Chapter 9
Piles and Pile-Driving Equipment

9.1. Introduction:

This chapter deals with the selection of load-bearing piles and the equipment required to drive the piles.

Load-bearing piles, as the name implies, are used primarily to transmit loads through soil formations with poor supporting properties into or onto formations that are capable of supporting the loads.

If the load is transmitted to the soil through skin friction between the surface of the pile and the soil, the pile is called ***friction pile***.

If the load is transmitted to the soil through the lower tip, the pile is called an ***end-bearing pile***.

9.2. Types of Piles:

Piles may be classified on the basis of their use or the materials from which they are made. On the basis of use there are two major classifications, ***Sheet Piles*** and ***Load-Bearing Piles***.

9.2.1. Sheet Piles:

Sheet piling is used primarily to resist the flow of water and loose soil.

Typical uses include cutoff walls under dams, cofferdams, bulkheads, trench sheeting, etc.

On the basis of materials from which they are made sheet piles may be classified as ***steel***, ***wood***, and ***concrete***.

9.2.2. Load-Bearing Piles:

Load-bearing piles may be classified on the basis of the material from which they are made and the method of constructing and driving them, as: ***Timber*** **(**Untreated, Treated with a preservative), ***Concrete*** (Precast, Cast in place), ***Steel*** (H section, Steel pipe) and ***Composite*****.**

Each type of the load-bearing piles has a place in the field of construction, and for some projects more than one type may seem satisfactory. It is the duty of the engineer to select the type which is most satisfactory for a given project.

9.3. Factors Affecting the Selection of the Suitable Type of Piles for a Given Project:

1. Type, size and weight of the structure to be supported.

2. Physical properties of the soil at site.
3. Depth to a stratum capable of supporting the piles.
4. Availability of materials for piles.
5. Number of piles required.
6. Facilities for driving piles.
7. Types of structures adjacent to the project.
8. Depth and kind of water, if any, above the ground into which the piles will be driven.

9.4. Timber Piles:

Timber piles are made from trunks of trees, while such piles are available in most countries of the world; it is becoming more difficult to obtain long, straight timber piles.

9.4.1. Advantages of Timber Piles:

1. The more popular lengths and sizes are available on short notice.
2. They are economical in cost.
3. They are handled easily, with little danger of breakage.
4. They can be cut to any desirable length after they are driven.
5. They can be pulled easily in the event removal is necessary.

9.4.2. Disadvantages of Timber Piles:

1. It may be difficult to obtain piles sufficiently long and straight for some projects.
2. It may be difficult or impossible to be driven into hard formations.
3. It is difficult to splice them to increase their lengths.
4. While they are satisfactory when used as friction piles, they are not suitable for use as end-bearing piles under heavy loads.
5. Their life may be short unless the piles are treated with a preservative.

9.5. Precast Concrete Piles:

Square and octagonal piles are cast in horizontal forms, while round piles are cast in vertical forms. After the piles are cast, they should be cured under damp sand, straw or mats for the period required by the specifications, frequently 21 days, if cured under ambient temperatures.

With the exception of short lengths, precast concrete piles must be reinforced with sufficient steel to prevent damage or breakage while they are being handled from the casting beds to the driving positions.

Precast concrete piles shall contain longitudinal reinforcing steel in an amount not less than 2% of the volume of pile.

Lateral steel shall be at least 6mm-diameter round bars, spaced not more than 300mm apart, except at the top and bottom of a pile, where the spacing shall not exceed 75mm. The concrete cover over the reinforcing steel shall be at least 50mm.

Concrete piles should be cast as near the site as possible in order to reduce the cost of handling them from the casting beds to the pile driver. They should be transported to the driver by a truck. For handling concrete piles, care must be exercised to prevent breakage or damage due to flexure stresses. Long piles should be picked up at several points to reduce the unsupported lengths.

One of the disadvantages of using precast concrete piles, especially for a project where different lengths are required, is the difficulty of reducing or increasing the lengths of the piles.

- If a pile is too long, it is necessary to cut off the excess length. This is done after a pile is driven to its maximum penetration, by chipping the concrete away from the reinforcing steel, cutting the reinforcing steel. This operation represents a waste of material and time, which can be very expensive.
- When a precast concrete pile does not develop sufficient driving resistance to support the design load, it may be necessary to increase the length and drive the pile to a greater depth. To do so, the reinforcing bars must extend above the top of a pile to permit additional reinforcing to be welded to the original bars.

9.5.1. Advantages of Precast Concrete Piles:

1. They have high resistance to chemical and biological attacks.
2. They have great strength.
3. A pipe may be installed along the center of a pile to facilitate jetting.

9.5.2. Disadvantages of Precast Concrete Piles:

1. It is difficult to reduce or increase the length.
2. Large sizes require heavy and expensive handling and driving equipment.
3. Inability to obtain piles by purchase may delay the starting of a project.
4. Possible breakage of piles during handling or driving produces a delay hazard.

9.6. Cast-in-Place Concrete Piles:

Cast-in-place concrete piles are constructed by depositing the freshly mixed concrete in place in the ground and letting it cure there.

There are two methods of constructing cast-in-place concrete piles:

1. Driving a metallic shell, leaving it in the ground, and filling it with concrete.
2. Driving a metallic shell and filling it with concrete as the shell is pulled from the ground.

9.6.1. Raymond Standard Concrete Piles:

The standard pile is installed by driving a closed end smooth spirally corrugated steel shell connected to a steel piece (that can be removed) at the bottom of the shell, used to drive the shell into the soil. After driving the shell to the desired penetration, the steel piece is pulled outside, and then the shell must be inspected and filled with concrete.

If the shell was damaged during driving, it is preferable to be pulled outside and replaced with a new one; the length of this kind of piles may reach (11m).

9.6.2. Raymond Step-Taper Concrete Piles:

The step-taper pile is installed by driving a spirally corrugated steel shell, made up of sections between 1.2m to 2.4m, with successive increases in diameter for each section. A corrugated sleeve at the bottom of each section is screwed into the top of the section immediately below it.

Piles of necessary length up to a maximum of (24m) are obtained by joining the proper number of sections at the job. The shells are available in various gauges of metal to fit different job conditions. The bottom of shell is closed prior to driving by a flat steel plate or a hemispherical steel boot.

After the shell is assembled in the desirable length, a step-tapered rigid steel core is inserted and the shell id driven to the desired penetration. The core is removed, and the shell is filled with concrete.

9.6.3. Advantages of Cast-in-Place Concrete Piles:

1. The lightweight shells may be handled and driven easily.
2. The length of a shell may be increased or decreased easily.
3. The shells may be shipped in short lengths and assembled at the job.
4. The danger of breaking a pile while driving is eliminated.
5. Additional piles may be provided quickly if they are needed.

9.6.4. Disadvantages of Cast-in-Place Concrete Piles:

1. A slight movement of the earth around an unreinforced pile may break it.
2. An uplifting force, acting on the shaft of an uncased and unreinforced pile may cause it to fail in tension.
3. The bottom of a pedestal pile may not be symmetrical.

9.7. Steel-Pipe Piles:

These piles are installed by driving pipes to the desired depth and filling them with concrete. A pipe may be driven with the lower end closed with a plate or a steel driving point, or the pipe may be driven with the lower end open. Pipes vary in diameter from 150mm to 750mm and the length may reach 60m.

A closed-end pipe pile is driven in any conventional manner, usually with a pile hammer. If it is necessary to increase the length of a pile, two or more sections may be welded together.

An open-end pipe pile is installed by driving the pipe to the required depth, removing the material from inside, by burst of compressed air, a mixture of water and compressed air; and filling the space with concrete.

Because open-end pipe piles offer less driving resistances than closed-end piles, a smaller pile hammer may be used.

The use of light hammers is desirable when piles are driven near a structure whose foundation might be damaged by impact of the blows from a large hammer. Open-end piles may be driven to depths which could never be reached with closed-end piles.

9.8. Steel Piles:

In construction foundations that require piles driven to great depths, steel H piles probably are more suitable than any other type. Steel piles may be driven through hard materials to a specified depth to eliminate the danger of failure due to scouring, such as under a pier in a river.

Steel piles may be driven to great depths through poor soils to bear on a solid rock stratum.

The great strength of steel combined with the small displacement of soil permits a large portion of the energy from a pile hammer to be transmitted to the bottom of a pile. As a result, it is possible to drive steel piles into soils which could not be penetrated by any other type of pile.

9.9. Pile Hammers:

The function of a pile hammer is to furnish the energy required to drive a pile. Pile-driving hammers are designated by type and size.

The types commonly used include the following:

1. Drop.
2. Single-acting steam.
3. Double-acting steam.
4. Differential-acting steam.
5. Diesel.
6. Vibratory.
7. Hydraulic.

The size of a drop hammer is designated by its weight, while the size of each of the other hammers is designated by theoretical energy per blow, expressed in (m.kg).

9.9.1. Drop Hammers:

A drop hammer is a heavy metal weight that is lifted by a rope, then released and allowed to fall on top of the pile.

Standard drop hammers are made in sizes which vary from about 225 to 1360 kg. The height of drop or fall most frequently used varies from 1.5 to 6 m.

When large energy per blow is required to drive a pile, it is better to use a heavy hammer with a small drop than a light hammer with a large drop.

Drop hammers may strike 4 to 8 blows per minute.

Drop hammers are suitable for driving piles on projects that require only a few piles and for which the time of completion is not an important factor.

9.9.1.1. Advantages of Drop Hammers:

1. Small investment in equipment.
2. Simplicity of operation.
3. Ability to vary the energy per blow by varying the height of fall.

9.9.1.2. Disadvantages of Drop Hammers:

1. Slow rate of driving piles.
2. Danger of damaging piles by lifting a hammer too high.
3. Danger of damaging adjacent buildings as a result of the heavy vibration caused by a hammer.
4. Cannot be used directly for underwater driving.

9.9.2. Single-Acting Steam Hammers:

A single-acting steam hammer is a freely falling weight, called a ***ram***, which is lifted by steam or compressed air, whose pressure is applied to the underside of a piston that is connected to the ram through a piston rod. When the piston reaches the top of the stroke, the steam pressure is released and the ram falls freely to strike the top of a pile.

Single-acting steam hammers may strike 50 or more blows per minute.

Single-acting steam hammers may be open or enclosed. The length of the stroke and energy per blow may be decreased slightly by reducing the steam pressure below that recommended by the manufacturer. The reduced pressure has the effect of decreasing the height to which the piston will rise before it begins its free fall.

9.9.2.1. Advantages of Single-Acting Steam Hammers Compared with Drop Hammers:

1. Greater number of blows per minute permits faster driving.
2. Reduction in the velocity of the ram decreases the danger of damage to piles during driving.
3. The enclosed types may be used for underwater driving.

9.9.2.2. Disadvantages of Single-Acting Steam Hammers Compared with Drop Hammers:

1. They require more investment in equipment such as steam boiler or an air compressor.
2. They are more complicated, with higher maintenance cost.
3. They require more time to set up and take down.
4. They require a large operating crew.

9.9.3. Double-Acting Steam Hammers:

In the double-acting steam hammer steam pressure is applied to the underside of the piston to raise the ram; then during the downward stroke steam is applied to the top side of the piston to increase the energy per blow. Thus, with a given weight ram, it is possible to attain a desired amount of energy per blow with a shorter stroke than with a single-acting steam hammer. The number of blows per minute will be approximately twice as great as for a single-acting steam hammer with the same energy rating.

9.9.3.1. Advantages of Double-Acting Steam Hammers Compared with Single-Acting Steam Hammers:

1. The greater number of blows per minute reduces the time required to drive piles.
2. Piles can be driven more easily.

9.9.3.2. Disadvantages of Double-Acting Steam Hammers Compared with Single-Acting Steam Hammers:

1. The light weight and high velocity of the ram make this type of hammer less suitable for use in driving heavy piles into soils having high frictional resistance.
2. This type of hammer is more complicated.

9.9.4. Differential-Acting Steam Hammers:

A differential-acting steam hammer is a modified double-acting hammer in which the steam pressure is used to lift the ram and to accelerate the ram on the down stroke. The ram has a large piston which operates in an upper cylinder and a small piston which operates in a lower cylinder. The lifting of the ram is effected by the difference in the pressure forces acting on the two pistons.

The number of blows per minute is comparable with that for a double-acting hammer, while the weight and equivalent free fall of the ram are comparable with those of a single-acting hammer. Thus, this type of hammer has the advantages of the single and double-acting hammers.

9.9.5. Diesel Hammers:

A diesel Pile driving hammer is a self-contained driving unit which does not require an external source of energy a steam boiler or an air compressor. Therefore, it is simpler and easily moved from one location to another than a steam hammer. A complete unit consists of a vertical cylinder, a piston or ram, an anvil, fuel tank, lubricating oil tank, a fuel pump, injectors, and a mechanical lubricator.

After the hammer is placed on top of a pile, the combined piston and ram are lifted to the upper end of the stroke and released to start the unit operating. As the ram nears the end of the down stroke, it activates a fuel pump that injects the fuel into a chamber between the ram and the anvil. The continued down stroke of the ram compresses the air and the fuel to ignition heat. The resulting explosion drives the pile downward and the ram upward to repeat its stroke.

9.9.5.1. **Advantages of Diesel Hammers:**

1. The hammer needs no external source of energy, and the maintenance is simple and fast.
2. The hammer is light in weight and is economical to operate.
3. It is convenient to operate in remote areas.
4. It operates well in cold weather, where it is difficult to provide steam.
5. Because the resistance of a pile to driving is necessary for continuing operation of a diesel hammer, it will not operate if a pile breaks or falls out from under a hammer.

9.9.5.2. **Disadvantages of Diesel Hammers:**

1. The hammer may not operate well when driving piles into soft ground.
2. The number of strokes per minute is less than that for a steam hammer.
3. The length of a diesel hammer is slightly greater than the length of a steam hammer of comparable energy rating.

9.10. Driving Piles Below Water:

If it is necessary to drive piles below water, either of the following two methods may be used:

1. When the driving unit is a drop hammer, an open-type steam hammer, or a diesel hammer, the pile is driven until the top is just above the surface of the water. Then a follower is placed on top of the pile, and the driving is continued through the follower. The follower may be made of wood or steel and must be strong enough to transmit the energy from the hammer to the pile.

2. When the driving unit is an enclosed steam hammer, the driving may be continued below the surface of the water, without a follower. It is necessary to install an exhaust hose to the surface of the water for the steam. Also, it is necessary to supply about 1.7 m^3/min of compressed air to the lower part of the hammer to prevent water from flowing into the casing and around the ram.

9.11. Pile Driving Equations:

There are many Pile-driving equations, each of which is intended to give the supporting strength of a pile.

The equations are empirical, with coefficients that have been determined for certain existing or assumed conditions under which they were developed.

None of the equations will give dependable values for the supporting strength of the piles for all the varying conditions that exist on foundation jobs:

1) For Drop Hammers:

$$R = \frac{2 \cdot W \cdot H}{S + 1.0} \qquad \text{...... (Eq. 9-1)}$$

2) For a Single-Acting Steam Hammer:

$$R = \frac{2 \cdot W \cdot H}{S + 0.1} \qquad \text{...... (Eq. 9-2)}$$

3) For a Double- and Differential-Acting Steam Hammer:

$$R = \frac{2 \cdot E}{S + 0.1} \qquad \text{...... (Eq. 9-3)}$$

Where:

R= Safe Load on a Pile, lb
W= Weight of a falling mass, lb
H= Height of free fall for mass W, ft
S= Average penetration per blow for last 5 or 10 blows, in
E= Total energy of ram at the bottom of its downward stroke, ft-lb

Ex. (9-1):

The falling ram of a drop hammer used to drive a timber pile is 6500 lb. the free-fall height during driving was 20 in, and the average penetration for the last eight blows was 0.5 in per blow. What is the safe rated load?

Solution:

From Eq. (9-1):

Safe rated load, $R = \frac{2 \cdot W \cdot H}{S + 1.0} = \frac{2 \times 6500 \times \left(\frac{20}{12}\right)}{(0.5 + 1)} = 14444.4\ lb$

Fig. (9-1) - Creosote-Treated Timber Pile Being Readied for Installation

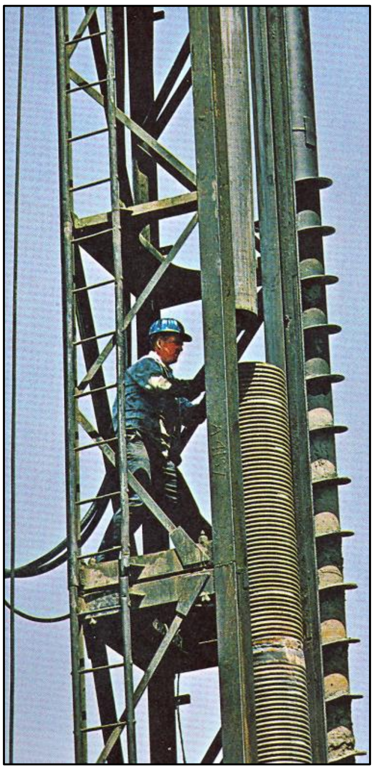

Fig. (9-2) - Raymond Step-Taper Pile Being Readied for Installation

Fig. (9-3) - Taper-tube Pile Being Positioned for Driving

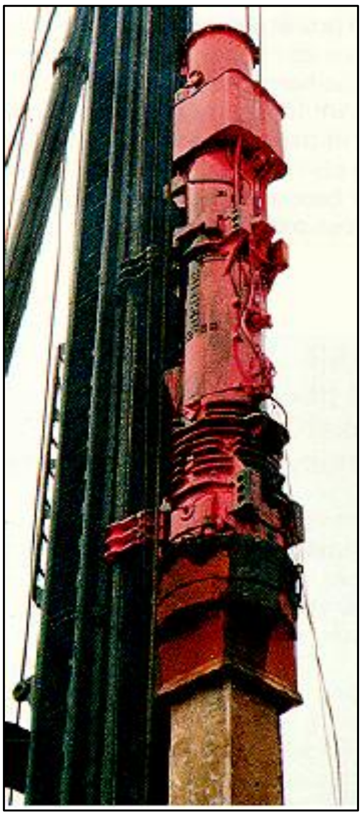

Fig. (9-4) - Diesel Hammer

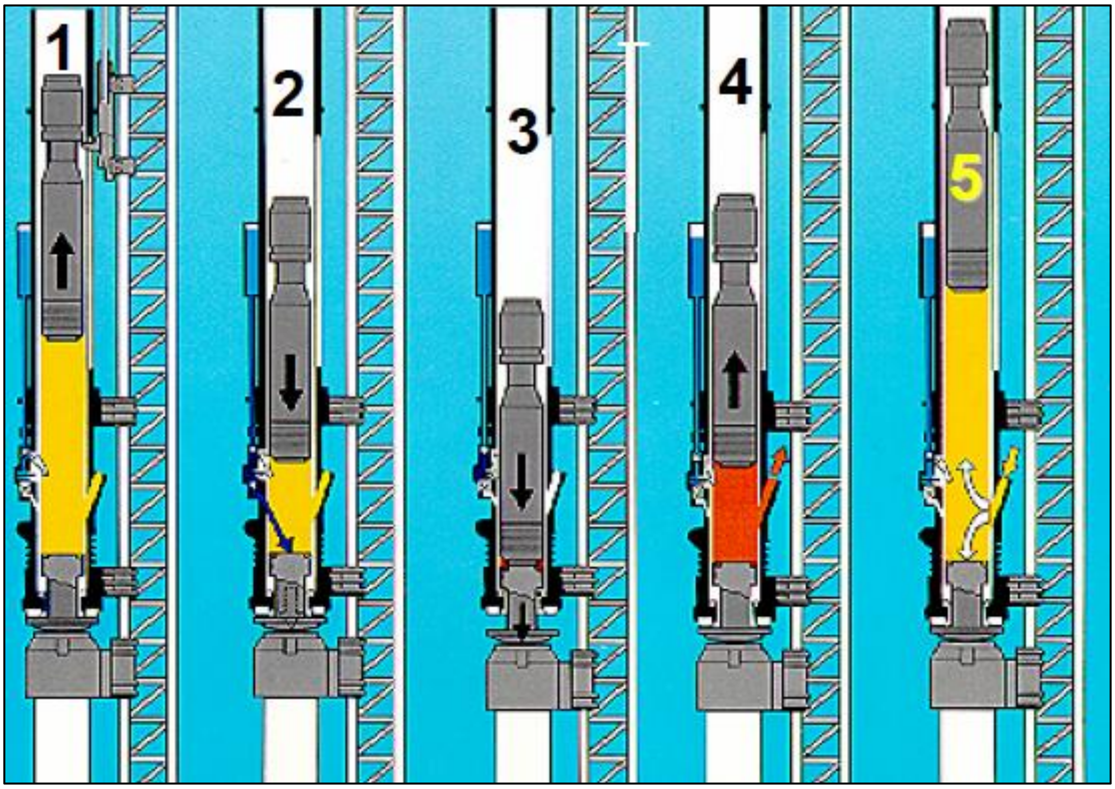

Fig. (9-4) – Steps of the Operation of a Diesel Hammer

1) Raise the piston to start.
2) Injection of diesel fluid and compression.
3) Impact and Explosion.
4) Exhaust ports exposed and gases escape.
5) Draws fresh air through the exhaust ports.