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The Wave Equation Page for Piling

An Overview of Pile Driving Equipment

Part I: Impact Hammers

Impact hammers are hammers which drive the pile by first inducing downward velocity in a metal ram, as shown in Figure 1. Upon impact with the pile accessory, the ram creates a force far larger than its weight, which if sufficiently large then moves the pile an increment into the ground. An idealized version of this force is shown in Figure 2.

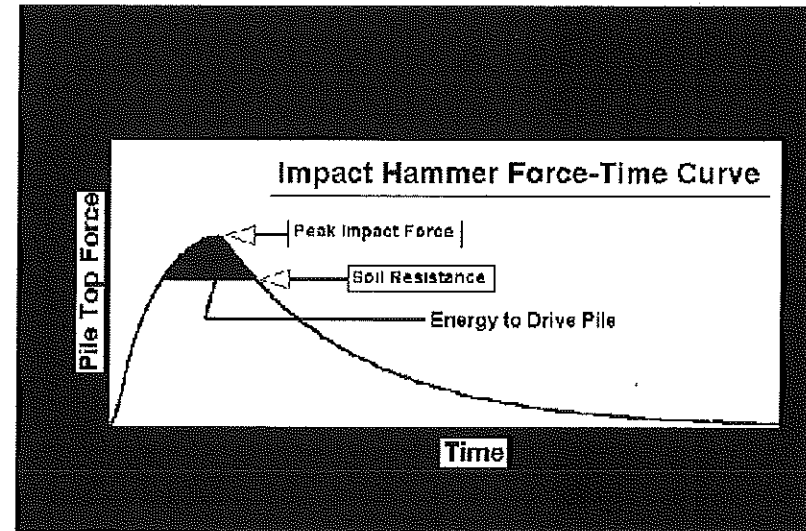
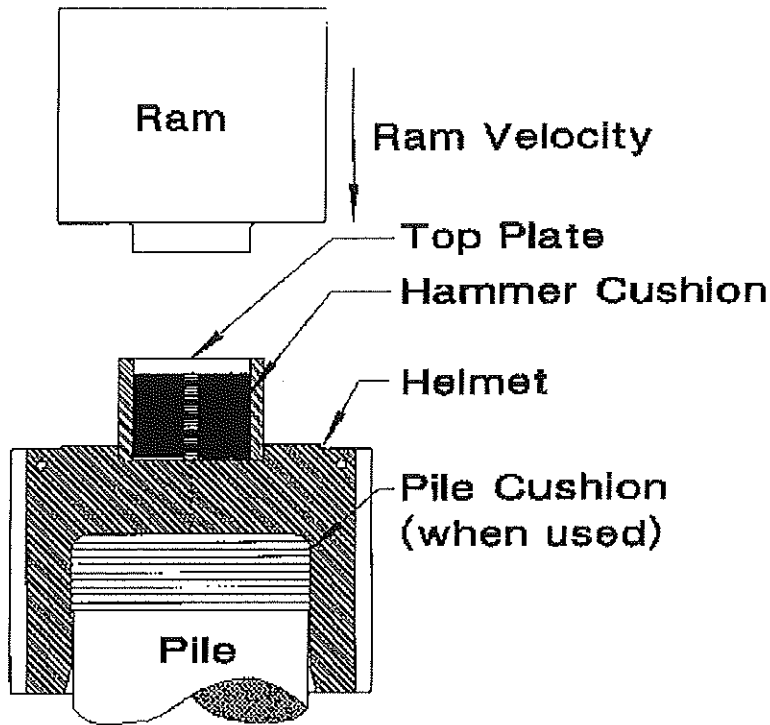


Figure 2 Idealized Hammer Force-Time Curve

Figure 1 Impact Hammer System Schematic

The characteristics, strengths, and weaknesses of various types of impact hammers is shown in Table 1. Impact hammers can be divided into two categories, external combustion and internal combustion hammers.

Table 1 Strengths and Weaknesses of Impact Hammer Types

Hammer Type	Description	Advantages	Disadvantages
External Combustion Hammers			
Drop Hammer	Hammer is raised by a rope running over the top of a framework and extending back to a drum or geared shaft; blow is delivered by the fall of the hammer under influence of gravity.	Allows greater variation in both weight and speed of blows. Very low frequency of blows. Low initial cost and relatively long service life. Simple to operate in remote locations where other equipment is not obtainable.	Efficiency reduced due to drag of rope and drum. Cannot be inverted and used as a pile extractor. Cannot be used in locations where headroom is limited. Not readily adaptable for driving batter piles.
Single-Acting Air/Steam Hammers	Steam or air raises the movable mass of the hammer, which drops by gravity.	Good performance. Simple in design and dependable in service. Usable in all soil conditions, but particularly effective in penetrating heavy clays.	Relatively low (50-60 blows per minute) blow rate. Cannot be used as an extractor.
Double-Acting Air/Steam Hammers	Steam or air raises the striking part and also impacts additional energy during downstroke.	High frequency (90-150 blows per minute) of blows keeps pile moving and speeds penetration. Can be used in horizontal position. Works best in sandy soil, but can be used in any soil. Can be inverted and used as a pile extractor.	Relatively high impact velocity results in pile head deformation of low compressive strength piles. Rebound effects make hammer energy output variable. Large compressor or boiler required for operation. Enclosed ram permits underwater driving.
Differential Acting Air/Steam Hammers	Variation of double-acting hammer with different valve arrangement.	Frequency of blows approaches that of double acting hammer while the effective stroke is the same as for single-acting hammers. Can be used in horizontal position. Works best in sandy soil, but can be used in any soil.	Rebound effects make hammer energy output variable. Large compressor or boiler required for operation.
Hydraulic Impact Hammers	Use hydraulic fluid to raise the ram; some units have assisted fall as well.	Efficient both in power pack energy conversion and generally with impact force transfer. Some units have sound attenuation features.	Expensive to rent or purchase. More difficult to maintain than other impact hammers.
Internal Combustion Hammers			

Single-Acting Diesel Hammers	Self-contained unit which uses ignition of fuel to impart additional energy during downstroke to drive pile downward and ram upward.	Independent of outside power sources (boiler, compressor, hydraulic power pack, etc.) Light weight and easily portable. Low operating cost. Ease of operation in cold weather.	Cannot be inverted and used as pile extractor. In soft driving, may stall due to inadequate rebound. Long stroke of ram may cause tension cracking in concrete piles. On hammers with atomized fuel system, fuel system is complicated. Low Frequency (40-60 blows per minute) blow rate.
Double-Acting Diesel Hammers	Similar to single acting diesels, except that trapped air or vacuum in top of hammer stores and releases energy during operation.	High frequency (80 blows per minute) blow rate. Relatively heavy hammer weight relative to single acting diesels. No external power source required.	Atomized fuel system can be difficult to service.

External Combustion Hammers

External combustion hammers are hammers which burn the fuel that provides the energy for the hammer's operation outside of the hammer itself. These hammers have external power sources, such as the crane itself, steam boilers, air compressors, or hydraulic power packs to provide the energy to move the ram upward and in some hammers downward as well. The various types of external combustion hammers are detailed below.

Drop Hammers

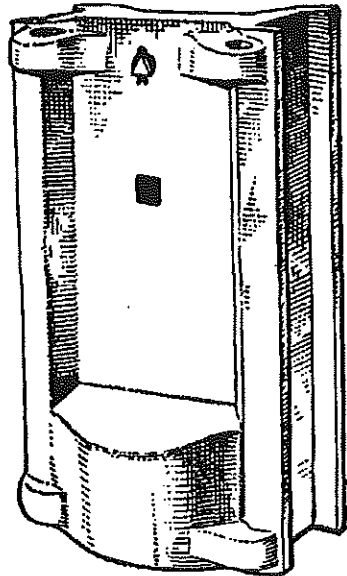


Figure 3 Typical Drop Hammer

The drop hammer is the oldest type of pile driving hammer in existence. A typical drop hammer is shown in Figure 3. The hammer is connected to a cable which is attached to a winch on the crane. The hammer is raised to the desired stroke. The winch has a clutch on it that then allows the operator to release the hammer, which falls by its own weight and strikes a pile cap and the pile. Drop hammers are mainly used on very small jobs and for small piling.

Single-Acting Air/Steam Hammers

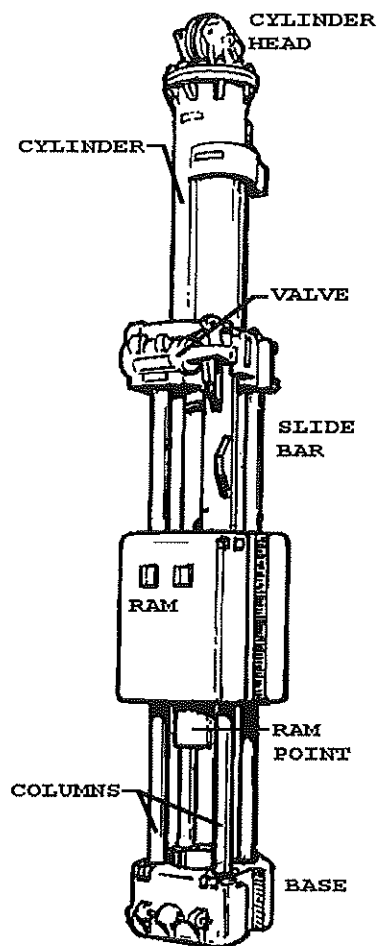
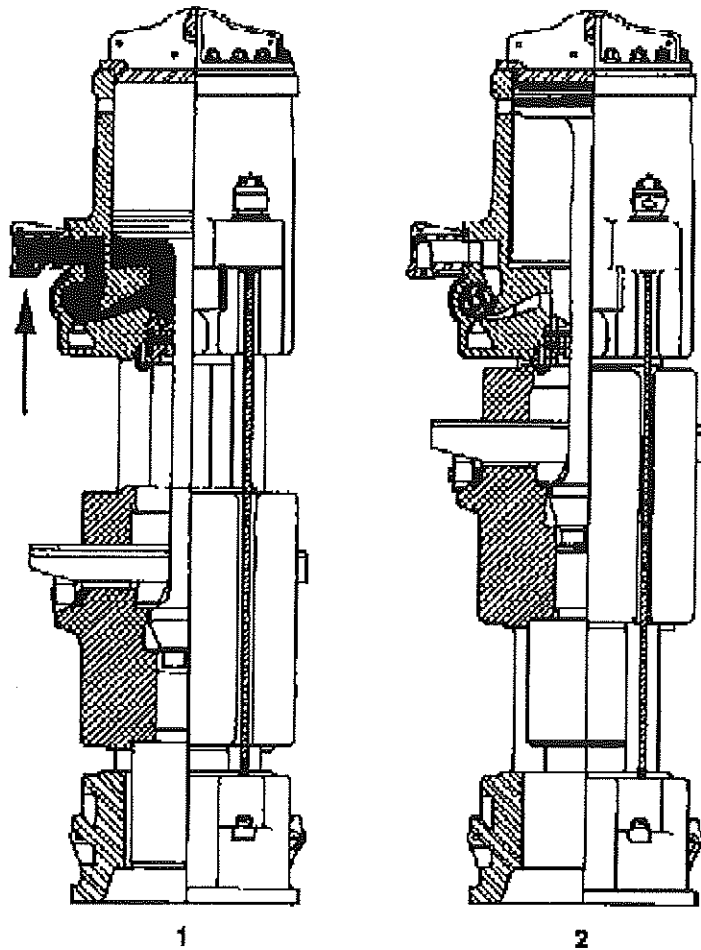


Figure 4 Typical Single Acting Air/Steam Hammer

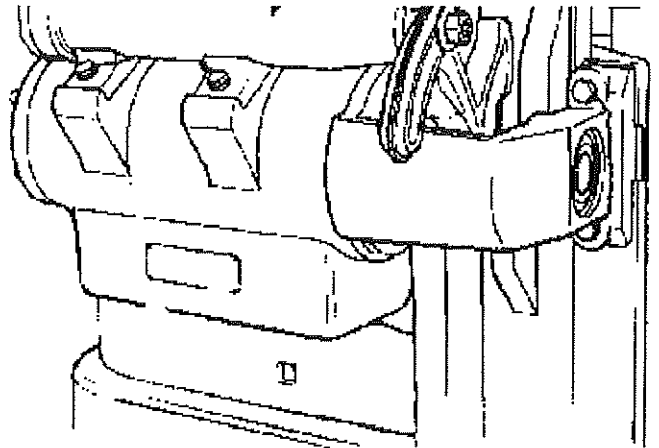
These hammers use steam or compressed air to raise the ram. At a point in the upstroke, the valve is moved and the ram floats to the top of the stroke; the ram then falls by its own weight and makes impact. These hammers are generally referred to as "air/steam" because they can be operated by either air or steam; a few are operable by only one or the other. A typical single acting air/steam hammer is shown in Figure 4; the operating cycle is shown in Figure 5. Many air/steam hammers contain a device to change the upstroke valve turnover point; this is shown in Figure 6, and enables the hammer to operate at two energies, which is especially important during the installation of concrete piles.



The cycle begins at impact, the valve is rotated in such a way as to admit steam or air into the cylinder and below the piston. This accelerates the ram upward as shown in View 1. This continues until the exhaust wedge on the slide bar actuates the trip and rotates the valve to close off the steam or air inlet and opens the area of the cylinder below the piston to the atmosphere where the compressed air or steam is exhausted. The ram continues its free rise upward, decelerating with gravity until the top of the piston passes the relief ports and closes in the dashpot at the top of the cylinder. This trapped air, shown in View 2, compresses and brings the rising ram to a halt. The ram then makes a free drop to impact. Shortly before impact the intake wedge rotates the valve to admit steam or air to the cylinder and the cycle starts once again.

Figure 5 Single-Acting Air/Steam Hammer Operating Cycle



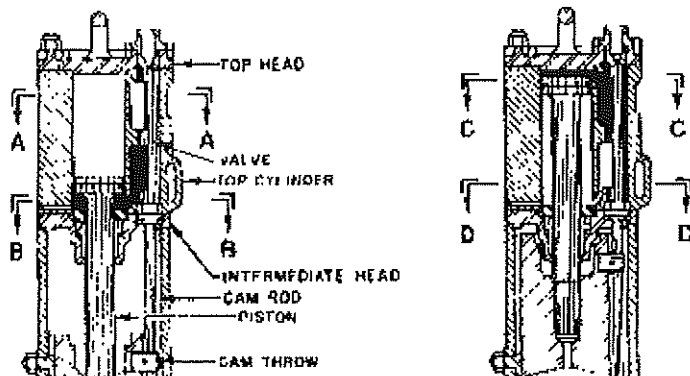


1. Vari-Cycle Cylinder
2. Piston Rod
3. Movable Trip

Figure 6 Stroke Changing Device for Air/Steam Hammers

Double-Acting Air/Steam Hammers

These hammers are similar to the single-acting hammers except that, upon upstroke valve turnover, they apply steam or air pressure to the top of the piston. This enables the stroke to be shorter, as it accelerates the ram to the desired impact velocity more quickly than with single acting hammers. This makes a higher blow rate possible, which is advantageous in some situations. A typical double acting air/steam hammer with a description of the operating cycle is shown in Figure 7. Double acting hammers are especially popular in driving sheet piling where vibratory hammers either cannot penetrate the soil or where they are favorable economically.



The ram carries a rigidly connected cam throw (some double acting hammers use a fluid valve) which engages a cam rod suspended in the intermediate head of the hammer. In operation, the motive fluid first enters the inlet port and flows through the lower opening of the valve to the underside of the piston. The top opening of the valve completes a

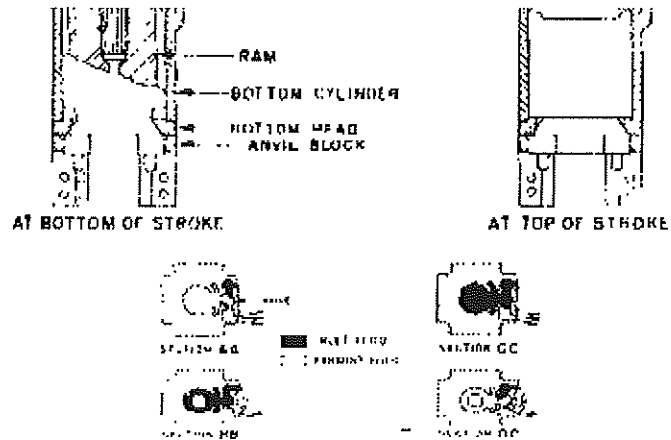
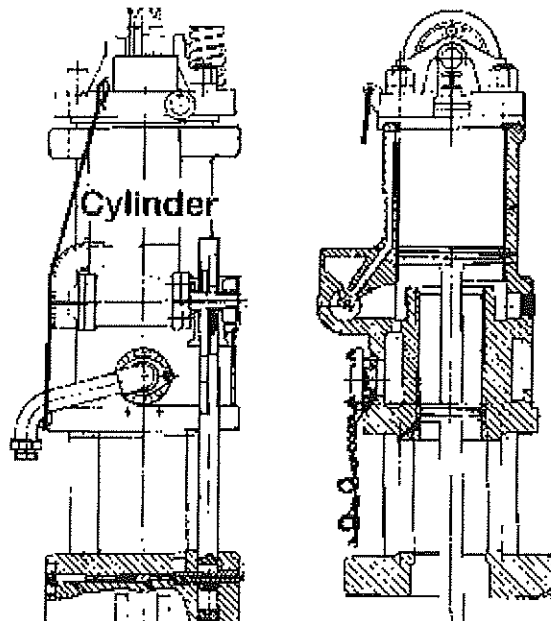


Figure 7 Typical Double-Acting Air/Steam Hammer

path from the topside of the piston to the exhaust port. As the fluid lifts the piston, thus lifting the ram, the lugs of the cam throw slide past the edges of the cam rod until, at the top of the stroke, they engage a spiral portion of the cam rod, causing it to rotate. The valve connected to the top of the cam rod also rotates, allowing the inlet motive fluid to enter the top of the cylinder, and permitting the exhaust fluid on the underside of the piston to escape through the exhaust port. The ram then falls, its velocity increased by the fluid pressure on the top of the piston. The cam throw lugs slide down where another spiral portion of the cam rod is engaged. The cam rod rotates; rotating the valve to the original position, and the motive fluid path reverses.

Differential Acting Air-Steam Hammers



These are similar to double acting hammers except that the air or steam is constantly pressurized under the piston. This allows for a simpler valve configuration than with a double acting hammer with similar operating characteristics. A typical differential acting hammer is shown in Figure 8; its operating cycle and characteristics are shown in Figure 9.

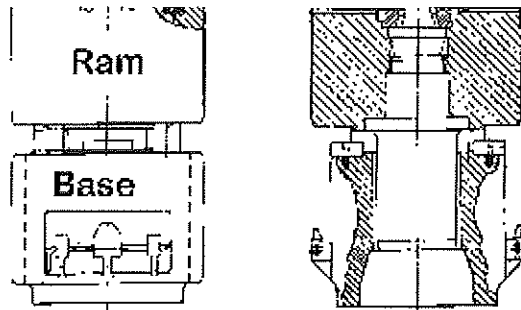
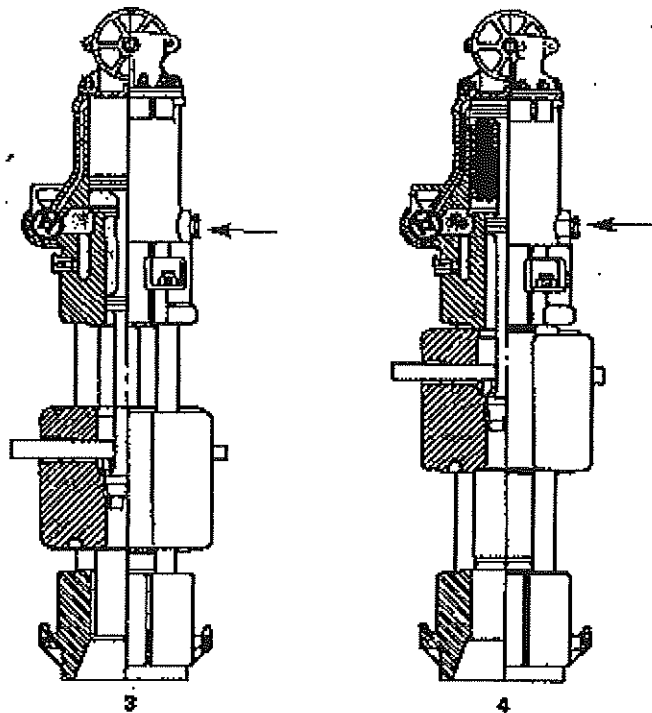


Figure 8 Typical Differential-Acting Air/Steam Hammer



The cycle begins at impact, the valve rotated so that the area above the large piston is open to the atmosphere and exhausting the compressed air or steam from the previous stroke, as shown in View 3. The area in the cylinder between the large and small pistons is always pressurized, and, as in the beginning of the cycle, when there is only atmospheric on the top of the large piston, this creates an unbalanced force on the piston and the ram accelerates upward. As the ram moves upward the intake wedge actuates the trip, rotating the valve and admitting steam to the cylinder above the large piston as shown in View 4. This produces an unbalanced force downward on the ram, bringing the ram to a halt at the top of the stroke. The ram is then forced downward, gaining kinetic energy both from gravity and the downward acting steam or air force, to impact. Just before impact the exhaust wedge rotates the valve once again to exhaust the compressed air or steam above the large piston and the cycle starts once again.

Figure 9 Operating Cycle for Differential-Acting Air/Steam Hammers

Hydraulic Impact Hammers

These hammers substitute hydraulic fluid for air or steam, and it is applied to the piston to move the ram. Hydraulic impact hammers can be single acting, double acting, differential acting or other variations. Most but not all hydraulic hammers employ the use of an electric valve operated with a variable timer, which allows for very flexible control of the output energy. A typical hydraulic hammer is shown in Figure 10.

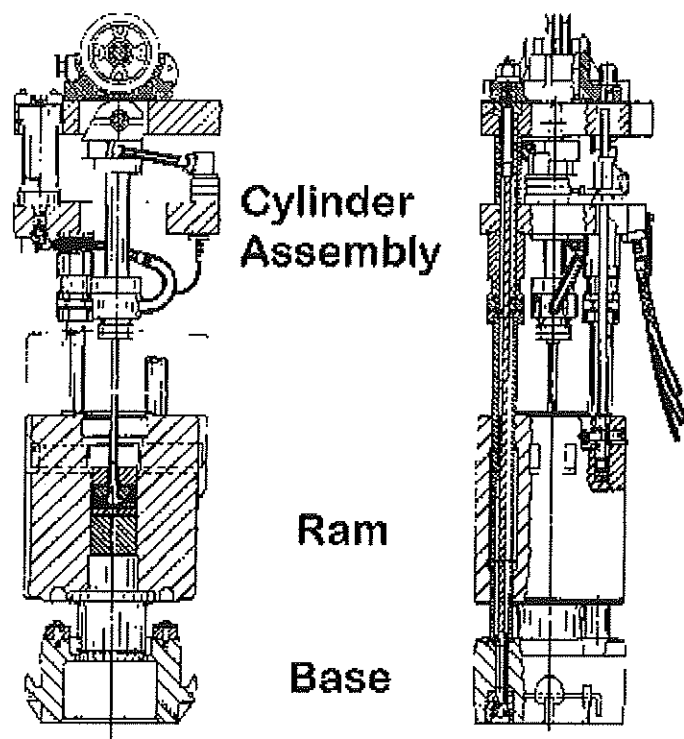


Figure 10 Typical Hydraulic Hammer

Jacking

Pile jacking machines are not true impact hammers but act by simply pushing the pile into the ground. Such a machine is depicted in Figure 11. They are most effective when the soil resistance is lower than the maximum ram force and when there are neighboring piles to jack against (such as with sheet piling.) They are most advantageous when vibrations

and noise must be minimized.

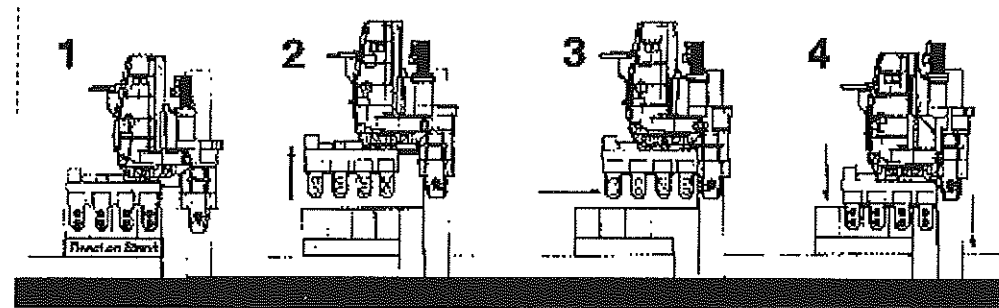


Figure 11 Pile Jacking Device

Operating Cycle

1. The jack is set on the reaction stand for the installation of the first two sheet piles.
2. The jack moves by elevating its travel carriage while supporting itself on the last installed pile.
3. The travel carriage then slides forward.
4. The travel carriage lowers itself and drops onto the installed sheet piles and continues its hydraulic installation process.

After the third or fourth pile is driven, the jack moves off of the reaction stand and travels independently on the piles.

Internal Combustion Hammers

These hammers burn the fuel that powers them inside of the hammer, and for the most part the diesel hammers are the only constituent of this class.

Open End Diesel Hammers

The open end diesel hammer operates as is shown in Figure 12. The piston with the assistance of the starting device driven either from the winch of the pile driving rig or hydraulically is raised to an upper position, at which point it is released by the starting device and falls down under its own weight. Before the bottom of the ram passes the exhaust ports the piston pushes the fuel pump lever and fuel from the pump is supplied to the spherical recess of the anvil (some models directly inject atomized fuel into the combustion chamber.) At the bottom of the stroke the piston impacts the anvil. The energy of impact is divided between fuel vaporization and its mixing with heated air and driving of the pile. After a short period of time the air-fuel mixture is ignited and due to the pressure of the expanding exhaust gases the piston is raised up and additional driving impulse is transmitted to the pile. A typical open ended diesel hammer is shown in Figure 13.

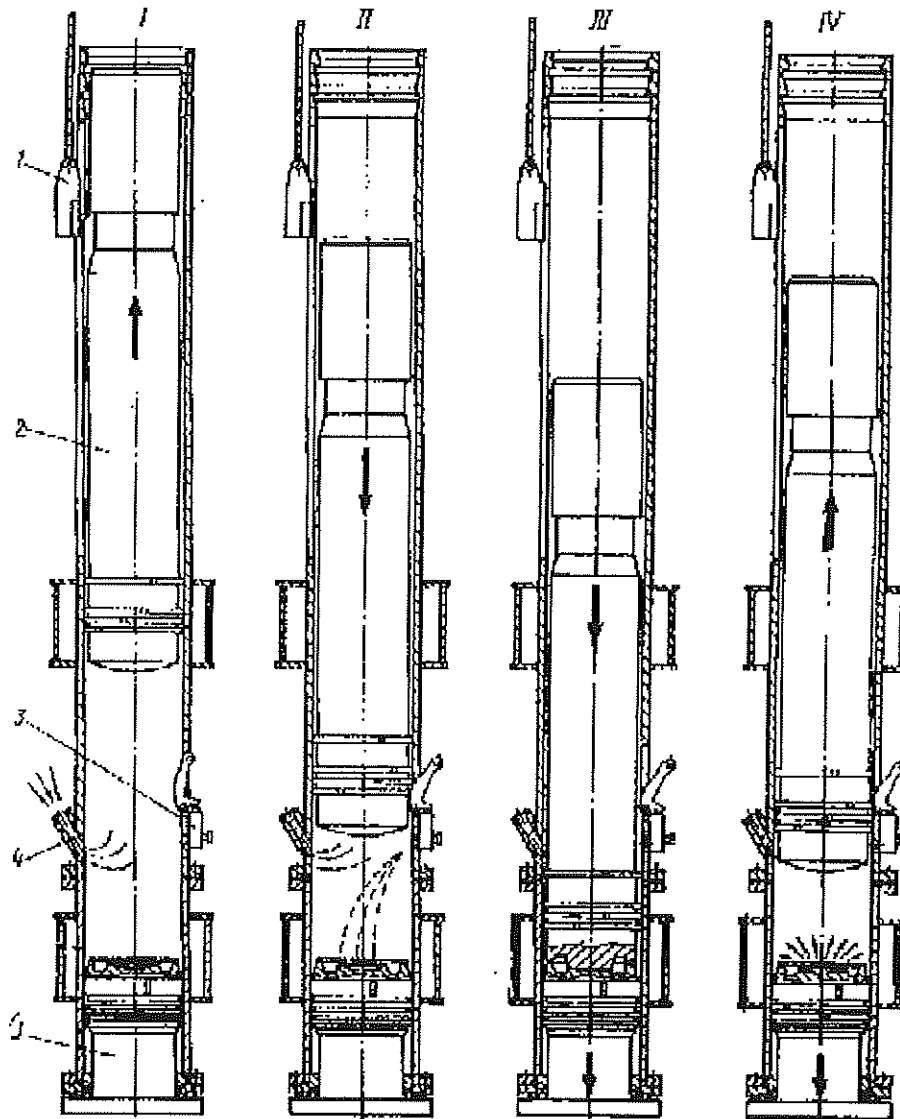


Figure 12 Operating Diagram of Diesel Hammer

Hammer Parts:

1. starting device
2. piston
3. fuel pump
4. inlet
5. cylinder
6. anvil

Stages in Cycle:

- I) ram up (start), scavenging
- II) termination of scavenging, fuel feed
- III) termination of compression stroke, blow delivered on anvil block, fuel combustion
- IV) termination of fuel combustion, exhaust, beginning of scavenging

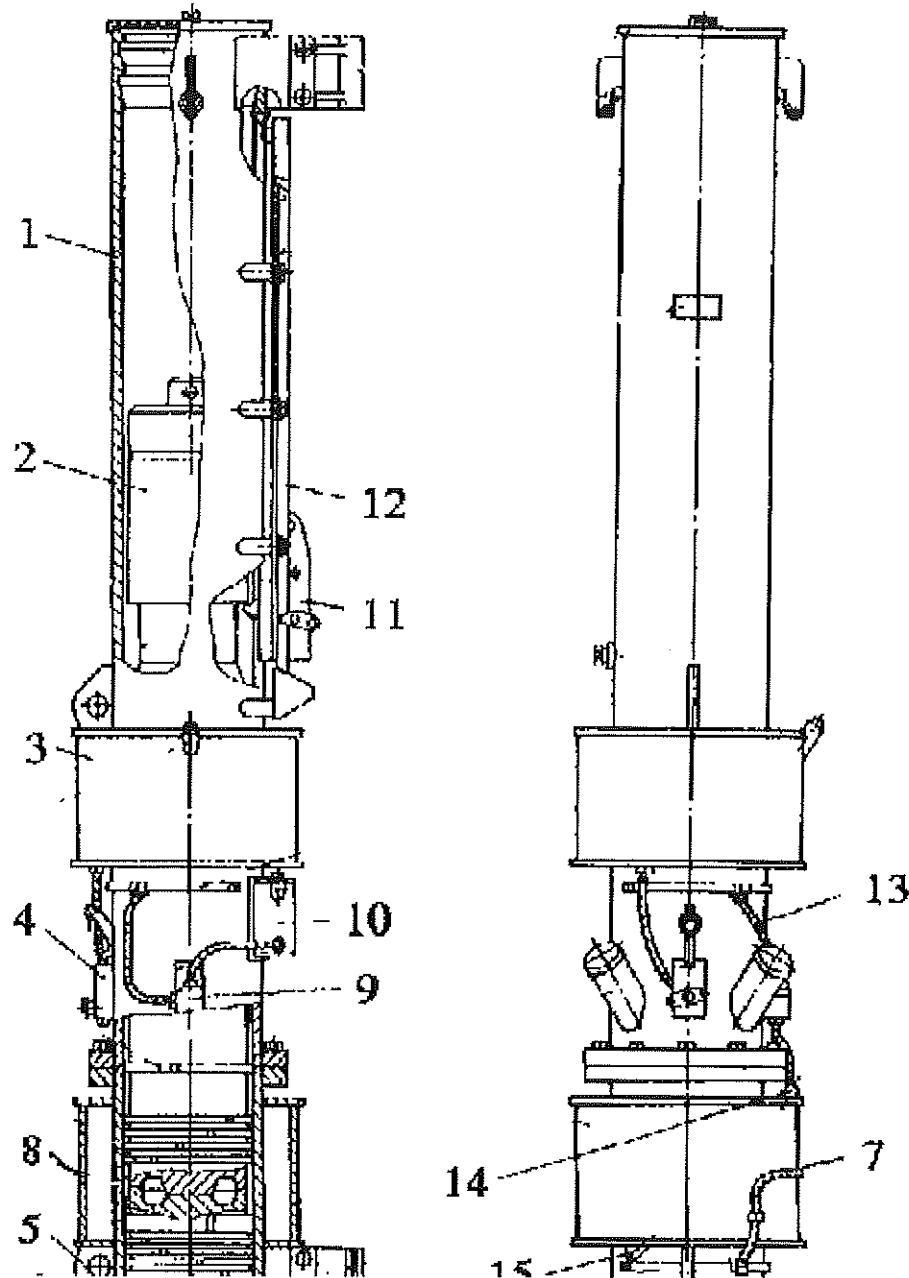


Figure 13 Typical Open End Diesel Hammer

Parts:

1. Upper Cylinder
2. Piston
3. Fuel Tank
4. Fuel Pump
5. Lower Cylinder
6. Anvil Block
7. Oil Hose for Anvil Block Lubrication
8. Water Tank
9. Oil Pump
10. Oil Tank
11. Starting Device or Crab
12. Starting Device or Crab Guide
13. Oil Hose for Ram Rings Lubrication
14. Filling Throat Plug
15. Drain Throat Plug



Closed End Diesel Hammers

These are similar in operating principle to the open ended type except that a compression chamber or vacuum is employed on top of the piston to assist the ram in the downstroke. This speeds up the blow rate of the hammer, but some of these hammers have a heavier ram relative to the energy than the open ended type. A typical closed end diesel hammer is shown in Figure 14.

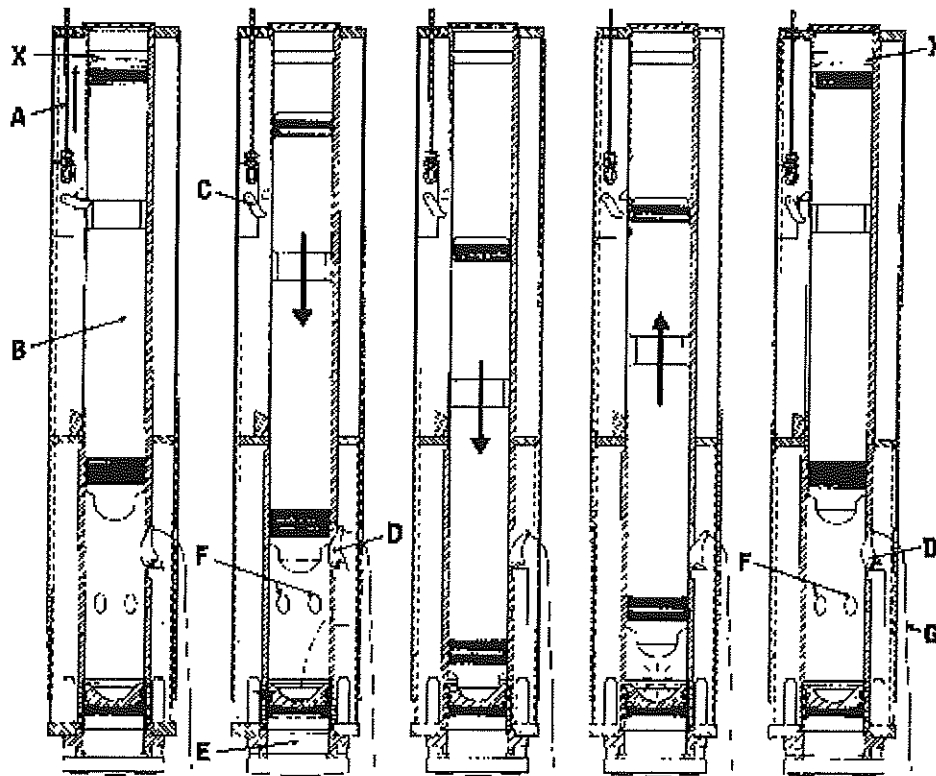


Figure 14 Typical Closed End Diesel Hammer

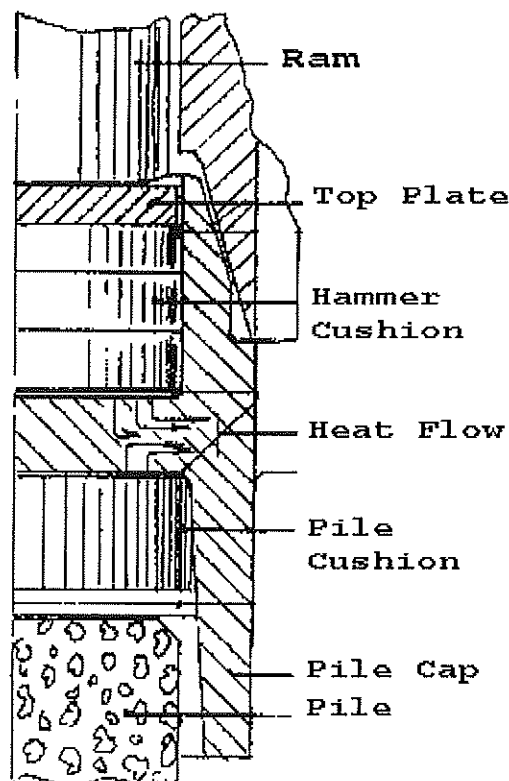
- A) Lifting Line from Crane
- B) Ram
- C) Starting Device
- D) Fuel Pump
- E) Anvil
- F) Exhaust Ports
- G) Fuel Pump Lever Rope
- X) Compression Chamber

Driving Accessories

It is not possible for the striking end of the ram of an impact hammer to directly adapt itself to all shapes of piles; therefore, it is necessary to have driving accessories of various types to be inserted between the bottom of the hammer and the pile, to both mate the two geometrically and to transmit the force of impact from hammer to pile.

Hammer Cushion

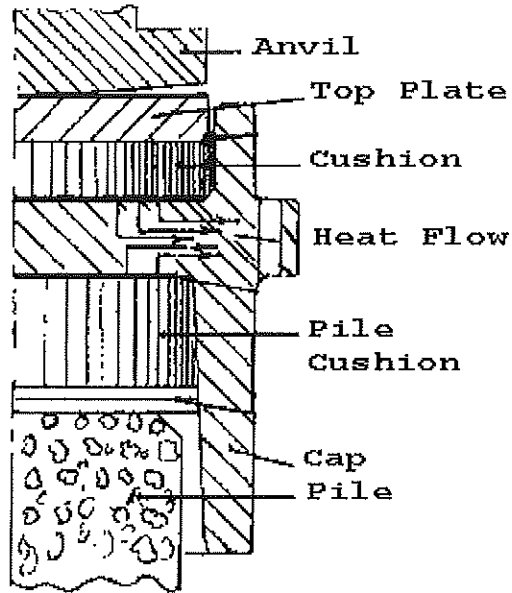
Most impact hammers have some kind of cushion under the end of the ram which receives first the striking energy of the hammer. This cushion is necessary to protect the striking parts from damage; it also modulates the force-time curve of the striking impulse, and can be used to match the impedance of the hammer to the pile, thus increasing the efficiency of the blow. The actual material of the cushion and its configuration will vary, depending upon the hammer configuration and the cushion material being used. Any hammer cushion should be installed and used in accordance with the recommendations of the hammer manufacturer. Figure 15 shows a variety of cushion configurations; Table 2 shows a summary of the various types of cushion materials and their characteristics.



The figure to the left shows typical cushion configurations for both air/steam and diesel hammers. Pile cushion is only included in concrete and plastic piling; with steel and wood piling, no pile cushion is normally needed.

In some instances, no hammer cushion is required. Some hydraulic hammers have no hammer cushion. With wood piling, some air/steam hammers can be equipped with special bases to drive wood piling without cushion material.

**Air-Steam Hammers
Integral Ring**



Diesel Hammers

The air/steam configuration to the left is shown with an integrally cast cushion pot. Most air/steam hammers can use as an alternative a capblock follower or shield, where micarta and aluminum cushion material is stacked into a piece separate from the pile cap. Such a configuration is shown in the figure below.

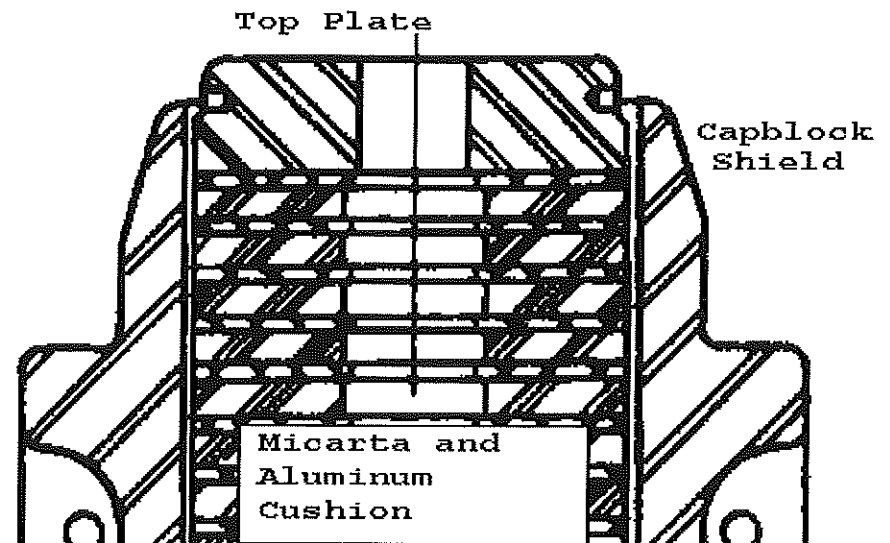
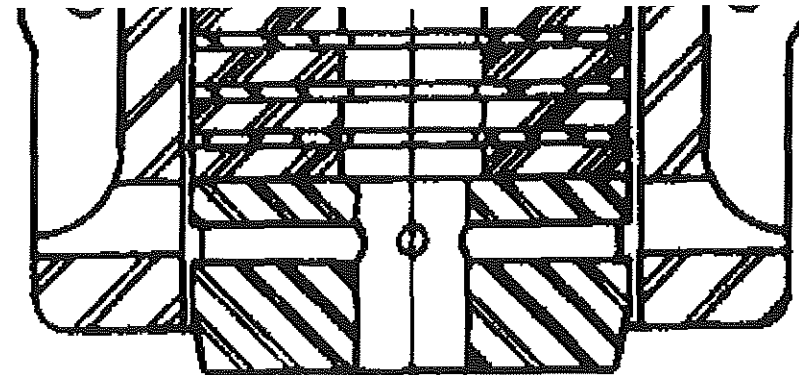


Figure 15 Cushion Configurations



Bottom Plate

Table 2 Summary of Cushion Material Characteristics

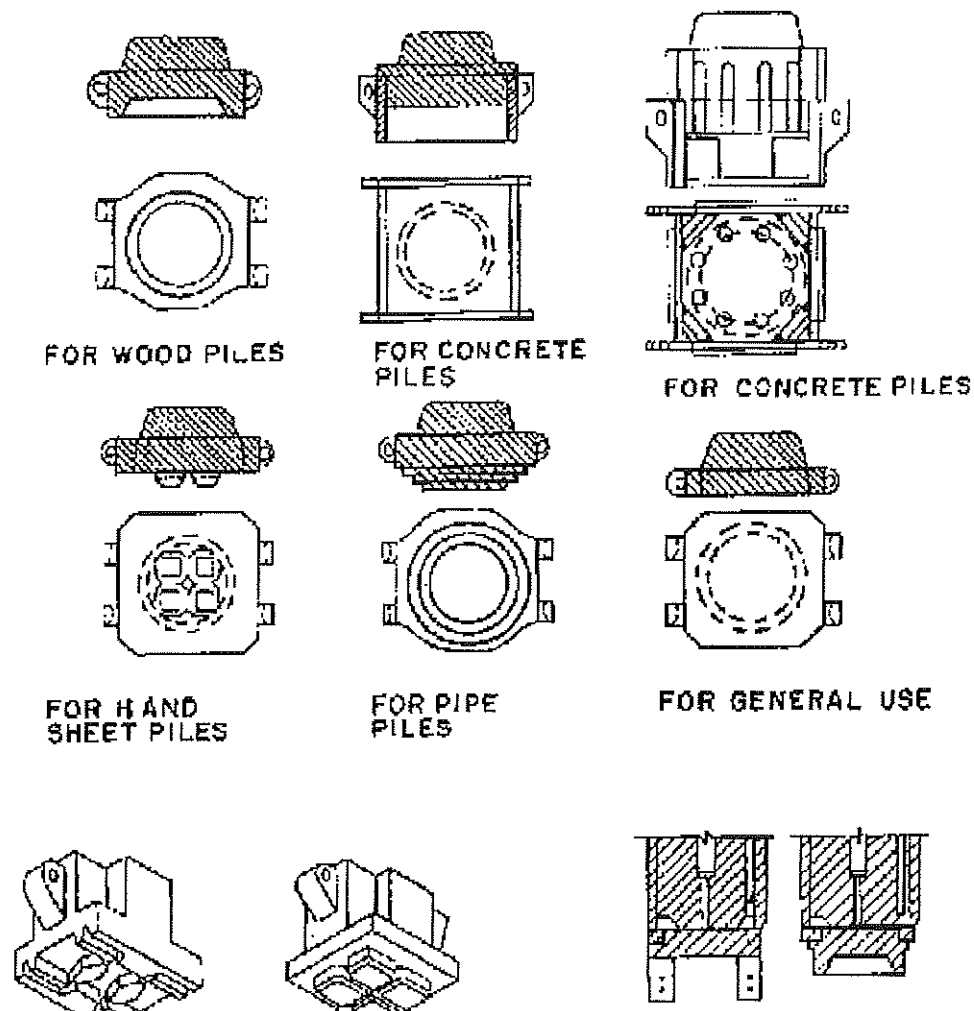
Name of Material	Description	Advantages	Disadvantages
Wire Rope Biscuits	Wire rope coiled into flat biscuits, then placed into cushion receptacle.	Inexpensive; material plentiful on job site.	Material hardens rapidly into steel mass; extensive hammer and pile damage possible.
Force Ten	Wires braided into steel cloth plates.	Long life	Material hardens rapidly into steel mass; extensive hammer and pile damage possible.
Micarta and Aluminum; Conbest	Phenolic plates alternated with aluminum plates. Aluminum plates used for heat dissipation, frequently omitted with diesel hammers.	Long life; versatile, can be used with many hammers.	Material too hard to be used with some hammers.
Hamortex	Aluminum foil bonded with various plastic and paper materials and spirally wound into disks.	Excellent range of elasticity moduli. Can be used as concrete pile cushion as well as hammer cushion.	Inconsistent life; varies widely from job to job.
MC-904; Blue Nylon	Type of nylon, cast into discs. Sometimes alternated with aluminum for heat dissipation.	Excellent range of elasticity moduli.	Material breaks up and melts easily under hard conditions; best suited for diesel hammers.
Plywood	Plywood sheets stacked and mounted onto concrete pile; used almost exclusively as a pile cushion.	Inexpensive and soft.	Poor coefficient of restitution; absorbs much impact energy.
End grain hardwood (oak, hickory, bongossi, etc.)	Wood cut to use in cushion receptacle as single block or into blocks which are then fit into receptacle.	Good range of modulus of elasticity.	Low coefficient of restitution; sometimes expensive and hard to find; burns during use.

Anvil

The rams of most external combustion hammers strike the cushion material or top plate directly. With internal combustion hammers, an anvil is necessary to trap the combustible mixture and thus allow it to build pressure. Figure 12 shows an anvil setup. The term "anvil" is also sometimes used to describe the drive cap or helmet (see next paragraph.)

Helmet

The helmet actually mates the hammer system to the pile, and in doing so distribute the blow from the hammer more uniformly to the head of the pile, and also to minimize pile damage. Figure 16 shows some typical driving helmets.



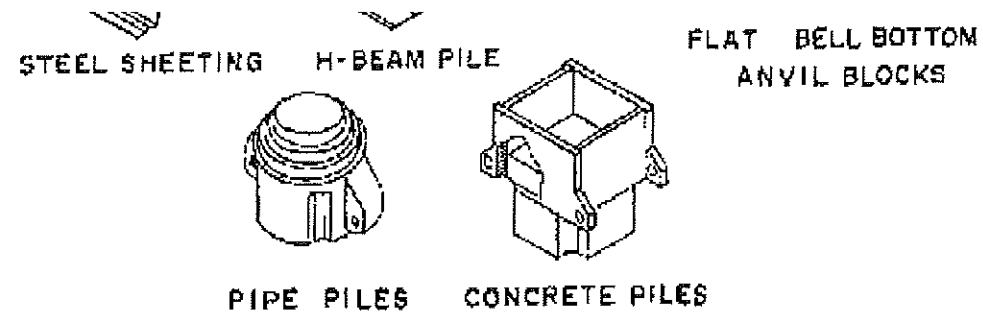


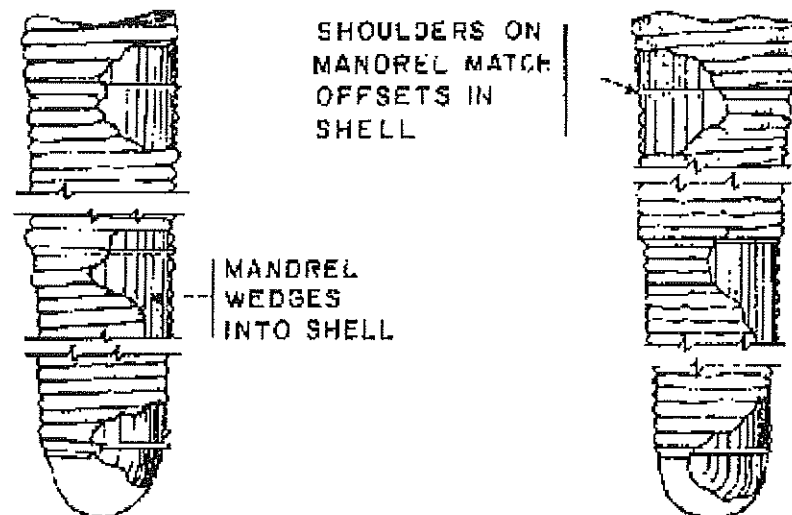
Figure 16 Typical Driving Helmets

Pile Cushion

When driving concrete piles, it is necessary to use a cushion between the hammer and a pile. This cushion is generally made of plywood; one cushion is made for each concrete pile to be driven and either installed on top of the concrete pile before it is driven or in the cap. The depth of this cushion can vary from 150-450 mm (6-18".) Figure 1 shows a typical pile cushion configuration.

Mandrel

A mandrel is used to install thin wall shell piles which are subsequently filled with concrete. The mandrel is necessary because the wall is too thin to withstand the stresses of driving. Figure 17 shows examples of mandrels.



T A P E R
(a)

S T E P - T A P E R
(b)

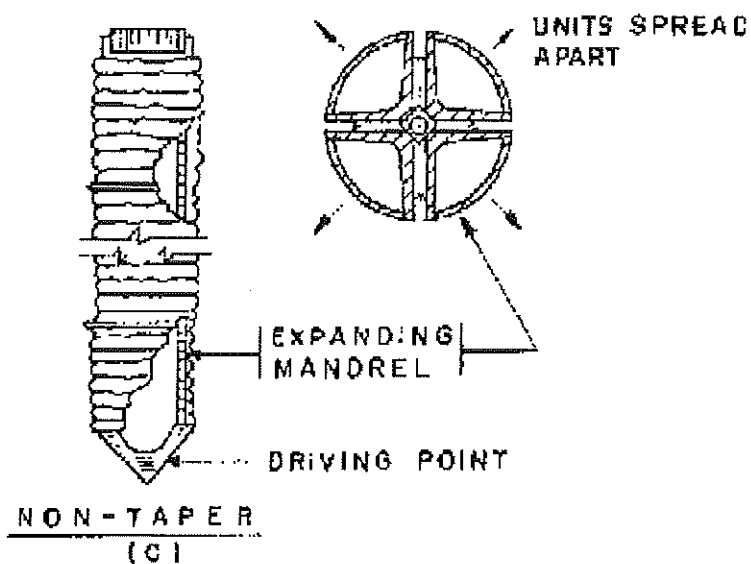


Figure 17 Mandrel for Shell Piles.

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