

# THE PERFORMANCE OF PILE DRIVING SYSTEMS:

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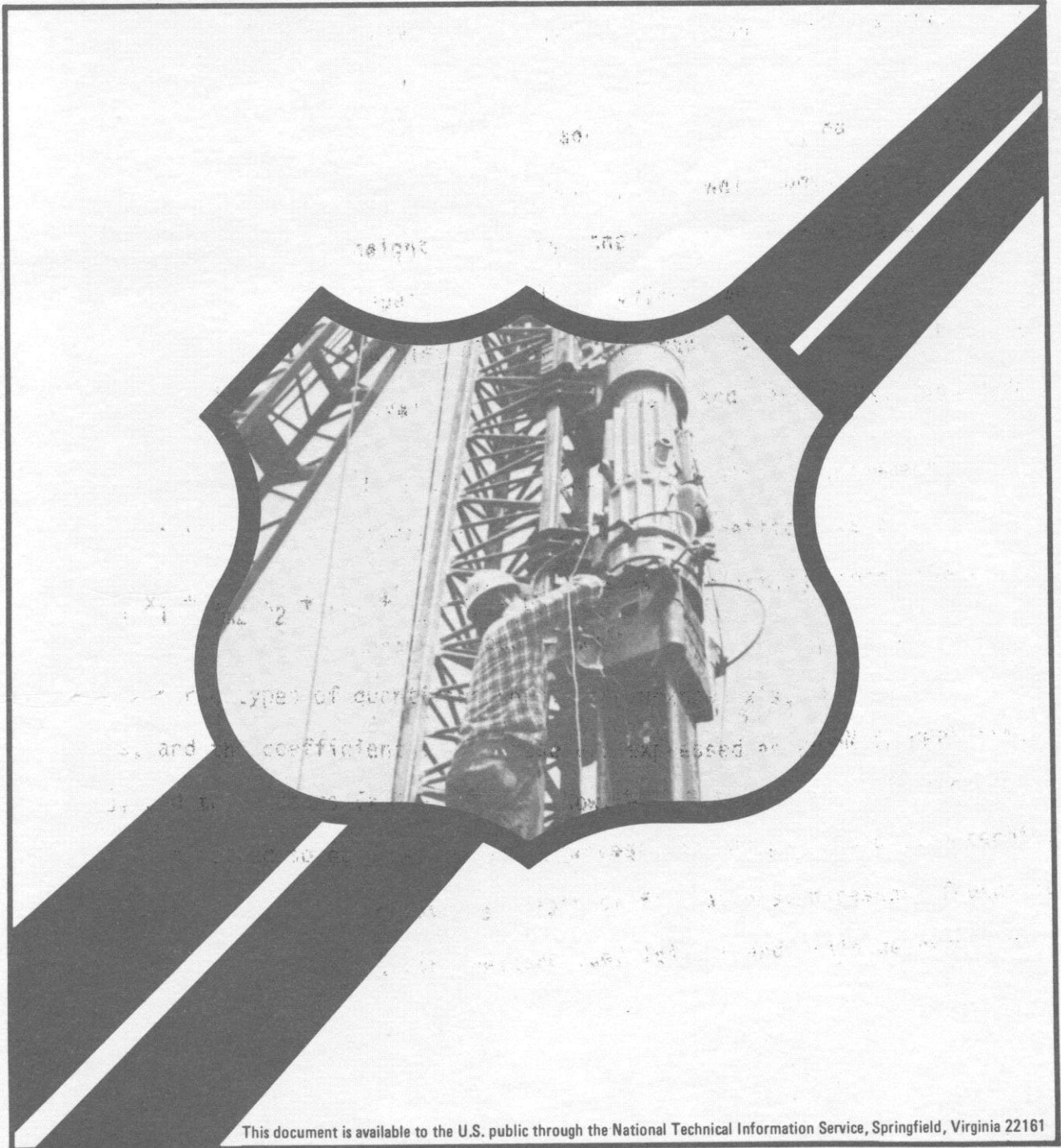
## INSPECTION MANUAL

U.S. Department  
of Transportation

**Federal Highway  
Administration**

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## FOREWORD

This report presents the results of a comprehensive investigation of the performance of pile driving systems. It is an inspection manual for impact hammers and includes pile cushions, helmets, and leads. The manual also includes pile hammer data sheets for use on the job site. This report will be of interest to bridge engineers and geotechnical engineers concerned with the inspection of pile driving operations.

Sufficient copies of the report are being distributed by FHWA Bulletin to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State highway agency. Direct distribution is being made to division offices.



Richard E. Hay, Director  
Office of Engineering and Highway  
Operations Research and Development

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16. Abstract  A study was undertaken on the performance of pile driving systems and the existing technology for the measurement of performance parameters was reviewed. This report is an inspection manual for use by pile driving inspectors and engineers to ascertain that the pile hammer conforms to certain minimum standards, and to record observations on hammer and driving system behavior.  The manual considers only impact hammers; i.e., a large weight is alternately being raised and then accelerated downward, impacting against the pile top. Vibratory hammers, which operate on a different principle altogether, have been excluded from this manual.  In addition to pile impact hammers, the manual addresses the complete driving system to include cushions, helmets, and leads. Also included as an aid to the inspector/engineer, are comprehensive field inspection data forms.					
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# METRIC (SI\*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

### AREA

in <sup>2</sup>	square inches	645.2	millimetres squared	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.0929	metres squared	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.836	metres squared	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.59	kilometres squared	km <sup>2</sup>
ac	acres	0.395	hectares	ha

### MASS (weight)

oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

### VOLUME

fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft <sup>3</sup>	cubic feet	0.0328	metres cubed	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.0765	metres cubed	m <sup>3</sup>

NOTE: Volumes greater than 1000 L shall be shown in m<sup>3</sup>.

### TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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## APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

### AREA

mm <sup>2</sup>	millimetres squared	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	metres squared	10.764	square feet	ft <sup>2</sup>
km <sup>2</sup>	kilometres squared	0.39	square miles	mi <sup>2</sup>
ha	hectares (10 000 m <sup>2</sup> )	2.53	acres	ac

### MASS (weight)

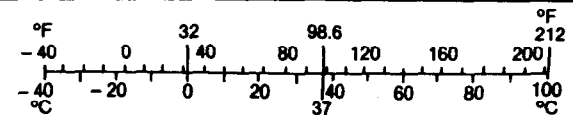
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

### VOLUME

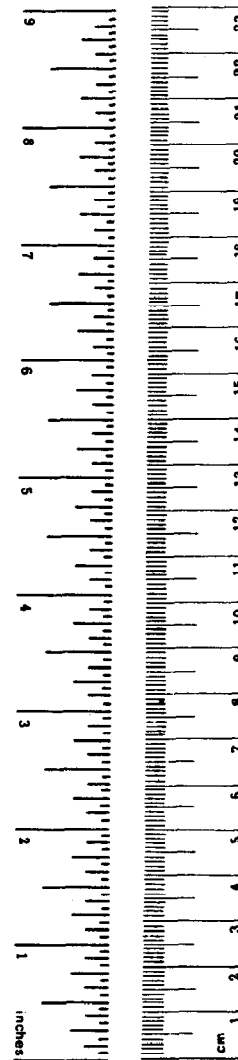
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m <sup>3</sup>	metres cubed	35.315	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	metres cubed	1.308	cubic yards	yd <sup>3</sup>

### TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
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These factors conform to the requirement of FHWA Order 5190.1A.



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## CHAPTER 1 - INTRODUCTION

Pile driving systems are a rather archaic part of construction technology. They consist of a heavy mass which pounds on a "stick" until it ends up buried in the ground. Once in the ground the stick may be bent or straight, and it may be capable of carrying a high or a low load. Since most of the stick is underground and out of sight, one is not too sure.

Over the years, technology advanced toward the development of ever bigger and faster hammers. These developments included rams that were raised by ropes through human or horse muscle, those hoisted by steam winches or powered by steam, air, or hydraulic pressure, and finally the diesel hammer. In order to speed up operations, double acting hammers were developed. Hammers from all stages of this technological advance are still encountered on the construction site.

If the only purpose of a hammer was to pound a stick into the ground, then the efficiency of that hammer would not matter. However, the vertical advance of a pile under a given hammer blow can be used as a measure of the pile's bearing capacity. Thus, the hammer takes on a second function, and doubles as a piece of testing equipment. In recent years, this simple form of "pile testing" has gained widespread acceptance. Field observations must be interpreted according to a pile set vs. capacity curve determined by using a computational procedure known as a wave equation. This procedure gives rather accurate predictions of the load which a pile may be able to support if it is known how the hammer and other components of the driving system behaved.

Thus, for a good "test," it is not important that a hammer works with 100% efficiency; however, it must be known how it worked. Thus, field inspection has two important purposes:

- . Ascertain that the hammer conforms to certain minimum standards.
- . Record observations on hammer and driving system behavior.

These two functions will enable the analyzing engineer to reduce the uncertainty (or guesswork) in his results. Furthermore, better productivity (and therefore money savings) plus a reduced likelihood of construction claims can be expected.

This manual contains six main chapters and five appendices. Chapter 2 describes driving systems, i.e., all of those components which aid a hammer in installing a pile. Chapters 3 through 6 describe the four main categories of pile driving hammers:

- . External Combustion Hammers - Single Acting.
- . External Combustion Hammers - Double Acting.
- . Internal Combustion Hammers - Single Acting.
- . Internal Combustion Hammers - Double Acting.

"External combustion" means that the power to raise the ram comes from an outside source (rope, steam, air, hydraulic). "Internal combustion" applies only to diesel hammers. "Single acting" means that the ram falls under

gravity only. "Double acting," on the other hand, implies that there is a force applied to the ram during both the up and the down stroke.

There are further subcategories and Figure 1 gives a hierarchy of all common hammer types. It should be mentioned, for example, that double acting external combustion hammers may be built with three different mechanisms: the differential, the actual double acting, or the compound mechanism. Such details will be explained, although the inspector cannot actually inspect or evaluate the soundness of a particular mechanism since its major components are hidden inside the hammer.

Among the diesel hammers, the difference between atomized and liquid fuel injection will be mentioned. Again, these details may have an effect on the actual hammer behavior. However, they do not significantly affect the inspection.

All of the above mentioned hammer types are impact hammers, i.e., a large weight is alternately being raised and then accelerated downward, impacting against the pile top. Vibratory hammers, which operate on a different principle altogether, have been excluded from this manual.

Appendices were added to aid in the use of the manual. For example, the glossary summarizes all terms in the manual, plus a few others, which are "pile driver language." Appendix B explains the background of the Saximeter™, a tool designed to simplify the inspector's task. Appendix C explains the difference between atomized and liquid fuel injection. Appendix D lists all common hammers and their category plus additional pertinent information. Finally, Appendix E provides a data sheet (with room for observations) for most common hammer types which are used for bearing pile driving.

# IMPACT PILE DRIVING HAMMERS

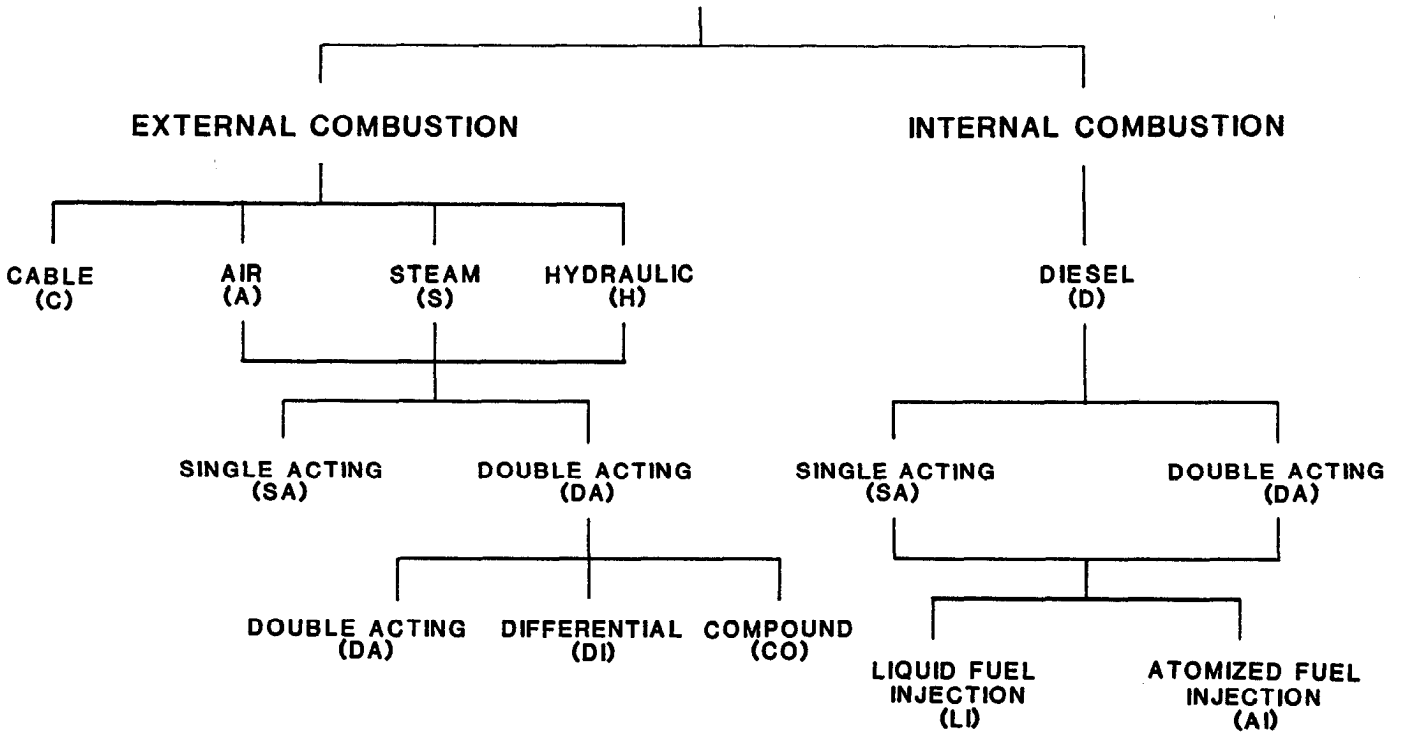


Figure 1. Impact Pile Driving Hammers.

## CHAPTER 2 - THE DRIVING SYSTEM

### A. Introduction

For this Inspection Manual, the driving system consists of the following components:

- . The lead, also called the set of leads, sometimes including a brace which allows for the adjustment of the lead angle without setting the leads on the ground.
- . The hammer cushion, which protects the hammer as well as the pile from excessive stress. Cushion material is relatively soft compared to steel. Usually, the cushion is protected by a striker plate.
- . The helmet, which aligns pile top and hammer. It is usually a steel casting.
- . The pile cushion. This is only needed on concrete piles, and usually consists of several layers of plywood.

All components of the driving system have some effect on the performance of a hammer and/or how the hammer transfers its energy into a pile.

### B. Lead Systems

Depending on the relative positions of the crane and the pile, a specific type of lead system may need to be employed. There are four main categories of lead systems; the inspector should be aware of their working principles.

#### (1) The Swinging Lead

A lightweight pile with a moderate batter (the angle formed between the axis of the pile and the vertical) may be driven with swinging leads. A swinging lead (Figure 2) is supported at its top by a line from the crane. Its second point of support is the ground. Swinging leads have spikes mounted at their bottom, and these have to penetrate the ground surface.

#### (2) The Fixed Lead

Fixed leads have a pivot point at the crane's boom top and are braced between crane and lead bottom (Figure 3). The brace is usually extendable (hydraulically or by hoist line) such that the pile batter can be easily achieved. Fixed leads offer good control; of course, they are more expensive than swinging leads and they may be limited where the crane's working surface is substantially higher than pile grade (e.g., the crane is on original ground and the pile is driven in an excavation).

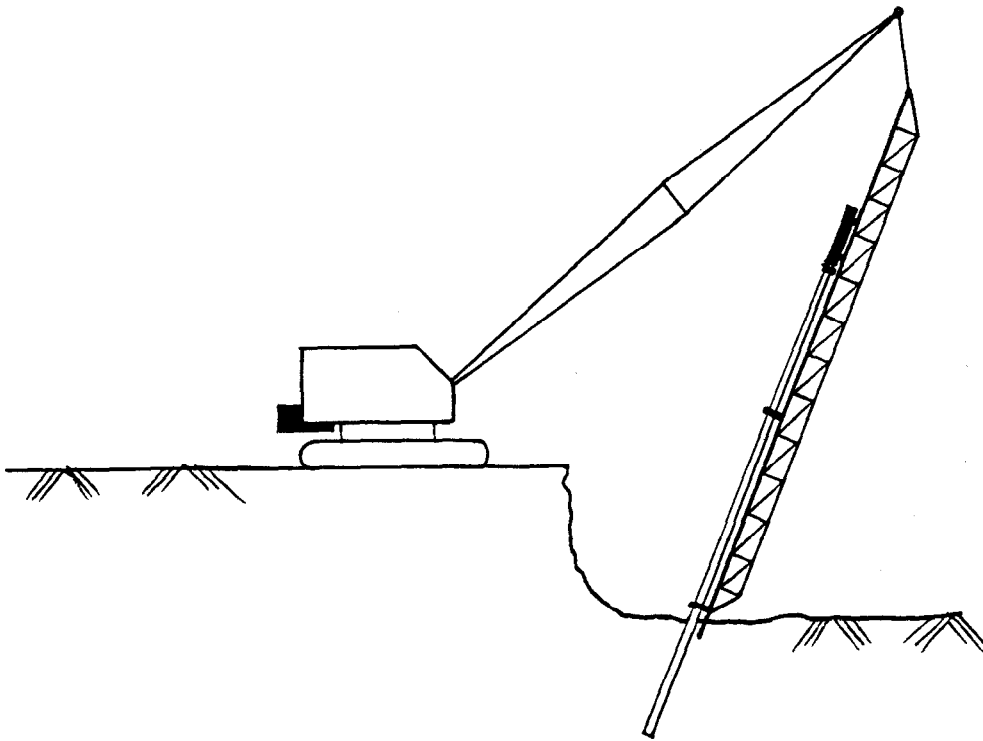
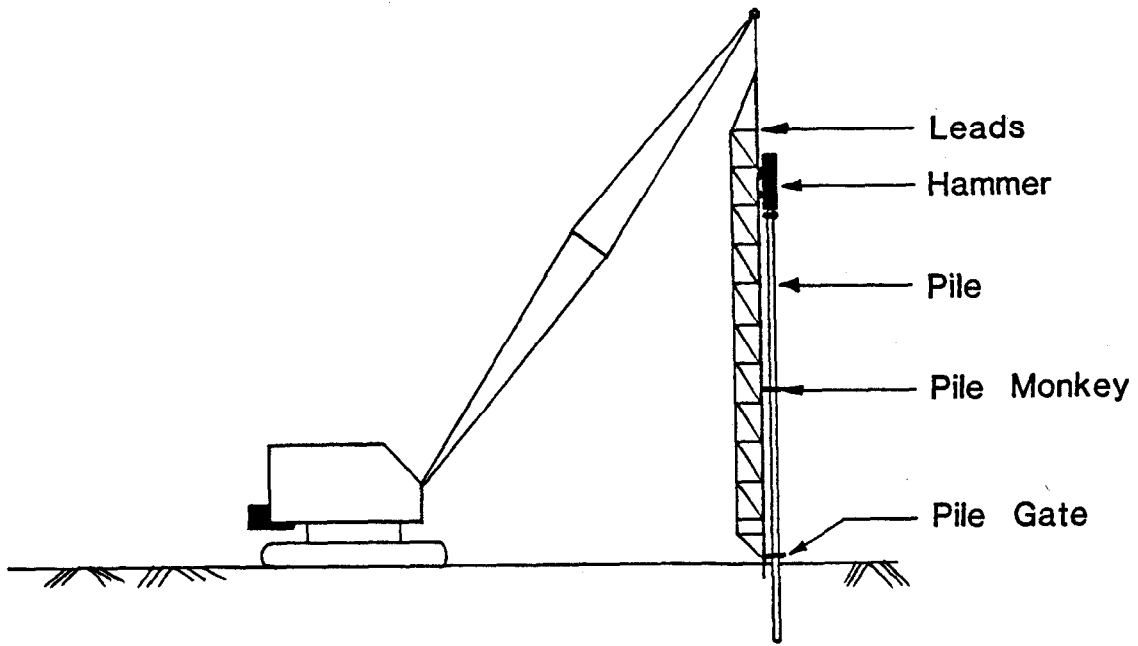


Figure 2. Swinging Leads.

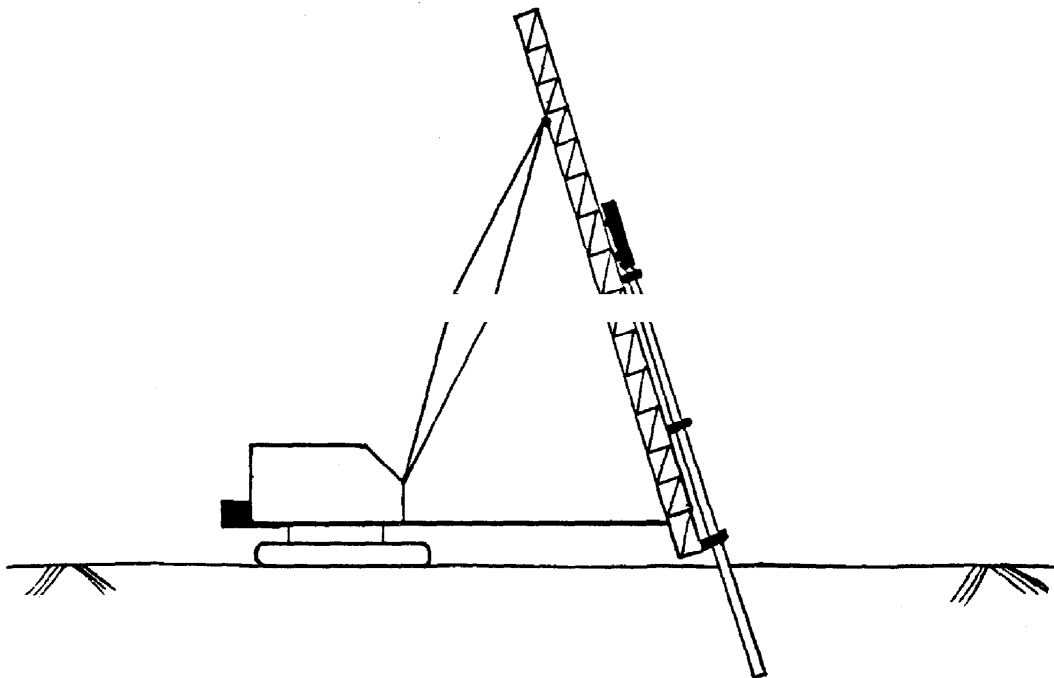
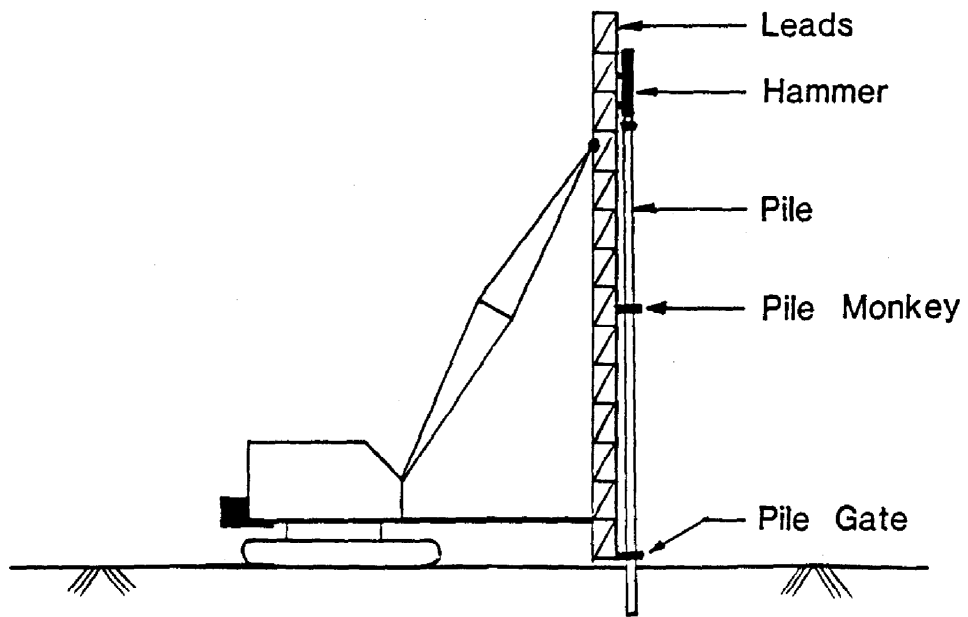


Figure 3. Fixed Leads

### (3) The Semi-Fixed Lead

The good control of the fixed lead and the flexibility of the swinging lead are combined in the semi-fixed lead. In this type of lead system, the lead can slide axially along the pivoted boom point. The lead, pile, and hammer weight are supported by the lead line which attaches near the bottom of the lead. Semi-fixed leads are usually fitted with an extendable brace (Figure 4).

### (4) The Offshore Lead

Where the pile is guided by a template and where the crane is located on a barge which moves relative to the template, an offshore lead is needed. This lead only aligns hammer and pile; the pile's batter and position are maintained by the template (Figure 5).

## C. Maintaining Pile Position

Pile position is maintained by the leads (offshore leads are an exception). The pile is held at its top by the helmet. A second guiding point is the gate, which is usually located at the lead bottom (see Figure 6). The gate should allow for only small lateral pile movements.

During driving, most crane-lead systems shift to some degree because of the constantly varying positions of hammer and pile load. Thus, corrections have to be made, particularly in strongly battered applications.

If the pile is forcibly moved out of position by some obstruction in the ground (pile walking), then it is not advisable to force the pile back or it will be destroyed. Swinging leads usually adjust themselves; braced leads may need operator attention.

## D. The Helmet

The helmet (Figure 7) is the heavy and rigid steel block between hammer and pile. It should be carefully fitted to a pile. First, it is important that the helmet's striking surface is smooth and contacts the pile top evenly. Second, it should not allow more than approximately 2 inches of lateral movement. Often the hammer manufacturer supplies certain helmet inserts or adaptors. For analysis purposes it is necessary to know the weight of the helmet.

A poor helmet-pile seating will cause high localized stresses at the pile top. In addition, a poor seating may cause the exposed portion of a long pile to buckle elastically under each hammer blow (this is known as "pile whipping").

## E. The Hammer Cushion

On top of the helmet there is usually a pot shaped recess which contains the hammer cushion (Figure 7). The hammer cushion should be protected by a

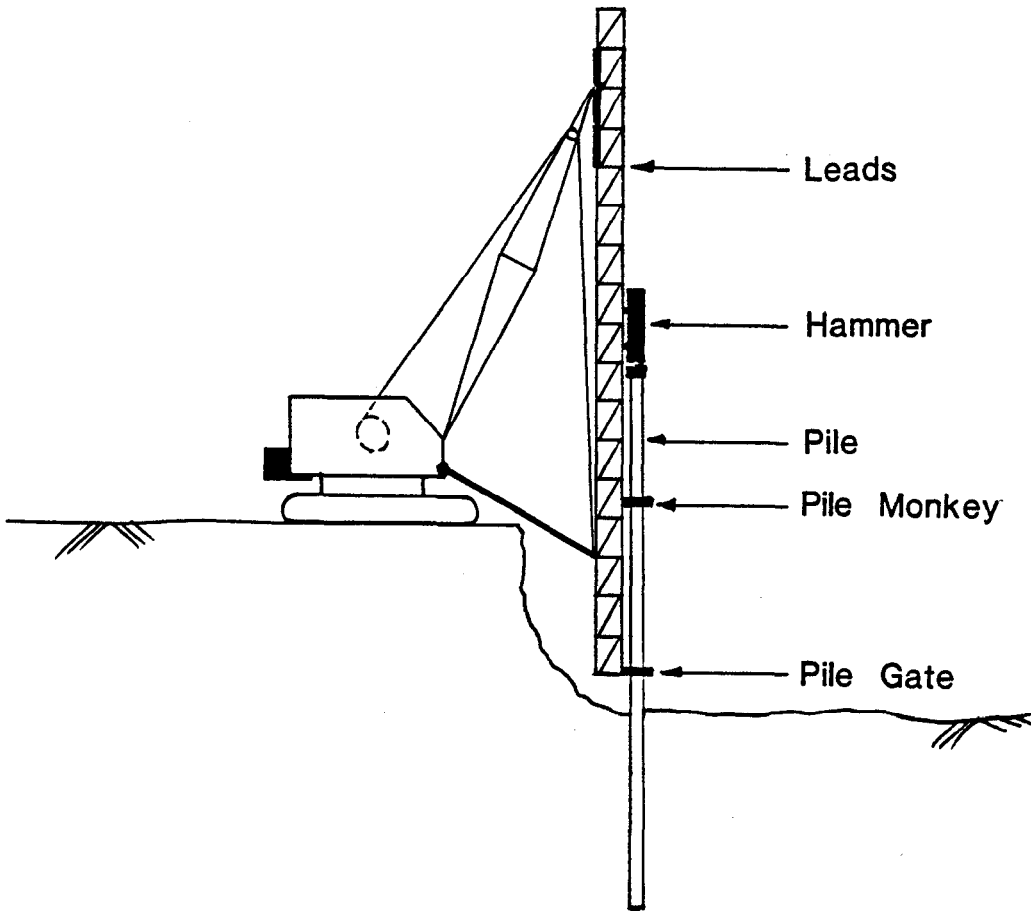


Figure 4. Semi-Fixed Leads.



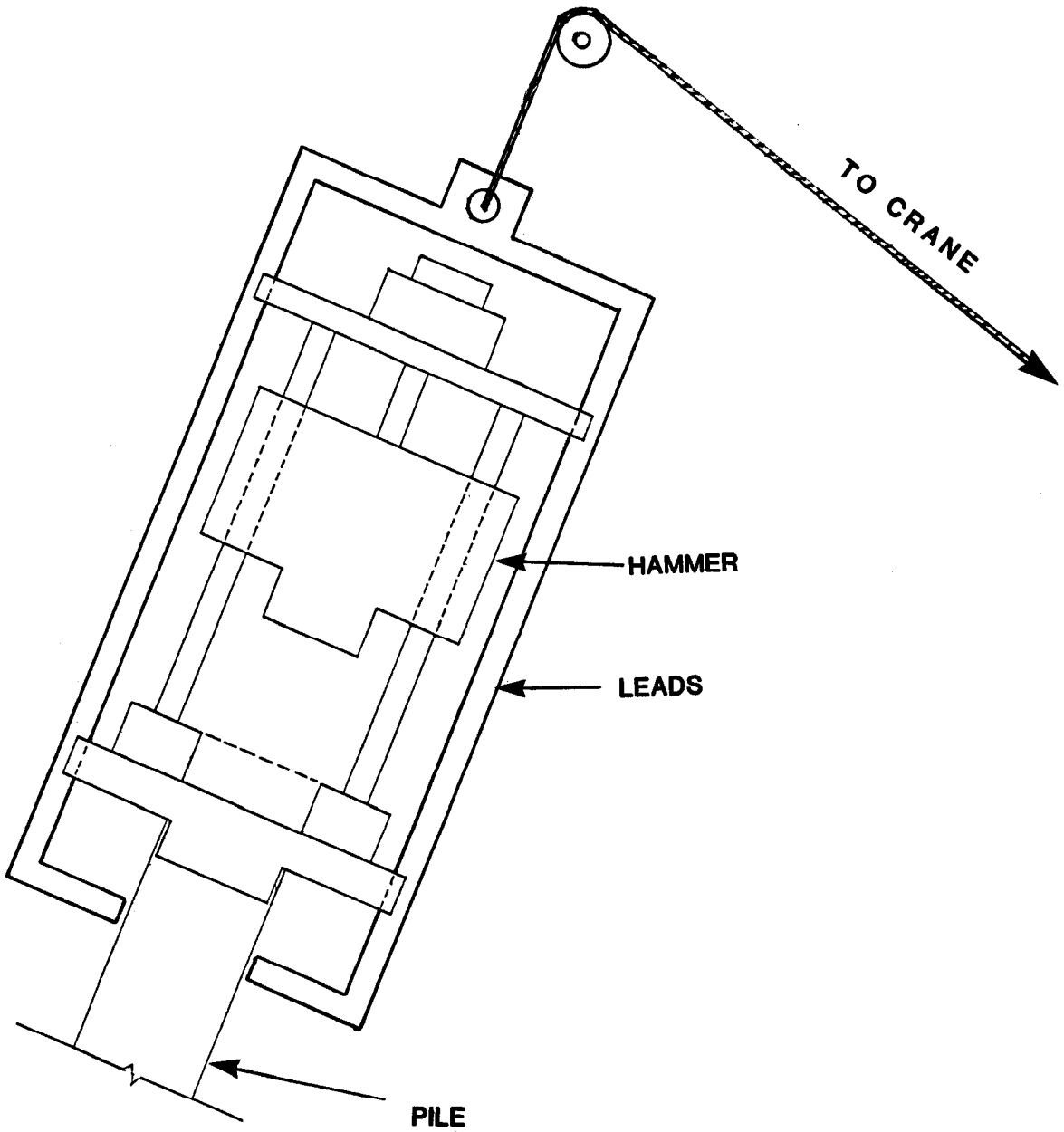


Figure 5. Offshore Leads

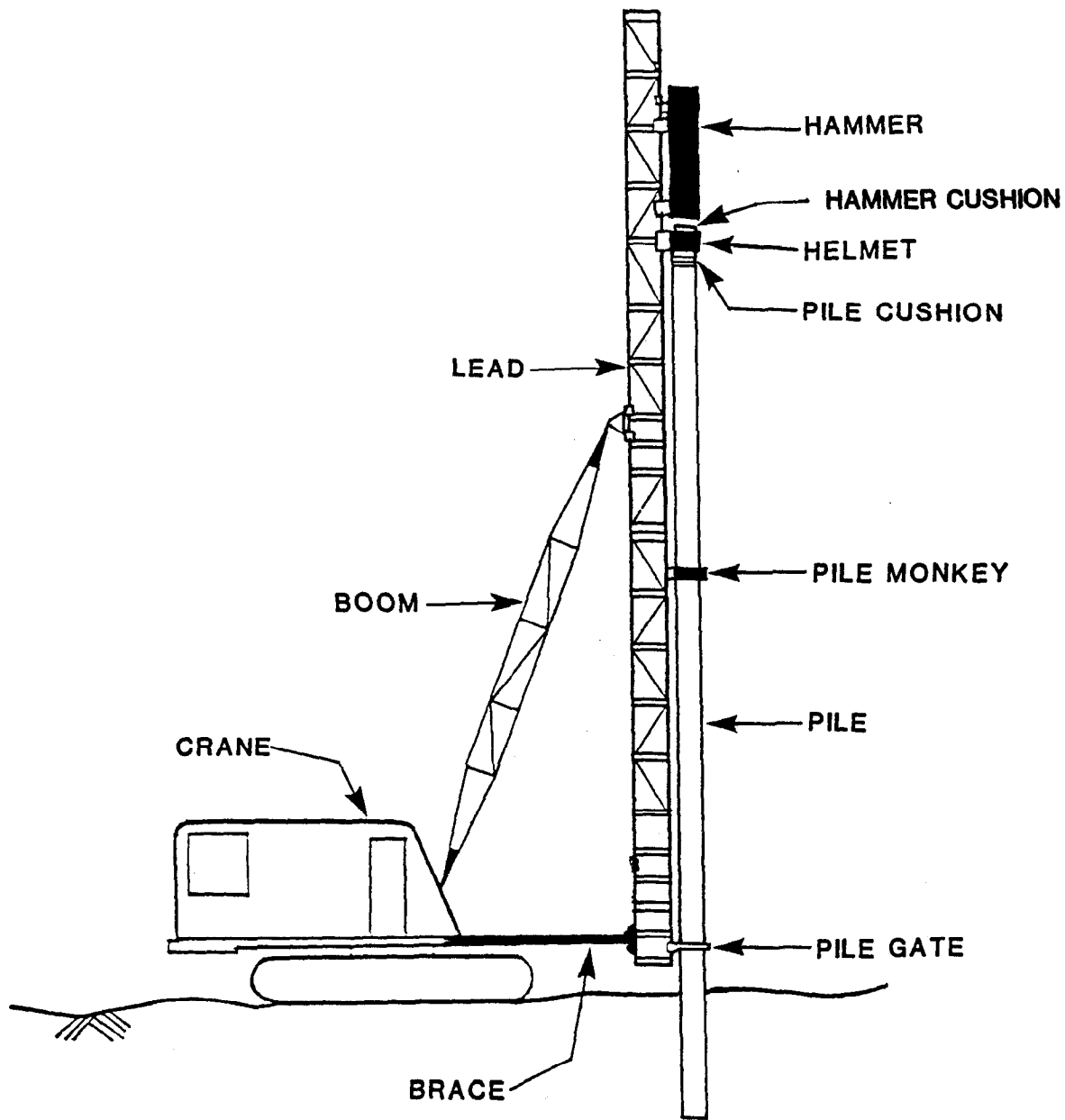


Figure 6. Pile Support System.

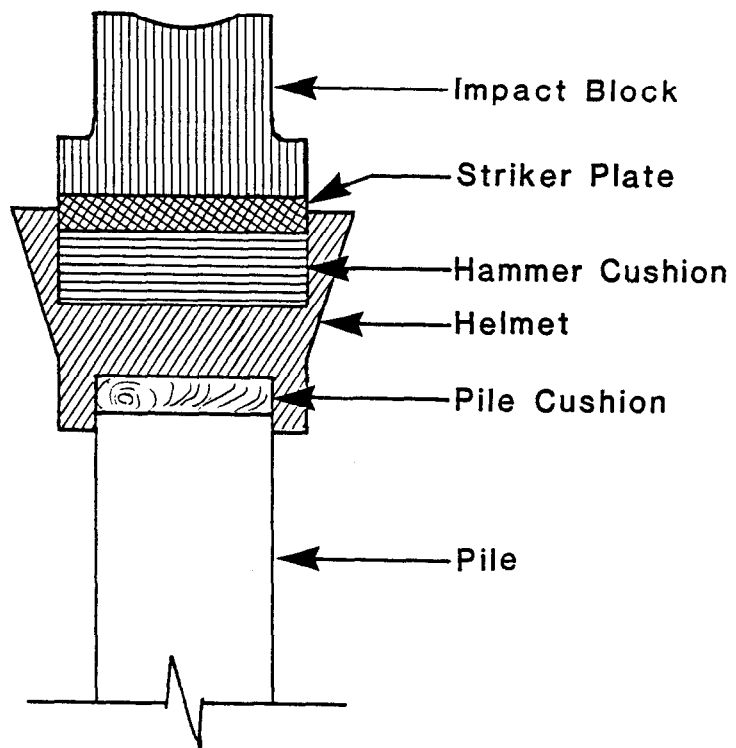


Figure 7. Helmet and Adjoining Parts.

striker plate, such that the material is compressed as uniformly as possible. The hammer cushion primarily protects the hammer.

Most hammer cushions have a limited life. They compress, and material may need to be added to maintain a certain thickness. Badly broken or burnt hammer cushions are inefficient. Hammer cushions with poor properties or improper thickness lead to inefficient hammer operation and/or hammer failure.

There are a number of man-made materials used as hammer cushioning which have predictable properties. A discussion of a few of these materials follows.

(1) Micarta (Conbest)

This is actually an electrical insulating material composed of fabric and phenol. It must be replaced when it starts to powderize or when it disintegrates into various layers.

(2) Nylon (Blue Or Other Colors)

This material comes in two-inch thick blocks. Occasional vertical cracking is not detrimental. However, after the cushion develops horizontal cracks, it should be replaced.

(3) Asbestos (Ascon)

For health reasons, it should not be used. This material tends to powderize and become thinner and thinner. Additional asbestos is then added.

(4) Hamortex

This material consists of metallized paper reels. It has good engineering properties but needs attention as it may compress or disintegrate.

(5) Cable

Woven steel cables have good properties. They must be carefully watched since hard driving tends to fuse them into a solid steel plate. Once this cushion appears to have fused into a continuous slab and the cable appearance is gone, this material must be replaced. A daily inspection is necessary.

(6) Hardwood

For a hammer cushion, hardwood is only acceptable if it is well fitted into the helmet and if it is placed with the wood grain parallel to the hammer-pile axis. Where the wood shows signs of burning or brooming, it should be replaced. An inspection should be done after 2000 blows or daily, whichever comes first.

(7) Force 10, Forbon, Fosterlon

These materials are usually acceptable. The manufacturer should supply a data sheet including elastic modulus and coefficient of restitution.

(8) Plywood

Plywood is not acceptable as a hammer cushion.

(9) Wood Chips

Wood chips are not acceptable as a hammer cushion.

(10) Aluminum

Aluminum is often used to separate layers of softer cushioning material. The aluminum does no cushioning itself; however, it is thought to extract the heat from the cushion stack. Once the aluminum is deformed or broken, it should be replaced.

F. The Pile Cushion

In the United States, plywood is the most common pile cushion material. Hardwood boards may also be used with the grain perpendicular to the pile axis. A pile cushion is only needed for the protection of concrete piles (Figure 7). If the pile is in danger of being broken in tension during driving, then pile cushions are often very thick (up to 18 inches). For the protection of the pile top against a compressive failure, thinner cushions are usually sufficient.

The wood pile cushion should be dry and unburned. Once the wood cushion burns, it should be replaced. Also, after approximately 1000 hammer blows the cushion may become overly compressed and hard. Recommendations must be obtained for each individual concrete pile job as to the required cushion properties and frequency of replacement.

## CHAPTER 3 - SINGLE ACTING EXTERNAL COMBUSTION HAMMERS

### A. Introduction

Pile driving hammers consist of a ram and an apparatus that allows this ram to move quickly upwards and then fall onto the driving system and pile. The ram must have a mass which is sufficiently large to move the pile. The mass falls a certain distance called the stroke. If the stroke is too low, the pile will not move into the ground. If the stroke is too high, the pile may be damaged. For this reason, the stroke of a pile driving hammer is usually between three and ten feet (.9 and 3 m).

A good hammer strikes the pile in quick succession. It transfers a large portion of its potential energy (the product of ram weight times stroke) into the pile. There are no other requirements for a good pile driving hammer.

Impact pile driving utilizes the physical phenomenon that an impacting mass can momentarily create forces much greater than its own weight. The only technical development has been in the mode of raising the ram after impact for a new fall.

Historically, the ram lifting was done by humans or horses or by means of winches. In the 19th century, steam replaced muscle power for the turning of the winches. Even today, the use of cable hoisted rams is still widespread, although now diesel or gasoline engines are used to pull the cable which lifts the ram.

At the end of the 19th century, hammers appeared which resembled a steam engine. Steam was now fed directly to the hammer; the ram was attached to a piston, and this assembly was moved by steam entering a cylinder. In the 20th century, compressed air started to take the place of steam in smaller hammers. Today, hammer developments make an increased use of hydraulic pressure.

Thus, there are cable hoisted, or drop hammers, as well as units which use steam, compressed air, or pressurized hydraulic fluid to move the ram. All of these hammers derive their power from an outside source, and are therefore called External Combustion Hammers.

Internal Combustion Hammers use diesel combustion inside the hammer itself to move the ram. Developed in the 20th century, the diesel hammer is completely self-contained.

Major hammer categories will be discussed and suggestions will be made for their inspection. There are a host of new hammer types appearing almost every month. Most of these new hammers live only for a short time or are produced in only small quantities. Not much will be said about them in this manual.

## B. Drop Hammers

### (1) General Description

Today, drop hammers are usually lifted by a hoist from the same crane which supports the pile and the leads (Figure 8). After lifting the ram to the desired stroke, it is dropped by either a tripping mechanism or by releasing the hoisting drum. In the former case, all energy remains in the ram; in the latter case, some energy is needed to unwind the rope from the drum.

A pile cap and leads should always be part of a driving system to ensure that the ram hits the pile axially, and to protect the pile top from damage.

The available energy per blow of a drop hammer is the product of the ram weight times the drop height (Figure 9). Standard ram weights range from 500 to 10,000 lbs (2.5 to 50 kN). The most frequent drop heights are in the neighborhood of 4 ft (1.2 m). For a given hammer, the energy per blow can be varied by varying the drop height.

### (2) Advantages:

- . Simplicity of operation.
- . Ease of mobilization and demobilization.
- . Low investment and maintenance costs.
- . Drop height can be easily changed.

### (3) Disadvantages:

- . Relatively slow rate of operation.
- . Driving efficiency depends upon operator's skills.
- . Variations in drop height.

### (4) Performance Characteristics Of Drop Hammers

If the ram has to unwind the rope from the drum during its fall, the effective energy of the hammer is reduced because of the friction loss and the inertia of the drum and the rope. Just before impact the operator sometimes "catches" the ram, thereby reducing the impact velocity. The operator often does not achieve constant strokes, and variable energy outputs result from blow to blow. The most important cause for energy losses is probably the friction between the ram and the leads.

### (5) Checklist For Drop Hammer Inspection:

#### (a) Before Driving Starts:

- . Check ram weight; if in doubt have the ram weighed.
- . Check material, size, and the condition of the hammer cushion.
- . Check the pile cushion (if present), size and condition.
- . Check that helmet and pile are well matched.
- . Check helmet weight; if in doubt have it weighed.
- . Check straightness of leads and connections of lead parts for tightness.

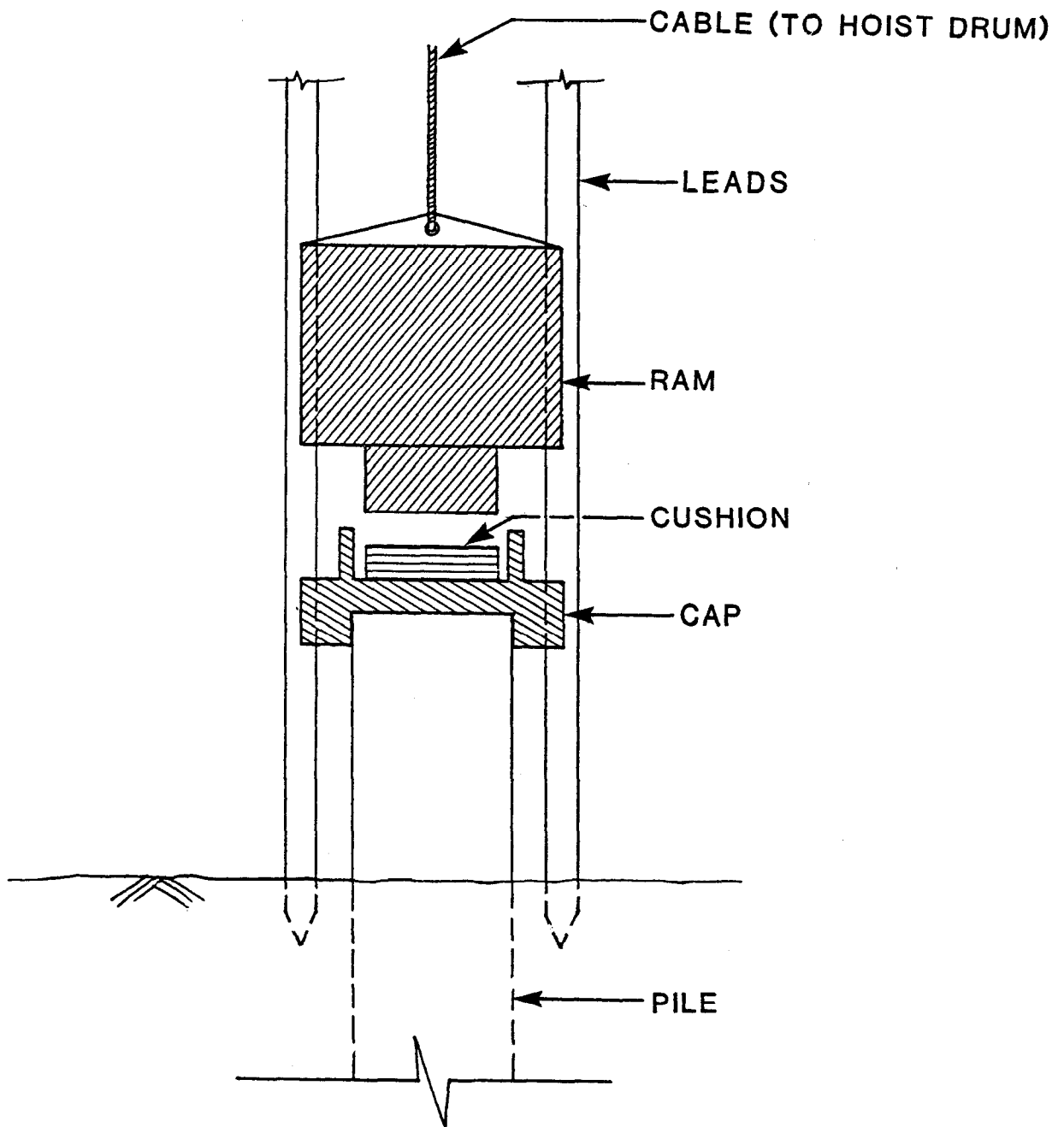
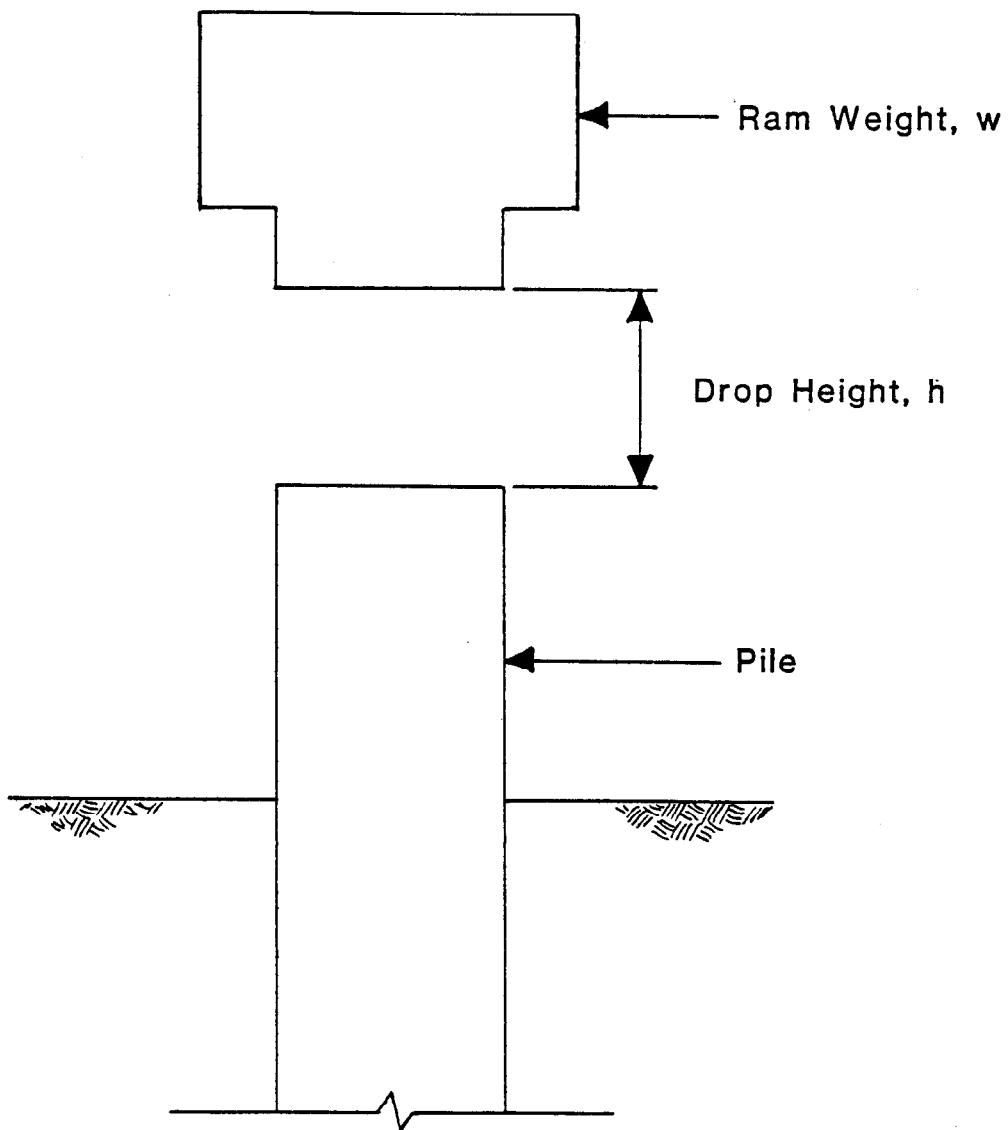


Figure 8. Basic Components of a Drop Hammer





RATED ENERGY = RAM WEIGHT X DROP HEIGHT

$$E = w \times h$$

Figure 9. Rated Energy of a Drop Hammer.

- . Make sure that the portion of the leads that guides the ram, as well as all pulleys used, are well greased.
- . Clearly mark leads as a reference for drop height observations.
- . Check the alignment between the leads and the pile.
- . Make sure that the rope and the drum components are well lubricated.
- . Check the condition of the hoisting cable.

(b) During Driving:

- . If a trip mechanism is not used, be certain that the hoisting cable is spooling freely, i.e., that there is no tension in the cable just before and during impact.
- . Make sure that the desired hammer stroke is maintained.
- . Check that ram, helmet, and pile stay in alignment during driving (no excessive swaying due to the lifting and releasing of the ram).

C. Single Acting Air/Steam Hammers

(1) General Description

The single acting air/steam hammers most commonly encountered in the United States are manufactured by Vulcan, Conmaco, MKT, Menck, and Raymond. Vulcan and Conmaco have very similar designs. Single acting air/steam units from Menck are commonly used to drive piles offshore. The design differences will only be mentioned when essential for inspection purposes.

Single acting air/steam hammers are essentially drop hammers, except that the hoisting cable is replaced by pressurized air or steam (motive fluid). The ram is usually a short, stocky block of steel that is connected at its top to a piston. It rides along guides or columns or inside guiding enclosures, depending on the particular design. Figure 10 shows the main components of an external combustion hammer.

(Note: Some MKT and Menck models use a hollow ram as the cylinder and a stationary piston; this variation does not materially affect the following discussions).

Individual hammer components are often fastened together with steel keys. These keys seem to survive the rough driving environment better than other types of fasteners. However, they may loosen, causing erratic hammer performance.

The maximum available energy per blow for an A-S/SA hammer is expressed as the product of ram weight times stroke. Typical ram weights are between 3 and 300 kips (15 and 1,500 kN). Strokes vary from 2 to 5 ft (.6 to 1.5 m). Thus, energy ratings may be between 6 and 1,500 kip-ft (10 and 2,250 kNm).

Most single acting air/steam hammers have a fixed stroke. A so-called slide bar with cams is attached to the ram for the tripping of valves on the ram cylinder (see Figure 11). However, the stroke of some hammers can be varied if the slide bar is equipped with a dual set of cams and with a valve

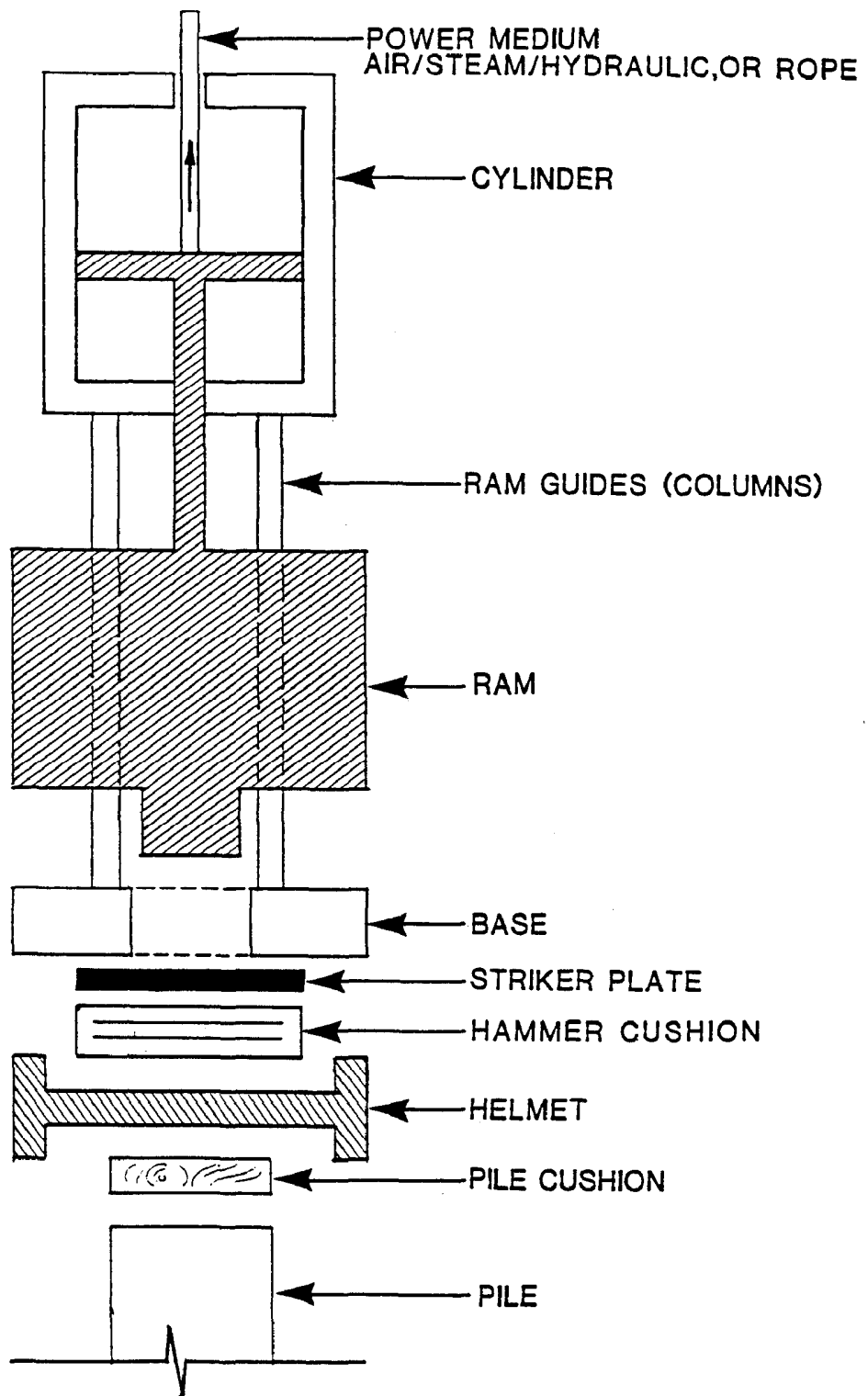


Figure 10. Basic Components of an External Combustion Hammer.

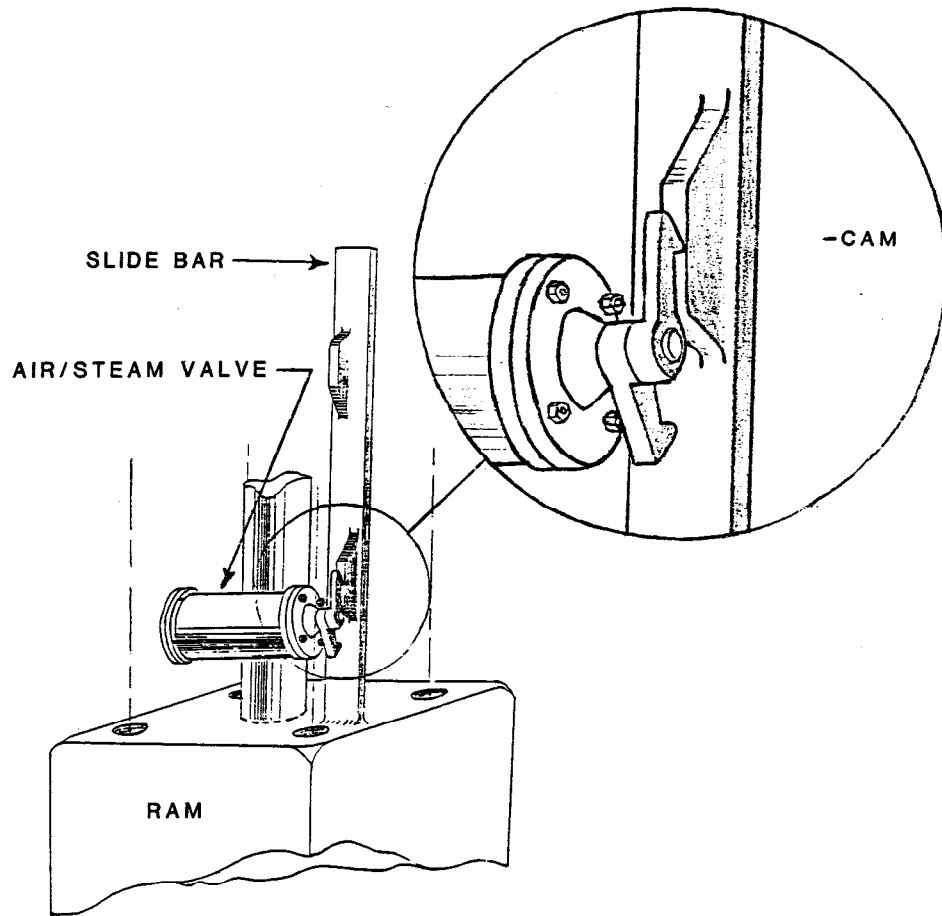


Figure 11. Slide Bar with Cams

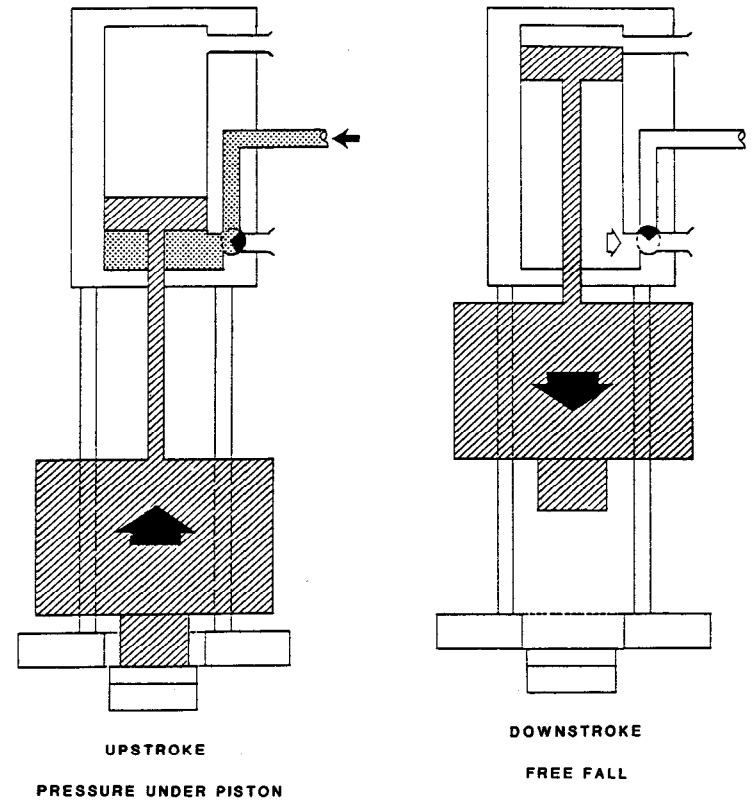


Figure 12. Single Acting Air/Steam Hammer.

trip which can be moved to either set of cams. This adjustment is usually done remotely by means of a hydraulic line. The primary advantage of variable stroke hammers is their ability to reduce damaging driving stresses.

The operating rate of A-S/SA hammers range between 35 and 60 blows per minute. This rate is comparable to most other hammer types except the double acting units which may strike at twice the rate.

## (2) Operation

A blow of an A-S/SA hammer is initiated (see Figure 12) by introducing the motive fluid at constant pressure in a cylinder under the piston. The pressure builds up in the cylinder and causes the ram to move upward. At a certain height (usually at about 2/3 of the maximum fall height), the pressure inlet valve is closed and the pressure chamber is opened to the atmosphere. The ram will coast upwards under its momentum for an additional distance. When the ram reaches the top of the hammer, it still may have such a high velocity that the piston penetrates a safety chamber formed by trapped air above the so-called cylinder vent.

Upon its descent, the ram reaches a position - usually immediately preceding impact - where the valve opens to allow motive fluid to enter the cylinder. The exhaust is closed at the same time.

Obviously, if pressurized motive fluid enters the cylinder too soon before impact occurs, this pressure will tend to slow the fall of the ram. This effect is called preadmission; it may very strongly reduce the effectiveness of a hammer. A low hammer cushion, poorly adjusted valves, or an improper slide bar may cause this problem.

During impact, the ram pushes the helmet and pile downwards, allowing the hammer base, columns, and cylinder (these components are also called the assembly) to fall under the action of both gravity and the reaction forces of the pressurized fluid. When the hammer base meets the helmet, a so-called "assembly impact" occurs.

Since the A/S hammer is an external combustion hammer, its performance depends to a great deal on the boiler (steam generator) or air compressor. Either unit must be of sufficient capacity to provide the operating pressures at the necessary fluid flow rate. The hammer specifications therefore call for an operating pressure and an operating volume (e.g., cubic feet per minute or cubic meters per minute).

The specified pressures must be available at the hammer, and system losses must be overcome. Pressure losses may be expected in leaky or worn hoses, or in hoses of insufficient number or size or excessive length.

Single acting air/steam hammers should be used with a pile helmet inserted between the ram and the pile top. The helmet usually supports the hammer assembly, and houses the striker plate and the hammer cushion, if so required by the manufacturer. The helmet must be well matched to both pile type and hammer model. For high hammer cushion stacks, a follower (shaped like a pipe) may be inserted between hammer and helmet; its effect is to

extend the upper portion of the helmet. Such a follower should only be used after obtaining approval from the engineer.

It was already mentioned that a correct cushion thickness is important for the rated performance of a hammer. A thinner than specified cushion may cause preadmission, which cushions the blow. A high cushion stack shortens the ram stroke. The shorter stroke will, of course, produce blows with lower energy. If the cushion thickness increases even further, then the inlet valve may not open at all, and the hammer will not run. Thus, in order to ensure proper hammer performance, it is very important to start with and maintain a hammer cushion thickness as specified by each manufacturer for each hammer model.

Leads are also a necessary part of the driving system. They align hammer and pile. Note that the ram is guided on the columns of the hammer assembly. The hammer itself has to follow the pile's penetration during a blow. This movement may be impeded by bent and/or binding leads.

### (3) Advantages Of Single Acting Air/Steam Hammers:

- . Higher rate of impact than drop hammers.
- . Relatively consistent operation.
- . Simple hammer design (compared to all except drop hammers).

### (4) Disadvantages Of Single Acting Air/Steam Hammers:

- . More complicated to operate and maintain than drop hammers.
- . Additional equipment needed (boiler, compressor, hoses, etc.).
- . Relatively heavy hammer; requires higher crane and handling equipment capacities.

### (5) Checklist For Single Acting Air/Steam Hammers:

#### (a) Before Driving Starts:

- . Check hammer model and serial number to ensure that the hammer has the proper energy rating.
- . Check material, size, and the condition of the hammer cushion. When measuring the hammer cushion thickness, the thickness of the striker plate should also be checked and then added.
- . Check the pile cushion (if present) for size and condition.
- . Check that helmet and pile are well matched.
- . Check helmet weight; if in doubt have it weighed.
- . Check straightness of leads and connections of lead parts for tightness.
- . Make sure that the portions of the leads that guide the hammer do not offer excessive friction.
- . Check the alignment between the leads and the pile.
- . Mark ram guides or check hammer for reference points as a reference for stroke observations.
- . Check number, size, and length of air/steam hoses.
- . Make sure that hoses are blown down before they are connected to the hammer.
- . Check that the motive fluid lubricator is filled with an

appropriate lubricant.

- . Inspect the slide rod and its cams for excessive wear.
- . Check that columns (ram guides), piston rod and slide bar are well lubricated.
- . Make sure that the ram keys and column keys are all tight.

(b) During Driving:

- . Make sure that the desired hammer stroke is maintained.
- . Check that ram, helmet, and pile stay in alignment during driving.
- . Check that pressure at compressor or boiler is equal to the rated pressure plus hose losses. Pressure should not vary significantly during driving.
- . Measure the rate of operation of the hammer in blows per minute. This may be accomplished by a stop watch or a Saximeter™.
- . Make sure that the motive fluid is well lubricated. After a short period of pile driving, lubricant should drip out of ports.
- . Continuously check the quality of the motive fluid; condensation or icing of air, and water in steam are all signs of a motive fluid in bad condition.
- . Check that the hammer hoist line is always slack.
- . Record when hammer or pile cushioning material is replaced or added to the driving system. New cushioning should not be added towards the end of driving; at least 100 blows should be applied before final blow counts are taken.

D. Single Acting Hydraulic Hammers

This hammer type is only rarely encountered in United States pile driving practice. Among the producers of single acting hydraulic hammers are Banut and Uddcomb. Their designs feature a hydraulic jack which lifts the ram and then retracts quickly, thereby allowing the ram to fall freely. Because of the rather infrequent use of this hammer in the U.S., further discussions are not warranted.

## CHAPTER 4 - DOUBLE ACTING EXTERNAL COMBUSTION HAMMERS

### A. General Description

The desire to create a hammer that applies blows in rather quick succession for increased productivity led to the double acting air/steam hammers. For an increase in blow rate, the stroke was shortened, and in order to maintain a comparable energy rating, the ram was accelerated during its downstroke by means of active pressure.

There are three types of mechanisms which are important for driving bearing piles. The first one is the common double acting type in which full active pressure acts either upwards or downwards on the ram (note that "double acting" may either refer to a hammer with both upward and downward pressure application or to a particular mechanism). MKT manufactures the "3" series hammers, which operate in this manner (e.g., the MKT 9B3). The second type is called differential acting; it has two pistons of different size. The resulting pressure force depends on the different sizes of the pistons. Vulcan and Raymond manufacture differential acting hammers. The third mechanism is the compound one; it is a combination of the other two types.

Again, it should be emphasized that the term "double acting" refers in general to the fact that the ram is subjected to pressure on its downstroke. The double acting mechanism is simpler and used in fewer hammers than the differential acting mechanism and therefore will be discussed in less detail. The compound type is even more rarely encountered in bearing pile driving.

A so-called slide bar with cams is attached to the ram for the tripping of valves on the ram cylinder (see Figure 11). Individual hammer components are often fastened together with steel keys. These keys seem to survive the rough driving environment better than other types of fasteners. However, they may loosen, causing erratic hammer performance.

### B. Operation Of Double Acting Air/Steam Hammers

#### (1) Operation Of The Common Double Acting Mechanism

The stroke cycle of a double acting air/steam hammer (see Figure 13) is started by introducing the motive fluid, at constant pressure, in the cylinder under the piston, forcing the piston and the ram to move upward. At a prescribed height, a valve opens to the atmosphere, exhausting all the pressure under the piston. At the same time, the motive fluid is redirected to act (under constant pressure) on top of the piston head, accelerating the ram during its downward fall. At the bottom of the stroke, a valve is opened to the atmosphere, exhausting the pressure on top of the ram in preparation for a new stroke cycle.

The MKT double acting hammers are designed for a metal-to-metal impact between the ram and the impact block, also called the anvil. The impact block may be seated directly on the pile without cushioning. The ram is guided by the hammer housing, also called the cylinder. This housing completely



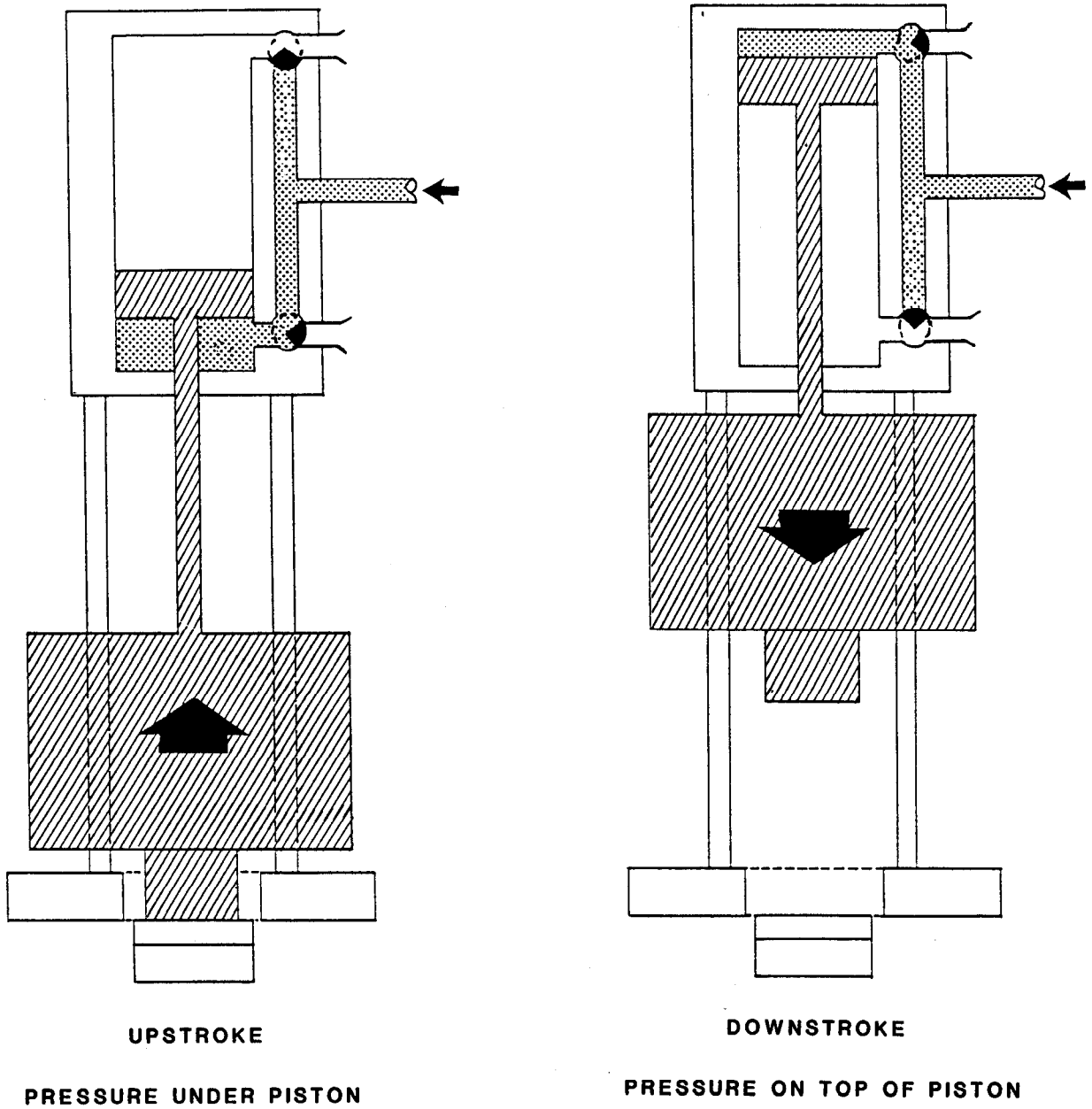


Figure 13. Double Acting Air/Steam Hammer.

encloses the ram and other moving parts, and an inspection is therefore difficult.

With the MKT double acting hammers, preadmission due to improper hammer cushion thickness cannot occur, since there is no hammer cushion. However, preadmission is still possible if the valves are poorly adjusted. Another unique feature of this hammer type is the possibility of driving a pile without cushioning; energy is no longer lost in that component. On the other hand, the impact causes the hammer cylinder to be accelerated along with the pile. Thus, the ram energy is not fully transferred to the pile.

Since hammer and pile experience ram impact at the same time, no discernable assembly drop is present for this hammer type. On the other hand, there may be several separations between the impact block and the pile top.

## (2) Operation Of The Differential Acting Mechanism

In a differential acting air/steam hammer (see Figure 14), the piston rod connects to two pistons. The larger of the two pistons operates in the upper cylinder. A cycle is started when motive fluid enters the inlet valve and creates a net upward force between the larger and smaller cylinders. With the upper side of the upper cylinder vented, the pressure against the upper, larger piston causes the ram to move upwards.

Near the top of the stroke, a valve closes the exhaust over the upper cylinder, and pressurized fluid is allowed to enter the upper cylinder. There are now three pressurized areas, two in the downward direction, which therefore governs. Thus, the pistons and the ram are pushed downwards. Of course, gravity also acts on the ram.

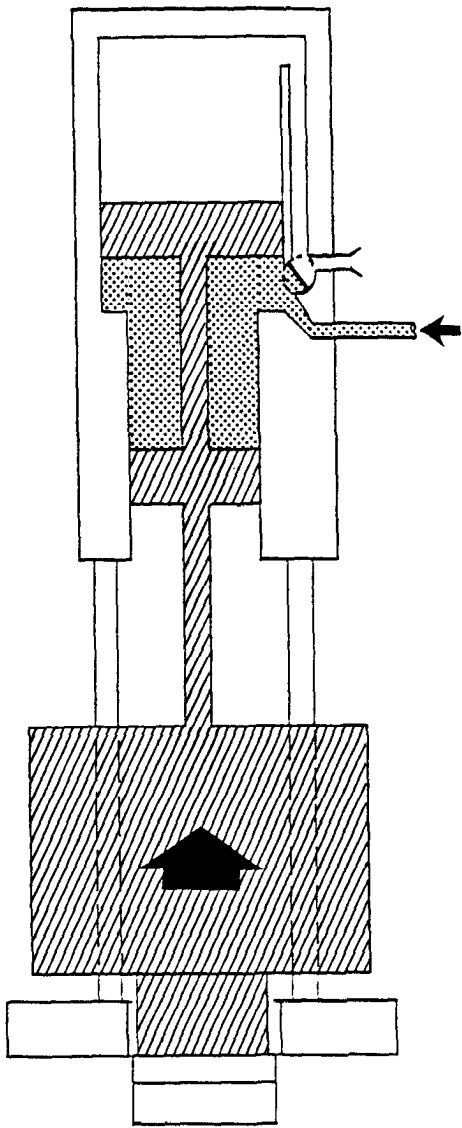
Shortly before the ram impacts against striker plate and hammer cushion, the slide bar activated valve is turned such that the upper cylinder is vented and the net pressure is again in the upwards direction.

The differential acting hammers are always used with a hammer cushion and helmet. As for single acting hammers with visible rams, the cushion thickness should be well within specified limits in order to avoid preadmission (thin cushion) or a shortened stroke (high cushion).

During impact, the ram pushes the helmet and pile downwards, allowing the hammer base, columns, and cylinder (these components are also called the assembly) to fall under the action of both gravity and the reaction forces of the pressurized fluid. When the hammer base meets the helmet, a so-called "assembly impact" occurs.

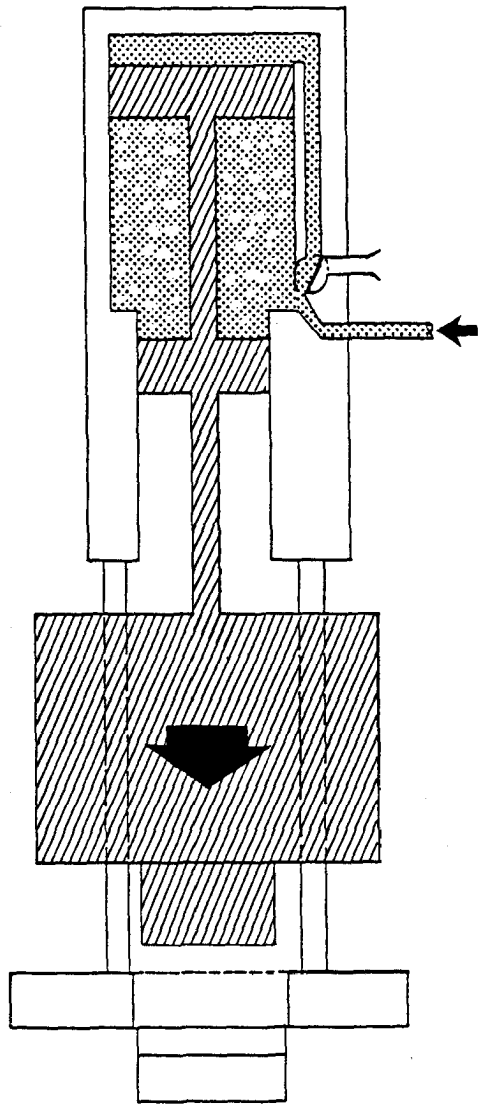
## (3) Operation Of The Compound Acting Mechanism

For the sake of completeness of this discussion on double acting air/steam hammers, a schematic of the operation of a compound hammer is presented in Figure 15. The ram of a compound hammer is raised under full pressure and with the upper chamber vented. After reaching the top of the stroke, the upper chamber is closed to the outside and opened to the lower chamber which is containing full pressure in the beginning of the downward stroke. At the same time, the inlet valve is closed and as the ram descends, the motive



**UPSTROKE**

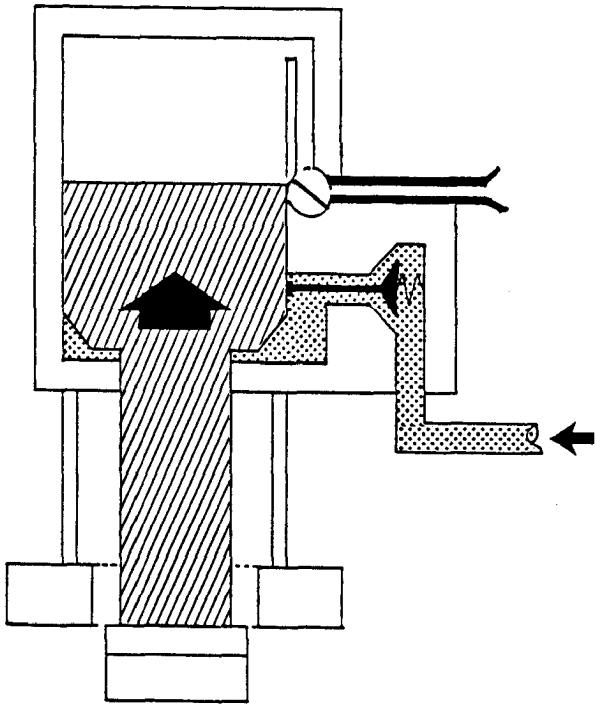
**PRESSURE BETWEEN PISTONS**



**DOWNSTROKE**

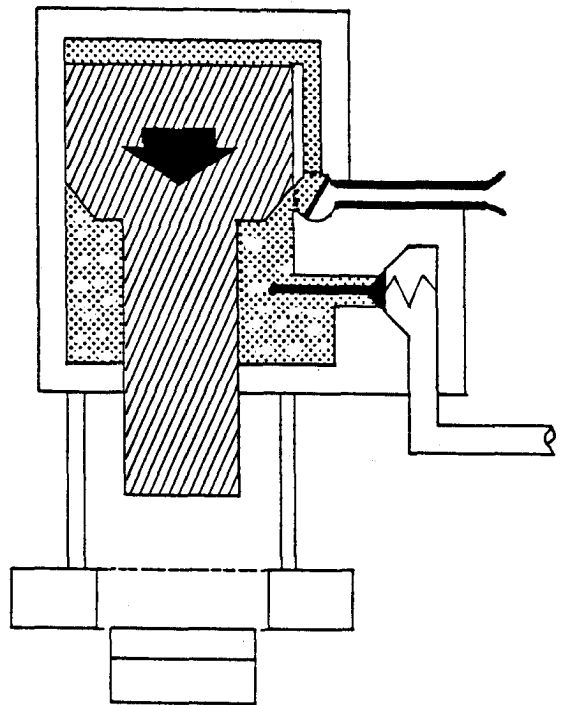
**PRESSURE BOTH BETWEEN PISTONS  
AND ON TOP OF UPPER PISTON**

Figure 14. Differential Acting Air/Steam Hammer.



**UPSTROKE**

**PRESSURE BELOW RAM**



**DOWNSTROKE**

**PRESSURE ON TOP OF RAM**

Figure 15. Compound Air/Steam Hammer

fluid expands in both upper and lower chambers with decreasing pressures. Since the top ram area is significantly larger than the bottom area, a net downward force results which accelerates the ram at a rate greater than gravity.

Compound mechanisms, similar to differential ones, utilize the motive fluid more economically than double acting mechanisms. Again, for full efficiency, this hammer must be supplied with as much pressure as specified.

### C. General Operation Of Double Acting Air/Steam Hammers

Since the A/S hammer is an external combustion hammer, its performance depends to a great deal on the boiler (steam generator) or air compressor. Either unit must be of sufficient capacity to provide the operating pressures at the necessary fluid flow rate. The hammer specifications therefore call for an operating pressure and an operating volume (e.g., cubic feet per minute or cubic meters per minute).

For double (differential) acting hammers, the requirement of having a pressure at the hammer equal to the rated pressure is even more important than for single acting units. Approximately 50% of the impact energy comes from pressure forces (the other 50% from gravity). Thus, a 20% drop in pressure during the downstroke amounts to a 10% loss of energy.

To ensure that specified pressures are available at the hammer, system losses must be overcome. Pressure losses may be expected in leaky or worn hoses, or, in hoses of insufficient number or size or excessive length.

If the pile rebound is strong, then the piston will tend to hit the upper end of the upper cylinder. The pressure of the hammer must then be reduced or an unstable driving situation will result. Thus, in hard driving, double (differential) acting air/steam hammers have to be run with lower energies than in easy driving, which is opposite to the desired effect.

Differential acting air/steam hammers should be used with a pile helmet inserted between the ram and the pile top. The helmet usually supports the hammer assembly and houses the striker plate and the hammer cushion, if so required by the manufacturer.

As always, the helmet must be well matched to the pile top. For high hammer cushion stacks, a follower (shaped like a pipe) may be inserted between hammer and helmet; its effect is to extend the upper portion of the helmet. For MKT double acting hammers, which strike the pile directly, the hammer itself must be well fitted to the pile top.

Leads are always a necessary part of the driving system. They align hammer and pile. Note that the ram is guided on the columns of the hammer assembly or in the hammer housing. The hammer itself has to follow the pile's penetration during a blow. This movement may be impeded by bent and/or binding leads.

D. Advantage Of Double Acting Air/Steam Hammers:

- . The speed of operation of a double acting hammer is approximately twice that of a single acting hammer, i.e., 120 instead of 60 blows per minute.

E. Disadvantages Of Double Acting Air/Steam Hammers:

- . Sensitive mechanisms make these hammers more complicated to operate and maintain.
- . Energy output is extremely sensitive to proper valve timing, and to pressure and volume of the motive fluid.
- . The available energy of each blow is more difficult to inspect and to verify.
- . Hammer energy output sensitive to soil resistance (uplift).

F. Checklist For Double Acting Air/Steam Hammer

(1) Before Driving Starts:

- . Check hammer model and serial number to ensure that the hammer has the proper energy rating.
- . Check material, size, and the condition of the hammer cushion. When measuring the hammer cushion thickness, the thickness\* of the striker plate should also be checked and then added (R,C,V ).
- . Check the pile cushion (if present), for size and condition.
- . Check that helmet and pile are well matched. If the hammer type is such that no helmet is necessary, check that the hammer and pile are well matched.
- . Check helmet weight; if in doubt have it weighed.
- . Check straightness of leads and connections of lead parts for tightness.
- . Make sure that the portion of the leads that guide the hammer do not offer excessive friction.
- . Check the alignment between the leads and the pile.
- . Mark ram guides or check hammer for reference points as a reference for stroke observations (R,C,V).
- . Check number, size, and length of air/steam hoses.

- . Make sure that hoses are blown down before they are connected to the hammer.
- . Check that the motive fluid lubricator is filled with appropriate lubricant.
- . Inspect the slide rod and its cams for excessive wear. (R,C,V).
- . Check that columns (ram guides), piston rod, and slide bar are well lubricated.
- . Make sure that ram keys and column keys are all tight.

\*R,C,V ... for Raymond, Conmaco, or Vulcan type differential acting hammers.

(2) During Driving:

- . Make sure that the desired hammer stroke is maintained. (R,C,V).
- . Check that ram, helmet, and pile stay in alignment during driving.
- . Check that the pressure at the compressor or boiler is equal to the rated pressure plus hose losses. Pressure should not vary significantly during driving.
- . Record when and to what level pressure needs to be reduced because of uplift.
- . Measure the rate of operation of the hammer in blows per minute. This may be accomplished by using a stopwatch or a Saximeter™.
- . Make sure that the motive fluid is well lubricated. After a short period of pile driving, lubricant should drip out of ports.
- . Continuously check the quality of the motive fluid; condensation or icing of air, and water in steam are all signs of a motive fluid in bad condition.
- . Check that the hammer hoist line is always slack.
- . Record when hammer or pile cushioning material is replaced or added to the driving system. New cushioning should not be added towards the end of driving; at least 100 blows should be applied before final blow counts are taken.

G. Double Acting Hydraulic Hammers

Connecting a double acting hydraulic jack to a ram essentially produces a double acting hydraulic hammer. Such units were developed by Raymond and Menck. Raymond's hammers closely resemble their equivalent air/steam hammers.

Menck's double acting hydraulic hammers have relatively long slender rams and are fully enclosed. They have ram weights between 5.5 and 207 kips (25 and 940 kN).

Inspection of the Raymond hydraulic units should follow the recommendations for differential acting air/steam hammers. Ram speed measurements using a Hammer Performance Analyzer™ may give additional clues. The Menck units are very difficult to inspect since their rams are completely enclosed. Only indirect measurements, e.g., using a Pile Driving Analyzer™, can lead to reliable results.

The energy delivered by a double acting hydraulic hammer depends to a great deal on the accuracy of the valve settings. If preadmission exists because of an early opening of the inlet valve under the piston, then the blow self-cushions. This condition cannot be diagnosed by a visual inspection.



## CHAPTER 5 - INTERNAL COMBUSTION HAMMERS - SINGLE ACTING (OPEN END DIESEL HAMMERS)

### A. General Description

An open end diesel hammer consists of a long slender piston (the ram), which moves inside a cylinder. The cylinder is open at its upper end, thus allowing the ram to partially emerge from the cylinder. Since the ram falls only under gravity, the OED is also called single acting.

There are five major manufacturers of open end diesel hammers distributing their products in the U.S. They are (alphabetically): Bermingham, Delmag, Foundation Equipment Corporation, Kobelco and Mitsubishi. The hammer ratings vary from 5 to more than 300 kip-ft with ram sizes between 1 and 35 kips.

Most of these hammers are built using the same fuel combustion principle: impact atomization. This is also referred to as liquid fuel injection. The Delmag O2 models (e.g., D30-02) use a medium pressure injection which may be classified as impact atomization. Kobelco makes a few hammers with atomized fuel injection. Differences between atomized and liquid fuel injection are discussed in Appendix C.

Each open end diesel hammer consists of seven major parts (Figure 16):

- . A piston or ram with piston rings.
- . An impact block, also with rings, onto which the ram impacts.
- . A cylinder in which ram and impact block move.
- . One or more fuel pumps.
- . Fuel injector(s).
- . Exhaust ports.
- . Recoil dampener.

The impact block usually has enlarged top and bottom diameters. The cylinder bottom through which the center of the impact block passes is narrowed down to a diameter just large enough to allow free movement. Thus, the impact block can move up and down a few inches, but is prevented from falling out of the cylinder when the entire hammer is raised. The exhaust ports are merely openings in the cylinder wall. The recoil dampener is located between the cylinder bottom and the impact block bottom. Its purposes is to cushion the cylinder against a strong upward impact block movement, due to pile rebound.

### B. Open End Diesel Hammer Operation

The hammer is started by lifting the ram a certain distance above the exhaust ports. This is accomplished by means of a tripping device and either a hoist or a hydraulic jack. When the ram has reached the starting height, the trip is released and the ram starts to fall under gravity. (See Figure 17).

When the bottom of the ram passes the exhaust ports, it closes them and a certain volume of air is trapped inside the chamber formed by the cylinder,

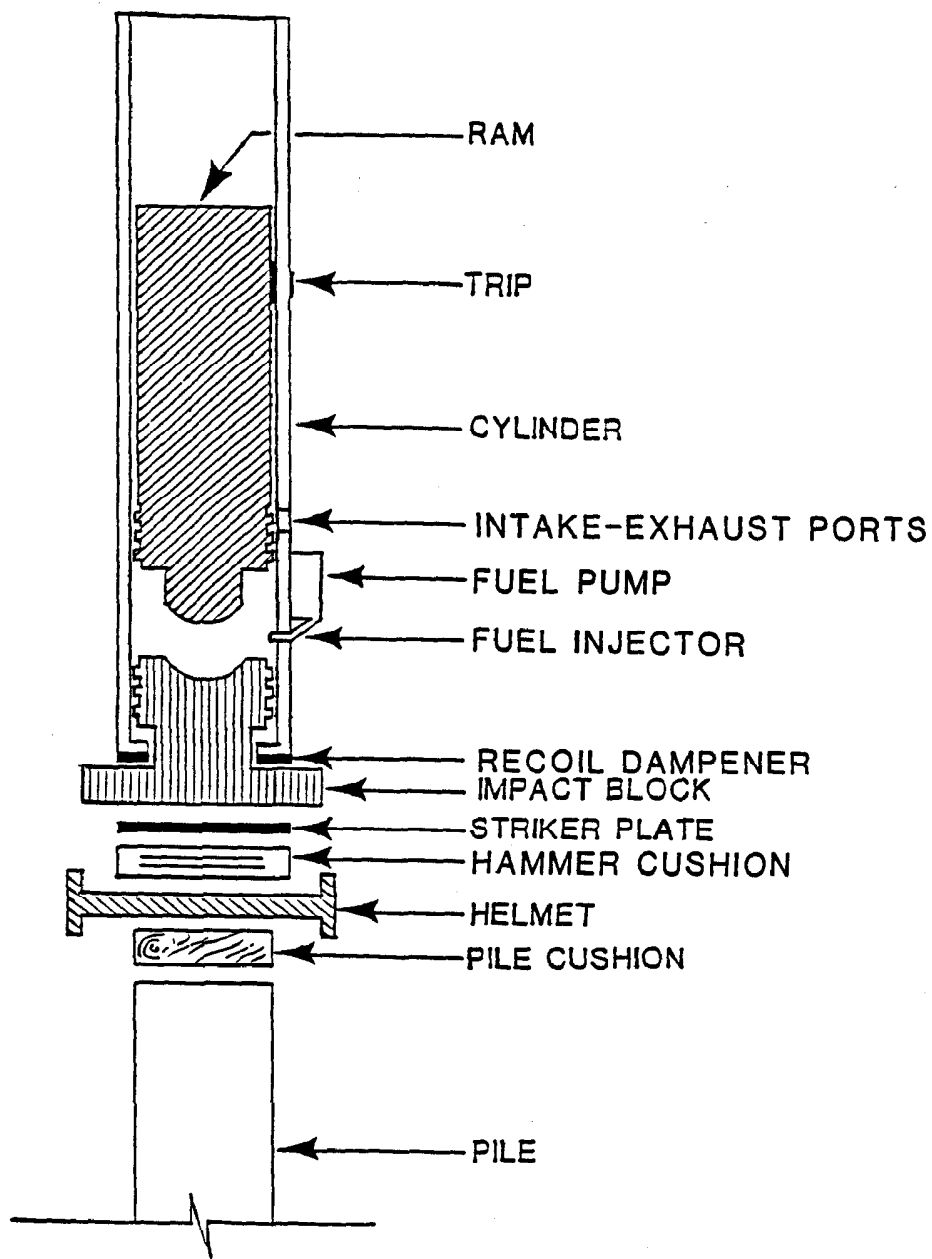
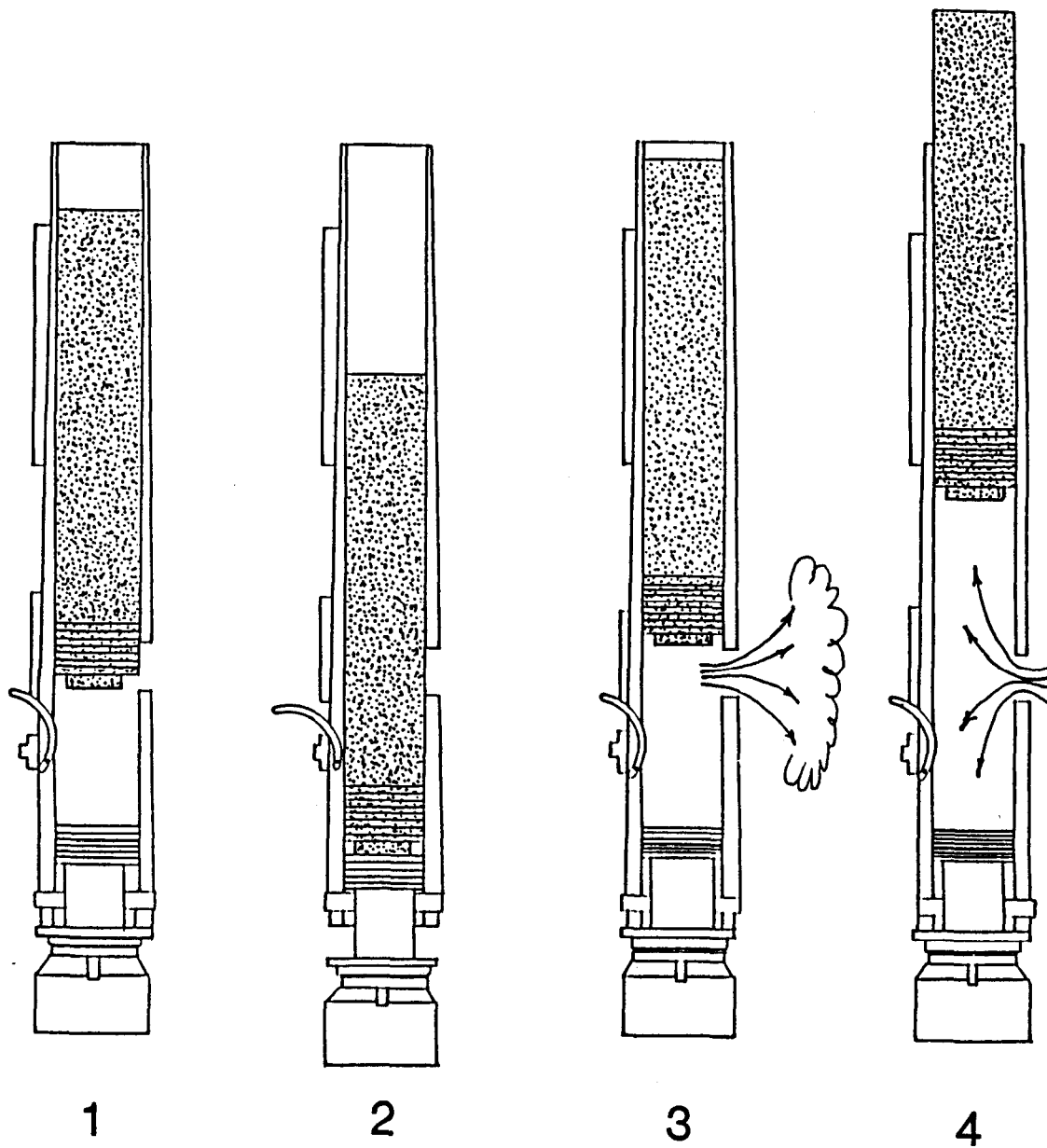


Figure 16. Single Acting Diesel Hammer.



1. STARTING POSITION
2. IMPACT AND IGNITION
3. EXHAUST
4. INTAKE, FOLLOWED BY REPETITION OF THE CYCLE

Figure 17. Operating Cycle of a Single Acting Diesel.

ram, and impact block. As the ram descends further, it compresses the trapped air which therefore becomes hot.

After the ram has reached a certain position between the ports and the impact block, it pushes a lever and plunger system into the fuel pump, which in turn injects a certain quantity of fuel into the chamber.

At this point, the difference between impact atomization and atomized fuel injection becomes important. For most hammers, the fuel is injected into the chamber at a low pressure and therefore in liquid form. Even though the air in the chamber is hot, combustion of the liquid fuel will not happen before the ram impacts against the impact block, thereby atomizing the fuel.

For atomized fuel injection, combustion will start shortly after injection starts (assuming that the air in the cylinder has become sufficiently hot) and will last as long as the injection.

Upon impact, the ram pushes the impact block, hammer cushion, helmet, and pile top rapidly downward, allowing the cylinder to fall under gravity. The impact block separates from the ram within a very short time and the pressure of the combusting air-fuel mixture will cause further separation as the ram is forced upward.

Depending on the pile length, the pile starts to rebound a certain time after impact, thereby pushing the impact block upwards. The impact block then collides with the cylinder, which is softened by the recoil dampener. For short piles, the rebound happens quickly and then a second impact between impact block and ram may occur. A rebounding pile will always return energy to the ram, since the gas pressure increases as the impact block moves upwards. The upward moving ram eventually clears the exhaust ports and excess pressure is blown off. The ram continues on upwards, now subject only to the slowing force of gravity and friction of the ram on the cylinder wall. Naturally, the larger the ram's upward velocity at the time it clears the ports, the higher the height it reaches before starting to descend for the next blow.

The magnitude of the upwards ram velocity depends on:

- . The hammer combustion pressure.
- . The pile mass and stiffness.
- . The stiffness of the hammer and pile cushions.
- . The soil stiffness and/or resistance.

Thus, practically all components of the hammer-pile-soil system have an effect on the diesel hammer's stroke. Under normal conditions, the ram stroke increases as pile driving becomes harder. In soils with high resistance but low stiffness, a "spongy" driving situation results, and the stroke will be relatively low. A similar situation exists with very long and flexible piles.

### C. Performance Characteristics Of Open End Diesel Hammers

The inspection of a diesel hammer has to center around the following two questions:

- . Is the stroke of the hammer adequate?
- . Is the energy output at a given stroke adequate?

#### (1) Lack Of Stroke

There are a number of ways in which the stroke of an open end diesel hammer can be measured. The most basic approach is to attach a so-called "jump stick" with foot marks to the cylinder. As the top of the ram emerges from the cylinder, the stroke can be read with reasonable accuracy. Binoculars are recommended equipment.

Jump sticks are not a very good means of measuring hammer strokes, particularly since they often break off, thereby causing a safety hazard.

A better solution is the use of a Saximeter™. This unit measures the time period between blows and, from this information, calculates the ram stroke. The computations performed by the Saximeter™ and an example on how to calculate the stroke using a stopwatch and a simple equation are given in Appendix B.

If a diesel hammer does not reach 80% of its full stroke in hard driving (blow count of six blows per inch or more), then the following potential causes for poor hammer performance should be investigated:

- . Soft driving system, long flexible piles, spongy soils.
- . Lack of fuel or improper fuel.
- . Excessive friction.
- . Lack of compression.

Soft and/or spongy driving conditions (cause 1) were discussed earlier. These conditions can be identified by closely observing the hammer cylinder. If the cylinder experiences a high recoil, say more than one inch, then a "bouncy" driving situation exists. The cylinder motion can most easily be observed by its movement relative to the impact block.

Lack of fuel often causes low strokes. Most commonly, the first check on a diesel hammer concerns the fuel pump. Routine inspections are difficult, however, as they involve the removal of the fuel line from the injector and a manual activation of the pump. With a measuring glass, the amount of fuel injected per blow can then be determined. If the fuel pump is working properly, then a clogged injector may be the cause for low fuel injection. Improper fuel should be a rare occurrence. Improper fuel may cause low strokes if diesel fuel of type II is not chosen; other fuel types may cause early or late ignition. Of course, if water or dirt entered the fuel system, poor hammer performance would result. Draining of the fuel through a clear cloth may indicate the presence of contaminants.

Excessive friction not only reduces the stroke but also causes a low energy transfer to the pile. Although other hammer components also need attention, for a maximum stroke the ram lubrication is most important. Fortunately, open end diesels show the upper ram during driving and it is easily ascertained whether or not the ram has a wet, shiny, lubricated surface. Scratches or dried patches of residue on the ram indicate that lubrication is insufficient. Note that too much lubrication may result in burning of grease

and oil and thereby possibly cause preignition. This condition would be indicated by black smoke.

The last common reason for a low stroke is poor compression. If either piston or impact block rings allow pressure to leak off, then full compression and thus full combustion pressure will not develop. Furthermore, if the recoil dampener is too thin, then the hammer's starting volume will be small, and full compression will not be developed. (This is a less likely reason for poor compression.) In very bad situations, the leakage of pressure past the impact block can be noticed during pile driving when smoke appears between the recoil dampener and the impact block bottom. Compression is easily checked under a "cold blow" on a bearing pile. To perform this check, the ram is picked up as if the hammer was to be started, but the fuel pump line is kept stretched such that no fuel is pumped. The ram is then released and, after impact, it should continue to bounce on the air trapped in the chamber. Each bounce can be easily heard. At least ten bounces should occur if the hammer has good compression.

## (2) Other Hammer Problems

A diesel hammer with a high stroke may still perform poorly. There are three major reasons:

- . Preignition.
- . Friction.
- . Overheating without preignition.

Preignition means that the fuel combusts before impact occurs. Thus, preignition reduces the ram impact velocity and cushions the impact.

When a hammer preignites, the full ram energy is not transmitted to the pile, but rather returned to the ram, which therefore strokes very high. The low energy in the pile results in a high blow count. Thus, the preignition situation has all the symptoms of a hard driving condition with a potentially low soil resistance. Preignition usually occurs in situations where a hammer has overheated after long periods of hard driving. It is then often caused by burning lubrication oil or early vaporization of fuel.

The following are signs of preignition in hard driving (when it may be particularly detrimental to a successful pile installation):

- . Black smoke while strokes are high.
- . Flames in exhaust ports.
- . Blistering paint (due to excessive heat).
- . No obvious metal to metal impact sound.

If preignition is suspected, then the hammer should be stopped, allowed to cool down for say half an hour, and then restarted. Stroke and blow count should then be accurately monitored. If strokes are lower and blow counts also lower during the first two minutes of driving, then chances are that the hammer preignited before the cooling period.

Most atomized fuel injection hammers have some preignition by design. The fuel usually starts to burn when the ram is a small distance above the

impact block. If the ram descends slowly, the pressure has more time to act on the ram than in the case of a high stroke, when the ram reaches the impact block within a short time. Thus, in hard driving, with high strokes and therefore high ram velocities, such a "design preignition" is of little consequence. For easy driving it is often beneficial in keeping the hammer running.

Friction, of course, is one of the most serious reasons for low energy outputs. Fortunately, during driving, open end diesels usually show their ram above the cylinder, and it can be easily checked whether or not the ram is shiny from lubrication. If the ram appears dry or scratched, then friction losses may be serious.

Not only the ram, but also the impact block must be well greased. Remember that the impact block moves a certain distance relative to the cylinder during impact. Most manufacturers require that the impact block be greased at half hour intervals.

Overheating of a hammer may not only cause the hammer to preignite, it may also lead to problems with the lubrication and fuel systems. The diesel fuel line may develop a vapor lock and reduced strokes could result. Burning of the lubricants may reduce combustion efficiency and increase friction. Thus, overheating should be avoided as much as possible, particularly in a hot climate, by ensuring continuous maintenance of the hammer.

#### D. Advantages Of Open End Diesel Hammers:

- . Self contained unit, does not require additional equipment.
- . Increasing strokes in hard driving provide increasing energies, low strokes in easy driving protect concrete piles.
- . Relatively low ram weight compared to energy (high strokes).

#### E. Disadvantages Of Open End Diesel Hammers:

- . Stroke dependent on hammer-pile-soil system.
- . Relatively low blow rates (blows per minute) with high strokes.

#### F. Checklist For Open End Diesel Hammers:

##### (1) Before Driving Starts:

- . Check and record hammer model and serial numbers.
- . Check the material, size, and the condition of the hammer cushion.  
When measuring the hammer cushion thickness, the thickness of the striker plate should also be measured and recorded.
- . Check the pile cushion (if present).

- . Check that helmet and pile are well matched. If the hammer type is such that no helmet is necessary, check that the hammer and pile are well matched.
- . Check helmet weight; if in doubt, have it weighed.
- . Check straightness of leads, and check lead connections for tightness.
- . Make sure that the portion of the leads that guide the hammer do not offer excessive friction.
- . Check the alignment between leads and pile.
- . Make sure that all exhaust ports are open.
- . Inspect recoil dampener for damage.
- . Fuel tank to be filled.
- . Check that lubrication of all hammer grease nipples is regularly done.

(2) During General Driving:

- . Using a Saximeter™ or stopwatch, calculate the stroke of the open end diesel hammer and record these results together with the blow count.
- . Check that the ram, helmet, and pile stay in alignment during driving.
- . As the ram moves out of the cylinder, check its surface for signs of uniform lubrication and ram rotation.
- . Ascertain that the cylinder rests on the recoil dampener between blows.

(3) During Driving As Resistance Builds Up:

- . Observe and record color of smoke.
- . Check whether smoke escapes between cylinder and impact block bottom.
- . Check for any signs of hammer overheating, such as blistering paint.
- . Check and record whether cylinder rebounds excessively.
- . Listen as ram impacts. There should be a clear metallic sound.



## CHAPTER 6 - INTERNAL COMBUSTION HAMMERS - DOUBLE ACTING (CLOSED END DIESEL HAMMERS)

### A. General Description

A closed end diesel hammer consists of a long slender piston (the ram), which moves inside a cylinder. The cylinder is closed at its upper end, thus causing the ram to compress the air trapped between ram and cylinder top. When the ram falls, it is subject to both gravity and the pressure in the "bounce chamber." For this reason the CED is also called double acting.

There are three manufacturers of closed end diesel hammers distributing their products in the U.S. They are (alphabetically): Bermingham, ICE and MKT Geotechnical Systems. The hammer ratings vary from 5 to not more than 80 kip-ft, with ram sizes between 1 and 10 kips.

The MKT hammers are built using liquid fuel injection. ICE and Bermingham's closed end models utilize atomized fuel injection. The difference between the two methods is explained in Appendix C.

A closed end diesel hammer consists of eight major parts (Figure 18):

- . A piston or ram with piston rings.
- . An impact block also with rings, onto which the ram impacts.
- . A cylinder in which ram and impact block move.
- . One or more fuel pumps.
- . Fuel injector(s).
- . Exhaust ports.
- . Recoil dampener.
- . A bounce chamber including bounce chamber ports which allow for a regular venting of the bounce chamber.

The exhaust ports are merely openings in the cylinder wall. The impact block usually has enlarged top and bottom diameters. The cylinder bottom, through which the center of the impact block passes, is closed down to a diameter just large enough to allow free movement. Thus, the impact block can move up and down a few inches, but is prevented from falling out of the cylinder when the entire hammer is raised. The recoil dampener is located in between the cylinder bottom and the impact block bottom. Its purpose is to cushion the cylinder against a strong upward impact block movement, due to pile rebound.

### B. Closed End Diesel Hammer Operation

The hammer is started by lifting the ram a certain distance above the exhaust ports. This is accomplished by means of a tripping device and either a hoist or a hydraulic jack. As the ram rises, it closes the bounce chamber ports and air is compressed in the upper (bounce) chamber (see Figure 19).

When the ram has reached the starting height, the trip is released and the ram starts to fall under the action of both gravity and the pressure of the air in the bounce chamber.

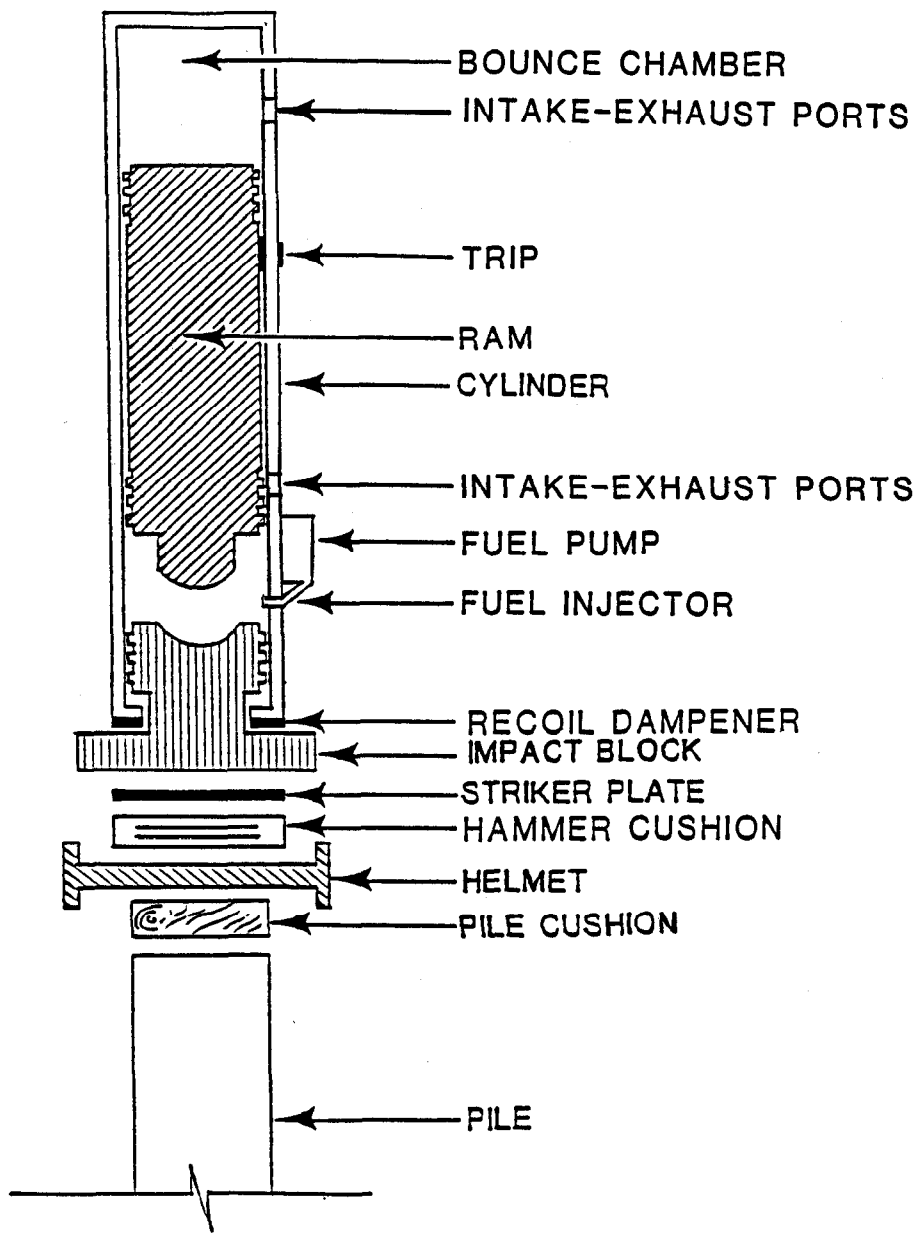
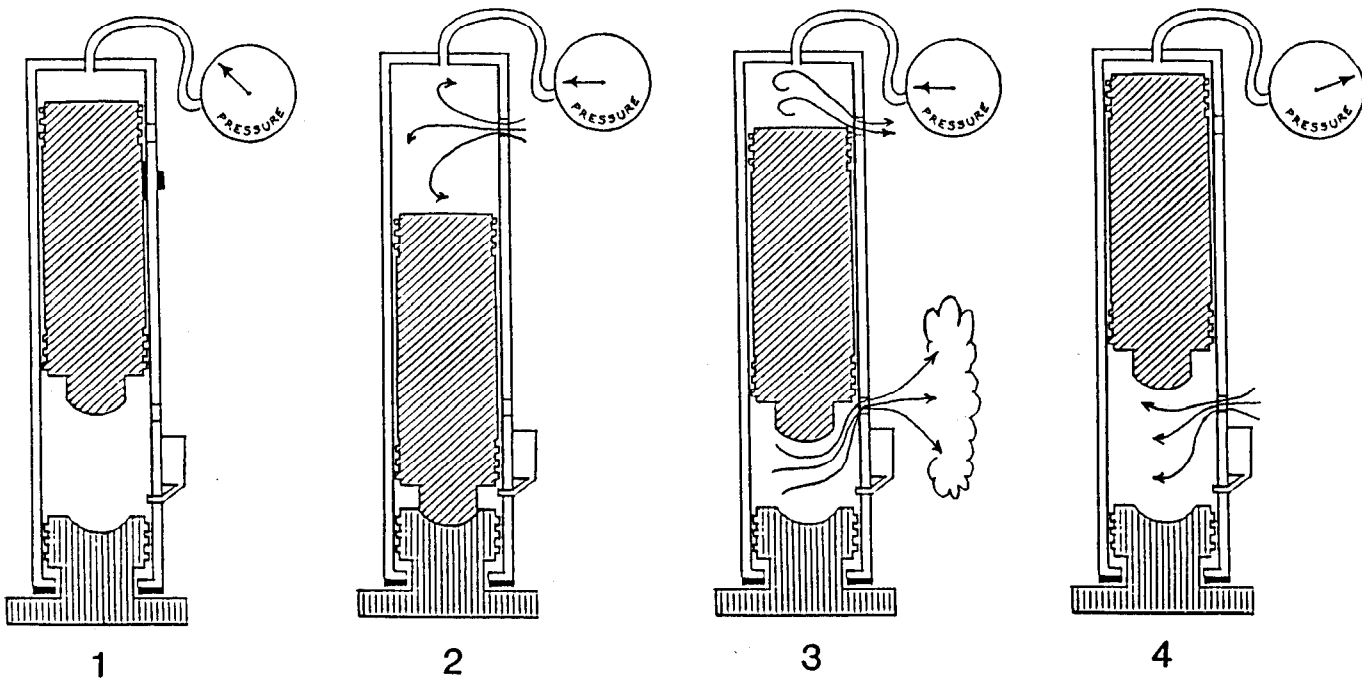


Figure 18. Double Acting Diesel Hammer.



1. STARTING POSITION
2. IMPACT AND IGNITION
3. EXHAUST
4. INTAKE IN MAIN CHAMBER AND COMPRESSION IN BOUNCE CHAMBER,  
FOLLOWED BY REPETITION OF THE CYCLE

Figure 19. Operating Cycle of a Double Acting Diesel.

When the bottom of the ram passes the exhaust ports, it closes them and a certain volume of air is trapped inside the chamber formed by the cylinder, ram, and impact block. As the ram descends further, it compresses the trapped air which, therefore, becomes hot.

After the ram has reached a certain position between the ports and the impact block, it pushes a lever and plunger system into the fuel pump, which in turn injects a certain quantity of fuel into the chamber.

At this point the difference between impact atomization and atomized fuel injection becomes important. For most hammers, the fuel is injected into the chamber at a low pressure and therefore in liquid form. Even though the air in the chamber is hot, combustion of the liquid fuel will not happen before the ram impacts against the impact block, thereby atomizing the fuel.

For atomized fuel injection, combustion will start shortly after injection starts (assuming that the air in the cylinder has become sufficiently hot) and will last as long as the injection.

Upon impact, the ram pushes the impact block, hammer cushion, helmet, and pile top rapidly downward, allowing the cylinder to fall under gravity. The impact block separates from the ram within a very short time and the pressure of the combusting air-fuel mixture will cause further separation.

Depending on the pile length, the pile starts to rebound a certain time after impact, thereby pushing the impact block upward. The impact block then collides with the cylinder, which is cushioned by the recoil dampener. For short piles, the rebound happens so soon that a second impact between impact block and ram may occur. A rebounding pile will always return energy to the ram since the gas pressure increases as the impact block moves upward. The upward moving ram eventually clears the exhaust ports, and excess pressure is blown off. The ram continues upward, now fighting against the forces of both the bounce chamber pressure and gravity. Naturally, the higher the ram's upward velocity at the time it clears the ports, the higher the height it reaches before it starts to descend for the next blow.

The magnitude of the upward ram velocity depends on:

- . The hammer combustion pressure.
- . The pile mass and stiffness.
- . The stiffness of the hammer and pile cushions.
- . The soil stiffness and/or resistance.
- . The rate at which the pressure in the bounce chamber increases.

Thus, practically all components of the hammer-pile-soil system have an effect on the diesel hammer's stroke. Under normal conditions, the ram stroke increases as pile driving becomes harder. In soils with high resistance but low stiffness, a "spongy" driving situation results, and the stroke will be relatively low. A similar situation exists with very long and flexible piles.

## C. Performance Characteristics Of Closed End Diesel Hammers

The inspection of a diesel hammer has to center around the following two questions:

- . Is the stroke of the hammer adequate?
- . Is the energy output at a given stroke adequate?

### (1) Lack Of Stroke

The stroke of a closed end diesel hammer can be indirectly measured by means of a bounce chamber pressure gauge (BCPG). This pneumatic gauge is commonly connected to the bounce chamber by means of a hose. There are a few MKT hammer models with a BCPG directly attached to the hammer cylinder. Such a gauge type is difficult to read.

For each blow, the dial of the BCPG registers the peak bounce chamber pressure. The hammer manufacturer usually provides a chart which allows the conversion from bounce chamber pressure to equivalent stroke (equivalent to the free fall stroke) or the corresponding energy (the product of ram weight and equivalent stroke). Note that it is really not important to know the actual stroke.

Of course, bounce chamber pressure is an indirect indicator of the ram stroke. The measurement is sufficiently accurate if the manufacturer's calibrated hoses are used and if the bounce chamber volume is not changed by lubrication oil. Lubrication oil may enter the compression tank (ICE hammers) or stay within unvented bounce chambers. Thus, if the hammer manufacturer recommends draining the bounce chamber, then this should be done daily or the measured bounce chamber pressures may be meaningless.

Suppose the bounce chamber pressure reaches such a magnitude that the cylinder weight cannot balance it. Then the cylinder lifts up, together with the ram, and then settles back onto the recoil dampener when the ram falls. Such a driving condition is highly undesirable since it is rather unstable. Thus, when liftoff occurs, the hammer operator must reduce the amount of fuel injected into the hammer. From that point on, the energy output of the hammer will be smaller than at the time just before liftoff became imminent. This is because there is no longer as much combustion pressure acting on the pile top. A record of this condition should be taken and bounce chamber pressures established after the fuel pump adjustment has been made.

In addition to measuring the bounce chamber pressure, the hammer rate should be checked by means of a stopwatch or Saximeter™. This unit measures the time between hammer blows and prints "blows per minute." Although not as important for closed end as for open end diesels, the hammer speed is related to the stroke and therefore establishes an independent check.

If a closed end diesel hammer does not reach 80% of its full energy rating in hard driving (blow count of six blows per inch or more), then the following potential causes for low strokes should be investigated:

- . Soft driving system, long flexible piles, spongy soils.
- . Lack of fuel or improper fuel.

- . Excessive friction.
- . Lack of compression.

Soft and/or spongy driving conditions (cause 1) were discussed earlier. These conditions can be identified by closely observing the hammer cylinder. If the cylinder experiences a high recoil, say more than one inch, then a "bouncy" driving situation exists. The cylinder motion can most easily be observed by its movement relative to the impact block.

Lack of fuel often causes low strokes. Most commonly, the first check on a diesel hammer concerns the fuel pump. Routine inspections are difficult, however, as they involve the removal of the fuel line from the injector and a manual activation of the pump. With a measuring glass, the amount of fuel injected per blow can then be determined. If the fuel pump is properly working, then a clogged injector may be the cause for low fuel injection. Improper fuel should be a rare occurrence. Improper fuel may cause low strokes if diesel fuel of type II is not chosen; other fuel types may cause early or late ignition. Of course, if water or dirt entered the fuel system, poor hammer performance would result. Draining the fuel through a clean cloth may indicate the presence of contaminants.

Excessive friction not only reduces the stroke but also causes a low energy transfer to the pile. Although other hammer components also need attention, for a maximum stroke the ram lubrication is most important. Closed end diesels do not show their ram. However, the rams of certain hammers can be seen through either the exhaust ports or a trip slot in the back of the cylinder. Thus, an inspection of the ram's surface condition during driving interruptions is advised. It should look well lubricated. Scratches or dried patches of residue on the ram indicate that lubrication is insufficient. Note that too much lubrication may result in a burning of grease and oil and thereby possibly cause preignition. This condition would be indicated by black smoke.

The last common reason for a low stroke is poor compression. If either cylinder or impact block rings allow pressure to leak off, then full compression, and thus full combustion pressure, will not develop. Furthermore, if the recoil dampener is too thin, then the hammer's starting volume will be small and full compression will not be developed. (This is a less likely reason for poor compression.) In very bad situations, the leakage of pressure past the impact block can be noticed during pile driving when smoke appears between the recoil dampener and the impact block bottom. Compression is easily checked under a "cold blow" on a bearing pile. To perform this check, the ram is picked up as if the hammer was to be started, but the fuel pump line is kept stretched such that no fuel is pumped. The ram is then released, and after impact it should continue to bounce on the air trapped in the chamber. Each bounce can be easily heard. At least ten bounces should occur if the hammer has good compression.

## (2) Other Hammer Problems

A diesel hammer with a high stroke may still perform poorly. There are three major reasons:

- . Preignition.
- . Friction.
- . Overheating without preignition.

Preignition means that the fuel combusts before impact occurs. Thus, preignition reduces the ram impact velocity and cushions the impact.

When a hammer preignites, the full ram energy is not transmitted to the pile, but rather returned to the ram, which therefore strokes very high. The low energy in the pile results in a high blow count. Preignition, therefore, has all the symptoms of a hard driving condition at a potentially low soil resistance. Overheated hammers often preignite after long periods of hard driving when lubrication oil starts to burn or fuel vaporizes prematurely due to heat.

The following are signs of preignition in hard driving (when it may be particularly detrimental to a successful pile installation):

- . Black smoke while strokes are high.
- . Flames in exhaust ports.
- . Blistering paint (due to excessive heat).
- . No obvious metal to metal impact sound.

If preignition is suspected, then the hammer should be stopped, allowed to cool down for say one-half hour, and then restarted. Stroke and blow count should then be accurately monitored. If both strokes and blow counts are lower during the first two minutes after the resumption of driving, then the proof of a preignition condition before the cooling period is established.

Most atomized fuel injection hammers have some design preignition. The fuel usually starts to burn when the ram is a small distance above the impact block. If the ram descends slowly, the pressure has more time to act on the ram than in the case of a high stroke, when the ram reaches the impact block within a short time. Thus, in hard driving, with high strokes and therefore high ram velocities, such a "design preignition" is of little consequence. For easy driving, it is often beneficial to keep the hammer running.

Friction, of course, is one of the most serious reasons for low energy outputs. As already pointed out, closed end diesels are not easily inspected regarding ram lubrication. However, the ram may be seen through the exhaust ports and/or trip slot and the existence of lubrication verified.

Not only the ram, but also the impact block, must be well greased. Remember that the impact block moves a certain distance relative to the cylinder during impact. Most manufacturers require that the impact block be greased at one-half hour intervals.

Overheating of a hammer may not only cause the hammer to preignite, it may also lead to problems with the lubrication and/or fuel system. The diesel fuel line may develop a vapor lock and reduced strokes could result. Burning of the lubricants may reduce combustion efficiency and increase friction. Thus, overheating should be avoided as much as possible, particularly in a hot climate, by ensuring continuous maintenance of the hammer.

D. Advantages Of Closed End Diesel Hammers:

- . Self contained unit not requiring additional equipment.
- . High blow rate (blows per minute) compared to open end diesels.

E. Disadvantage Of Closed End Diesel Hammers:

- . Uplift in hard driving.

F. Checklist For Closed End Diesel Hammers:

(1) Before Driving Starts:

- . Check and record hammer model and serial numbers.
- . Check the material, size, and the condition of the hammer cushion. When measuring the hammer cushion thickness, the thickness of the striker plate should also be measured and recorded.
- . Check the pile cushion (if present).
- . Check that helmet and pile are well matched. If the hammer type is such that no helmet is necessary, check that the hammer and pile are well matched.
- . Check helmet weight; if in doubt, have it weighed.
- . Check straightness of leads, and check lead connections for tightness.
- . Make sure that the portions of the leads that guide the hammer do not offer excessive friction.
- . Check the alignment between leads and pile.
- . Make sure that all exhaust ports are open.
- . Inspect recoil dampener for damage.
- . Fuel tank to be filled.
- . Check that lubrication of all hammer grease nipples is regularly done.

(2) During General Driving:

- . Using the manufacturer's gauge and the correct connection hose, measure the bounce chamber pressure and record it.
- . Using a stopwatch or Saximeter™, measure blows per minute and record this, together with the blow counts.



- . Check that the ram, helmet, and pile stay in alignment during driving.
- . Ascertain that the cylinder rests on the recoil dampener between blows.

(3) During Driving As Resistance Builds Up:

- . Observe and record color of smoke.
- . Check whether smoke escapes between cylinder and impact block bottom.
- . Check for any signs of hammer overheating, such as blistering paint.
- . Check and record whether cylinder rebounds excessively.
- . Listen as ram impacts. There should be a clear metallic sound.
- . Observe and record whether liftoff occurs, and also when fuel pump adjustments are made.

Suggested Readings:

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8. Compton, G. R., "Panel on Pile Hammers and Equipment," Associated Pile & Fitting Corp. PILETALK Seminar, San Francisco, CA, March 1977.
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## APPENDIX A - GLOSSARY

Adapter	Structural fabrication or casting placed in a helmet to adjust to a different type or size of pile. Also called filler or insert.
Allowable Pile Load	The load permitted on a pile. It is computed from the pile capacity (ultimate) by dividing with an appropriate safety factor.
Anvil	The part of a pile hammer seated directly under the ram which transmits the blow of the ram to the pile. (For diesel hammers, also called "impact block." For other hammers, often called "striker plate.")
Atomization, Impact	A type of fuel atomization used in a diesel hammer which the raw fuel injected and trapped between the ram and the impact block is atomized by impact of the ram on the impact block. Impact atomization may also be referred to as "liquid fuel injection."
Atomization, Injection	A type of fuel atomization used in a diesel hammer in which the fuel is atomized by high pressure injection.
Assembly	All hammer parts except ram.
Assembly Drop	Impact between assembly and helmet when pile rebounds.
Batter Pile	A pile driven at an angle.
Bounce Chamber Pressure	The pressure in the air compressed by the upward moving piston of a closed-end diesel hammer. The pressure is read by a gauge connected to the upper chamber by a hose.
Bouncing	A strong pile rebound after a large temporary pile penetration, motion with cylinder uplift and unstable driving conditions.
Brace	A structural member used to attach the bottom of the leads to the crane base, and used to position or batter leads in or out, left or right. Can be mechanically, hydraulically, or pneumatically operated; it is used with either fixed leads or semifixed leads. Also called "bottom brace," "a-frame," "spotter," "spreader bar," "spider," "kicker," "stinger," "strut," "apron."
Closed End Hammer	See Diesel.

Coefficient of Restitution	A number used in the dynamic analysis of collisions indicating the amount of strain energy returned when a body (for example cushion) returns to its original shape. $COR = 1$ - all energy is returned (elastic), $COR = 0$ - no energy is returned.
Combustion Delay	The time between impact and combustion in an impact atomization diesel pile hammer.
Compressive Stroke	Distance traveled by a diesel hammer ram while compressing cylinder gas. Measured from bottom of air intake port to point of impact.
Cushion	Material such as wood, plastic, compressed paper, aluminum, or rope. Main purpose of a cushion block is uniform distribution of impact forces. Hammer cushion is helmet. Pile cushion is located between helmet and pile top.
Cylinder Lift	The point at which the cylinder of a double acting air/steam or diesel hammer begins to lift or float. The point at which the force of fluid in the hammer overcomes the weight of the hammer casing or cylinder.
Design Load	See Allowable Pile Load.
Diesel Hammer	A pile hammer which carries its own power source (internal combustion hammer). An open end diesel hammer falls under the action of gravity. A closed end diesel (double acting) compresses air on its upward stroke and therefore runs faster than open end hammers.
Differential-Acting Hammer	See External Combustion Hammer.
Double-Acting Diesel Hammer	See Diesel Hammer.
Double-Acting Hammer	Hammer which falls under the action of both gravity and power.
Driving Criteria	<ol style="list-style-type: none"> <li>1) Requirement for resistance of a pile to penetration, stated in blows per increment of depth.</li> <li>2) Required tip elevation of pile.</li> </ol>
Driving Log	Record of physical pile properties of a pile, including location on site, hammer type, driving resistance in blows per unit, penetration, time of pile installation, and restrike information.
Drop Hammer	Usually a cable raised ram which is dropped by releasing the hoist.

Eccentric Loading Load does not bear vertically or axially on pile, usually due to pile being driven out of plumb or plan location.

Elastic Shortening Reduction in length of a pile, or structural member, due to load. An important factor in evaluating apparent pile movement under test load.

Final Blow Count The number of blows per inch, foot, or other unit length of measure. Recorded immediately prior to the end of driving of the pile.

Final Set The net penetration a pile moves under one blow or a specified series of blows at the end of driving. (Reciprocal of final blow count).

Fluid Power Steam, combustion gases, or hydraulic oil used to move the ram of the hammer and to drive the pile. Also call "motive fluid."

Follower 1) An attachment, shaped like a short pipe, used to extend the upper portion of the helmet.  
2) A member interposed between a pile hammer and a pile to transmit blows when the pile head is below the reach of the hamemr. Also called "dolly."

Gate See Pile Gate.

Grade The elevation of the natural ground level of any point on a project site.

Guides The part of a pile hammer which loads the ram. Often referred to as "columns." The part of the pile lead which forms a pathway for the hammer.

Hammer Cushion See Cushion.

Hammer Efficiency The ratio of kinetic energy of the ram immediately prior to impact divided by the rated energy.

Hammer Energy The product of ram weight and equivalent stroke measured in ft-lbs or kips-ft.

Hammer Speed The number of hammer blows per minute.

Hammer Uplift See Cylinder Lift.

Hanging Leads See Leads, Swinging.

Helmet	Steel block placed over a pile to prevent damage from driving. It contains a recess on top for cushion material. The bottom is formed to accept a specific shaped pile, along with its cushion, if used. Also called "cap" or "driving head."
Impact Atomization	See Atomization, Impact.
Impact	The collision and ensuing energy transmission of two bodies.
Impact Velocity	The velocity of the ram of a gravity or single-acting steam/air or diesel hammer when it strikes the anvil.
Inlet Port	The inlet fluid path of external combustion hammers.
Inlet Pressure	Pressure of motive fluid at the inlet of an external combustion hammer.
Inspector, Pile	The individual who observes pile installation for conformance with contract requirements.
Kip	A force unit equal to 1,000 lbs.
Leaders	See Leads.
Leads	A structure on which a pile hammer travels up and down and with which the hammer and pile assembly is aligned in driving position.
Leads, Fixed	A lead system which is pivot supported at the crane boom top and by a brace at its bottom.
Leads, Semifixed	A trade name for a type lead which may be raised or lowered independently of the boom by a cable from the crane. Also called "vertical-travel leads."
Leads, Swinging	Are hung by their top from one load line of a crane. The second support point is at the ground through spikes.
Leads, Offshore	Also called "free riding leads," they align hammer and pile, but the pile must be supported by a template or other means.
Line Oiler	Lubricator inserted in pressure air or steamline to lubricate hammer piston or cylinder.
Monkey	See Pile Monkey.
Motive Fluid	See Fluid Power.

Needle Gauge	A pressure gauge with a needle stem for measuring air or steam pressure in a pressure hose, by puncturing the wall of the hose with the needle stem.
Overdriving	Driving in a way that damages material in a pile, most often by continuing to pound after penetration of the pile stops.
Penetration Resistance	The resistance to penetration from driving expressed in blows per increment of advance of the pile.
Pile	A column made of timber, steel, or concrete. Installed in the ground to resist or transfer vertical, horizontal, or combination loads imposed upon it.
Pile Cap	A structural member placed upon the tops of piles to transmit and distribute the load of the structure down to the head of a pile, a row of piles, or a pile group.
Pile Cushion	See Cushion.
Pile Driver	1) A rig consisting of leads, hoisting apparatus and a pile hammer. 2) A member of the pile crew.
Pile Driving Cap	See Helmet.
Pile Gate	A device at the base of the pile hammer leads which is closed around the pile to maintain alignment between the pile and the leads.
Pile Hammer	General term for machine which drives piling by impact or vibration. Power source may be mechanical, air, steam, diesel, or hydraulic.
Pile Head	The top of the pile.
Pile Log	See Driving Log.
Pile Monkey	Trade name for a mechanical device controlled by the crane operator to position the pile underneath the helmet.
Pile Refusal	See Refusal.
Pile Rig	See Pile Driver.
Pile Set	See Set.
Pile Skin	The pile's outside surface between head and toe.

Pile Toe	The bottom end of a pile. Also called "foot" or "tip."
Pipe Pile	A steel or concrete cylindrical shell of specified strength and thickness. It is driven either open or closed ended and is usually filled with concrete.
Piston	The ram of a diesel hammer. For internal combustion hammer, pistons are also used to move the ram.
Plumb Pile	A vertical pile, i.e., a zero batter pile.
Practical Refusal	See Refusal.
Preadmission	An early opening of the inlet valve of an external combustion hammer. It allows a pressure build up before impact.
Prefiring	See Preignition.
Preignition	A combustion in a diesel hammer prior to impact.
R	Symbol for pile capacity in tons. Example: 2R is a term meaning twice design capacity.
Racking Hammer	Severe bouncing of the casing of a pile hammer during driving operations.
Raker Pile	See Batter Pile.
Ram	The moving and driving part of any hammer. It delivers an impact blow to an anvil and to the pile.
Ram Point	The impacting part of the ram.
Rated Speed	The specified operation speed for a pile hammer in blows per minute.
Rebound	Amount of upward movement of the head of a pile following a hammer blow.
Refusal	The condition reached when a pile being driven by a hammer has a penetration per blow which is smaller than a specified value (e.g., 1/20 inch).
Resistance	The sum total of all the forces that oppose the penetration of a pile.
Saximeter™	Trade name for a device used for remote measuring of the stroke of an open end diesel hammer or the measurement of the hammer speed.
Single Acting Diesel Hammer	See Diesel Hammer.



Single Acting Hammer	A pile hammer in which fluid lifts the ram on the up stroke and gravity alone acts on the down stroke.
Skin Friction	The soil resistance acting on the pile skin.
Stabbing Points, Leads	Fabricated steel points or spikes fastened to the very bottom of swinging leads.
Steel H-Pile	A rolled steel section with web and flange the same thickness. Wide flange and other steel sections are also used as piles.
Step-Tapered Pile	A cast-in-place pile whose diameter is stepped up in increments, usually in 8 to 12 feet sections of corrugated, thin-metal shell, and internally driven with a mandrel (a heavy steel pipe).
Test Pile	<ol style="list-style-type: none"> <li>1) A pile driven to ascertain driving conditions and probable required lengths.</li> <li>2) A pile on which a loading test also may be performed to determine the carrying capacity of the soil.</li> <li>3) A pile which will later be used as a guide for efficient design of pile foundations.</li> </ol>
Timber Pile	A tree trunk, usually driven small end down. Probably the earliest form of pile. Frequently, it is treated with creosote as a preservative. A fabricated or pressed steel tip, and frequently, a steel ring around the top to ensure against damage during driving.
Trip	<ol style="list-style-type: none"> <li>1) A block in the leads of a drop hammer causing the release of the weight at a predetermined height.</li> <li>2) Mechanical device used in diesel hammers to both pick up the ram and to start the hammer.</li> </ol> <p>Also called "trip block" or "tripping device."</p>
Ultimate Resistance	The maximum load that a single pile will support; a load such that any increase will cause objectionable progressive settlement and constitute failure.
Vertical Travel Leads	See Leads.
Working Load	See Allowable Pile Load.

APPENDIX B - THE CALCULATION OF RAM STROKE FROM BLOW RATE  
FOR OPEN END DIESEL HAMMERS

Since the ram falls freely until it is even with the exhaust ports, and since it falls only a short distance against an appreciable pressure, the assumption of a free-fall condition is fairly accurate. If the time of fall is  $t_d$ , and if only the gravitational force exists, then the height of fall is

$$h = (g/2)t_d^2 \quad (\text{Eq. 1})$$

Since the ram has to both fall and rise, the time of one complete cycle,  $t_p$ , is

$$t_p = 2t_d \quad (\text{Eq. 2})$$

and the stroke may be computed from

$$h = (g/2)(t_p/2)^2 \quad (\text{Eq. 3})$$

However, comparisons of strokes measured with a jump stick, and those computed according to Equation 3, indicated that the computed value would generally be high by 0.3 ft (0.1 m). For this reason, a correction was made. Introducing the gravitational acceleration ( $g = 32.2 \text{ ft/s}^2$  or  $g = 9.81 \text{ m/s}^2$ ) the Saximeter™ formula becomes

$$h = 4.02t_p^2 - 0.3 \text{ (ft)} \quad (\text{Eq. 4)-English units}$$

$$h = 1.23t_p^2 - 0.1 \text{ (m)} \quad (\text{Eq. 4)-SI units}$$

The Saximeter™ formula may be used with a stopwatch. In that case, for accuracy, the stopwatch should be started with a blow numbered "1" and stopped with blow 11. Thus, ten time periods have elapsed and the time  $t_p$  is one tenth of the measured time.

EXAMPLE

The time between 11 blows was 12.5 seconds. The time between two blows was therefore approximately 1.25 seconds. Using Equation (4)-English, one obtains

$$h = 4.02(1.25)^2 - 0.3 = 8.1 - 0.3 = \underline{7.8 \text{ ft}}$$

It is simpler to use a Saximeter™ which gives a stroke value for each blow. This unit also averages. Note that the Saximeter™ formula is not strictly applicable to battered piles, and a correction has to be made. For further information, the Saximeter™ manual should be read.

## APPENDIX C - DIESEL HAMMER FUEL SYSTEMS

### A. Liquid Fuel Injection

Liquid fuel injection, low pressure injection, and impact atomization are all names for the same process, which is unique to pile driving hammers. In this process, the falling ram compresses the air trapped in the combustion chamber, and fuel is then injected such that it collects in liquid form on top of the impact block. The impacting ram then disperses this fuel, which is thereby mixed with the hot, compressed air. Combustion takes place soon afterward.

For a cool hammer, it may be two milliseconds after impact before combustion starts. As the hammer heats up, the fuel will begin to evaporate as soon as it is injected, and combustion may commence without delay at the time of impact. The hotter the hammer, the more likely an early combustion. An overheated hammer is likely to preignite, i.e., the combustion will be well advanced by the time of impact.

Diesel hammer manufacturers have been paying particular attention to the fuel injection process and the shape of the impacting ram and impact block surfaces. One reason for experimenting has been the sometimes poor starting behavior of impact atomization hammers. At the beginning of driving, pile rebound is usually so weak that the stroke tends to remain small. Thus, in easy driving, high hammer energy is required to maintain a good stroke. At the same time, however, the hammer is cold and the relative speed of ram and impact block is low. Thus, the fuel neither evaporates nor does it become as finely atomized as in hard driving. A relatively inefficient combustion results.

### B. Atomized Fuel Injection

Using the same principles as seen in other types of diesel engines, AFI diesel hammers compress an air charge in the cylinder, and once the air is hot and compressed, fuel is injected under high pressure. This injection pressure may be 1000 psi (6895 kPa) or more.

High pressure injection causes the fuel to enter the chamber as a finely distributed mist. (One calls the fuel "atomized," which is probably an inaccurate term.) As soon as this fuel mist enters the hot air, it will start to burn. The time of the start of injection corresponds (with only slight variations) to a certain distance between the ram and the impact block, and therefore to a certain volume. Similarly, injection and/or combustion ends after the ram has reached a certain point during rebound.

In easy driving, combustion will start independent of the relative speed between the ram and impact block. However, since the ram is falling slowly (short stroke), the time between the start of combustion and impact will be long. This allows the combustion pressure to develop to the point where it stops the ram before impact. Thus, little energy is transferred into the pile.

Atomized fuel injection hammers work very well if they are maintained

perfectly. It is important that the fuel injection timing is accurate down to the millisecond. Worn injectors, or fuel pump parts, or damaged fuel lines between the pump and injector can all greatly affect performance.

APPENDIX D - COMMON IMPACT PILE DRIVING HAMMERS

Main Category - power medium: A-S...Air/Steam; H...Hydraulic; D...Diesel.  
 First Subcategory - Mode: SA...Single Acting; DA...Double Acting.  
 Second Subcategory - Type of Mode: DA...Double Acting; DI...Differential Acting; CO... Compound; LI...Liquid Injection, AI...Atomized Injection

EXTERNAL COMBUSTION HAMMERS

ID	Manufacturer	Model	Rated Energy kip-ft	Ram Weight kips	Category
1	CONMACO	50E3	15.00	5.00	A-S/SA
2	CONMACO	65E3	19.50	6.50	A-S/SA
3	CONMACO	50E5	25.00	5.00	A-S/SA
4	CONMACO	80E3	26.00	8.00	A-S/SA
5	CONMACO	100E3	32.50	10.00	A-S/SA
6	CONMACO	65E5	32.50	6.50	A-S/SA
7	CONMACO	115E3	37.375	11.50	A-S/SA
8	CONMACO	80 E5	40.00	8.00	A-S/SA
9	CONMACO	140E3	42.00	14.00	A-S/SA
10	CONMACO	160E3	48.75	16.25	A-S/SA
11	CONMACO	100E5	50.00	10.00	A-S/SA
12	CONMACO	115E5	57.50	11.50	A-S/SA
13	CONMACO	200E3	60.00	20.00	A-S/SA
14	CONMACO	125E5	62.50	12.50	A-S/SA
15	CONMACO	300E3	90.00	30.00	A-S/SA
16	CONMACO	200E5	100.00	20.00	A-S/SA
17	CONMACO	300E5	150.00	30.00	A-S/SA
18	CONMACO	450E5	225.00	45.00	A-S/SA
19	CONMACO	700E5	350.00	70.00	A-S/SA
20	CONMACO	850E6	510.00	85.00	A-S/SA
21	McKIERNAN-TERRY	5	1.00	0.20	A-S/DA/DA
22	McKIERNAN-TERRY	6	2.50	0.40	A-S/DA/DA
23	McKIERNAN-TERRY	7	4.15	0.80	A-S/DA/DA
24	McKIERNAN-TERRY	9 B 3	8.75	1.60	A-S/DA/DA
25	McKIERNAN-TERRY	10 B 3	13.10	3.00	A-S/DA/DA
26	McKIERNAN-TERRY	C-5	14.20	5.00	A/DA/CO
27	McKIERNAN-TERRY	C-5	16.00	5.00	S/DA/DA
28	McKIERNAN-TERRY	S-5	16.25	5.00	A-S/SA
29	McKIERNAN-TERRY	11 B 3	19.15	5.00	A-S/DA/DA
30	McKIERNAN-TERRY	C-826	21.21	8.00	A-S/DA/CO
31	McKIERNAN-TERRY	C-826	24.38	8.00	S-DA/CO
32	McKIERNAN-TERRY	S-8	26.00	8.00	A-S/SA
33	McKIERNAN-TERRY	S-10	32.50	10.00	A-S/SA
34	McKIERNAN-TERRY	S-14	37.50	14.00	A-S/SA
35	McKIERNAN-TERRY	MS-350	30.80	7.72	A-S/SA
36	McKIERNAN-TERRY	MS-500	46.35	11.30	A-S/SA
37	McKIERNAN-TERRY	S-20	60.00	20.00	A-S/SA

EXTERNAL COMBUSTION HAMMERS

ID	Manufacturer	Model	Rated Energy kip-ft	Ram Weight kips	Category
38	RAYMOND	INT 'L 1	15.00	5.00	A-S/SA
39	RAYMOND	INT 'L 1-S	19.50	6.50	A-S/SA
40	RAYMOND	INT 'L 65 C	19.50	6.50	A-S/DA/DI
41	RAYMOND	INT 'L 65 CH	19.50	6.50	H/DA/DI
42	RAYMOND	INT 'L 0	24.375	7.50	A-S/SA
43	RAYMOND	INT 'L 80 C	24.45	8.00	A-S/DA/DI
44	RAYMOND	INT 'L 80 CH	24.45	8.00	H/DA/DI
45	RAYMOND	INT 'L 2/0	32.50	10.00	A-S/SA
46	RAYMOND	INT 'L 3/0	40.625	12.50	A-S/SA
47	RAYMOND	INT 'L 150 C	48.75	15.00	A-S/DA/DI
48	RAYMOND	INT 'L 4/0	48.75	15.00	A-S/SA
49	RAYMOND	INT 'L 5/0	56.875	17.50	A-S/SA
50	RAYMOND	INT 'L 30 X	75.00	30.00	A-S/SA
51	RAYMOND	INT 'L 8/0	81.25	25.00	A-S/SA
52	RAYMOND	INT 'L 40 X	100.00	40.00	A-S/SA
53	RAYMOND	INT 'L 60 X	150.00	60.00	A-S/SA
54	VULCAN	2	7.26	3.00	A-S/SA
55	VULCAN	30 C	7.26	3.00	A-S/DA/DI
56	VULCAN	1	15.00	5.00	A-S/SA
57	VULCAN	50 C	15.10	5.00	A-S/DA/DI
58	VULCAN	65 C	19.20	6.50	A-S/DA/DI
59	VULCAN	06	19.50	6.50	A-S/SA
60	VULCAN	06-106	19.50	6.50	A-S/SA
61	VULCAN	65CA	19.58	6.50	A-S/DA/DI
62	VULCAN	0	24.375	7.50	A-S/SA
63	VULCAN	80 C	24.45	8.00	A-S/DA/DI
64	VULCAN	08	26.00	8.00	A-S/SA
65	VULCAN	85 C	26.00	8.52	A-S/DA/DI
66	VULCAN	506	32.50	6.50	A-S/SA
67	VULCAN	010	32.50	10.00	A-S/SA
68	VULCAN	100 C	32.88	10.00	A-S/DA/DI
69	VULCAN	140 C	36.00	14.00	A-S/DA/DI
70	VULCAN	012	39.00	12.00	A-S/SA
71	VULCAN	508	40.00	8.00	A-S/SA
72	VULCAN	014	42.00	14.00	A-S/SA
73	VULCAN	016	48.75	16.25	A-S/SA
74	VULCAN	510	50.00	10.00	A-S/SA
75	VULCAN	200 C	50.20	20.00	A-S/DA/DI
76	VULCAN	512	60.00	12.00	A-S/SA
77	VULCAN	320	60.00	20.00	A-S/SA
78	VULCAN	020	60.00	20.00	A-S/SA
79	VULCAN	030	90.00	30.00	A-S/SA
80	VULCAN	330	90.00	30.00	A-S/SA
81	VULCAN	520	100.00	20.00	A-S/SA

## EXTERNAL COMBUSTION HAMMERS

ID	Manufacturer	Model	Rated Energy kip-ft	Ram Weight kips	Category
82	VULCAN	040	120.00	40.00	A-S/SA
83	VULCAN	340	120.00	40.00	A-S/SA
84	VULCAN	530	150.00	30.00	A-S/SA
85	VULCAN	060	180.00	60.00	A-S/SA
86	VULCAN	360	180.00	60.00	A-S/SA
87	VULCAN	540	200.00	40.90	A-S/SA
88	VULCAN	560	300.00	62.50	A-S/SA
89	VULCAN	3100	300.00	100.00	A-S/SA
90	VULCAN	5100	500.00	100.00	A-S/SA
91	VULCAN	5150	750.00	150.00	A-S/SA
92	VULCAN	5250	1250.00	250.00	A-S/SA
93	VULCAN	6300	1800.00	300.00	A-S/SA

## INTERNAL COMBUSTION HAMMERS

ID	Manufacturer	Model	Rated Energy kip-ft	Ram Weight kips	Category
1	BERMINGHAMMER	B-200	18.00	2.00	D/SA/LI
2	BERMINGHAMMER	B-225	29.00	3.00	D/SA/LI
3	BERMINGHAMMER	B-300	34.00	3.75	D/SA/LI
4	BERMINGHAMMER	B-400	46.00	5.00	D/SA/LI
5	BERMINGHAMMER	B-500	79.00	6.90	D/SA/LI
6	DELMAG	D 5	8.25	1.10	D/SA/LI
7	DELMAG	D 8-22	17.65	1.762	D/SA/LI
8	DELMAG	D 12	23.70	2.75	D/SA/LI
9	DELMAG	D 15	28.40	3.30	D/SA/LI
10	DELMAG	D 16-32	39.335	3.52	D/SA/LI
11	DELMAG	D 22	40.60	4.97	D/SA/LI
12	DELMAG	D 22-13	48.50	4.85	D/SA/LI
13	DELMAG	D 22-23	51.24	4.85	D/SA/LI
14	DELMAG	D 30	59.7	6.60	D/SA/LI
15	DELMAG	D 25-32	61.48	5.51	D/SA/LI
16	DELMAG	D 30-02	66.20	6.60	D/SA/LI
17	DELMAG	D 30-13	66.20	6.60	D/SA/LI
18	DELMAG	D 30-23	73.80	6.60	D/SA/LI
19	DELMAG	D 30-32	73.80	6.60	D/SA/LI
20	DELMAG	D 36	83.80	7.94	D/SA/LI
21	DELMAG	D 36-02	83.80	7.90	D/SA/LI
22	DELMAG	D 36-13	83.80	7.93	D/SA/LI
23	DELMAG	D 36-23	88.50	7.93	D/SA/LI
24	DELMAG	D 36-32	88.50	7.93	D/SA/LI
25	DELMAG	D 44	90.20	9.46	D/SA/LI
26	DELMAG	D 46-13	96.50	10.14	D/SA/LI
27	DELMAG	D 46	107.10	10.14	D/SA/LI
28	DELMAG	D 46-23	107.10	10.14	D/SA/LI
29	DELMAG	D 46-02	107.10	10.10	D/SA/LI
30	DELMAG	D 46-32	113.10	10.14	D/SA/LI
31	DELMAG	D 55	125.00	11.86	D/SA/LI
32	DELMAG	D 62-02	152.50	13.67	D/SA/LI
33	DELMAG	D 62-12	152.50	13.66	D/SA/LI
34	DELMAG	D 62-22	152.50	13.66	D/SA/LI
35	DELMAG	D 80-12	186.33	17.62	D/SA/LI
36	DELMAG	D 80-23	196.74	17.62	D/SA/LI
37	DELMAG	D 80	225.00	19.50	D/SA/LI
38	DELMAG	D 100-13	246.00	22.03	D/SA/LI



## INTERNAL COMBUSTION HAMMERS

ID	Manufacturer	Model	Rated Energy kip-ft	Ram Weight kips	Category
39	FEC	1200	22.50	2.75	D/SA/LI
40	FEC	1500	27.10	3.30	D/SA/LI
41	FEC	2500	50.00	5.50	D/SA/LI
42	FEC	3000	63.00	6.60	D/SA/LI
43	FEC	3400	73.00	7.48	D/SA/LI
44	HERA HAMMERS	1250	24.875	2.755	D/SA/LI
45	HERA HAMMERS	1500	29.820	3.305	D/SA/LI
46	HERA HAMMERS	2500	49.715	5.510	D/SA/LI
47	HERA HAMMERS	2800	55.715	6.175	D/SA/LI
48	HERA HAMMERS	3500	69.610	7.715	D/SA/LI
49	HERA HAMMERS	H5000	99.475	11.025	D/SA/LI
50	HERA HAMMERS	5000	99.475	11.025	D/SA/LI
51	HERA HAMMERS	5700	113.415	12.750	D/SA/LI
52	HERA HAMMERS	6200	123.340	13.670	D/SA/LI
53	HERA HAMMERS	H7500	149.235	16.540	D/SA/LI
54	HERA HAMMERS	7500	149.235	16.540	D/SA/LI
55	HERA HAMMERS	8800	175.040	19.400	D/SA/LI
56	ICE	180	8.10	1.725	D/DA/AI
57	ICE	440	18.55	4.000	D/DA/AI
58	ICE	422	23.10	4.000	D/DA/AI
59	ICE	520	30.39	5.070	D/DA/AI
60	ICE	640	40.56	6.000	D/DA/AI
61	ICE	660	51.60	7.570	D/DA/AI
62	ICE	1070	72.60	10.000	D/DA/AI
63	KOBE	K 13	25.40	2.87	D/SA/LI
64	KOBE	K 22	41.30	4.85	D/SA/LI
65	KOBE	KC 25	51.52	5.15	D/SA/AI
66	KOBE	K 25	51.50	5.51	D/SA/LI
67	KOBE	K 32	60.10	7.05	D/SA/LI
68	KOBE	KC 35	72.18	7.72	D/SA/AI
69	KOBE	K 35	72.20	7.72	D/SA/LI
70	KOBE	K 42	79.00	9.26	D/SA/LI
71	KOBE	KC 45	92.75	9.92	D/SA/AI
72	KOBE	K 45	92.80	9.92	D/SA/LI
73	KOBE	K 60	105.60	13.20	D/SA/LI
74	KOBE	KB 60	130.20	13.23	D/SA/LI
75	KOBE	KB 80	173.60	17.64	D/SA/LI

## INTERNAL COMBUSTION HAMMERS

ID	Manufacturer	Model	Rated Energy kip-ft	Ram Weight kips	Category
76	LINK BELT	105	6.50	1.445	D/DA/AI
77	LINK BELT	180	8.10	1.725	D/DA/AI
78	LINK BELT	312	14.95	3.855	D/DA/AI
79	LINK BELT	440	18.55	4.000	D/DA/AI
80	LINK BELT	520	27.66	5.070	D/DA/AI
81	LINK BELT	660	51.60	7.570	D/DA/AI
82	McKIERNAN-TERRY	DA-15C	8.20	1.10	D/DA/LI
83	McKIERNAN-TERRY	DE-10	8.80	1.10	D/SA/LI
84	McKIERNAN-TERRY	DA-15C	9.35	1.10	D/SA/LI
85	McKIERNAN-TERRY	DE-20	16.00	2.00	D/SA/LI
86	McKIERNAN-TERRY	DE-20B	17.00	2.00	D/SA/LI
87	McKIERNAN-TERRY	DA-35C	21.00	2.80	D/DA/LI
88	McKIERNAN-TERRY	DE-30	22.40	2.80	D/SA/LI
89	McKIERNAN-TERRY	DA-35C	23.80	2.80	D/SA/LI
90	McKIERNAN-TERRY	DE-30B	23.80	2.80	D/SA/LI
91	McKIERNAN-TERRY	DE-33	28.05	3.30	D/SA/LI
92	McKIERNAN-TERRY	DA-45	30.70	4.00	D/DA/LI
93	McKIERNAN-TERRY	DE-40	32.00	4.00	D/SA/LI
94	McKIERNAN-TERRY	DA-45	34.00	4.00	D/SA/LI
95	McKIERNAN-TERRY	DA-55B	38.00	5.00	D/DA/LI
96	McKIERNAN-TERRY	DA-55C	38.20	5.00	D/DA/LI
97	McKIERNAN-TERRY	DA-55B	40.00	5.00	D/SA/LI
98	McKIERNAN-TERRY	DE-50	42.50	5.00	D/SA/LI
99	McKIERNAN-TERRY	DE-50B	42.50	5.00	D/SA/LI
100	McKIERNAN-TERRY	DA-55C	42.50	5.00	D/SA/LI
101	McKIERNAN-TERRY	DE-70B	59.50	7.00	D/SA/LI
102	McKIERNAN-TERRY	DE-110	93.50	11.00	D/SA/LI
103	McKIERNAN-TERRY	DE-150	127.50	15.00	D/SA/LI

## INTERNAL COMBUSTION HAMMERS

ID	Manufacturer	Model	Rated Energy kip-ft	Ram Weight kips	Category
104	MITSUBISHI	M 14	25.25	2.97	D/SA/LI
105	MITSUBISHI	M-14S	26.00	2.97	D/SA/LI
106	MITSUBISHI	MH 15	28.10	3.31	D/SA/LI
107	MITSUBISHI	M-23	43.01	5.06	D/SA/LI
108	MITSUBISHI	MH 25	46.90	5.51	D/SA/LI
109	MITSUBISHI	M-33	61.71	7.26	D/SA/LI
110	MITSUBISHI	MH 35	65.60	7.72	D/SA/LI
111	MITSUBISHI	M-43	80.41	9.46	D/SA/LI
112	MITSUBISHI	MH 45	85.40	10.05	D/SA/LI
113	MITSUBISHI	MH 72 B	135.10	15.90	D/SA/LI
114	MITSUBISHI	MB 70	141.00	15.84	D/SA/LI
115	MITSUBISHI	MH 80 B	149.60	17.60	D/SA/LI
116	VULCAN	30 D	30.00	3.00	D/SA/LI
117	VULCAN	33 D	33.00	3.30	D/SA/LI
118	VULCAN	66 D	66.00	6.61	D/SA/LI
119	VULCAN	80 D	80.00	8.00	D/SA/LI

## APPENDIX E - DISCUSSION OF FIELD INSPECTION DATA SHEETS

### General Notes

The forms were prepared to satisfy two requirements:

(1) As an aid to the inspector. The inspector should follow the sheet, starting at the top, and answer all questions. Once the sheet is completed, a comprehensive hammer check has been made. In addition, if certain observations deviate from those given as recommended values, then the immediate correction of a problem may sometimes be possible.

(2) As an aid to the engineer. The sheet should be of particular value to an enegineer who has performed a wave equation analysis. Comparing the actual situation with the analyzed one, he may be able to draw conclusions on the reliability of his prediction. The "OBSERVATIONS WHEN BEARING IS CONFIRMED" therefore need to be filled in only for the final driving situation. If the driving criterion is a depth and not a blow count, then these observations are more a matter of record keeping and less a matter of bearing capacity confirmation.

The data forms will undergo regular revisions. Please do not hesitate to make suggestions for improvement. If you find that any information is incorrect, please notify:

Frank Rausche  
Goble Rausche Likins and Associates, Inc.  
4535 Emery Industrial Parkway  
Cleveland, Ohio 44128

Phone: 216-831-6131

FORM 1: Air/Steam/Hydraulic Hammers With Visible Ram

(Note: This form may be used for either single or double acting hammers).

Select proper sheet according to designation in upper right hand corner.

On the upper right hand side, fill in an identification for PROJECT/PILE, enter date and general weather conditions, temperature, humidity (approximate), altitude (if unusually high), and time of day.

While the hammer is on the ground, try to find an identifying imprint on the hammer. If apparent, record its serial number and/or other identifiers and enter under the CATEGORY. At the same time, inspect slide bar and trips for tightness and grease. Similarly, check the columns for grease and the tightness of the attachments of columns to hammer base and top.

Before using the hammer, the hammer cushion material and its thickness has to be checked. Compare its appearance with the descriptions in the inspection manual. The frequency of this check depends on the number of blows which the hammer cushion has already endured. Note that the total striker plate plus hammer cushion thickness is usually allowed to vary from the specified value by approximately one inch. If a follower is being used, check its size or type and manufacture. Using a follower requires a matching cushion thickness. Similarly, identify the helmet and inserts, if any, such that a determination of its weight is possible.

If a pile cushion has to be used, check the engineer's specifications for the frequency of replacement. Merely maintaining a certain cushion thickness by adding material may produce a very hard cushion after some time. You should be able to tell how many blows have been applied to each layer of cushioning. For plywood, 1500 blows is maximum.

Record the pile material, length, cross sectional size, and batter.

Compare the power hose diameter with the specified one, estimate the hose length and record, and at least in the beginning of the job, or whenever the hoses are reconnected, have the hose blown out (for air/steam only). At that time, the presence of leaks may also be checked.

Check whether the air or steam supply is fitted with a lubricator and whether it does contain lubricant. Once the hammer is running, check the pressure of air/steam or hydraulic fluid. It may be necessary that the pressure is up to 25% higher than specified, if the hoses are very long. While the hammer is running, check the fluctuations of the pressure gauge, if apparent, and record your observation. Record the make, model, and rating of the compressor, boiler, or other external combustion device.

Full ram stroke is sometimes a difficult observation. Do not enter an observation unless you are reasonably sure to be correct. From the Saximeter™ output, obtain the final blows per minute and record, together with blows per foot. Make sure to attach the complete Saximeter™ record. Observe the gap between helmet or follower and hammer base and see whether an unusually high rebound can be observed.

FORM 1 (continued)

If the hammer is double (differential) acting, observe whether hammer uplifting occurs, and record time of day when pressure has to be reduced. It is particularly important to know the motive fluid pressure at the time of final blow count.

If the pile has a long unsupported length, check to see whether it whips, i.e., whether it moves laterally. At the same time, check the hammer pile alignment, preferably from two directions. If there are problems, try to have them corrected. If they cannot be corrected, record your observations.

Crane and lead type may only need to be observed once, however, the straightness and greasing of the leads should be checked daily, particularly where the hammer is in contact with the leads. Furthermore, during pile driving, check whether the air/steam lubricant keeps the piston rod shiny and whether the exhaust indicates the presence of lubricant. If the exhaust indicates freezing (compressed air), or a lot of water (steam) after the hammer has warmed up, then appropriate notes should be taken and the contractor alerted to the problem.

FORM 2: Enclosed Air/Steam/Hydraulic Hammers

(Note: This form may be used for either single or double acting hammers).

Select proper sheet according to designation in the upper right hand corner.

On the upper right hand side, fill in an identification for PROJECT/PILE, enter date and general weather conditions, temperature, humidity (approximate), altitude (if unusually high), and time of day.

While the hammer is on the ground, try to find an identifying imprint on the hammer. If apparent, record its serial number and/or other identifiers and enter under the CATEGORY.

Often this hammer type is run without hammer cushion. However, if it does drive through a cushion, its material and thickness has to be checked. Compare its appearance with the descriptions in the inspection manual. The frequency of this check depends on the number of blows which the hammer cushion has already endured.

Identify the helmet and inserts, if any, such that a determination of its weight is possible.

If a pile cushion has to be used, check the engineer's specifications for the frequency of replacement. Merely maintaining a certain cushion thickness by adding material may produce a very hard cushion after some time. You should be able to tell how many blows have been applied to each layer of cushioning. For plywood, 1500 blows is maximum.

Record the pile material, length, cross sectional size, and batter.

Compare the power hose diameter with the specified one, estimate the hose length and record, and at least in the beginning of the job, or whenever the hoses are reconnected, have the hose blown out (this is not to be done with hydraulic hoses). At that time, the presence of leaks may also be checked.

Check whether the air or steam supply is fitted with a lubricator and whether it does contain lubricant. Once the hammer is running, check the pressure of air/steam or hydraulic fluid. It may be necessary that the pressure is up to 25% higher than specified, if the hoses are very long. While the hammer is running, check the fluctuations of the pressure gauge, if apparent, and record your observation. Record the make, model, and rating of the compressor, boiler, or other external combustion device.

If the hammer is double (differential, compound) acting, observe whether hammer uplifting occurs and record time of day when pressure has to be reduced. It is particularly important to know the motive fluid pressure at the time of final blow count.

From the Saximeter™ output obtain the final blows per minute and record together with blows per foot. Make sure to attach the complete Saximeter™ record. Observe the gap between helmet or follower (if present) and hammer base and see whether an unusually high rebound can be observed.

FORM 2 (continued)

If the pile has a long unsupported length, check to see whether it whips, i.e., whether it moves laterally. At the same time, check the hammer pile alignment, preferably from two directions. If there are problems, try to have them corrected. If they cannot be corrected, record your observations.

Crane and lead type may only need to be observed once, however, the straightness and greasing of the leads should be checked daily, and in particular where the hammer is in contact with the leads. Check whether the exhaust indicates the presence of lubricant. If the exhaust indicates freezing (compressed air), or a lot of water (steam) after the hammer has warmed up, then appropriate notes should be taken and the contractor alerted to the problem.



FORM 3: Open End Diesel Hammers

Select proper sheet according to designation in the upper right hand corner.

On the upper right hand side, fill in an identification for PROJECT/PILE, enter date and general weather conditions, temperature, humidity (approximate), altitude (if unusually high), and time of day.

While the hammer is on the ground, try to find an identifying imprint on the hammer. If apparent, record its serial number and/or other identifiers and enter under the CATEGORY. At the same time, check whether the hammer had been cared for by covering the cylinder top and the exhaust ports. Remove cover on cylinder top and inspect smoothness of cylinder. Take notes if you observe an unusual item.

Before using the hammer, the hammer cushion material and its thickness has to be checked. Compare its appearance with the descriptions in the inspection manual. The frequency of this check depends on the number of blows which the hammer cushion has already endured. Similarly, identify the helmet and inserts, if any, such that a determination of its weight is possible. Check and record the appearance of the recoil dampener. Before driving starts, assure that all cylinder and exhaust port covers are removed and that the impact block is greased (a few hammers have an automatic greasing of the impact block; check this with the contractor).

If a pile cushion has to be used, check the engineer's specifications for the frequency of replacement. Merely maintaining a certain cushion thickness by adding material may produce a very hard cushion after some time. You should be able to tell how many blows have been applied to each layer of cushioning. More than 1500 blows on plywood is excessive.

Record the pile material, length, cross sectional size, and batter. From the Saximeter™ output, obtain the computed stroke or ram energy. Try to ascertain blows per foot using the Saximeter™, or observe independently and record. Make sure to attach the complete Saximeter™ record to your data sheet.

Observe the gap between impact block (recoil dampener) and cylinder, and see whether an unusually high rebound can be observed. Similarly, attempt to realize whether or not the pile rebounds excessively. If the pile has a long unsupported length, check to see whether it whips, i.e., whether it moves laterally. At the same time, check the hammer pile alignment, preferably from two directions. If there are problems, try to have them corrected. If they cannot be corrected, record your observations.

Crane and lead type may only need to be recorded in the beginning of the job. However, the straightness and greasing of the leads should be checked occasionally, particularly where the hammer is in contact with the leads. Furthermore, during pile driving, check the color of the smoke. In hard driving, listen carefully for steel-to-steel impact. If you suspect a preignition problem, take a break in pile driving and restart after 15 minutes.

#### FORM 4: Closed End Diesel Hammers

Select proper sheet according to designation in the upper right hand corner.

On the upper right hand side, fill in an identification for PROJECT/PILE, enter date and general weather conditions, temperature, humidity (approximate), altitude (if unusually high), and time of day.

While the hammer is on the ground, try to find an identifying imprint on the hammer. If apparent, record its serial number and/or other identifiers and enter under the CATEGORY. At the same time, check whether the hammer had been cared for by covering the exhaust ports.

Before using the hammer, the hammer cushion material and its thickness has to be checked. Compare its appearance with the descriptions in the inspection manual. The frequency of this check depends on the number of blows which the hammer cushion has already endured. Similarly, identify the helmet and inserts, if any, such that a determination of its weight is possible. Check and record the appearance of the recoil dampener. Before driving starts, ensure that all exhaust port covers are removed and that the impact block is greased (a few hammers have an automatic greasing of the impact block, check this with the contractor).

If a pile cushion has to be used, check the engineer's specifications for the frequency of replacement. Merely maintaining a certain cushion thickness by adding material may produce a very hard cushion after some time. You should be able to tell how many blows have been applied to each layer of cushioning. More than 1500 blows is excessive for plywood.

Record the pile material, length, cross sectional size, and batter.

Obtain bounce chamber gauge from the contractor. Measure bounce chamber gauge hose length, write it in form, and obtain chart relating bounce chamber pressure to energy. Note that the bounce pressure indicates lower for longer hose length. Be sure that gauge and hose match your particular hammer. If the hammer is fitted with a compression tank, check that its oil is drained daily or else your bounce chamber pressures may be wrong.

From the Saximeter™ output, obtain blows per minute. Measure blows per foot using the Saximeter™, or observe blow count independently and record. Make sure to attach the complete Saximeter™ record to your data sheet.

During driving, check whether liftoff occurs and whether or not the hammer runs at full throttle. Record time of day and blow count when fuel reduction is made. Again, it is important that the fuel setting at the time of final blow count is known.

Observe the gap between impact block (recoil dampener) and cylinder, and see whether an unusually high rebound can be observed. Similarly, attempt to realize whether or not the pile rebounds excessively. If the pile has a long unsupported length, check to see whether it whips, i.e., whether it moves laterally. At the same time, check the hammer pile alignment, preferably from

FORM 4 (continued)

two directions. If there are problems, try to have them corrected. If they cannot be corrected, record your observations.

Crane and lead type may only need to be recorded in the beginning of the job. However, the straightness and greasing of the leads should be checked occasionally, particularly where the hammer is in contact with the leads. Furthermore, during pile driving, check the color of the smoke. In hard driving, listen carefully for steel-to-steel impact. If you suspect a preignition problem, take a break in pile driving and restart after 15 minutes.

PROJECT/PILE: \_\_\_\_\_  
 DATE: \_\_\_\_\_  
 CONDITIONS: \_\_\_\_\_

HAMMER NAME: \_\_\_\_\_  
 CATEGORY: \_\_\_\_\_  
 ID: \_\_\_\_\_

OBJECT	REQUIREMENT	OBSERVATION
Slide Bar/Trips	Greased? Tight?	Yes/No Remarks _____
Piston Rod		
Columns . . . .	Greased? . . . .	Yes/No
Ram Keys . . . .	Tight? . . . .	Yes/No
Column Keys or Cables . . . .	Tight? . . . .	Yes/No
Striker Plate	t=___dia.=_____	t=_____dia.=_____
Hammer Cushion	t=___dia.=_____	t=_____dia.=_____
		Material _____
		How Long in Use? _____
Follower . . . . .		Yes/No Type? _____
Helmet . . . . .		Type or Weight? _____
Pile Cushion . . . . .		Material _____
		Size _____
		How Long in Use? _____
Pile . . . . .		Material _____
		Length _____ Size _____
		Batter _____
Hose . . . . .	Size ___"I.D. . .	Size _____"I.D.
		Length _____
		Leaks Apparent? _____
		Obstructions? _____
Lubricator . . . .	Filled? . . . .	Yes/No
Pressure . . . . .	___psi at Hammer	Measured psi _____ at _____ ft from Hammer
		Fluctuating during driving? Yes/No How Much? _____
<input type="checkbox"/> Compressor? . .	Size _____ CFM . .	Size _____
<input type="checkbox"/> Boiler?		Make _____
(check appropriate)		

**MANUFACTURER'S HAMMER DATA**

Ram Weight \_\_\_\_\_  
 Max. Stroke \_\_\_\_\_  
 Rated Energy \_\_\_\_\_  
 Blows/Min. in Hard \_\_\_\_\_  
 Driving \_\_\_\_\_

**ATTACH SAXIMETER PRINTOUT**

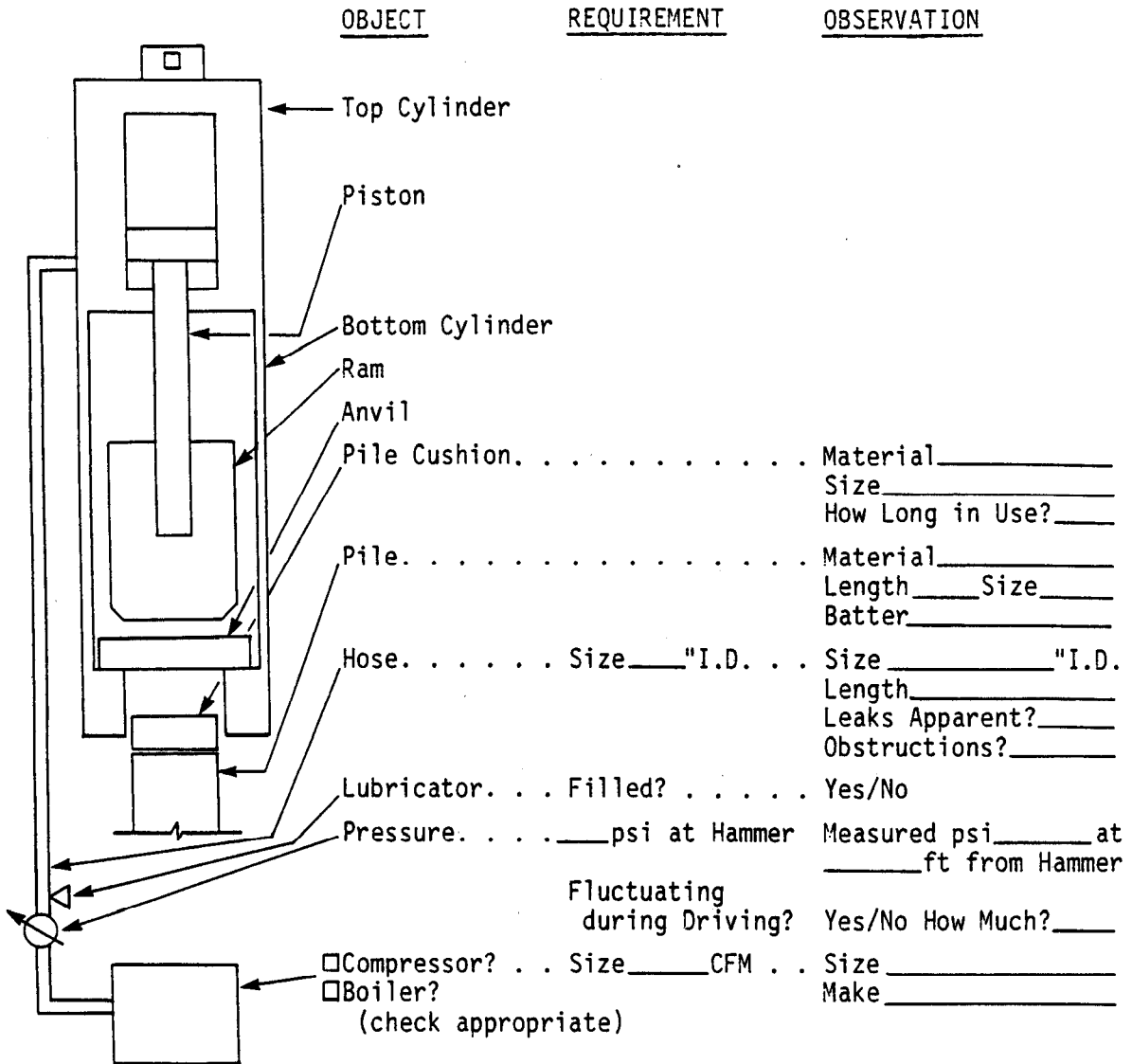
**OBSERVATION WHEN BEARING IS CONFIRMED**

Full Ram Stroke	Yes/No	% _____
Blows/Minute		_____
Blows/Foot		_____
High Pile Rebound	Yes/No	
Pile Whipping	Yes/No	
Pile-Hammer Alignment	Front/Back	___ Sides ___
Crane Size and Make		_____
Lead Type		_____
Hammer Lead Guides Lubricated	Yes/No	
Piston Rod Lubricated	Yes/No	
Exhaust, Description	Freezing? Condensating?	
	Lubricant Apparent?	

Figure 20. Field Inspection Form No. 1

PROJECT/PILE: \_\_\_\_\_  
 DATE: \_\_\_\_\_  
 CONDITIONS: \_\_\_\_\_

HAMMER NAME: \_\_\_\_\_  
 CATEGORY: \_\_\_\_\_  
 ID: \_\_\_\_\_



OBJECT

REQUIREMENT

OBSERVATION

Material \_\_\_\_\_  
 Size \_\_\_\_\_  
 How Long in Use? \_\_\_\_\_  
 Material \_\_\_\_\_  
 Length \_\_\_\_\_ Size \_\_\_\_\_  
 Batter \_\_\_\_\_  
 Size \_\_\_\_\_ "I.D." \_\_\_\_\_  
 Length \_\_\_\_\_  
 Leaks Apparent? \_\_\_\_\_  
 Obstructions? \_\_\_\_\_  
 Yes/No  
 Measured psi \_\_\_\_\_ at \_\_\_\_\_ ft from Hammer  
 Fluctuating during Driving? Yes/No How Much? \_\_\_\_\_  
 Size \_\_\_\_\_ CFM \_\_\_\_\_  
 Make \_\_\_\_\_

MANUFACTURER'S HAMMER DATA

Ram Weight \_\_\_\_\_  
 Max. Stroke \_\_\_\_\_  
 Rated Energy \_\_\_\_\_  
 Blows/Min. in Hard Driving \_\_\_\_\_

ATTACH SAXIMETER PRINTOUT

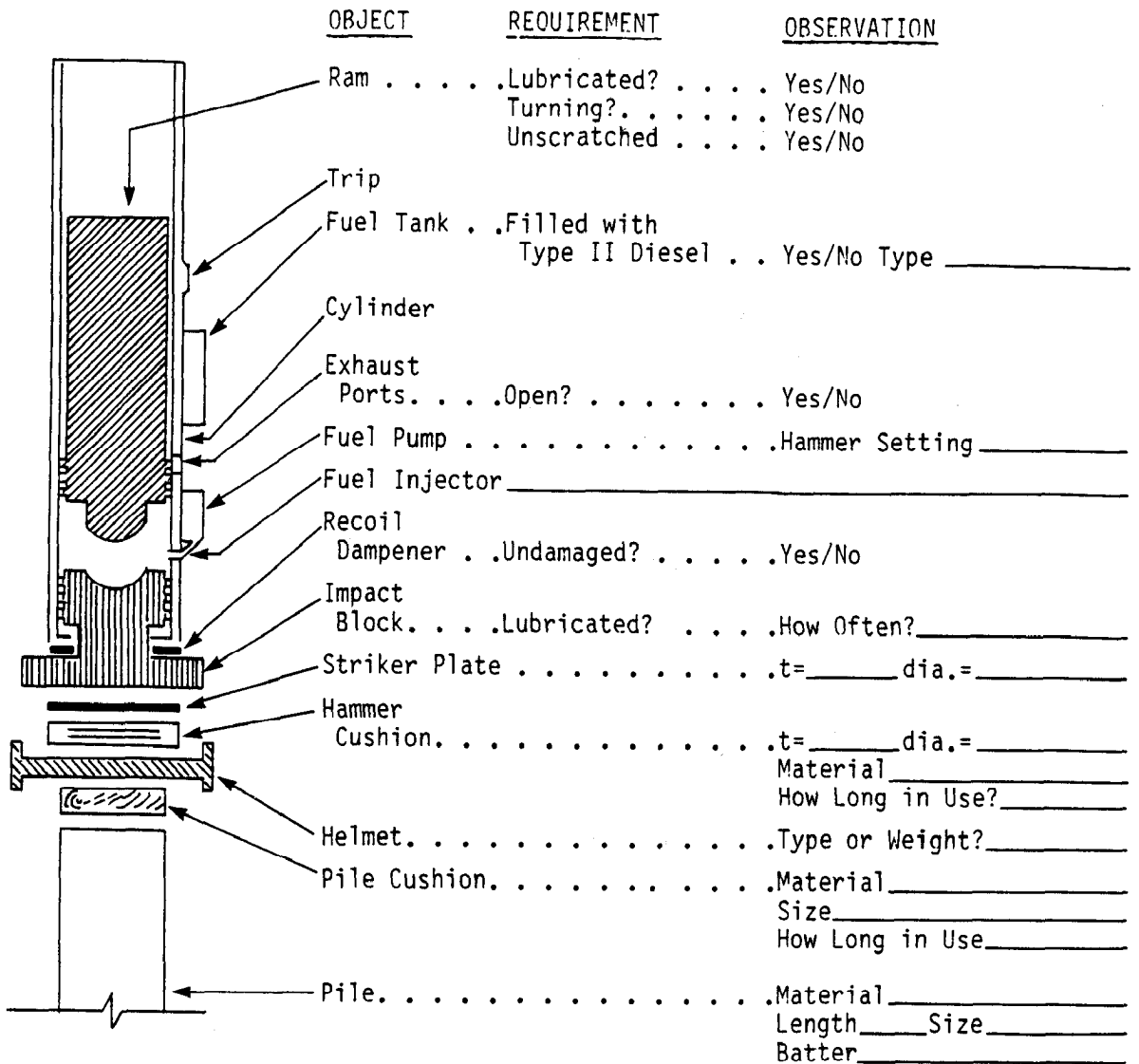
OBSERVATION WHEN BEARING IS CONFIRMED

Hammer Uplifting Yes/No  
 Reduced Pressure Yes/No  
 Blows/Minute \_\_\_\_\_  
 Blows/Foot \_\_\_\_\_  
 High Pile Rebound Yes/No  
 Pile Whipping Yes/No  
 Pile-Hammer Alignment Front/Back \_\_\_\_\_ Sides \_\_\_\_\_  
 Crane Size and Make \_\_\_\_\_  
 Lead Type \_\_\_\_\_  
 Hammer Lead Guides \_\_\_\_\_  
 Lubricated Yes/No

Figure 21. Field Inspection Form No. 2

PROJECT/PILE: \_\_\_\_\_  
 DATE: \_\_\_\_\_  
 CONDITIONS: \_\_\_\_\_

HAMMER NAME: \_\_\_\_\_  
 CATEGORY: \_\_\_\_\_



MANUFACTURER'S HAMMER DATA

Ram Weight \_\_\_\_\_

Hammer Setting	Rated Energy kip-ft	Rated Stroke ft
min.		
max.		

ATTACH SAXIMETER PRINTOUT

OBSERVATION WHEN BEARING IS CONFIRMED

Excessive Cylinder Rebound	Yes/No
High Pile Rebound	Yes/No
Pile Whipping	Yes/No
Pile-Hammer Alignment	Front/Back ___ Sides _____
Crane Size and Make	_____
Lead Type	_____
Hammer Lead Guides	_____
Lubricated	Yes/No
Color of Smoke	_____
Steel-to-Steel Impact Sound	_____

Figure 22. Field Inspection Form No. 3

PROJECT: \_\_\_\_\_  
 DATE: \_\_\_\_\_  
 CONDITIONS: \_\_\_\_\_

HAMMER NAME: \_\_\_\_\_

CATEGORY: \_\_\_\_\_

<u>OBJECT</u>	<u>REQUIREMENT</u>	<u>OBSERVATION</u>
Bounce Chamber		
Compression Tank . . . . .	.Drained Daily?	Yes/No
Ram . . . . .	.Lubricated?	Yes/No
Cylinder		
Trip		
Fuel Tank . . . . .	.Filled with Type II Diesel?	Yes/No Type? _____
Exhaust Ports . . . . .	.Open? . . . . .	Yes/No
Fuel Pump		
Fuel Injector		
Recoil Dampener	Undamaged? . . . . .	Yes/No
Impact Block . . . . .	Lubricated? . . . . .	Yes/No
Striker Plate . . . . .		t=____ dia.= _____
Hammer Cushion . . . . .		t=____ dia.= _____ Material _____ How Long in Use? _____
Helmet . . . . .		Type or Weight? _____
Pile Cushion . . . . .		Material _____ Size _____ How Long in Use? _____
Pile . . . . .		Material _____ Length _____ Size _____ Batter _____
Bounce Chamber Pressure Gauge		
Hose . . . . .		Length _____

MANUFACTURER'S HAMMER DATA

Ram Weight \_\_\_\_\_  
 Max. Stroke \_\_\_\_\_

Bounce Chamber Pressure (psi)	Rated Energy (kip-ft)

OBSERVATION WHEN BEARING IS CONFIRMED

Bounce Chamber Pressure \_\_\_\_\_  
 Cylinder Lift-Off \_\_\_\_\_  
 Excessive Cylinder Rebound \_\_\_\_\_  
 High Pile Rebound \_\_\_\_\_  
 Pile Whipping \_\_\_\_\_  
 Pile-Hammer Alignment \_\_\_\_\_  
 Crane Size and Make \_\_\_\_\_  
 Lead Type \_\_\_\_\_  
 Hammer Lead Guides Lubricated \_\_\_\_\_  
 Color of Smoke \_\_\_\_\_  
 Steel-to-Steel Impact Sound \_\_\_\_\_

Time or Depth \_\_\_\_\_  
 Yes/No \_\_\_\_\_  
 Yes/No \_\_\_\_\_  
 Front/Back \_\_\_\_\_ Sides \_\_\_\_\_  
 \_\_\_\_\_  
 Yes/No \_\_\_\_\_  
 Yes/No \_\_\_\_\_

ATTACH SAXIMETER PRINTOUT

Figure 23. Field Inspection Form No. 4

TABLE 1: Single/Double Acting Air/Steam, Hydraulic Hammers

Hammer Name	Model	Category	Form No.	Striker Thick in	Plate Diam. in	Hammer Thick in	Cushion Diam. in	Compressor/Boiler Size CFM/HP	Air/Steam Hose(s) Diameter in	Press. @ Hammer psi	Bl/Min In Hard Driv. b/min	Ram Wt. kips	Max. Stroke ft	Rated Energy kip-ft
CONMACO	50E3	A-S/SA	1	2.50	12.00	6.25 <sup>a</sup>	11.75	--	2.00	80	64	5.00	3.00	15.00
CONMACO	65E3	A-S/SA	1	2.50	12.00	6.25 <sup>a</sup>	11.75	--	2.00	100	61	6.50	3.00	19.50
CONMACO	50E5	A-S/SA	1	2.50	12.00	6.25 <sup>a</sup>	11.75	--	2.00	90	48	5.00	5.00	25.00
CONMACO	80E3	A-S/SA	1	3.00	14.50	8.00 <sup>a</sup>	14.25	--	2.50	83	56	8.00	3.25	26.00
CONMACO	100E3	A-S/SA	1	3.00	14.50	8.00 <sup>a</sup>	14.25	--	2.50	100	55	10.00	3.25	32.50
CONMACO	65E5	A-S/SA	1	2.50	12.00	6.25 <sup>a</sup>	11.75	--	2.00	110	50	6.50	5.00	32.50
CONMACO	115E3	A-S/SA	1	3.00	14.50	8.00 <sup>a</sup>	14.25	--	2.50	120	52	11.50	3.25	37.375
CONMACO	80E5	A-S/SA	1	3.00	14.50	8.00 <sup>a</sup>	14.25	--	2.50	80	47	8.00	5.00	40.00
CONMACO	140E3	A-S/SA	1	3.50	18.00	6.00 <sup>b</sup>	17.75	--	3.00	110	55	14.00	3.00	42.00
CONMACO	160E3	A-S/SA	1	3.50	18.00	6.00 <sup>b</sup>	17.75	--	3.00	120	50	16.25	3.00	48.75
CONMACO	100E5	A-S/SA	1	3.00	14.50	8.00 <sup>a</sup>	14.25	--	2.50	100	47	10.00	5.00	50.00
CONMACO	115E5	A-S/SA	1	3.00	14.50	8.00 <sup>a</sup>	14.25	--	2.50	100	42	11.50	5.00	57.50
CONMACO	200E3	A-S/SA	1	3.50	23.25	8.00 <sup>c</sup>	23.00	--	3.00	120	55	20.00	3.00	60.00
CONMACO	125E5	A-S/SA	1	3.00	14.50	8.00 <sup>a</sup>	14.25	--	2.50	100	41	12.50	5.00	62.50
CONMACO	300E3	A-S/SA	1	3.50	23.25	8.00 <sup>c</sup>	23.00	--	3.00	150	52	30.00	3.00	90.00
CONMACO	200E5	A-S/SA	1	3.50	23.25	8.00 <sup>c</sup>	23.00	--	4.00	110	46	20.00	5.00	100.00
CONMACO	300E5	A-S/SA	1	3.50	23.25	8.00 <sup>c</sup>	23.00	2148 <sup>d</sup>	4.00	160	40	30.00	5.00	150.00
CONMACO	450E5	A-S/SA	1	6.00	32.125	9.00	31.875	--	4.00	130	45	45.00	5.00	225.00
CONMACO	700E5	A-S/SA	1	6.00	42.375	9.00	42.125	4502 <sup>d</sup>	4.00	160	43	70.00	5.00	350.00
CONMACO	850E6	A-S/SA	1	6.00	42.375	9.00	42.125	5889 <sup>d</sup>	6.00	180	40	85.00	6.00	510.00
MKT	5	A-S/DA/DA	2	--	--	--	--	250 <sup>e</sup> /20	1.25	100	300	.20	.58	1.00
MKT	6	A-S/DA/DA	2	--	--	--	--	400 <sup>e</sup> /25	1.25	100	275	.40	.73	2.50
MKT	7	A-S/DA/DA	2	--	--	--	--	450 <sup>e</sup> /35	1.50	100	225	.80	.79	4.15
MKT	9B3	A-S/DA/DA	2	--	--	--	--	600	2.00	100	145	1.60	1.42	8.75
MKT	10B3	A-S/DA/DA	2	--	--	--	--	750	2.50	100	105	3.00	1.58	13.10
MKT	C-5(AIR)	A-S/DA/CO	2	--	--	--	--	--	2.50	100	100-110	5.00	1.46	14.21
MKT	C-5(STEAM)	A-S/DA/DA	2	--	--	--	--	--	2.50	100	100-110	5.00	1.50	16.21
MKT	S-5	A-S/SA	2	--	--	--	--	--	2.00	80	60	5.00	3.25	16.25
MKT	11B3	A-S/DA/DA	2	--	--	--	--	900	2.50	100	95	5.00	1.58	19.15
MKT	C-826(AIR)	A-S/DA/CO	2	--	--	--	--	--	2.50	125	85-95	8.00	1.46	21.21
MKT	C-826(STEAM)	A-S/DA/CO	2	--	--	--	--	--	2.50	125	85-95	8.00	1.50	24.38
MKT	S-8	A-S/SA	2	--	--	--	--	850 <sup>e</sup> /120	2.50	80	55	8.00	3.25	26.00
MKT	MS-350	A-S/SA	1	--	--	--	--	900 <sup>e</sup>	2.50	105	40-50	7.716	4.00	30.80
MKT	S-10	A-S/SA	2	--	--	--	--	1000 <sup>e</sup> /130	2.50	80	55	10.00	3.25	32.50
MKT	S-14	A-S/SA	2	--	--	--	--	/155	3.00	100	60	14.00	2.67	37.50
MKT	MS-500	A-S/SA	1	--	--	--	--	1200 <sup>e</sup>	3.00	115	40-50	11.00	4.00	44.00
MKT	S-20	A-S/SA	2	--	--	--	--	/190	3.00	150	60	20.00	3.00	60.00
RAYMOND	1	A-S/SA	1	2.00	10.50	18.00	10.50	600 /81	1.50	80	60	5.00	3.00	15.00
RAYMOND	1-S	A-S/SA	1	2.00	10.50	18.00	10.50	750 /94	1.50	100	58	6.50	3.00	19.50
RAYMOND	65C	A-S/DA/DI	1	2.00	10.50	18.00	10.50	991 /152	2.00	120	110	6.50	1.33	19.50
RAYMOND	65CH	H/DA/DI	1	2.00	10.50	18.00	10.50	--	1.00	5000	128-136	6.50	1.33	19.50
RAYMOND	0	A-S/SA	1	3.50	13.70	16.50	13.70	841 /128	2.00	110	50	7.50	3.25	24.375
RAYMOND	80C	A-S/DA/DI	1	3.50	13.70	16.50	13.70	1300 /180	2.50	120	95-105	8.00	1.38	24.45
RAYMOND	80CH	H/DA/DI	1	3.50	13.70	16.50	13.70	--	1.00	5000	110-120	8.00	1.38	24.45
RAYMOND	2/0	A-S/SA	1	3.50	13.70	16.50	13.70	1050 /150	2.00	110	50	10.00	3.25	32.50

08



TABLE 1 (Cont.): Single/Double Acting Air/Steam, Hydraulic Hammers

Hammer Name	Model	Category	Form No.	Striker Thick in	Plate Diam. in	Hammer Thick in	Cushion Diam. in	Compressor/Boiler Size CFM/HP	Air/Steam Hose(s) Diameter in	Press. @ Hammer psi	Bl/Min In Hard Driv. b/min	Ram Wt. kips	Max. Stroke ft	Rated Energy kip-ft
RAYMOND	3/0	A-S/SA	1	3.50	13.70 <sup>f</sup>	16.50 <sup>g</sup>	13.70 <sup>f</sup>	--	2.50	120	50	12.50	3.25	40.625
RAYMOND	150C	A-S/DA/DI	1	3.75	17.30	16.00	17.30	--	3.00	120	95-105	15.00	1.50	48.75
RAYMOND	4/0	A-S/SA	1	3.50	13.70 <sup>f</sup>	16.50 <sup>g</sup>	13.70 <sup>f</sup>	--	2.50	120	46	15.00	3.25	48.75
RAYMOND	5/0	A-S/SA	1	3.50	13.70 <sup>f</sup>	16.50 <sup>g</sup>	13.70 <sup>f</sup>	--	3.00	150	44	17.50	3.25	56.875
RAYMOND	30X	A-S/SA	1	3.50	17.30	19.25	17.30	--	3.00	150	70	30.00	2.50	75.00
RAYMOND	8/0	A-S/SA	1	5.625	17.30	23.25	17.30	--	3.00	135	40	25.00	3.25	81.25
RAYMOND	40X	A-S/SA	1	3.50	17.30	19.25	17.30	--	3.00	135	64	40.00	2.50	100.00
RAYMOND	60X	A-S/SA	1	3.50	17.30	19.25	17.30	--	4.00	210	60	60.00	2.50	150.00
VULCAN	2	A-S/SA	1	1.50	10.25	7.00	10.25	336 <sup>d</sup> /49	1.50	80	70	3.00	2.42	7.26
VULCAN	30C	A-S/DA/DI	1	1.50	10.25	7.00	10.25	488 <sup>d</sup> /40	1.50	120	133	3.00	1.04	7.26
VULCAN	1(1-105)	A-S/SA	1	1.50	11.25	7.375	11.25	600 /81	2.00	80	60	5.00	3.00	15.00
VULCAN	50C	A-S/DA/DI	1	1.50	11.25	7.375	11.25	900 /125	2.00	120	117	5.00	1.29	15.10
VULCAN	65C	A-S/DA/DI	1	1.50	11.25	7.375	11.25	991 /152	2.00	150	117	6.50	1.29	19.20
VULCAN	06	A-S/SA	1	1.50	11.25	7.375	11.25	750 /94	2.00	100	60	6.50	3.00	19.50
VULCAN	06-106	A-S/SA	1	1.50	11.25	7.375	11.25	750 /94	2.00	100	60	6.50	3.00	19.50
VULCAN	65CA	A-S/DA/DI	1	2.00	13.75	8.50	13.75	1200 /160	2.50	95	107	6.50	1.375	19.58
VULCAN	0	A-S/SA	1	2.00	13.75	8.50	13.75	841 /128	2.50	80	50	7.50	3.25	24.375
VULCAN	80C	A-S/DA/DI	1	2.00	13.75	8.50	13.75	1300 /180	2.50	120	109	8.00	1.375	24.45
VULCAN	08	A-S/SA	1	2.00	13.75	8.50	13.75	900 /125	2.50	83	50	8.00	3.25	26.00
VULCAN	85C	A-S/DA/DI	1	2.00	13.75	8.50	13.75	1245 /180	2.50	128	111	8.525	1.375	26.00
VULCAN	506	A-S/SA	1	1.50	11.25	7.375	11.25	900 /112	2.00	100	46	6.50	5.00	32.50
VULCAN	010	A-S/SA	1	2.00	13.75	8.50	13.75	1050 /150	2.50	105	50	10.00	3.25	32.50
VULCAN	100C	A-S/DA/DI	1	2.00	13.75	8.50	13.75	1245 /180	2.50	140	103	10.00	1.375	32.88
VULCAN	140C	A-S/DA/DI	1	2.00	17.25	7.00	17.25	1600 /211	3.00	140	101	14.00	1.29	36.00
VULCAN	012	A-S/SA	1	2.00	13.75	8.50	13.75	1200 /175	2.50	125	50	12.00	3.25	39.00
VULCAN	508	A-S/SA	1	2.00	13.75	8.50	13.75	900 /150	2.50	65	41	8.00	5.00	40.00
VULCAN	014	A-S/SA	1	2.00	17.25	7.00	17.25	1300 /200	3.00	110	59	14.00	3.00	42.00
VULCAN	016	A-S/SA	1	2.00	17.25	7.00	17.25	1300 /210	3.00	120	58	16.25	3.00	48.75
VULCAN	510	A-S/SA	1	2.00	13.75	8.50	13.75	1050 /160	2.50	83	41	10.00	5.00	50.00
VULCAN	200C	A-S/DA/DI	1	2.00	19.50	7.00	19.50	2002 /222	4.00	142	95	20.00	1.29	50.20
VULCAN	512	A-S/SA	1	2.00	13.75	8.50	13.75	1200 /200	2.50	100	41	12.00	5.00	60.00
VULCAN	320	A-S/SA	1	4.00	22.50	5.00	22.50	1600 /200	3.00	102	55	20.00	3.00	60.00
VULCAN	020	A-S/SA	1	4.00	19.50	7.00	19.50	--	3.00	120	59	20.00	3.00	60.00
VULCAN	030	A-S/SA	1	4.00	19.50	7.00	19.50	2000 /250	3.00	150	54	30.00	3.00	90.00
VULCAN	330	A-S/SA	1	4.00	22.50	5.00	22.50	2000 /250	3.00	150	54	30.00	3.00	90.00
VULCAN	520	A-S/SA	1	4.00	22.50	5.00	22.50	2000 /250	3.00	102	42	20.00	5.00	100.00
VULCAN	040	A-S/SA	1	4.00	25.25	9.50	25.25	3400 <sup>d</sup> /354	3.00	120	60	40.00	3.00	120.00
VULCAN	340	A-S/SA	1	4.00	25.25	9.50	25.25	3400 <sup>d</sup> /354	3.00	120	60	40.00	3.00	120.00
VULCAN	530	A-S/SA	1	4.00	22.50	5.00	22.50	2400 /300	3.00	150	42	30.00	5.00	150.00
VULCAN	060	A-S/SA	1	6.00	27.25	6.50	27.25	4626 <sup>d</sup> /750	4.00	130	62	60.00	3.00	180.00
VULCAN	360	A-S/SA	1	6.00	27.25	6.50	27.25	4626 <sup>d</sup> /750	4.00	130	62	60.00	3.00	180.00
VULCAN	540	A-S/SA	1	6.00	27.25	7.50	27.25	3753 <sup>d</sup> /400	4.00	130	48	40.90	5.00	204.50
VULCAN	560	A-S/SA	1	6.00	31.25	7.50	31.25	5410 <sup>d</sup> /606	4.00	150	47	62.50	5.00	312.50
VULCAN	3100	A-S/SA	1	6.00	36.25	7.50	36.25	--	4.00	130	60	100.00	3.00	300.00
VULCAN	5100	A-S/SA	1	6.00	41.25	7.50	41.25	9326 <sup>d</sup> /1043	4.00	150	48	100.00	5.00	500.00
VULCAN	5150	A-S/SA	1	6.00	45.25	9.50	45.25	11399 <sup>d</sup> /1317	6.00	175	46	150.00	5.00	750.00

TABLE 1 (Cont.): Single/Double Acting Air/Steam, Hydraulic Hammers

Hammer Name	Model	Category	Form No.	Striker Thick in	Plate Diam. in	Hammer Thick in	Cushion Diam. in	Compressor/Boiler Size CFM/HP	Air/Steam Hose(s) Diameter in	Press. @ Hammer psi	B1/Min In Hard Driv. b/min	Ram Wt. kips	Max. Stroke ft	Rated Energy kip-ft
VULCAN	5250	A-S/SA	1	8.00	66.00	10.50	66.00	13846 <sup>d</sup> /1639	6.00	200	38	250.00	5.00	1250.00
VULCAN	6300	A-S/SA	1	8.00	71.25	10.50	71.25	21061 <sup>d</sup> /2450	6.00	175	42	300.00	6.00	1800.00

NOTES:

- a Thickness can also be 18.5 in.
- b Thickness can also be 18.0 in.
- c Thickness can also be 29.0 in.
- d Increase 30% for actual size.
- e Should be able to deliver 150%.
- f Diameter can also be 17.3 in.
- g Thickness can also be 23.5 in.

TABLE 2: Single Acting Diesel Hammers

Hammer Name	Model	Category	Form No.	Ram Weight kip	Stroke @ Hammer Settings				Rated Energy @ Hammer Settings			
					1 ft	2 ft	3 ft	4 ft	1 kip-ft	2 kip-ft	3 kip-ft	4 kip-ft
BERMINGHAMMER	B-200	D/SA/LI	3	2.000	9.00	--	--	--	18.00	--	--	--
BERMINGHAMMER	B-225	D/SA/LI	3	3.000	9.67	--	--	--	29.00	--	--	--
BERMINGHAMMER	B-300	D/SA/LI	3	3.750	9.07	--	--	--	34.00	--	--	--
BERMINGHAMMER	B-400	D/SA/LI	3	5.000	9.20	--	--	--	46.00	--	--	--
BERMINGHAMMER	B-500	D/SA/LI	3	6.900	11.45	--	--	--	79.00	--	--	--
DELMAG	D5	D/SA/LI	3	1.100	7.50	--	--	--	8.25	--	--	--
DELMAG	D8-22	D/SA/LI	3	1.762	5.33	6.92	8.46	10.02	9.40	12.20	14.90	17.65
DELMAG	D12	D/SA/LI	3	2.750	8.62	--	--	--	23.70	--	--	--
DELMAG	D15	D/SA/LI	3	3.300	8.61	--	--	--	28.40	--	--	--
DELMAG	D16-3	D/SA/LI	3	3.520	5.36	7.30	9.24	11.18	18.86	25.70	32.52	39.34
DELMAG	D22	D/SA/LI	3	4.970	8.17	--	--	--	40.60	--	--	--
DELMAG	D22-13	D/SA/LI	3	4.850	5.34	6.91	8.45	10.00	25.90	33.50	41.00	48.50
DELMAG	D22-23	D/SA/LI	3	4.850	6.30	7.73	9.14	10.57	30.56	37.50	44.35	51.24
DELMAG	D25-32	D/SA/LI	3	5.510	6.82	8.27	9.71	11.16	37.60	45.60	53.50	61.50
DELMAG	D30	D/SA/LI	3	6.600	9.04	--	--	--	59.70	--	--	--
DELMAG	D30-02	D/SA/LI	3	6.600	5.36	6.91	8.47	10.03	35.40	45.60	55.90	66.20
DELMAG	D30-13	D/SA/LI	3	6.600	5.36	6.91	8.47	10.03	35.40	45.60	55.90	66.20
DELMAG	D30-23	D/SA/LI	3	6.600	6.83	8.29	9.73	11.18	45.10	54.70	64.20	73.80
DELMAG	D30-32	D/SA/LI	3	6.600	6.83	8.29	9.73	11.18	45.10	54.70	64.20	73.80
DELMAG	D36	D/SA/LI	3	7.930	5.18	6.99	8.78	10.57	41.10	55.40	69.60	83.80
DELMAG	B36-02	D/SA/LI	3	7.930	5.18	6.99	8.78	10.57	41.10	55.40	69.60	83.80
DELMAG	D36-13	D/SA/LI	3	7.930	5.18	6.99	8.78	10.57	41.10	55.40	69.60	83.80
DELMAG	D36-23	D/SA/LI	3	7.930	6.83	8.27	9.71	11.16	54.20	65.60	77.00	88.50
DELMAG	D36-32	D/SA/LI	3	7.930	6.83	8.27	9.71	11.16	54.20	65.60	77.00	88.50
DELMAG	D44	D/SA/LI	3	9.500	9.49	--	--	--	90.20	--	--	--
DELMAG	D46-13	D/SA/LI	3	10.140	5.15	6.61	8.07	9.52	52.20	67.00	81.80	96.50
DELMAG	D46	D/SA/LI	3	10.140	5.18	6.95	8.76	10.56	52.50	70.50	88.80	107.10
DELMAG	D46-02	D/SA/LI	3	10.140	5.18	6.95	8.76	10.56	52.50	70.50	88.80	107.10
DELMAG	D46-23	D/SA/LI	3	10.140	6.56	7.89	9.23	10.56	66.50	80.00	93.60	107.10
DELMAG	D46-32	D/SA/LI	3	10.140	7.15	8.42	9.82	11.15	72.50	85.40	99.60	113.10
DELMAG	D55	D/SA/LI	3	11.860	6.59	7.90	9.22	10.54	78.10	93.70	109.40	125.00
DELMAG	D62-02	D/SA/LI	3	13.660	5.58	7.44	9.30	11.16	76.20	101.60	127.00	152.50
DELMAG	D62-12	D/SA/LI	3	13.660	5.81	7.60	9.38	11.16	79.40	103.80	128.10	152.50
DELMAG	D62-22	D/SA/LI	3	13.660	5.81	7.60	9.38	11.16	79.40	103.80	128.10	152.50
DELMAG	D80-12	D/SA/LI	3	17.620	7.16	8.30	9.44	10.57	126.10	146.20	166.25	186.33
DELMAG	D80-23	D/SA/LI	3	17.620	7.16	8.49	9.83	11.16	126.10	149.60	173.20	196.74
DELMAG	D80	D/SA/LI	3	19.500	6.47	7.42	8.60	11.54	126.19	144.62	167.75	225.00
DELMAG	D100-13	D/SA/LI	3	22.030	7.16	8.49	9.83	11.16	157.70	187.00	216.50	246.00
FEC	1200	D/SA/LI	3	2.750	3.28	5.75	6.95	8.18	9.00	15.80	19.10	22.50
FEC	1500	D/SA/LI	3	3.300	3.28	5.75	6.98	8.21	10.84	18.97	23.04	27.10
FEC	2500	D/SA/LI	3	5.500	3.64	6.36	7.73	9.09	20.00	35.00	42.50	50.00
FEC	3000	D/SA/LI	3	6.600	3.82	6.68	8.11	9.55	25.20	44.10	53.55	63.00
FEC	3400	D/SA/LI	3	7.480	3.88	6.82	8.29	9.76	29.00	51.00	62.00	73.00

TABLE 2 (Cont.): Single Acting Diesel Hammers

Hammer Name	Model	Category	Form No.	Ram Weight kip	Stroke @ Hammer Settings				Rated Energy @ Hammer Settings			
					1 ft	2 ft	3 ft	4 ft	1 kip-ft	2 kip-ft	3 kip-ft	4 kip-ft
HERA	1250	D/SA/LI	3	2.755	9.02	--	--	--	24.88	--	--	--
HERA	1500	D/SA/LI	3	3.305	9.02	--	--	--	29.82	--	--	--
HERA	2500	D/SA/LI	3	5.510	9.02	--	--	--	49.72	--	--	--
HERA	2800	D/SA/LI	3	6.175	9.02	--	--	--	55.72	--	--	--
HERA	3500	D/SA/LI	3	7.715	9.02	--	--	--	69.61	--	--	--
HERA	H-5000	D/SA/LI	3	11.025	9.02	--	--	--	99.48	--	--	--
HERA	5000	D/SA/LI	3	11.025	9.02	--	--	--	99.48	--	--	--
HERA	5700	D/SA/LI	3	12.750	9.02	--	--	--	113.42	--	--	--
HERA	6200	D/SA/LI	3	13.670	9.02	--	--	--	123.34	--	--	--
HERA	H7500	D/SA/LI	3	16.540	9.02	--	--	--	149.24	--	--	--
HERA	7500	D/SA/LI	3	16.540	9.02	--	--	--	149.24	--	--	--
HERA	8800	D/SA/LI	3	19.400	9.02	--	--	--	175.04	--	--	--
KOBE <sup>a</sup>	K13	D/SA/LI	3	2.870	4.60	8.33	8.61	8.85	13.20	23.90	24.70	25.40
KOBE	K22	D/SA/LI	3	4.850	8.52	--	--	--	41.30	--	--	--
KOBE	KC25	D/SA/AI	3	5.150	10.00	--	--	--	51.52	--	--	--
KOBE <sup>a</sup>	K25	D/SA/LI	3	5.510	4.26	8.53	8.91	9.35	23.50	47.00	49.10	51.50
KOBE	K32	D/SA/LI	3	7.050	8.52	--	--	--	60.10	--	--	--
KOBE	KC35	D/SA/AI	3	7.720	9.35	--	--	--	72.18	--	--	--
KOBE <sup>a</sup>	K35	D/SA/LI	3	7.720	4.11	8.69	9.02	9.35	31.70	67.10	69.60	72.20
KOBE	K42	D/SA/LI	3	9.260	8.53	--	--	--	79.00	--	--	--
KOBE	KC45	D/SA/AI	3	9.920	9.35	--	--	--	92.75	--	--	--
KOBE <sup>b</sup>	K45	D/SA/LI	3	9.920	3.93	7.16	9.09	9.35	39.00	71.00	90.20	92.80
KOBE	K60	D/SA/LI	3	13.200	8.00	--	--	--	105.60	--	--	--
KOBE	KB60	D/SA/LI	3	13.230	9.84	--	--	--	130.20	--	--	--
KOBE	KB80	D/SA/LI	3	17.640	9.84	--	--	--	173.60	--	--	--
MKT <sup>c</sup>	DE-10	D/SA/LI	3	1.100	8.00	--	--	--	8.80	--	--	--
MKT <sup>c</sup>	DA-15C	D/SA/LI	3	1.100	6.00	--	--	8.50	6.60	--	--	9.35
MKT <sup>c</sup>	DE-20	D/SA/LI	3	2.000	8.00	--	--	--	16.00	--	--	--
MKT <sup>c</sup>	DE-20B	D/SA/LI	3	2.000	6.00	--	--	8.50	12.00	--	--	17.00
MKT <sup>c</sup>	DE-30	D/SA/LI	3	2.800	8.00	--	--	--	22.40	--	--	--
MKT <sup>c</sup>	DA-35C	D/SA/LI	3	2.800	6.00	--	--	8.50	16.80	--	--	23.80
MKT <sup>c</sup>	DE-30B	D/SA/LI	3	2.800	6.00	--	--	8.50	16.80	--	--	23.80
MKT <sup>c</sup>	DE-33	D/SA/LI	3	3.300	6.00	--	--	8.50	19.80	--	--	28.05
MKT <sup>c</sup>	DE-40	D/SA/LI	3	4.000	8.00	--	--	--	32.00	--	--	--
MKT <sup>c</sup>	DA-45	D/SA/LI	3	4.000	6.00	--	--	8.50	24.00	--	--	34.00
MKT <sup>c</sup>	DA-55B	D/SA/LI	3	5.000	8.00	--	--	--	40.00	--	--	--
MKT <sup>c</sup>	DE-50	D/SA/LI	3	5.000	8.50	--	--	--	42.50	--	--	--
MKT <sup>c</sup>	DE-50B	D/SA/LI	3	5.000	6.00	--	--	8.50	30.00	--	--	42.50
MKT <sup>c</sup>	DA-55C	D/SA/LI	3	5.000	6.00	--	--	8.50	30.00	--	--	42.50
MKT <sup>c</sup>	DE-70B	D/SA/LI	3	7.000	6.00	--	--	8.50	42.00	--	--	59.50
MKT <sup>c</sup>	DE-110	D/SA/LI	3	11.000	6.05	--	--	8.50	66.60	--	--	93.50
MKT <sup>c</sup>	DE-150	D/SA/LI	3	15.000	6.00	--	--	8.50	90.00	--	--	127.50

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TABLE 2 (Cont.): Single Acting Diesel Hammers

Hammer Name	Model	Category	Form No.	Ram Weight kip	Stroke @ Hammer Settings				Rated Energy @ Hammer Settings			
					1	2	3	4	1	2	3	4
					ft	ft	ft	ft	kip-ft	kip-ft	kip-ft	kip-ft
mitsubishi	M14	D/SA/LI	3	2.970	8.50	--	--	--	25.25	--	--	--
mitsubishi	M-145	D/SA/LI	3	2.970	8.75	--	--	--	26.00	--	--	--
mitsubishi	MH-15	D/SA/LI	3	3.310	8.49	--	--	--	28.10	--	--	--
mitsubishi	M23	D/SA/LI	3	5.060	8.50	--	--	--	43.01	--	--	--
mitsubishi	MH25	D/SA/LI	3	5.510	8.51	--	--	--	46.90	--	--	--
mitsubishi	M-33	D/SA/LI	3	7.260	8.50	--	--	--	61.71	--	--	--
mitsubishi	MH35	D/SA/LI	3	7.720	8.50	--	--	--	65.60	--	--	--
mitsubishi	M43	D/SA/LI	3	9.460	8.50	--	--	--	80.41	--	--	--
mitsubishi	MH45	D/SA/LI	3	10.050	8.50	--	--	--	85.40	--	--	--
mitsubishi	MH72B	D/SA/LI	3	15.900	8.50	--	--	--	135.10	--	--	--
mitsubishi	MB70	D/SA/LI	3	15.840	8.90	--	--	--	141.00	--	--	--
mitsubishi	MH80B	D/SA/LI	3	17.600	8.50	--	--	--	149.60	--	--	--
VULCAN	30D	D/SA/LI	3	3.000	10.00	--	--	--	30.00	--	--	--
VULCAN	33D	D/SA/LI	3	3.307	9.98	--	--	--	33.00	--	--	--
VULCAN	66D	D/SA/LI	3	6.614	9.98	--	--	--	66.00	--	--	--
VULCAN	80D	D/SA/LI	3	8.000	10.00	--	--	--	80.00	--	--	--

## NOTES:

- a The strokes and rated energies listed are for hammer settings 1, 5, 7, and 9 (9 position fuel pump).
- b The strokes and rated energies listed are for hammer settings 1, 4, 10, and 13 (13 position fuel pump).
- c These MKT hammers do not have a 4 position fuel pump. The listed strokes and rated energies represent the minimum and maximum range for hammer setting 1 and 4, respectively.

TABLE 3: Double Acting Diesel Hammers

Hammer Name	Model	Category	Form No.	Ram Weight kips	Max Stroke ft	Rated Energy @ Various Bounce Chamber Pressures				
						1	2	3	4	5
						kip-ft @ psi				
ICE	180	D/DA/AI	4	1.725	3.14	4.06 @ 10	5.25 @ 14	6.32 @ 18	7.28 @ 22	8.10 @ 25.74
ICE	440	D/DA/AI	4	4.000	3.12	6.90 @ 6	10.51 @ 10	13.70 @ 14	16.57 @ 18	18.55 @ 21
ICE	422	D/DA/AI	4	4.000	4.17	8.91 @ 6	13.35 @ 10	17.08 @ 14	20.28 @ 18	23.10 @ 22
ICE	520	D/DA/AI	4	5.070	4.03	16.67 @ 12	20.49 @ 16	23.88 @ 20	26.94 @ 24	30.39 @ 29
ICE	640	D/DA/AI	4	6.000	4.90	25.40 @ 14	30.12 @ 19	34.23 @ 24	37.89 @ 29	40.56 @ 33
ICE	660	D/DA/AI	4	7.570	4.17	24.03 @ 9	32.36 @ 13	39.89 @ 17	46.79 @ 21	51.60 @ 24
ICE	1070	D/DA/AI	4	10.000	5.57	35.25 @ 8	47.53 @ 12	57.82 @ 16	66.68 @ 20	72.60 @ 23
LINK-BELT	105	D/DA/AI	4	1.444	2.94	6.50	--	--	--	--
LINK-BELT	180	D/DA/AI	4	1.725	3.14	4.06 @ 10	5.25 @ 14	6.32 @ 18	7.28 @ 22	8.10 @ 25.74
LINK-BELT	312	D/DA/AI	4	3.857	2.58	8.46 @ 10	10.41 @ 13	12.21 @ 16	13.89 @ 19	14.95 @ 21
LINK-BELT	440	D/DA/AI	4	4.000	3.12	6.90 @ 6	10.51 @ 10	13.70 @ 14	16.57 @ 18	18.55 @ 21
LINK-BELT	520	D/DA/AI	4	5.070	3.80	16.67 @ 12	19.58 @ 15	22.24 @ 18	24.68 @ 21	27.66 @ 25
LINK-BELT	660	D/DA/AI	4	7.570	4.17	24.03 @ 9	32.36 @ 13	39.89 @ 17	46.79 @ 21	51.60 @ 24
MKT	DA-15C	D/DA/LI	4	1.100	4.25	8.20	--	--	--	--
MKT	DA-35C	D/DA/LI	4	2.800	4.67	21.00	--	--	--	--
MKT	DA-45	D/DA/LI	4	4.000	4.50	30.70	--	--	--	--
MKT	DA-55B	D/DA/LI	4	5.000	4.75	38.00	--	--	--	--
MKT	DA-55C	D/DA/LI	4	5.000	4.75	38.20	--	--	--	--

# FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH, DEVELOPMENT, AND TECHNOLOGY

The Offices of Research, Development, and Technology (RD&T) of the Federal Highway Administration (FHWA) are responsible for a broad research, development, and technology transfer program. This program is accomplished using numerous methods of funding and management. The efforts include work done in-house by RD&T staff, contracts using administrative funds, and a Federal-aid program conducted by or through State highway or transportation agencies, which include the Highway Planning and Research (HP&R) program, the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board, and the one-half of one percent training program conducted by the National Highway Institute.

The FCP is a carefully selected group of projects, separated into broad categories, formulated to use research, development, and technology transfer resources to obtain solutions to urgent national highway problems.

The diagonal double stripe on the cover of this report represents a highway. It is color-coded to identify the FCP category to which the report's subject pertains. A red stripe indicates category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, and green for category 9.

## *FCP Category Descriptions*

### **1. Highway Design and Operation for Safety**

Safety RD&T addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act. It includes investigation of appropriate design standards, roadside hardware, traffic control devices, and collection or analysis of physical and scientific data for the formulation of improved safety regulations to better protect all motorists, bicycles, and pedestrians.

### **2. Traffic Control and Management**

Traffic RD&T is concerned with increasing the operational efficiency of existing highways by advancing technology and balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, coordinated signal timing, motorist information, and rerouting of traffic.

### **3. Highway Operations**

This category addresses preserving the Nation's highways, natural resources, and community attributes. It includes activities in physical

maintenance, traffic services for maintenance zoning, management of human resources and equipment, and identification of highway elements that affect the quality of the human environment. The goals of projects within this category are to maximize operational efficiency and safety to the traveling public while conserving resources and reducing adverse highway and traffic impacts through protections and enhancement of environmental features.

### **4. Pavement Design, Construction, and Management**

Pavement RD&T is concerned with pavement design and rehabilitation methods and procedures, construction technology, recycled highway materials, improved pavement binders, and improved pavement management. The goals will emphasize improvements to highway performance over the network's life cycle, thus extending maintenance-free operation and maximizing benefits. Specific areas of effort will include material characterizations, pavement damage predictions, methods to minimize local pavement defects, quality control specifications, long-term pavement monitoring, and life cycle cost analyses.

### **5. Structural Design and Hydraulics**

Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highway structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

### **9. RD&T Management and Coordination**

Activities in this category include fundamental work for new concepts and system characterization before the investigation reaches a point where it is incorporated within other categories of the FCP. Concepts on the feasibility of new technology for highway safety are included in this category. RD&T reports not within other FCP projects will be published as Category 9 projects.