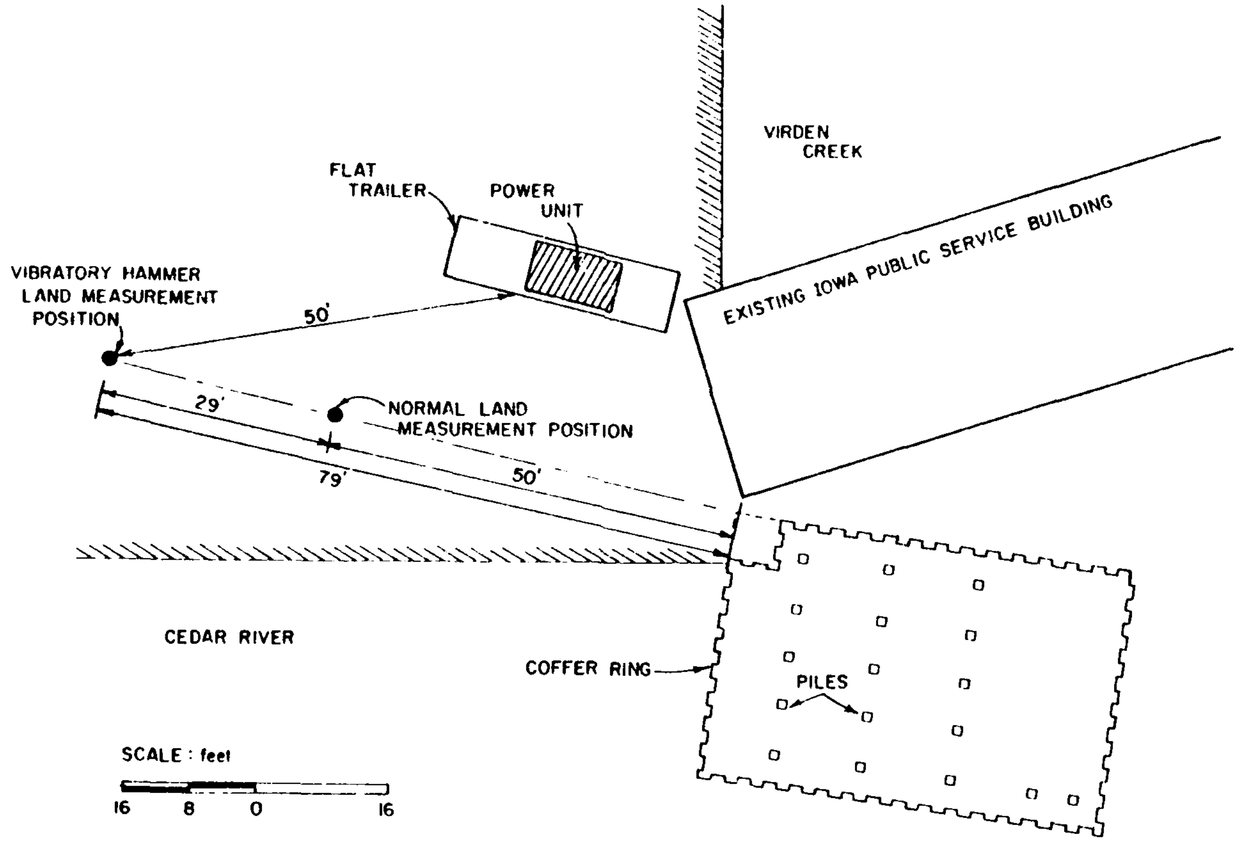
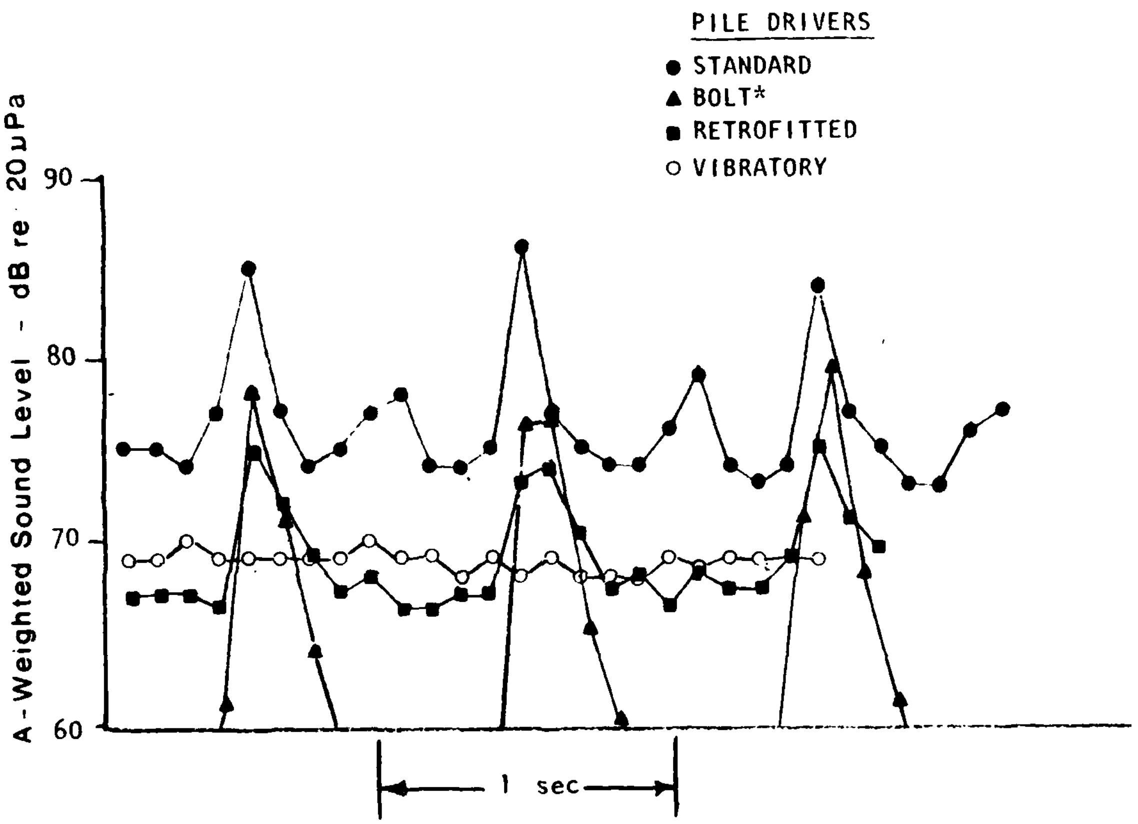


Figure 14. Land-Based Sound Level Measurement Location (Note the location of the power unit for the vibratory pile driver.)



*Bolt noise was measured at 15 m and extrapolated to 80 m.

Figure 15. Time History of Pile Driver Noise at 80 m as Measured From a Boat in the Cedar River

4.3 Costs of Pile Driver Noise Control

As indicated in Section 1.2.3, any noise control technique contains two cost elements: (1) capital costs and (2) operating costs. In developing the capital costs, no distinction is made between the standard equipment and the retrofit hardware such as the enclosure or muffler. All equipment are amortized over their expected useful life. Operating costs include contractors' overhead, profit, labor, and expendables. Based on these data, one can develop total weekly costs which include both operating costs and capital expenditures amortized on a per-week basis. These various costs are developed and tabulated in Appendix C.

The "bottom line," however, is not total weekly costs, but rather the cost to drive a pile, that is, dollars per pile. This metric (dollars per pile) is easily calculated if one knows (1) total weekly costs, and (2) number of piles driven per week. In this demonstration project, total weekly costs have been well developed for the various noise abatement techniques employed (Appendix C). Unfortunately, the nature of the study did not allow the same specificity for the second parameter, piles per week.

For this demonstration, data were gathered on the driving of 15 piles. Seven different configurations were tested in all. These consisted of the standard nonquieted impact pile driver, the standard pile driver retrofitted with five different noise control approaches, and the vibratory hammer. Table 4 tabulates these test configurations.

The remainder of this section is divided into two subsections; Section 4.3.1 which analyzes the total weekly costs for the various abatement techniques, and Section 4.3.2 which discusses productivity, that is, the number of piles driven per week.

4.3.1 Total weekly costs

Total weekly costs for the seven test configurations are given in Table 5. This table shows that there is no significant cost increase for retrofitting the standard pile drive with an enclosure and muffler (the two principal noise abatement measures). Clearly, the other test configurations increase total weekly costs in various amounts.

Use of pile damping is significantly more expensive than the other retrofit options because of the high material and labor costs incurred in applying the damping compound.

The cost effectiveness of the retrofitted pile driver using the elastomeric damping pads is largely dependent upon the durability of the pads. At a cost of $52 per pad and using 6 pads per bonnet, the incremental cost per pile could be very significant if the pads were not very durable. Their probable life is subject to a variety of factors. The manufacturer claimed that with proper care and under normal operating conditions they could last as long as the pile driver.[17] On the other hand, during the demonstration test the pads were changed much more frequently than appeared to be necessary because of uncertainty on the part of the contractor.

Table 4. Various Pile Driver Configurations

Pile Driver Configurations	Number of Piles Driven
Unsilenced	4
Enclosure, no muffler	1
Silenced* with pad	2
Silenced with damping	2
Silenced with damping and pad	3
Vibratory	3
	15

*"Silenced" means enclosure plus muffler.

Table 5. Estimated 1-Week Pile Driving Costs[1,2]

	$/Week	% Increase Over Standard
Standard Pile Driver[2]	11,597	-
Retrofitted Pile Driver		
Option A - Enclosure, no muffler	11,626	0.3
Option B - Silenced[3]	11,646	0.4
Option C - Silenced with damping	16,196	39.7
Option D - Silenced with damping and pads	16,430	41.8
Option E - Silenced with pads	11,880	2.4
Vibratory Pile Driver[2]	12,603	8.7

[1]Weekly costs are developed from monthly rental rates on a per week basis (See Table C-5b).

[2]Productivity Assumptions: Effective working hours
labor: 8 hours/day
cranes: 6 hours/day
pile drivers, compressors, power pack: 2 hours/day

[3]"Silenced" means enclosure plus muffler.

The vibratory pile driver has higher total weekly costs because the capital costs for the vibratory hammer itself are much higher than for the standard pile driver.

4.3.2 Productivity

Productivity, or the number of piles driven per week, is the sum of two factors: (1) the driving time per pile and (2) the set-up time per pile. These two factors are discussed below.

Driving times are shown in Tables 6 and 7. The vibratory unit clearly had a much higher average driving time than the other units, with an average driving depth nearly identical to the average for all 15 piles--8 m (26 ft.) vs 7.7 m (25.3 ft). Clearly, the use of the vibratory pile driver meant decreased driving time productivity; however, this may be due to the type of material at the river bottom.

The standard pile driver had the lowest average driving time, but the average depth driven by this unit was not as deep as the demonstration average. Had all the piles been driven to the same depth, it is likely that there would be less difference between test configurations. However, the driving time at this site was strongly influenced by the time to drive the last few feet and by any large rocks or rock layers encountered during the driving process and thus, no "normalization" to a common depth is possible. Also, as noted in section 4.1, the damping treatment did delay the driving process when the guard chains caught on the damping material. Average blows per minute were less influenced by the above factors. Table 6 shows what is believed to be little significant difference in average blows per minute between the unsilenced and retrofitted units except for a slight indication that piles with damping had fewer average blows per minute. The four piles driven by the unsilenced unit averaged 64.6 blows/minute, the three retrofitted piles without damping averaged 71.0 blows/minute and the three retrofitted piles with damping averaged 50.2 blows/minute. Thus, the tentative conclusion is that the retrofitted pile driver (except possibly with

Table 6. Performance Data

Pile Number	Description	No. of Blows	Depth	Driving Time	Blows/ Minute
3	Silenced with damping	262	19'0"	12 min.	21.8
4	Silenced with pad	460	24'0"	10 min.	46.0
5	Silenced with pad and damping	389	23'6"	10 min.	38.9
6	Silenced with pad and damping	1051	33'6"	14 min.	75.1
7	Silenced with pad and damping	614	28'6"	11 min.	55.8
8	Silenced with pad	983	28'0"	9 min.	109.0
9	Silenced with damping	593	26'0"	10 min.	59.3
10	Enclosure, no muffler	706	28'0"	12 min.	58.8
11	Vibratory	Vibratory	26'0"	15 min.	
12	Vibratory	Vibratory	26'0"	22 min.	
13	Vibratory	Vibratory	26'5"	18 min.	
14	Unsilenced	595	27'6"	9 min.	66.1
15	Unsilenced	507	17'6"	7 min.	72.4
16	Unsilenced	370	18'6"	6 min.	61.7
17	Unsilenced	409	16'0"	7 min.	58.4

Source: Ref. 18

Table 7. Driving Time Comparisons

	No. Driven	Average Time/Pile	Average Depth	Average Blow/Min.
Standard Pile Driver	4	7.25 minutes	19.9'	64.6
Retrofitted Pile Driver				
Option A - Enclosure, no muffler	1	12.0 minutes	28.0'	58.8
Option B - Silenced*	2	not available	30.5'	not aval.
Option C - Silenced with damping	2	11.0 minutes	22.5'	40.6
Option D - Silenced with damping and pads	3	11.6 minutes	28.5'	56.6
Option E - Silenced with pads	2	9.5 minutes	26.0'	77.2
Vibratory Pile Driver	3	18.3 minutes	26.2'	not appl.
Demonstration Totals	17	11.5 minutes	25.3'	60.2

*"Silenced" means enclosure plus muffler.

Source: Ref. 18

damping) does not increase driving time over the standard unit's driving time. Indeed, there is little difference. The vibratory unit does appear to increase driving time.

The above driving time figures offer an indication of productivity. They do not take into account the time required to set each pile in place and prepare it for driving. More piles per day were driven by the unsilenced unit than by the silenced unit (at the rate of 8 piles per day and 4 piles per day, respectively). However, because of the small number driven, these differences are not statistically significant.

As indicated earlier, the experience at this site with this crew using wooden piles was that work progressed very slowly during the first week as the crew became accustomed to the situation. After this first week, a great increase in productivity resulted. For this demonstration, piles were driven using the retrofitted and vibratory pile drivers first. After the demonstration week, the standard (unsilenced) unit was used. Thus, both the set-up time and the driving time may have decreased by the time the unsilenced units were used because of the experience the crew had gained in setting up the previous piles.

5.0 ALTERNATIVE ROUTE SELECTION

5.1 Normal Haul Truck Transportation Route

Choosing the appropriate route for the transportation of materials to the site is often a very cost-effective means of reducing the overall noise impact of construction operations. In this demonstration, the primary route for the transportation of materials from the nearby concrete plant to the site is along West/East First Street and Lafayette Street, returning on East/West Mullan Avenue as shown in Figure 3. The trucks travel a one-way distance of 1.5 km (0.9 miles) in about 6.5-7.0 minutes (varying, according to the traffic lights), while traveling at approximately 3.2 km/hr (20 mph). This route passes by 42 residences along East First and Lafayette Streets as well as five commercial/industrial concerns north of the Cedar River. The residences were predominantly single-family, detached homes with some interspersed duplexes.

5.2 Alternate Route

An alternate route, also shown in Figure 3, is along Sycamore Street, parallel to Lafayette Street. This route covers a distance of 1.1. km (0.7 miles) in approximately 4.5-5.0 minutes (again depending on the traffic lights) while also traveling at 3.2 km/hr (20 mph). Yet this shorter route passes only five residences and eight commercial concerns north of the river. It also requires crossing railroad tracks at the end of Sycamore Street where there was no established, permanent grade crossing at the time this demonstration project was undertaken.

5.3 Site Data

The alternate route evaluation was attempted during the period of the pile driver study. Unfortunately, there was insufficient truck traffic to and from the site to perform significant sound measurements and obtain quantitative data. Again, because of the unusually heavy rains, the site was virtually shut down during much of the test period except for the pile driving activity. For the one concrete placement which did occur, only one truck came on and off the site per hour for a 4-hour period. This rate of truck traffic was insufficient to show meaningful shifts in hourly or daily L_{eq}. During other periods when gravel for banks was to be delivered, the route selection would certainly have shown benefits.

5.4 Costs

The costs required to establish a grade crossing were minimal. They included the costs of gravel delivery ($150) and the labor of two men for half a day for dressing and cleaning up the grade ($100) for a total cost of $250. The expense was more than justified in view of the potentially significantly decreased noise impact: five homes on the alternate route (as opposed to 42 homes on the primary route) are subjected to sounds emitted by trucks taking materials to and from the site.* In addition, the decreased fuel costs and shorter transit time due to the reduced distance of the alternate route eventually more than offset the grade construction costs as well.

*At 50 feet, the sound emitted by a heavy-duty diesel truck traveling at 30 mph is 75 dB, a significantly annoying level of noise.

6.0 CONCLUSIONS

The conclusions that can be drawn from the results of this demonstration project are as follows:

- A commitment to control noise at construction sites by providing feasible specifications for noise reduction, assessing alternate methods of achieving these specifications and evaluating the associated costs using these alternate methods can result in significantly lower (10 dB or more) site noise levels.

- The contract bid document can be an effective tool for bringing about the reduction of construction site noise.

- The contractor can, with minimal outside assistance, follow the requirements outlined in the bid specifications and final contract to produce a quieter operation. The demonstration project showed that a contractor can achieve significant reductions in the sound level generated by pile driving activities.

- Necessary sound control materials are readily available from various manufacturers and can easily be specified by brand name, physical composition, or minimum performance criteria.

- The use of such materials is, for the most part, fairly straightforward and requires minimal outside assistance. The exceptions occur when a new and technically complex piece of equipment such as a vibratory pile driver is used. In such instances, operators may require some instruction by a manufacturer's technical representative before being able to operate the equipment efficiently.

- A minimum of 10 dB decrease in emitted sound may result from application of noise control techniques. The decrease in sound level may be accompanied by an increase in costs and a decrease in productivity (piles driven/day). These cost increases decline proportionally on a per unit basis ($/pile, $/unit time, piles/day) the longer the job and the more piles that are driven.

- Noise reduction costs can be estimated by the contractor and the developer. With the productivity assumptions, the demonstration tests showed that the costs required to reduce pile driving sound levels are reasonable.

- Other means of controlling noise can be accomplished if planned, e.g., simple relocation of a haul truck route.

REFERENCES

1. Schomer, P.D. and Homans, B., Construction Noise: Specification, Control, Measurement and Mitigation, CERL Interim Report E-53, April 1975.

2. Schomer, P.D., Kessler, F.M., Chanaud, R.C., Homans, B.L., McBryan, J.C., Cost Effectiveness of Alternative Noise Reduction Methods for Construction of Family Housing, CERL Interim Report N-3, July 1976.

3. Kessler, F.M., Schomer, P.D., Chanaud, R.C., Rosendahl, E., Construction - Site Noise Control Cost-Benefit Estimation Technical Background, CERL Interim Report N-37, January 1978.

4. Dames & Moore, CERL/EPA Demonstration Project: Pile Driver Noise Control Cost-Benefit Analysis (Task 3), Prepared for CERL, April 1, 1979.

5. Jensen, Waldean, Project Engineer, United States Army Corps of Engineers, Waterloo District, Waterloo, Iowa, personal communication, February 1980.

6. EPA, Noise Emission Standards for Construction Equipment, Background Document for Portable Air Compressors, EPA 550/9-76-004, December 1975.

7. "Progress Report for Year Ending 30 September 1979."

8. Phone conversation to Merlyn Christenson, COE, Waterloo, Iowa, February 8, 1980.

9. Specifications from Vulcan Iron Works, Inc., Chattanooga, Tennessee, brochure material.

10. U.S. Army Corps of Engineers, Cedar River, Waterloo, Iowa: Local Flood Protection - Stage V-E Drawing Index, December 1978.

11. Sanders, Harris, "Measurement and Analysis of Pile Driver Noise," EPA Report #45, The City of New York Environmental Protection Administration, March 1973.

12. Hagerty, D.J., "Noise, Pile Driving and OSHA," presented at an APF Seminar, November 1974.

13. Kryter, Karl D., The Effects of Noise on Man, Academic Press, New York, 1970.

14. "'Sonics' Drive a Pile 71 Ft., While Steam Drives Another 3 In.," Engineering News-Record, Vol. 167, No. 19, November 9, 1961, pp. 24-26.

15. Bolt Associates, Norwalk, Connecticut. Pile driver brochure material.

16. Kessler, F.M., Dames & Moore, personal communication with P.D. Schomer, CERL, November 16, 1979.

17. Meredith, Dave, Peabody Noise Control, Dubline, Ohio, personal communication with P. Hopkins, Dames & Moore, February 1980.

18. U.S. Army Corps of Engineers, Waterloo District, "Pile Driving Records for the Noise Control Demonstration Project," August - September 1979.

19. Daniels, Dave, CONMACO, Inc., P.O. Box 150, Chicago, Illinois, personal communication with P. Hopkins, Dames & Moore, February 1980.

20. Margulis, Ben, CONMACO, Inc., Chaco, Illinois, personal communication with P. Hopkins, Dames & Moore, February 1980.

21. Coulter, Ken, American Hoist and Derrick, St. Paul, Minnesota, personal communication with P. Hopkins, Dames & Moore, February 1980.

22. Schultz, Don, Koehring Co., Milwaukee, Wisconsin, personal communication with P. Hopkins, Dames & Moore, February 1980.

23. Shappert Engineering Company, Belvidere, Illinois, personal communication with P. Hopkins, Dames & Moore, August 1979.

24. Stephens, Gary, CONMACO, Inc., Chicago, Illinois, personal communication with P. Hopkins, Dames & Moore.

25. Shappert Engineering Company, "Government Audit of Contract Modifications, Local Flood Protection, Waterloo, Iowa," Belvidere, Illinois, August 1979.

APPENDIX A

CORPS OF ENGINEERS
BID SPECIFICATION
(Reproduced in its entirety)

SECTION ID
NOISE CONTROL
DEMONSTRATION - INVESTIGATION

1. SCOPE. The Contractor shall deliver materials over designated access routes and drive piling as specified below for investigation and collection of noise control data by others. The Contractor shall be responsible for all construction supplies, materials, and equipment, including one vibratory or air-cushion pile driver and one conventional steam, air or diesel pile driver, and not less than one of each of the specified noise control devices. Monitoring such construction operations and metering the resultant noise, furnishing all test equipment, and recording the data obtained will be the responsibility of others.

2. TRANSPORTING HEAVY CONSTRUCTION MATERIALS. The study of noise associated with transporting heavy construction materials will be conducted over two 1-week periods. The Contractor shall schedule and coordinate delivery of heavy construction materials with those conducting the study. Both 1-week periods shall be selected at a time of intense delivery of materials such as piling, forms, reinforcing steel, concrete, fabricated structural steel items, sluice gates, pumps and motors, etc. During one of the 1-week periods when construction activity is downstream from Virden Creek all deliveries of heavy construction materials shall be made to the construction site via Sycamore Street and the temporary railroad crossing as indicated on the drawing attached hereto. During the other 1-week period when construction activity is upstream from Virden Creek, all deliveries of heavy construction material shall be made to the construction site via Lafayette Street as indicated on the drawing attached hereto. Such access routes shall be intercepted by delivery vehicles as soon as practicable and used to the greatest extent practicable for access to and from the site.

3. PILE DRIVING. The study on noise associated with pile driving will be conducted over two 2-day periods. The Contractor shall schedule and coordinate such periods at a time of intense pile driving activity with those conducting the study. During one 2-day period, the Contractor shall use either vibratory or air-cushion pile drivers. During the other 2-day period, the Contractor shall use the specified noise control devices either singly or in combination with each other, as directed, with conventional steam, air or diesel pile drivers.

3.1 <u>Acceptable vibratory and air-cushion pile drivers</u> include, but are not limited to:

Chelminski Pile Driver (Bolt Hammer)
Bolt Associates, Inc.
205 Wilson Avenue
Norwalk, CT 06854

MKT V-10
McKiernan-Terry
MKT Geotechnical Systems
Box 793
Dover, NJ 07801

Vibro Driver
L. B. Foster Co.
7 Parkway Center
Pittsburgh, PA 15220

3.2 Noise control devices for use singly or in combination with each other, as directed, with conventional steam, air or diesel pile drivers include, but are not limited to:

3.2.1 Muffler providing a minimum insertion loss of 15 decibels shall be fitted to the exhaust of the hammer. If a double acting hammer is used, both exhausts shall be silenced. Mufflers are available from some pile driver manufacturers and from independent manufacturers, e.g.:

Donaldson Co., Inc.
1400 W. 94th Street
Minneapolis, MN 55440

Burgess Industries
8101 Carpenter Freeway
Dallas, TX 75247

3.2.2 Impact cushion of minimum 4-inch thickness shall be used between the hammer and pile. Unless otherwise approved, the cushion shall be constructed of alternate layers of sheet aluminum (1/4-inch thick) and elastomeric material (1-inch thick). Acceptable sources for cushion materials are:

DYAD
Soundcoat Company, Inc.
175 Pearl Street
Brooklyn, NY 11201

C-2003
Ear Corporation
7911 Zionsville Road
Indianapolis, IN 46268

Flexoply
Consolidated Kinetics
249 Fornoff Lane
Columbus, OH 43207

Lord Corporation
1635 W. 12th Street
Erie, PA 16512

3.2.3 Enclosure consisting of 18 gage sheet steel lined with sound absorbent foam shall shield the hammer/pile impact area. To provide not less than 5 feet of shielding both above and below the impact point, the bottom of the enclosure shall consist of a flexible skirt of mass loaded vinyl. The lateral dimensions of the enclosure shall be as small as is reasonably possible. The vinyl material shall weigh approximately 0.75 lb/sq. ft. Such enclosure shall be attached to the downward traveling hammer mechanism to maintain shielding of the impact point as the pile cap approaches the ground (see Figure 1). Examples of acceptable materials and supplies for attachment to the sheet metal enclosure are listed below.

Soundcoat Embossed Foam
175 Pearl Street
Brooklyn, NY 11201

Cousticomposite 0-5-50
Ferro Corporation, Composites Div.
34 Smith Street
Norwalk, CT 06852

or

Consolidated Kinetics Corp.
249 Farnoff Lane
Columbus, OH 43207

Sound/Eaze TLB-M
Korfund Dynamics Corporation
P.O. Box 235
Contiague Road
Westbury, NY 11590

Complete enclosures are available from independent manufacturers, e.g.:

Frommelt Industries, Inc.
465 Huff Street
Dubuque, IA 52001

Industrial Noise Control, Inc.
312 Stewart Avenue
Addison, IL 60101

Insul-Coustic/Birma Corp.
Jernee Mill Road
Sayreville, NJ 08872

Spacetronics
1850 Lansdowne Avenue
Merrick, NY 11566

3.2.4 Damping material for end supported piles shall be applied to the sides of the piles in a layer approximately 1 in. thick to prevent ringing. Examples of acceptable damping materials are listed below.

Constidamp
Consolidated Kinetics Corp.
249 Farnoff Lane
Columbus, OH 43207

Soundcoat Company
175 Pearl Street
Brooklyn, NY 11201

4. TECHNICAL CLARIFICATIONS. Technical clarifications may be obtained from Dr. Frederick M. Kessler, Dames & Moore, 6 Commerce Drive, Cranford, NJ 07016.

5. PAYMENT. Payment for the noise control demonstration will be made at the contract lump-sum price for Item No. 19, "Noise Control Demonstration." Such price shall constitute full compensation for performing all operations necessary and for furnishing all plant, labor, materials, and equipment, including one vibratory or air-cushion pile driver and one conventional steam, air or diesel pile driver, not less than one of each specified noise control device, and all incidental items necessary to complete the noise control demonstration as specified herein.

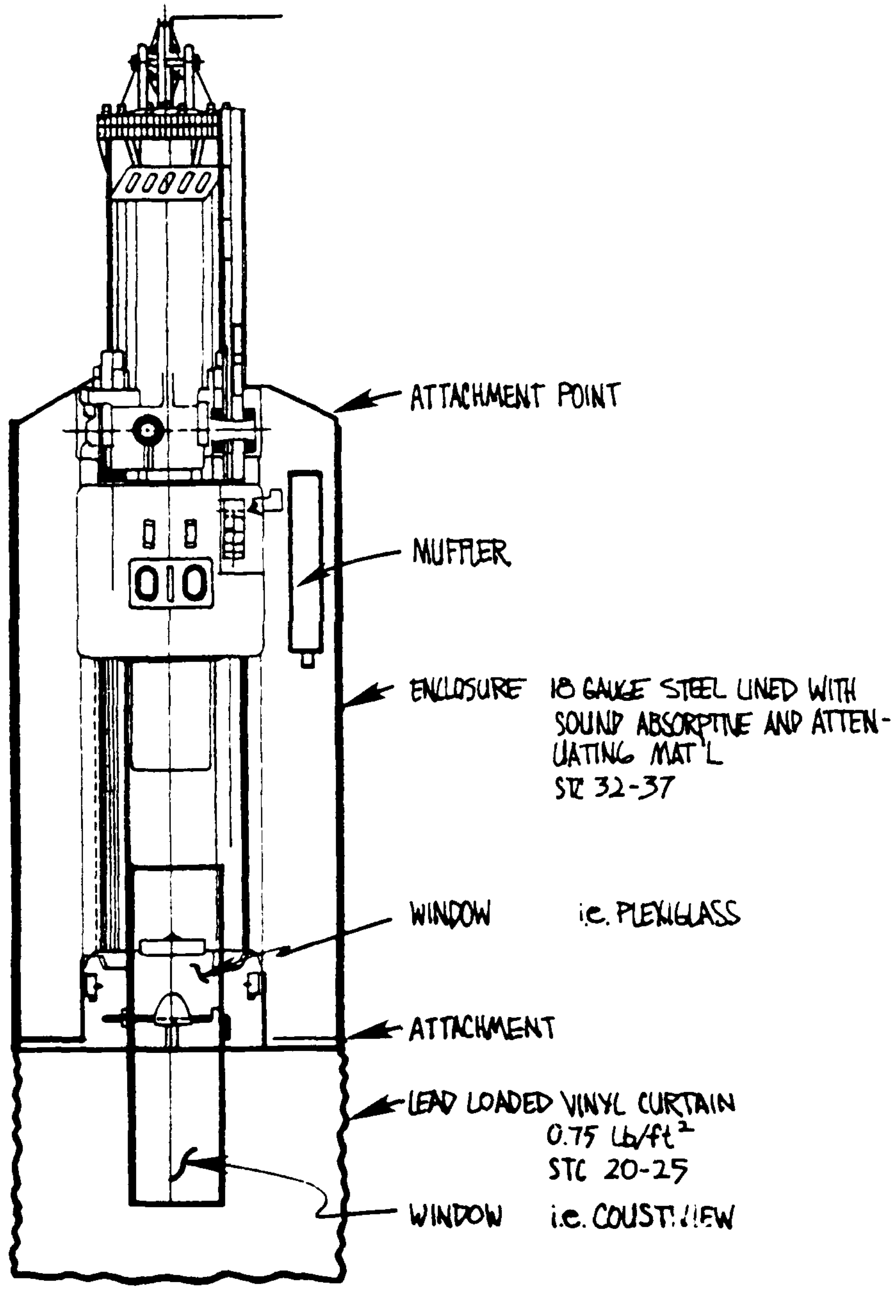


Figure A.1. Sketch of the Pile Driver Enclosure

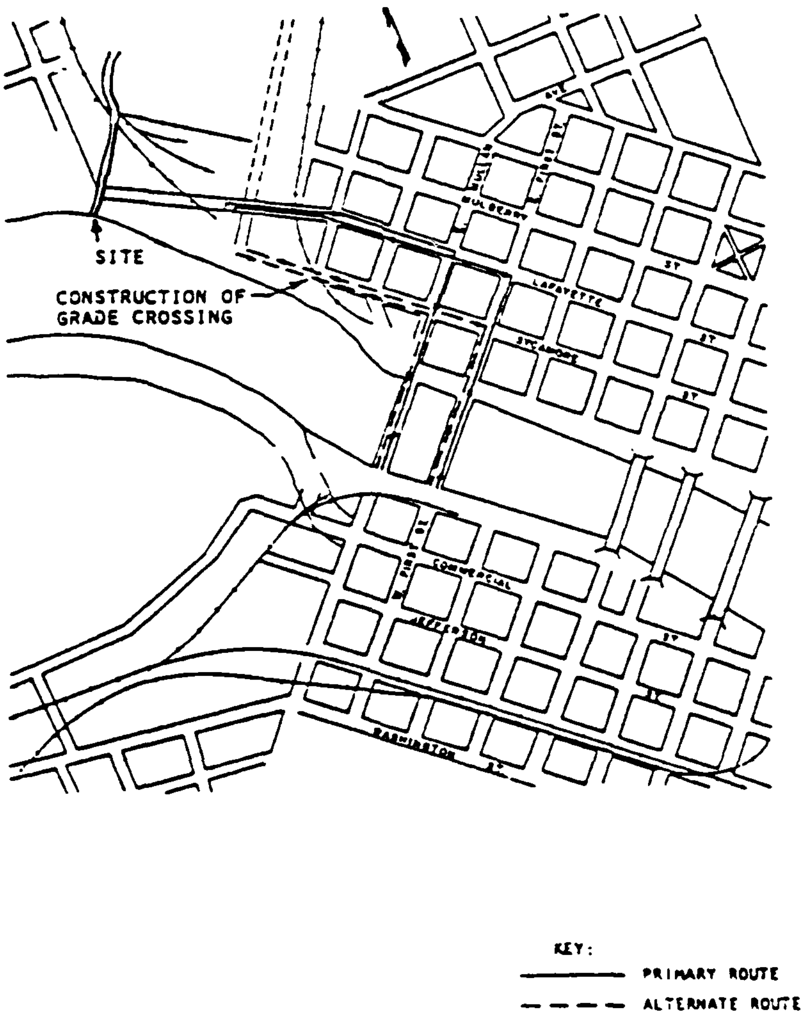


Figure A.2. Route Designation

APPENDIX B

SHAPPERT DESIGN AND COMPONENT MATERIAL BROCHURES

SHAPPERT ENGINEERING COMPANY

East Menominee & Blaine Streets   Belvidere, Illinois 61008   Phone (815) 547-548

Contractors
FOR
BRIDGES - DAMS - PILE DRIVING - STEEL ERECTION - POWER PLANTS - INDUSTRIAL - MARINE CONSTRUCTION

August 17, 1979

Department of the Army
Waterloo District
Corps of Engineers
533 Ansborough Avenue
Waterloo, Iowa 50701

SUBJECT: Contract No. DACW25-79-C-0022
Local Flood Protection Project
Waterloo - Stage VE
Cedar River, Black Hawk County, Iowa

Gentlemen:

Reference your letter of 18 July 1979 requesting additional submittals for the Pile Driving Noise Demonstration Procedure, we submit the following:

A revised drawing of the Pile Driver Enclosure showing the type of liner by Soundcoat and the ¼" thickness of the plexiglass.

Enclosed is the specification sheet for this 1 inch "Sound Coat" liner for the Pile Driver Enclosure.

Enclosed is the specification sheet for the 3/4 lb. lead loaded vinyl 4 ft. curtain as made by Singer Safety Products, Inc. (Reference to ¼" foam on curtain was in error).

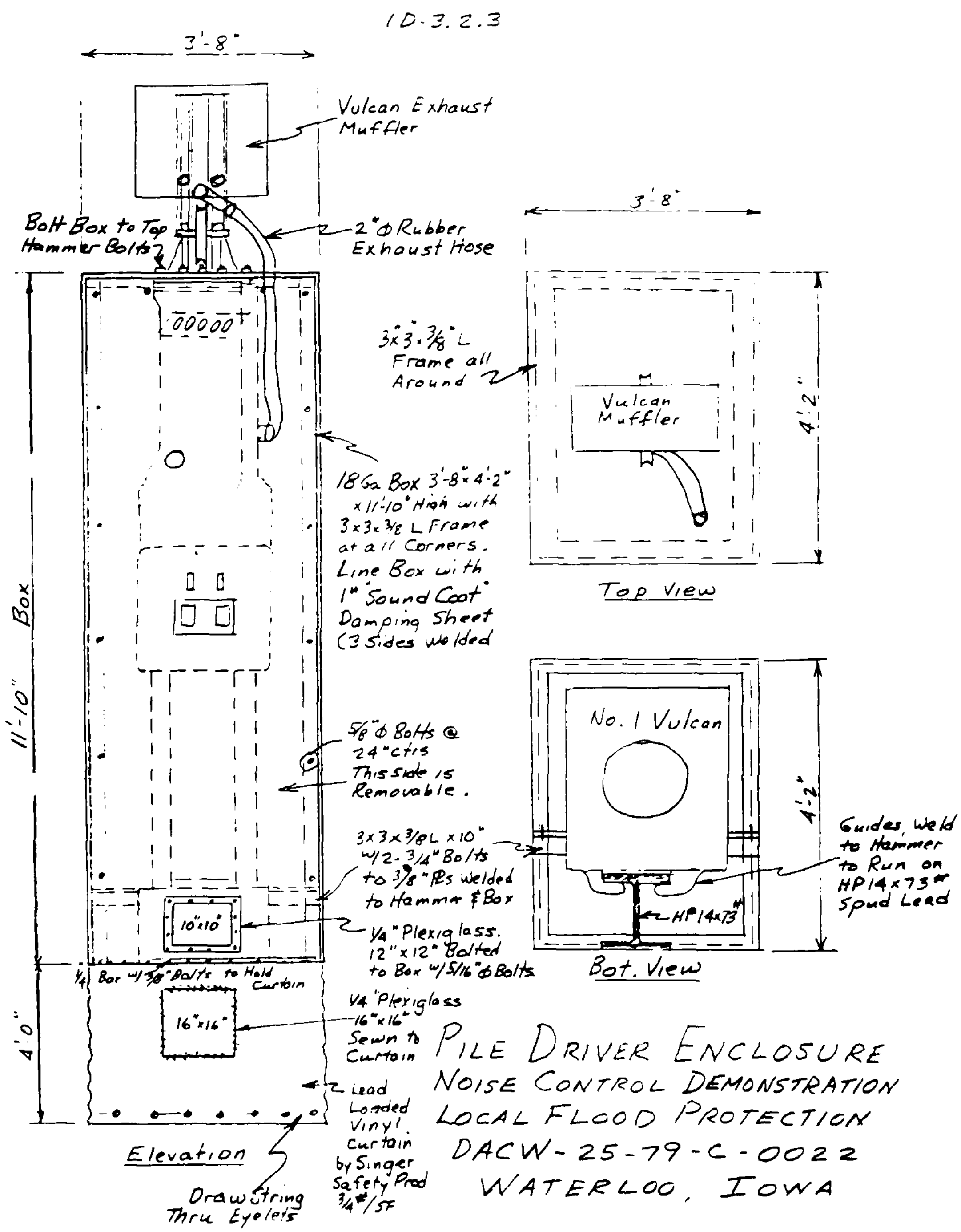
The material for the "Consti-view" window is also ¼" thick plexiglass and sewn to the vinyl. All other material approved on transmittal No. 47 previously submitted.

Sincerely,

SHAPPERT ENGINEERING COMPANY

William A. Sorensen
Chief Engineer

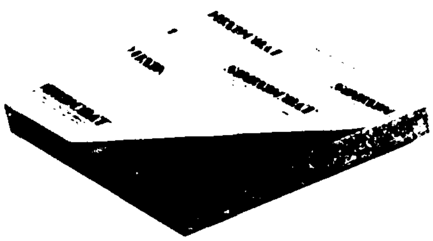
WAS:ljw


1D-3.2.3
3'-8"
Vulcan Exhaust Muffler
Bolt Box to Top Hammer Bolts
2"φ Rubber Exhaust Hose
18 Ga Box 3'-8"x4'-2" x11'-10" High with 3x3x3/8 L Frame at all Corners. Line Box with 1" Sound Coat Damping Sheet (3 Sides welded
11'-10" Box
5/8"φ Bolts @ 24" ctrs This side is Removable.
3x3x3/8L x10" w/2-3/4" Bolts to 3/8" PLs welded to Hammer & Box
10"x10"
1/4" Plexiglass. 12"x12" Bolted to Box w/5/16"φ Bolts
1/4 Bar w/3/8" Bolts to Hold Curtain
4'0"
16"x16"
1/4" Plexiglass 16"x16" Sewn to Curtain
Lead Loaded Vinyl Curtain by Singer Safety Prod 3/4#/SF
Elevation
Draw String Thru Eyelets
3'-8"
3x3x3/8" L Frame all Around
Vulcan Muffler
4'2"
Top View
No. 1 Vulcan
4'-2"
Guides, weld to Hammer to Run on HP14x73# Spud Lead
HP14x73#
Bot. View
PILE DRIVER ENCLOSURE
NOISE CONTROL DEMONSTRATION
LOCAL FLOOD PROTECTION
DACW-25-79-C-0022
WATERLOO, IOWA

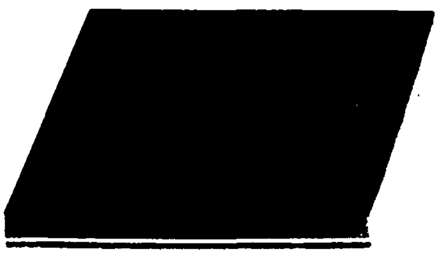
BULLETIN 702

SOUNDCOAT PRODUCT DATA SHEET

Soundfoam® Embossed



Embossed Soundfoam has patterned surface providing abrasive resistance and pleasing appearance. Available with pressure sensitive adhesive.



Soundmat-LF with Embossed face. A thin barrier of lead for noise attenuation is sandwiched between foam layers. This product provides a high degree of sound absorption and sound attenuation. See Bulletin 709C—Soundmat LF—for transmission loss data.

Embossed Foam Damping Sheet, with a layer of visco/elastic material for effective sound absorption and vibration damping. See Bulletin 704 for Damping values.

Advanced polyurethane technology has enabled manufacturers to optimize the foam structure for sound absorption. Factors which must be controlled in effective accoustical foams are:

a. Permeability (air flow resistance)   c. Density
b. Pore size and structure   d. Stiffness

Only a few manufacturers today control the basic foam structure to meet these requirements. Because variations in the foaming process can differ substantially, it is essential that the manufacturer have complete quality control and the ability to monitor the acoustical impedance and the sound absorption coefficient in his own laboratory.

SOUNDCOAT, with its advanced acoustical technology, has been able to provide these foams for industry. Over the years it became evident to SOUNDCOAT engineers that any increase in sound absorption coefficients would have to come through variations in the surface structure of these foams. SOUNDCOAT's Embossed Soundfoam is an example of this advanced technology.

Though a new process, SOUNDCOAT can now supply sound-absorbing foams with sound-absorption coefficients that are 20% to 35% greater, in the most critical frequency bands. SOUNDCOAT Embossed Soundfoam, in a ½" thickness, has the sound-absorption coefficient equivalent to ¾" thickness of plain acoustical materials. Thus, SOUNDCOAT makes it possible to save 50% in material while still providing an equivalent or superior acoustical performance. In addition, Embossed Soundfoam provides the following advantages:

1. The embossed surface has an attractive appearance.
2. A flexible, polyurethane foam that meets UL 94 classification HF-1.
3. Resists wicking oil and other heavy-viscosity liquids, which are a problem with plain foams and fibrous materials.

4. Increased resistance to mechanical abrasion—eliminating the danger of shedding fibers getting into and fouling bearings and other sensitive parts.
5. Does not shed or erode, even when impinged by high-velocity air streams. Embossed Soundfoam, with its controlled stiffness, deflects and returns to its original shape, without losing any of its acoustical efficiency.

SOUNDCOAT's continuous quality control assures uniform acoustical performance in successive shipments. In fact, SOUNDCOAT *guarantees* uniformity of acoustical performance—unique to the industry.

Embossed Soundfoam is available, with high-quality pressure-sensitive adhesive backing, in four thicknesses—¼", ½", ¾", and 1". It is also available in combination with visco-elastic damping layers, or with a heavy septum to impede sound transmission. It is easily cut to shape, and is flexible for wrapping around curved surfaces. It is lightweight and pleasant to the touch.

In summary, SOUNDCOAT has the technology now to provide even higher coefficients or absorption to meet customer requirements in specific frequency bands.

Specifications:

Size:	Sheets—24" x 54", 54" x 72", Rolls—54" wide
Temp. Range:	-45° to 225°F continuous, 250° intermittent
Density:	2 or 4 lbs./ft.³
Color:	Charcoal
Pore Size:	75 ± 10ppi
Thickness:	¼", ½", ¾", 1", 1½", and 2"
Flame Resistance:*	Foam listed UL 94 Classification HF-1 Passes FAR 25.853 Part B
Fungus:	Meet ASTM-1924-70
Thermal 'K':	0.25 BTU/in./hr./sq.ft./°F
Self-Adhesive Strength:	6 lbs. per inch. ASTM-D-903-49 180° Peel. Pull rate 12" per minute.
Absorption:	(See Figure below) Per ASTM-C-384-58

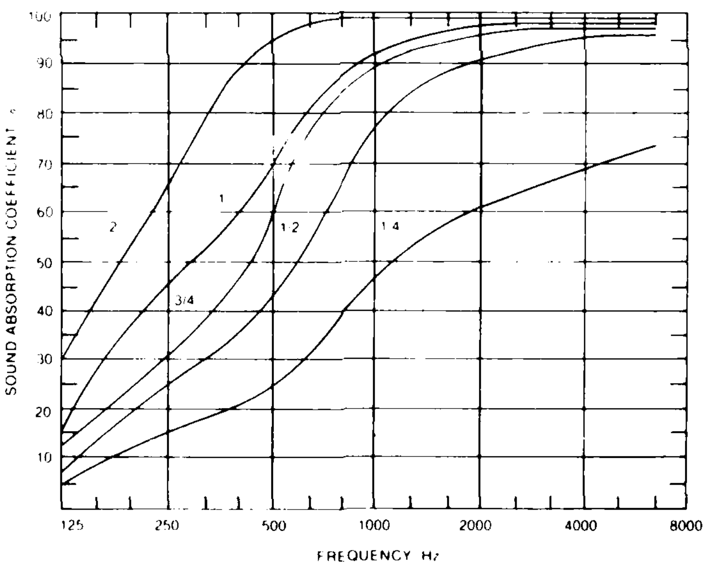
(Specifications subject to change without notice. Check with factory for latest revisions.)

NOTE: We recommend the use of our standard pressure sensitive adhesives when the material is subjected to heating up to 150°F. For temperatures up to 250°F specify Soundcoat HT-7 High Temp PSA.

* This numerical flame spread rating is not intended to reflect hazards presented by this or any other material under actual fire conditions.

The Federal Trade Commission consider that there are no existing test methods or standards regarding flammability that are accurate indicators of the performance of cellular plastic materials under actual fire conditions. Any results of existing test methods, such as ASTM D 1692 and UL 94, are intended only as measurements of the performance of such materials under specific controlled test conditions.

Embossed Soundfoam — Sound-Absorption Coefficients



SOUNDCOAT®

THE SOUNDCOAT COMPANY INC. • 175 Pearl Street, Brooklyn, N.Y. 11201 • Tel. (212) 858-4100 • Telex 12-5514
THE SOUNDCOAT COMPANY INC. • 3002 Croddy Way, Santa Ana, CA 92704 • Tel. (714) 979-9202 • Telex 69-2471

88115M

The information on pp 72 through 77 is from Noise Control Procedures, catalog No. 1080, published by the Singer Safety Co., Chicago, IL, 1980. This material is copyrighted and is reprinted with permission.

Noise.
Unwanted Sound.

Noise—unwanted sound—is a recognized problem in industry. With the advance in mechanization and automation, came larger and noisier machines and more hearing problems for workers. Environmental noise has increased substantially.

It has been proven that noise is damaging to hearing, creates stress, and has been responsible for many serious accidents.

A noisy environment is costly. It produces inefficiency in workers and hearing loss. Courts are now awarding larger settlements for damages to hearing and insurance costs mount with each claim.

Your own interest in noise control may center around problems with speech communication, employee irritability about unusual noise and your own desire to provide a better, safer and more productive work place.

Since 1965, Singer Partitions Division of Singer Safety Products, a pioneer in industrial noise reduction, has designed a variety of proven system-engineered solutions to noise and vibration problems. The unique SOUND STOPPER Systems approach has demonstrated measurable effectiveness in increasing worker efficiency, in safeguarding worker hearing, in protecting employers against compensation claims and the imposition of penalties arising from violation of governmental regulations.

A step-by-step solution to your noise problem is contained in this catalog. The initial pages explain the basic principles and applications of noise control systems. Beyond the INDEX are the *building blocks*—our SOUND STOPPER products—for creating a complete and successful noise control system to meet your exacting requirements.

Sound Stopper™

3 Basic Ways to Reduce Noise

There are a variety of products available for noise control. Before making a selection, here's a quick review of three basic principles involved in sound reduction. Each has a symbol keyed to the SOUND STOPPER products presented in this catalog.

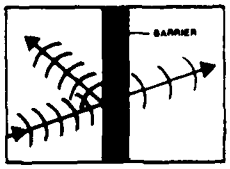
▨ ACOUSTICAL BARRIERS

An energy source produces noise as a radiating sound pressure wave which moves through the air in all directions. The most effective, economical and flexible method of noise reduction is usually the construction of a barrier (or enclosure) between the noise source and the receiver.

Barriers prevent the transmission of sound, but do not absorb sound. With a barrier, the sound is reflected back in the direction of its source.

The essential physical characteristic of a sound barrier is mass. Heavy, dense materials are good barriers, while soft, porous materials are poor barriers.

The second important characteristic of a good barrier is limpness. A rigid barrier material can transmit vibration and regenerate noise on the other side of the barrier, while a limp material will not shake or vibrate in a sound field.

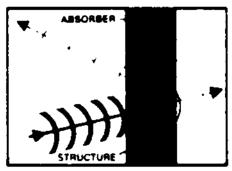


⊟ ACOUSTICAL ABSORBERS

Sound absorption is necessary to reduce the intensity *within* a room or enclosure. The process of absorption depends on the sound wave entering the material and being converted to heat by a frictional process on the porous material surface and cells.

The essential physical characteristic of absorbers is controlled porosity. Sound absorption is intended to reduce noise reverberation from reflective surfaces. Since the sound wave must flow through an absorbing material, *its effectiveness as a sound barrier is very limited.*

It is important to consider the use of sound absorbing material on the inside surfaces of a noise barrier, *especially* when a full or partial enclosure is being designed. The lack of sound absorbing materials causes a highly reverberant condition inside the enclosure, thus defeating the effectiveness of the design.

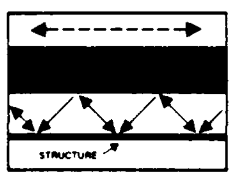


VIBRATION DAMPING

To control vibration, it is necessary to prevent the structural transmission of vibrational energy between the source and the surface. Vibrating surfaces are frequently damped by applying viscoelastic materials directly to the surface converting the vibrational energy to heat.

The minute flexing of the damping materials provides the energy dissipation and "decay" to reduce noise. Metal no longer "rings" when struck.

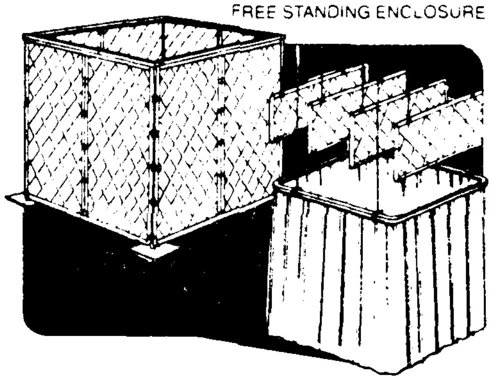
Damping materials are primarily used on light gauge vibrating metals, but may also be effective on wood or plastic.



How to Use Noise Control Materials

There are a few simple application methods for noise control materials and composites. Often, the best solution for a problem with multiple high-level noise sources (or when all the sources cannot be identified) is a ceiling-to-floor curtain enclosure or partition suspended from track-and-roller hardware.

Our full line of simple-to-assemble GLIDE WALL hardware is available to construct a framework where the track is attached directly to beam, ceiling or overhead surface. The curtain rolls effortlessly below the bottom edge of the track.



In other cases, a noise barrier is installed by suspending the track from beam or ceiling to the desired height from the floor by means of vertical lengths of threaded rod or angle iron. GLIDE WALL hardware is also available to mount a roller curtain parallel or at right angle to an existing wall.

Floor supported, free-standing suspension of flexible noise barriers is also easily accomplished. Floor bases, columns and steel track in 16 gauge or heavier can permit spans of up to 15 feet and barrier heights to 10 feet. Assembly requires ordinary hand tools.

Other problems may require the application of our free-standing line of sound mobile acoustic screen used singly or in three or four-panel foldable models for sound isolation of small machinery.

DIRECT TO SURFACE APPLICATION

This method is mainly used for vibration dampers or acoustical absorbers.

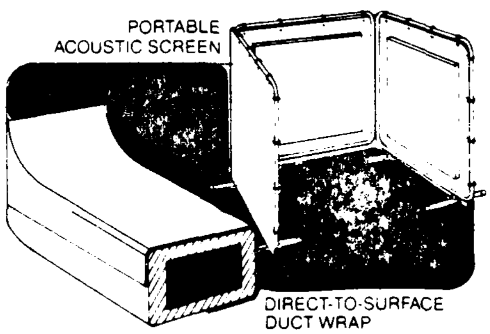
Damping products are always applied directly to one or both sides of vibrating metal surfaces, such as ducts, hoppers, bins and machinery guards.

Acoustical absorbers are primarily fastened directly to a wall or housing. Rolls or sheets are easily cut to the necessary shape and fastened mechanically or with adhesives to the inside of an existing structure.

Quantities of vertically suspended 2 ft by 4 ft baffles can be hung from factory ceilings to control reverberation, reduce overall noise levels and improve speech communications.

Sound absorbers are frequently suspended over the open top of an enclosure to achieve maximum noise reduction while permitting ventilation and illumination.

NOTE: All noise control materials can be installed using readily available hand tools.



LOADED VINYL MATERIAL

This is a reinforced lead-free material evenly coated on both sides with mass-filled vinyl. The result is a limp, dense, highly-flexible sound-barrier fabric.

- **6-16 dBA reduction, depending on the noise source**
- **Easy to fabricate**
- **Rugged, flame-resistant, impervious to oils, alkali and most chemicals; will not sag or rot; wipes clean**
- **Metallic grey color enhances area illumination for attractive appearance and energy efficiency.**

LOADED VINYL MATERIAL

PRODUCT	PART NO.	WEIGHT PER SQ FT	THICKNESS	DIMENSIONS	SOUND TRANSMISSION CLASS	TYPICAL dBA REDUCTION
Custom Curtains	**SC-157**	½ lb	.055"	width and height as specified	STC 20	6-12 dBA
Roll Goods	**15-015753**	½ lb	.055"	53" x 25 yds long	STC 20	6-12 dBA
Custom Curtains	**SC-158**	¾ lb	.075"	width and height as specified	STC 25	10-16 dBA
Roll Goods	**15-015853**	¾ lb	.075"	53" x 25 yds long	STC 25	10-16 dBA

APPENDIX C

ECONOMICS OF PILE DRIVER NOISE CONTROL

The total weekly costs include both capital expenditures and operating costs amortized on a per week basis.

Capital Expenditures

Shappert Engineering Company provided equipment supplier invoices from wnich the cost information shown in Table C.1 was derived for the standard and substitute pile drivers as well as for the retrofit components. Additional information was obtained from equipment leasing firms. Table C.2 contains the estimated amortized weekly capital costs for the capital equipment for the various pile driver options (standard unit, retrofitted unit, and vibratory unit). The one-time purchases (bonnet, lead, enclosure, and muffler) were capitalized over an assumed equipment working life (refer to Table C.2 for assumed useful lives of noise control equipment). Table C.3 presents the weekly capital costs for the various pile driver and component combinations. Estimated weekly operating costs are presented in Table C.4.

Another additional cost was incurred by the need to use the unconventional H-beam lead, because of the muffler. (A second crane was used because of the site layout and because the primary crane available did not have the capability to hold everything and also pick up a pile.) This is also due to the combined weight of the Vulcan pile driver and the enclosure.

The enclosure and muffler will last beyond this demonstration program. The unit costs presented in Table C.2 apportion these one-time costs over the assumed working lives shown in this table.

The data in Table C.5 indicate that for only a slightly larger total weekly cost, the vibratory unit provides significant reductions in sound levels. (Productivity tradeoffs and driving time are discussed in Section 5.3.) At a minimal increase in weekly cost, the retrofitted unit also reduces pile driver sound levels.

Table C.1. Cost Data for Pile Drivers and Retrofit Devices Used in the Demonstration

	Purchase
Vulcan #1 Hammer	$ 29,000
900 C.F. Ingersoll Rand	
Compressor (8 gallons/hr., diesel)	$ 96,000
American 5299, 55-ton capacity (3900 Manitowar-$5200/mo.)	$200,000
[a]Koehring 405 crane, 26.5 ton capacity	$145,000
[b]MKT V-20 vibratory hammer	$158,000
65' of 12" H-pile Spud Lead (Guide)	$ 1,500
100' of 2" air hose for compressor	$ 1,200
Enclosure	$ 4,900
[c]"Decelfo" muffler	$ 3,900
Damping material (for the 5 piles treated)	$ 622
Kinetics "Flexoply" pads (for the 2 sets of pads)	$ 787
Aluminum pads	$ 520
Regular lead (guide)	$ 500

[a]The actual Koehring crane used, Model 330, has been discontinued and replaced by Model 405.

[b]This price includes the required power pack (diesel engine) for the hydraulic pump, as well as the necessary hoses.

[c]The 1978 estimate of the purchase cost for the muffler was converted to 1979 dollars, yielding a cost of $3,900.

Note: The above costs do not include transportation costs, which vary widely from job to job.

Sources: References 19, 20, 21, 22, 23, 24

Table C.2. Capital Costs

	Purchase Costs	Weekly Costs Own	Weekly Costs Rent	Monthly Costs Own	Monthly Costs Rent
Vulcan #1 hammer	$ 29,000		$ 700		$1,395
900 CFM compressor	96,000		650		1,890
55-ton capacity crane	200,000		1,700		5,200
26.5-ton capacity crane	145,000		1,200		4,000
MKT vibratory hammer	158,000		3,450		9,600
Regular guide	500	$ 1.70		$ 6.80	
Muffler	3,900	19.30		77.00	
Enclosure	4,900	25.75		103.00	
12" H-beam guide	1,500	5.00		20.00	
Bonnet	2,200	7.40		29.60	
100' of 2" air hose	1,200	6.30		25.20	

Assumed Operating Lives

Regular guide	10 years
Muffler	5 years
Enclosure	5 years
Bonnet	10 years
Vibratory hammer	10 years
12" H-beam guide	10 years
100' of 2" air hose	5 years
Cranes	20 years
Vulcan hammer	10 years

Notes: Above capital costs include: depreciation and maintenance.

Rental rates were used for capital items requiring maintenance because it was felt they better approximated true capital costs.

Remaining capital costs were apportioned over assumed useful lives using a capital consumption allowance of 12% per year.

Sources: References 19, 20, 21, 22, 23, 24

Table C.3. Weekly Capital Costs for Pile Driver Combinations

	Weekly Rental	Monthly Rental to Per Week Basis
Standard Unit		
Vulcan #1 hammer	$ 700	$ 321
900 CFM compressor	650	435
55-ton crane	1,700	1,197
26.5-ton crane	1,200	921
[a]Accessory equipment	15	15
TOTAL BASE COST	$ 4,265	$ 2,889
[b]Retrofitted Units		
Standard Unit	4,265	2,889
Enclosure	29	29
	4,294	2,918
Standard Unit	4,265	2,889
Enclosure	29	29
Muffler	20	20
	4,314	2,938
Alternative Pile Driver		
MKT-V20		
Vibratory Hammer	3,450	2,209
55-ton crane	1,700	1,197
26.5-ton crane	1,200	921
[c]Plate	5	5
	6,355	4,332

[a]Accessory equipment = regular guide, bonnet, and 100 ft. of air hose.

[b]Use of the retrofitted unit involved the use of a larger lead, 65 ft. of 12-in. H-beam plus above accessory equipment.

[c]Plate on pile gripped by vibratory hammer.

Sources: References 19, 20, 21, 22, 23, 24

Table C.4. Weekly Operating Costs

	Weekly
I. <u>Equipment</u>[a]	
Vulcan #1 hammer	$ 42.60
55-ton crane	1,065.00
26.5-ton crane	580.00
900 CFM compressor	308.00
MKT V20 vibratory hammer (includes power pack)	216.80
II. <u>Labor</u>[b]	
3 crane operators @ $19.84/hr.	2,380.80
1 carpenter foreman @ $21.36/hr	854.40
3 carpenters @ $18.86/hr.	2,263.20
1 laborer @ $15.73/hr.	629.20
Total	$6,127.60
III. <u>Consumables</u>	
Aluminum and Phenolic pads	$ 585.00
Aluminum and Flexoply Pads	819.00
Damping	4,550.00

<u>Assumptions:</u>

Aluminum and phenolic pads: 5,000 blow life, $6.50/pad, 18 pads/set-up

[c]Aluminum and Flexoply pads: 1[illegible],500 flow life, $52/pad, 6 flexoply pads/set up along with [illegible] aluminum pads/set up.

Damping: $44/pile material cost, $47/pile labor cost, total $91/pile.

Pile Driving: 10 piles/day, [illegible] blows per pile

<u>Productivity Assumptions:</u> Effective working hours
labor: 8 hours/day
cranes: 6 hours/day
pile drivers, compressors, power pack: 2 hours/day

<u>Fuel Cost Assumptions:</u> Diesel, $.85/gallon, gasoline $.95 gallon; August 1979 prices.

[a]Equipment operating costs include contractor overhead and profit.

[b]Labor costs include: direct hourly wage, fringe benefits, contractors' overhead, and profit.

[c]Lifetime estimated by manufacturer.

Sources: Equipment = References 19, 20, 21, 22
Labor = Reference 25
Consumables = Reference 23

Operating Costs

Estimated weekly operating costs are presented in Table C.4. These costs were based on the actual unit operating costs ($/hr.) that are shown in Table C.6. The actual weekly operating costs are higher than was expected primarily because of the use of the second, smaller crane. When this item is excluded from the analysis, the estimated and actual operating costs are very similar. The notable exception to this is where damped piles are used, as the labor costs for the application of the damping compound are included.

Shappert Engineering estimated that it would take five hours of labor per pile to apply the compound to the five piles which were damped for the demonstration test. For purposes of analysis, it was assumed that this time would decline to three hours per pile as workers become more knowledgeable and adept at applying the material in the proper thickness. These labor costs for application of damping compound are a significant operating costs increment which must be considered when driving damped piles.

The operating costs for the vibratory hammer and the standard pile driver are quite similar. This is because the diesel engines which power the standard unit's air compressor and the vibratory hammer's hydraulic unit have nearly identical fuel consumption rates.[29]

Weekly Costs

Tables C.5a,b list the estimated total weekly operating costs based on the actual costs incurred during the demonstration test. In Table C.5a the weekly rental rate is assumed and in C.5b, the monthly rate is assumed (see Table C.2). The standard pile driver costs and those for two of the retrofitted options are fairly close. It is somewhat more expensive to operate the vibratory unit for a week than the aforementioned units. The damping options are not cost-effective; the sound level reduction is small for the added costs required.

Table C.5a
Total Weekly Costs
(Based on Weekly Rental Rates)

	Weekly Rental Capital	Equipment & Consumables	Labor	Total
Standard Pile Driver[a]	4,265.40	2,580.60	6,127.60	12,973.60
Retrofitted Pile Drivers[b]				
Standard + enclosure	4,294.95	2,580.60	6,127.60	13,002.65
Standard + enclosure and muffler	4,313.75	2,580.60	6,127.60	13,021.95
Standard + enclosure + muffler and damping	4,313.75	7,130.60	6,127.60	17,571.95
Standard + muffler and enclosure and damping and flexoply pads	4,313.75	7,364.60	6,127.60	17,805.95
Standard + enclosure and muffler and flexoply pads	4,313.75	2,814.60	6,127.60	13,255.95
Vibratory Pile Driver[b]	6,355.00	2,143.50	6,127.60	14,626.10

[a]Includes accessory equipment and consumables = regular lead, bonnet, air hose, and aluminum and phenolic pads.

[b]Includes use of heavier lead (guide).

Note: The weekly capital cost used for the pile driver, cranes, and compressor are the weekly rental rates. It was felt these better approximated true ownership costs.

The costs for accessory equipment were amortized over the assumed working lives based on the purchase prices.

Sources: References 19, 20, 21, 22, 23, 24

Table C.5b
Total Weekly Costs
(Based on monthly rental rates on a pro-week basis[a])

	Capital (mo. rental on)	Equipment & Consumables	Labor	Total
Standard Pile Driver[b]	2,889	2,580.60	6,127.60	11,597.00
Retrofitted Pile Drivers[c] Standard + enclosure	2,918	2,580.60	6,127.60	11,626.00
Standard + enclosure and muffler	2,938	2,580.60	6,127.60	11,646.00
Standard + enclosure + muffler and damping	2,938	7,130.60	6,127.60	16,196.00
Standard + muffler and enclosure and damping and flexoply pads	2,938	7,364.60	6,127.60	16,430.00
Standard + enclosure and muffler and flexoply pads	2,938	2,814.60	6,127.60	11,880.00
Vibratory Pile Driver[b]	4,332	2,143.40	6,127.60	12,603.00

[a]Monthly rental x 7 days x 12 months 365 days.

[b]Includes accessory equipment and consumables = regular lead, bonnet, air hose, and aluminum and phenolic pads.

[c]Includes use of heavier lead (guide).

Note: The weekly capital cost used for the pile driver, cranes, and compressor are the weekly rental rates. It was felt these better approximated true ownership costs.

The costs for accessory equipment were amortized over the assumed working lives based on the purchase prices.

Sources: References 19, 20, 21, 22, 23, 24.

Table C-6
Unit Hourly Operating Costs

	$/hr.
I. Construction Equipment	
Vulcan #1 Hammer	$ 4.26
55-ton crane	$ 35.50
26.5-ton crane	$ 19.34
900 CFM compressor	$ 30.86
MKT V-20 vibratory hammer (included power pack)	$ 45.58
II. Labor	
3 crane operators	$ 19.84
1 carpenter foreman	$ 21.36
3 carpenters	$ 18.86
1 laborer	$ 15.74

Assumptions

1) The above costs include direct hourly wage, fringe benefits (social security, pension, etc.) contractor and overhead profit.

2) Fuel cost assumptions
   diesel = $.85/gallon
   gasoline = $.95 gallon

3) Costs do not include capital consumption allowance.

4) Longer set-up times between the driving of piles were observed when employing the retrofitted pile driver. The base labor costs do not change, but the longer between-pile adjustment times meant fewer piles driven per day. (Please see section 4.1.)

APPENDIX D

MANUFACTURER NAMES AND ADDRESSES

CONTRACTOR: Shappert Engineering Company
East Menominee and Blaine Streets
Belvidere, Illinois 61008

PILE DRIVERS:

Model	Manufacturer	Type of Pile Driver
Chelminski	Bolt Associates, Inc. 205 Wilson Avenue Norwalk, CT 06854	Air-cushioned, electric motor-driven
Foster Vibro-Driver	L.B. Foster Co. 7 Parkway Center Pittsburgh, PA 15220	Vibratory
MKT V-20	McKiernan-Terry MKT Geotechnical Systems Box 793 Dover, NJ 07801	Vibratory
Hush	S.P. Civil Engineering, Ltd. Hush House Horndon Industrial Estate Station Road West Horndon Essex, CM13/3HP England	Silenced, diesel-driven

HAMMER:

Model	Manufacturer
010	Vulcan Iron Works, Inc. 2909 Riverside Drive Chattanooga, TN 37406

ENCLOSURES:

Frommelt Industries, Inc.
465 Huff Street
Dubuque, Iowa 52001

Industrial Noise Control, Inc.
312 Stewart Avenue
Addison, IL 60101

Insul-Coustic/Birma Corp.
Jernee Mill Road
Sayreville, NJ 08872

SOUND-ABSORBING MATERIAL TO LINE ENCLOSURE:

The Soundcoat Company ("Soundcoat Embossed Foam")
175 Pearl Street
Brooklyn, NY 11210

Ferro Corporation ("Cousticomposite 0-5-50")
Composites Division
34 Smith Street
Norwalk, CT 06852

Peabody Noise Control, Inc.
("Cousticomposite 0-5-50")
(formerly Consolidated Kinetics Corporation)
6300 Irelan Place
P.O. Box 655
Dublin, OH 43017

Korfund Dynamics Corporation ("Sound-Eaze TLB-M")
P.O. Box 235
Contiague Road
Westbury, Long Island 11590

MUFFLERS:

Vulcan Iron Works, Inc. ("Decelflo")
2909 Riverside Drive
Chattanooga, TN 37406

Donaldson Co., Inc.
1400 W. 94th Street
Minneapolis, MN 55440

Burgess Industries
8101 Carpenter Freeway
Dallas, TX 75247

PILE DAMPING MATERIAL:

Peabody Noise Control, Inc. ("Coustidamp")
(formerly Consolidated Kinetics Corporation)
6300 Irelan Place
P.O. Box 655
Dublin, OH 43017

ELASTOMERIC MATERIAL FOR IMPACT CUSHIONS:

The Soundcoat Company, Inc. ("DYAD")
175 Pearl Street
Brooklyn, NY 11201

Ear Corporation ("C-2003")
7911 Zionsville Road
Indianapolis, Indiana 46258

Peabody Noise Control, Inc. ("Flexoply")
(formerly Consolidated Kinetics Corporation)
6300 Irelan Place
P.O. Box 655
Dublin, OH 43017

Lord Corporation
1635 W. 12 Street
Erie, PA 16512

ACOUSTICAL CURTAIN:

Singer Safety Products ("Sound Stopper")
444 N. Lake Shore Drive
Chicago, Illinois 60611

APPENDIX E

Nomenclature

Ambient sound levels - The surrounding sound associated with a given environment, usually a composite of sound from many sources.

Amortized costs - Costs written off by prorating the costs over a fixed period.

Anvil - The base surface onto which the pile driver hammer falls.

A-weighted-sound level - A weighted sound level, obtained by the use of metering characteristics and the weighting, A, specified in the latest revision of American Standard Sound Level Meters for Measurement of Noise and Other Sounds, 724.3, 1944. The A-weighted network is used to account for the human ear's decreased sensitivity to low frequencies at normal sound levels.

Bonnet - Anything used as a protective covering to prevent the piles from being damaged by the hammer; same as a "helmet."

Cofferdam - A watertight, temporary structure fixed in the bottom of a river, lake, etc., to keep out water during the progress of work on a site.

Decibel - A unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power. This unit is used for measuring the volume of a sound, equal to the logarithm of the ratio of the intensity of the sound to the intensity of an arbitrarily chosen standard sound.

Equivalent sound levels - The average sound level for any given period of time which is equal to the total energy level due to a fluctuating sound level for the same period of time; a means of assigning a value to varying noise levels over a given period of time; also called "equivalent continuous sound level."

CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: DAEN-ASI-L (2)
ATTN: DAEN-CCP
ATTN: DAEN-CW
ATTN: DAEN-CWE
ATTN: DAEN-CWM-R
ATTN: DAEN-CWO
ATTN: DAEN-CWP
ATTN: DAEN-MP
ATTN: DAEN-MPC
ATTN: DAEN-MPE
ATTN: DAEN-MPO
ATTN: DAEN-MPR-A
ATTN: DAEN-RD
ATTN: DAEN-RDC
ATTN: DAEN-RDM
ATTN: DAEN-RM
ATTN: DAEN-ZC
ATTN: DAEN-ZCE
ATTN: DAEN-ZCI
ATTN: DAEN-ZCM

US Army Engineer Districts
ATTN: Library
Alaska
Al Batin
Albuquerque
Baltimore
Buffalo
Charleston
Chicago
Detroit
Far East
Fort Worth
Galveston
Huntington
Jacksonville
Japan
Kansas City
Little Rock
Los Angeles
Louisville
Memphis
Mobile
Nashville
New Orleans
New York
Norfolk
Omaha
Philadelphia
Pittsburgh
Portland
Riyadh
Rock Island
Sacramento
San Francisco
Savannah
Seattle
St. Louis
St. Paul
Tulsa
Vicksburg
Walla Walla
Wilmington

US Army Engineer Divisions
ATTN: Library
Europe
Huntsville
Lower Mississippi Valley
Middle East
Middle East (Rear)
Missouri River
New England
North Atlantic
North Central
North Pacific
Ohio River
Pacific Ocean
South Atlantic
South Pacific
Southwestern

Waterways Experiment Station
ATTN: Library

Cold Regions Research Engineering Lab
ATTN: Library

US Government Printing Office
Receiving Section/Depository Copies (2)

Defense Technical Information Center
ATTN: DDA (12)

Engineering Societies Library
New York, NY

FESA, ATTN: Library

ETL, ATTN: Library

Engr. Studies Center, ATTN: Library

Inst. for Water Res., ATTN: Library

Army Instl. and Major Activities (CONUS)
DARCOM - Dir., Instl., & Svcs.
ATTN: Facilities Engineer
ARRADCOM
Aberdeen Proving Ground
Army Matls. and Mechanics Res. Ctr.
Corpus Christi Army Depot
Harry Diamond Laboratories
Dugway Proving Ground
Jefferson Proving Ground
Fort Monmouth
Letterkenny Army Depot
Natick Research and Dev. Ctr.
New Cumberland Army Depot
Pueblo Army Depot
Red River Army Depot
Redstone Arsenal
Rock Island Arsenal
Savanna Army Depot
Sharpe Army Depot
Seneca Army Depot
Tobyhanna Army Depot
Tooele Army Depot
Watervliet Arsenal
Yuma Proving Ground
White Sands Missile Range

FORSCOM
FORSCOM Engineer, ATTN: AFEN-FE
ATTN: Facilities Engineers
Fort Buchanan
Fort Bragg
Fort Campbell
Fort Carson
Fort Devens
Fort Drum
Fort Hood
Fort Indiantown Gap
Fort Irwin
Fort Sam Houston
Fort Lewis
Fort McCoy
Fort McPherson
Fort George G. Meade
Fort Ord
Fort Polk
Fort Richardson
Fort Riley
Presidio of San Francisco
Fort Sheridan
Fort Stewart
Fort Wainwright
Vancouver Bks.

TRADOC
HQ, TRADOC, ATTN: ATEN-FE
ATTN: Facilities Engineer
Fort Belvoir
Fort Benning
Fort Bliss
Carlisle Barracks
Fort Chaffee
Fort Dix
Fort Eustis
Fort Gordon
Fort Hamilton
Fort Benjamin Harrison
Fort Jackson
Fort Knox
Fort Leavenworth
Fort Lee
Fort McClellan
Fort Monroe
Fort Rucker
Fort Sill
Fort Leonard Wood

INSCOM - Ch, Instl. Div.
ATTN: Facilities Engineer
Vint Hill Farms Station
Arlington Hall Station

WESTCOM
ATTN: Facilities Engineer
Fort Shafter

MDW
ATTN: Facilities Engineer
Cameron Station
Fort Lesley J. McNair
Fort Myer

HSC
HQ USAHSC, ATTN: HSLO-F
ATTN: Facilities Engineer
Fitzsimons Army Medical Center
Walter Reed Army Medical Center

USACC
ATTN: Facilities Engineer
Fort Huachuca
Fort Ritchie

MTMC
HQ, ATTN: MTMC-SA
ATTN: Facilities Engineer
Oakland Army Base
Bayonne MOT
Sunny Point MOT

US Military Academy
ATTN: Facilities Engineer
ATTN: Dept of Geography & Computer Science

USAES, Fort Belvoir, VA
ATTN: ATZA-DTE-EM
ATTN: ATZA-DTE-SU
ATTN: Engr. Library

Chief Inst. Div., I&SA, Rock Island, IL

USA ARRCOM, ATTN: Dir., Instl & Svc
TARCOM, Fac. Div.
TECOM, ATTN: DRSTE-LG-F
TSARCOM, ATTN: STSAS-F
NARAD COM, ATTN: DRDNA-F
AMMRC, ATTN: DRXMR-WE

HQ, XVIII Airborne Corps and Ft. Bragg
ATTN: AFZA-FE-EE

HQ, 7th Army Training Command
ATTN: AETTG-DEH (5)

HQ USAREUR and 7th Army
ODCS/Engineer
ATTN: AEAEN-EH (4)

V Corps
ATTN: AETVDEH (5)

VII Corps
ATTN: AETSDEH (5)

21st Support Command
ATTN: AEREH (5)

US Army Berlin
ATTN: AEBA-EN (2)

US Army Southern European Task Force
ATTN: AESE-ENG (5)

US Army Installation Support Activity, Europe
ATTN: AEUES-RP

8th USA, Korea
ATTN: EAFE
Cdr, Fac Engr Act (8)
AFE, Yongsan Area
AFE, 2D Inf Div
AFE, Area II Spt Det
AFE, Cp Humphreys
AFE, Pusan
AFE, Taegu

DLA ATTN: DLA-WI

USA Japan (USARJ)
Ch, FE Div, AJEN-FE
Fac Engr (Honshu)
Fac Engr (Okinawa)

ROK/US Combined Forces Command
ATTN: EUSA-HHC-CFC/Engr

416th Engineer Command
ATTN: Facilities Engineering

Norton AFB
ATTN: AFRCE-MX/DEE

USA ARRADCOM
ATTN: DRDAR-LCA-OK

Director of Facilities Engr
Miami, FL 34004

HQ US Army Materiel, DARCOM
ATTN: DRCPA-E/E. Proudman
ATTN: DRCIS-A
Alexandria, VA 22333

HQDA (SGRD-EDE)

Chief of Engineers
ATTN: DAEN-MPC-E/D. Spivey
ATTN: DAEN-MPO-B
ATTN: DAEN-MPR
ATTN: DAEN-MPZ-A
ATTN: DAEN-RDL
ATTN: DAEN-MPE-B/W. B. Holmes
ATTN: DAEN-MPC-E/P. Van Parys
ATTN: DAEN-MPE-I/F. P. Beck (2)
ATTN: DAEN-MPE-I/J. Halligan
ATTN: DAEN-ZCE-D/E. Herndon (2)

Ft. Belvoir, VA 22060
ATTN: Kingman Bldg, Library
ATTN: Canadian Liaison Officer (2)

DFAE Envir Quality Section
ATTN: Mike Halls
Ft. Carson, CO 80192

Ft. Leavenworth, KS 66027
ATTN: ATZLCA-SA

Ft. Monroe, VA 23651
ATTN: ATEN-FE-E/D. Dery
ATTN: James L. Aikin, Jr.
ATTN: Chief, Envr Branch
ATTN: ATEN-AD (3)

Ft. McPherson, GA 30330
ATTN: AFEN-FEB
ATTN: Robert Jarrett

Ft. Detrick, MD 21701
ATTN: LTC LeRoy H. Reuter

Ft. Rucker, AL 36360
ATTN: Robert T. Camo, Jr.
ATTN: CPT J. Patterson

USA-WES
ATTN: Jack Stoll WESSE

5th US Army
ATTN: AFKC-EN

7th US Army
ATTN: AETTM-HRD-EHD

Aberdeen Proving Ground, MD 21005
ATTN: DRDAR-BLL/Schmidt/Kahl
ATTN: STEAP-MT-E/Conley
Human Engineering Laboratory
ATTN: J. E. Weisz/AMZHE
ATTN: George Garintner
Army Environmental Hygiene Agency
ATTN: CPT George Luz/BioAcoustics

US Army Engineer District
New York
ATTN: Chief, Design Br
Philadelphia
ATTN: Chief, NAPEN-E
Baltimore
ATTN: Chief, Engr Div
Norfolk
ATTN: Chief, NAOEN-D
Huntington
ATTN: Chief, ORHED
Wilmington
ATTN: Chief, SAWEN-D

US Army Engineer District
Savannah
ATTN: Chief, SASAS-L
Mobile
ATTN: Chief, SAMEN-D
Louisville
ATTN: Chief, Engr Div
St. Paul
ATTN: Chief, ED-D
Chicago
ATTN: Chief, NCCPE-PES
Rock Island
ATTN: Chief, Engr Div
St. Louis
ATTN: Chief, ED-D
Omaha
ATTN: Chief, Engr Div
New Orleans
ATTN: Chief, LMNED-DG
Little Rock
ATTN: Chief, Engr Div
Tulsa
ATTN: Chief, Engr Div
Ft. Worth
ATTN: Chief, SWFED-D
ATTN: Bill G. Daniels
ATTN: Royce W. Mullens, Water Resource Planning
San Francisco
ATTN: Chief, Engr Div
Sacramento
ATTN: Chief, SPKED-D
Far East
ATTN: Chief, Engr Div
Seattle
ATTN: Chief, EN-DB-ST
Walla Walla
ATTN: Chief, Engr Div
Alaska
ATTN: Chief, NPASA-R

US Army Engineer Division
New England
ATTN: Chief, NEDED-T
North Atlantic
ATTN: Chief, NADEN-T
Middle East (Rear)
ATTN: Chief, MEDED-T
South Atlantic
ATTN: Chief, SADEN-TS
Huntsville
ATTN: Chief, HNDED-CS
ATTN: Chief, HNDED-SR
Ohio River
ATTN: Chief, Engr Div
Missouri River
ATTN: Chief, MRDED-T
Southwestern
ATTN: Chief, SWDED-T
South Pacific
ATTN: Chief, SPDED-TG
Pacific Ocean
ATTN: Chief, Engr Div
North Pacific
ATTN: Chief, Engr Div

National Defense HQDA
Director General of Construction
Ottawa, Ontario, Canada K1A 0K2

Division of Building Research
National Research Council
Ottawa, Ontario, Canada K1A 0R6

Airports and Construction Services Dir
Technical Information Reference Centre
Ottawa, Ontario, Canada K1A 0N8

McClellan AFB, CA 95652
2852 APG/DE

AF PREES
Bolling AFB, DC 20332

[illegible] AFB, [illegible] 32542
ATTN: [illegible]

AFESC/PRT
Tyndall AFB, FL 32403

Wright-Patterson AFB, OH 45433
ATTN: Dr. H. Von Gierke
ATTN: Jerry Speakman
ATTN: LTC D. Johnson

Naval Undersea Center, Code 401
ATTN: Bob Gales
ATTN: Dr. Robert Young, Code 512128
San Diego, CA 92152

Naval Air Station
ATTN: Ray Glass/Code 661
North Island, CA 92135

US Naval Oceanographic Office
Bay St. Louis, MS 39522

Naval Surface Weapons Center
ATTN: N-43/Pater
Dahlgren, VA 22485

Naval Air Systems Command
WASH DC 20361

NAVFAC
ATTN: Code 04
ATTN: David Kurtz Code 2013
Alexandria, VA 22332

Port Hueneme, CA 93043
ATTN: Library (Code L08A)

Washington, DC
ATTN: Building Research Advisory Board
ATTN: Transportation Research Board
ATTN: Library of Congress (2)
ATTN: Dept of Transportation Library

Federal Aviation Administration
ATTN: H. B. Safeer, Chief
Envr Policy Div

National Bureau of Standards
ATTN: Dan R. Flynn

Bureau of National Affairs
ATTN: Fred Blosser, RM 462

Office of Noise Abatement
ATTN: Gordon Banerian

Dept of Housing and Urban Development
ATTN: George Winzer, Chief Noise Abatement Program

NASA
ATTN: [illegible] Fields
ATTN: H. Hubbard

EPA Noise Office
ATTN: Al Hicks, Rm 2113
ATTN: Dr. Kent Williams, Rm [illegible]
ATTN: Tom O'Hare, Rm 907B

EPA Region III Noise Program
ATTN: Pat Anderson

Illinois EPA
ATTN: DNPC Greg Zak
ATTN: Bob Hellweg

EPA-[illegible] copies

USA Logistics Management Center
Bldg 12028
ATTN: MAJ K. Valentine

Federal Highway Administration
Region 15
ATTN: William Bowlby

Kessler, Fred M.
Noise control : pile driver demonstration project, Waterloo, Iowa / by Fred Kessler, Paul Schomer. -- Champaign, IL : Construction Engineering Research Laboratory ; Springfield, VA : available from NTIS, 1981.
91 p. (Technical report ; N-111)

1. Piling (civil engineering) -- noise. I. Schomer, Paul D. II. Title. III. Title : Pile driver demonstration project, Waterloo, Iowa. IV. Series : U.S. Army Construction Engineering Research Laboratory. Technical report ; N-111.

DAT
ILM