CHAPTER

Construction Planning, Equipment, and Methods

Sixth Edition

PILES AND PILE-DRIVING EQUIPMENT

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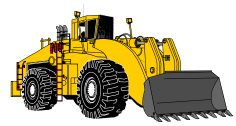

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PILES

Crawler crane w/ single acting air hammer and hydraulic leads.

Driving 12-in. concrete piles.

PILES

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

PILES

- If the load is transmitted to the soil through skin friction between the surface of the pile and the soil, the pile is called a friction pile.
- If the load is transmitted to the soil through the lower tip, the pile is called an end-bearing pile.

PILES

- Many piles depend on a combination of friction and end bearing for their supporting strengths.
- Piles may be classified on the basis of either their use or the materials from which they are made.

TYPES OF PILES

On the basis of use, there are two major classifications:

1. Sheet
2. Load bearing.

TYPES OF PILES

- Sheet piling is used primarily to resist the flow of water and loose soil. Typical uses include cutoff walls under dams, cofferdams, bulkheads, and trench sheeting.

TYPES OF PILES

- On the basis of the materials from which they are made, sheet pilings may be classified as:
  - ✓Steel
  - ✓Wood
  - ✓Concrete, or
  - ✓Composite.

PILE TYPES

Timber
- treated
- untreated

Concrete
- Precast
  - reinforced
  - prestressed

Steel

Composite

TYPES OF LOAD-BEARING PILES

- Considering both the type of the material from which they are made, and the method of constructing and driving them, load-bearing piles may be classified as follows:

1. Timber

a. Untreated

b. Treated with a preservative

TYPES OF LOAD-BEARING PILES

2. Concrete

a. Precast-prestressed

b. Cast-in-place with shells

c. Augered cast-in-place

3. Steel

a. H section

b. Steel pipe

TYPES OF LOAD-BEARING PILES

4. **Composite**

5. **Sheet**
   a. Steel
   b. Prestressed concrete
   c. Timber

SELECTION OF PILES

- It is the responsibility of the engineer to select the pile type which is best suited for a given project, taking into account all the factors that affect both installation and performance.

SELECTION OF PILES

- Factors that will influence the decision of selecting the pile type are:

1. The type, size, and weight of the structure to be supported.
2. The physical properties of the soil stratum at the site.

SELECTION OF PILES

3. The depth to a stratum capable of supporting the piles.
4. The variations across the site in the depth to a supporting stratum.
5. The availability of materials for piles.
6. The number of piles required.

SELECTION OF PILES

7. The driving equipment.
8. The comparative in-place costs.
9. The durability required.
10. The types of structures adjacent to the project.
11. The depth and kind of water, if any, above the ground into which the piles will be driven.

SITE INVESTIGATION AND TEST PILE PROGRAM

- For projects of intermediate to large scale a thorough site investigation can be very cost effective.
- The geotechnical information gathered from borings can be used to determine the soil characteristics and the depths to strata capable of supporting the design loads.

SITE INVESTIGATION AND TEST PILE PROGRAM

- The number of blows per foot, from geotechnical tests such as the standard ***penetration test***, is normally recorded during the soil sampling operations and can be extremely valuable for use in predicting pile lengths. From this information pile types, sizes, and capacities may be chosen.

SITE INVESTIGATION AND TEST PILE PROGRAM

- Once a pile type has been selected, or if several types are deemed practical for use on a particular project, a test pile program should be conducted.

LOAD TEST

- A reaction frame or beam is attached to the reaction piles and spans over the top of the test pile so that the test load may be applied by utilizing an hydraulic jack. The jack is located between the reaction beam and the top of the test pile. As the load is applied by the jack, the reaction beam transfers the load to the test pile, putting it in compression and putting the reaction piles in tension.

LOAD TEST

FIGURE 15-2
Load test of a 54-in. concrete cylinder pile utilizing reaction piles, beams, and a jack. *(Tidewater Construction Corporation.)*

LOAD TEST

Reaction frame and hydraulic jacks used to load test a 54-in. concrete cylinder pile.

LOAD TEST

- For either type test, direct load or reaction, the magnitude of the applied test load is normally 2 to 3 times the design bearing capacity of the pile.
- Any sudden or rapid movement of the pile indicates a failure of the pile.

TIMBER PILES

- Timber piles are made from the trunks of trees.
- The advantages of timber piles include the following:
  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. After driving they can be easily cut off to any desired length.
  5. Usually they can be extracted easily in the event that removal is necessary.

TIMBER PILES

- The disadvantages of timber piles include the following:
  1. It may be difficult to economically obtain piles that are sufficiently long and straight.
  2. They may be difficult or impossible to drive into hard formations.
  3. They are difficult to splice when increased lengths are necessary.
  4. While they are satisfactory when used as friction piles, they are not usually suitable for use as end bearings under heavy loads.
  5. The duration over which they maintain their structural capacity may be short unless the piles are treated with a preservative, and preservatives may have undesirable environmental effects.

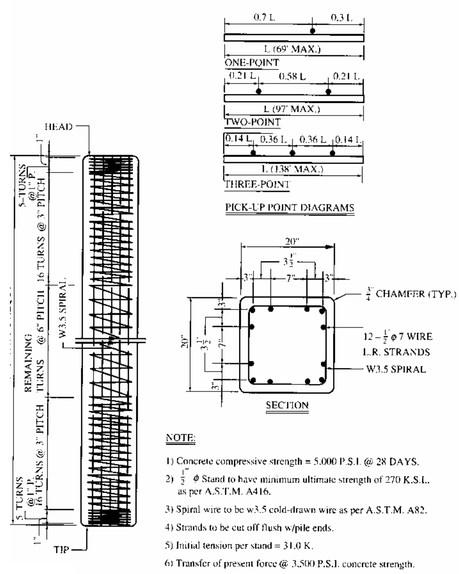
PRECAST-PRESTRESSED CONCRETE PILES

- Precast-prestressed concrete piles are normally manufactured at established plants utilizing approved methods in accordance with the PCI MNL-116-85 "Manual for Quality Control". Specifications for many projects, such as those used by state highway departments, require the piles to be manufactured at PCI certified plants.

PRECAST-PRESTRESSED CONCRETE PILES

- Square and octagonal piles are cast in horizontal forms on casting beds, whereas cylinder piles are cast in cylindrical forms and then centrifugally spun.

Precast-prestressed Concrete Piles



pical details of a 20-in. square prestressed concrete pile. (*Bayshore Concrete Products, Chesapeake, Inc.*)

PRECAST-PRESTRESSED CONCRETE PILES

- The advantages of concrete precast piles include the following:
  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 the pile to facilitate jetting

PRECAST-PRESTRESSED CONCRETE PILES

- The disadvantages of precast concrete piles include the following:
  1. It is difficult to reduce or increase the length
  2. Large sizes require heavy and expensive handling and driving equipment.
  3. The inability to obtain piles quickly by purchase may delay the starting of a project.
  4. Possible breakage of piles during handling or driving produces a delay hazard.

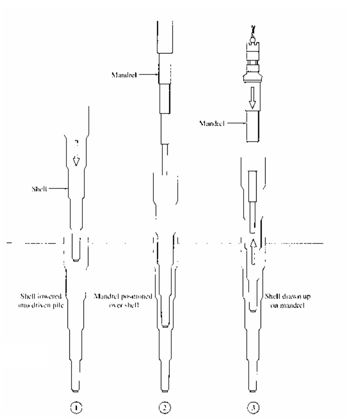
CAST-IN-PLACE CONCRETE PILES

- As the name implies, cast-in-place concrete piles are constructed by depositing the freshly mixed concrete in place in the ground and letting it cure there.

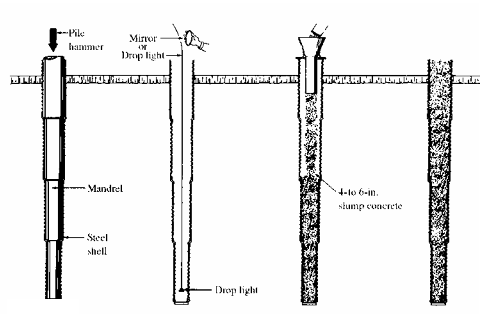
CAST-IN-PLACE CONCRETE PILES

- The two principal methods of constructing cast-in-place concrete piles are:
  1. Driving a metallic shell and leaving it in the ground, and then filling the shell with concrete.
  2. Driving a metallic shell and filling the resulting void with concrete as the shell is pulled from the ground

CAST-IN-PLACE CONCRETE PILES



Shell-up procedure for Raymond step-taper piles.



Installation sequence for Raymond step-taper piles.

CAST-IN-PLACE CONCRETE PILES

- The advantages of cast-in-place concrete piles include the following:
  1. The lightweight shells may be handled and driven easily.
  2. The variations in length do not present a serious problem. 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.

CAST-IN-PLACE CONCRETE PILES

4. The excess reinforcing, to resist stresses caused only by handling the pile, is eliminated
5. The danger of breaking a pile while driving is eliminated
6. Additional piles may be provided quickly if they are needed

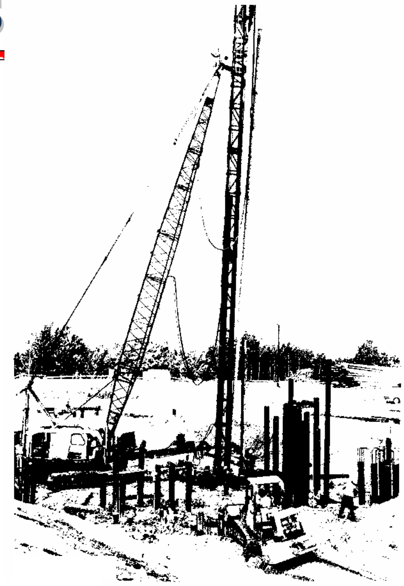
CAST-IN-PLACE CONCRETE PILES

- The disadvantages of cast-in-place concrete piles include the following:
  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

STEEL PILES

- In constructing foundations that require piles driven to great depths, steel piles probably are more suitable than any other type
- Steel **H section piles.** 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

STEEL PILES



Driving No. 5 gauge 12-in. monotube piles up to 200 ft long with a 37,000 ft-lb steam hammer. (*The Union Metal Manufacturing Company.*)

STEEL PILES

- **Steel-pipe piles**. These piles are installed by driving pipes to the desired depth and, if desired, filling them with concrete. A pipe may be driven with the lower end closed with a plate or steel driving point, or the pipe may be driven with the lower end open.

COMPOSITE PILES

- When extremely hard soils or soil layers are encountered, it may be cost-effective to consider the use of a composite pile.
- The top portion of the pile would be a prestressed concrete pile and the tip would be a steel H pile embedded into the end of the concrete pile.

COMPOSITE PILES

- The composite design is suggested for marine applications, where the concrete pile section offers resistance to deterioration and the steel pile tip enables penetration of hard underlying soils.

SHEET PILES

- Sheet piles are used primarily to retain or support earth.
- Sheet piles are commonly used for bulkheads and cofferdams and when excavation depths or soil conditions require temporary or permanent bracing to support the lateral loads imposed by the soil or by the soil and adjacent structures.

SHEET PILES

- Sheet piles supported loads include any live loads imposed by construction operations.
- Sheet piles can be made of steel, concrete, or timber.
- Each of sheet pile types can support limited loads without additional bracing or tieback systems.
- When the depth of support is large or when the loads are great, it is necessary to incorporate a tieback or bracing system with the sheet piles.

THE RESISTANCE OF PILES TO PENETRATION

- In general, the forces which enable a pile to support a load also cause the pile to resist the efforts made to drive it.
- The total resistance of a pile to penetration will equal the sum of the forces produced by skin friction and end bearing.

THE RESISTANCE OF PILES TO PENETRATION

- The relative portions of the resistance contributed by either skin friction or end bearing may vary from almost 0 to 100%, depending more on soil type than on the type of pile.
- A steel **H** pile driven to refusal in stiff clay should be classified as a skin friction pile, whereas the same pile driven through a mud deposit to rest on solid rock should be classified as an end-bearing pile.

PILE HAMMERS

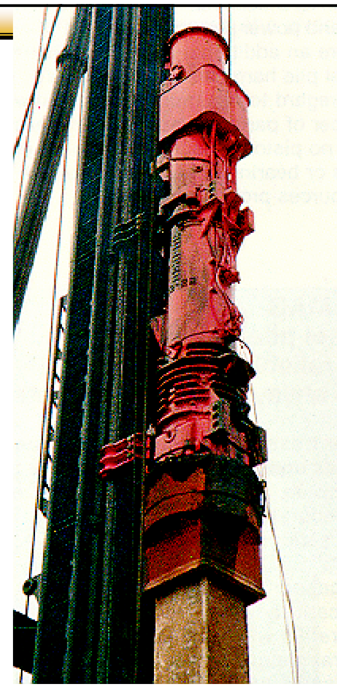
- The function of a pile hammer is to furnish the energy required to drive a pile. Pile driving hammers are designated by type and size.

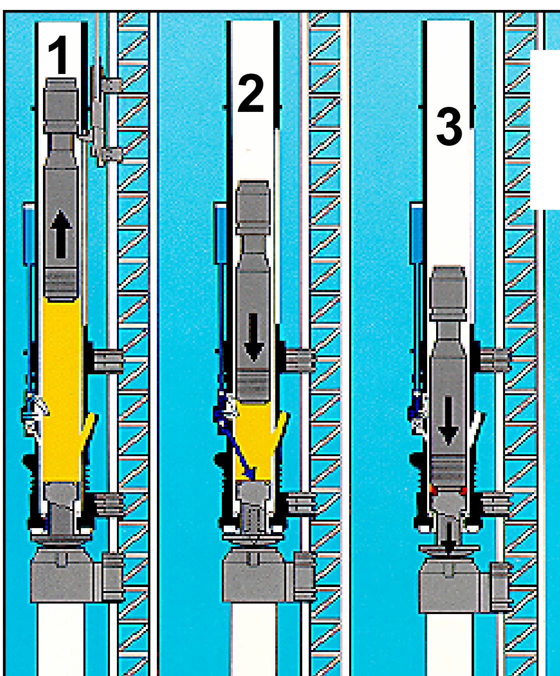
PILE HAMMERS

- The hammer types commonly used include the following:
  1. Drop
  2. Single-acting steam or compressed air
  3. Double-acting steam or compressed air
  4. Differential-acting steam or compressed air
  5. Diesel
  6. Hydraulic
  7. Vibratory drivers

DIESEL HAMMERS

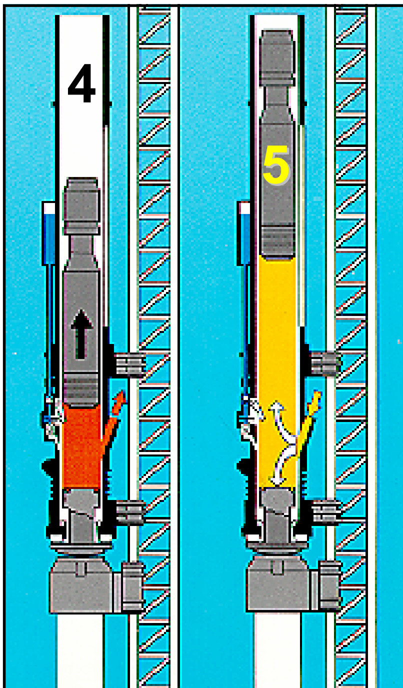
Diesel hammers impart compression, impact and explosion energy to the pile.





DIESEL HAMMERS

1. Raise the piston to start.
2. Injection of diesel fuel and compression.
3. Impact and explosion.



DIESEL HAMMERS

4. Exhaust ports exposed and gases escape.

5. Draws fresh air through the exhaust ports.

DIESEL HAMMERS

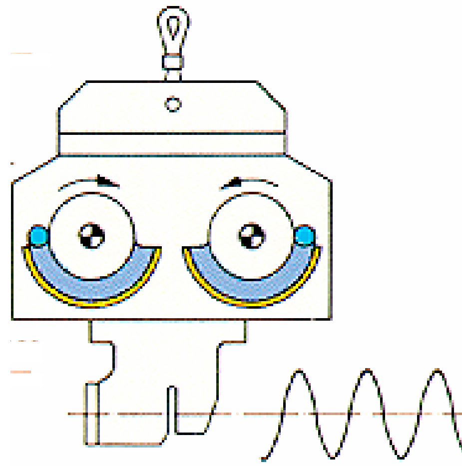
Fuel usage varies with the size of the hammer see Table 19-2b.

DELMAG

10,500 ft-lb	0.7 gal/hr
58,248 ft-lb	2.11 gal/hr
107,177 ft-lb	4.23 gal/hr
300,000 ft-lb	7.93 gal/hr

VIBRATORY HAMMERS

Vibratory hammers use exciting shafts rotating in opposite directions.



VIBRATORY HAMMER

VIBRATORY HAMMER

Can be driven by hydraulic or electric motors.

METHODS OF SUPPORTING AND POSITIONING PILES

- When driving piles, it is necessary to have a method which will position the pile in the proper location with the required alignment or batter, and which will support the pile during driving.

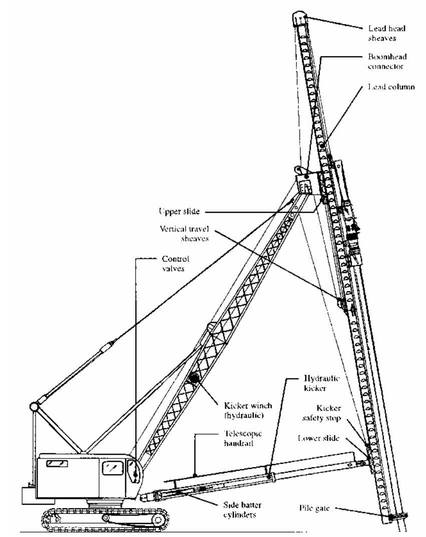
METHODS OF SUPPORTING AND POSITIONING PILES

- The following methods are utilized to accomplish such alignment and support:
  - ✓Fixed leads
  - ✓Swing leads
  - ✓Hydraulic leads
  - ✓Templates

METHODS OF SUPPORTING AND POSITIONING PILES

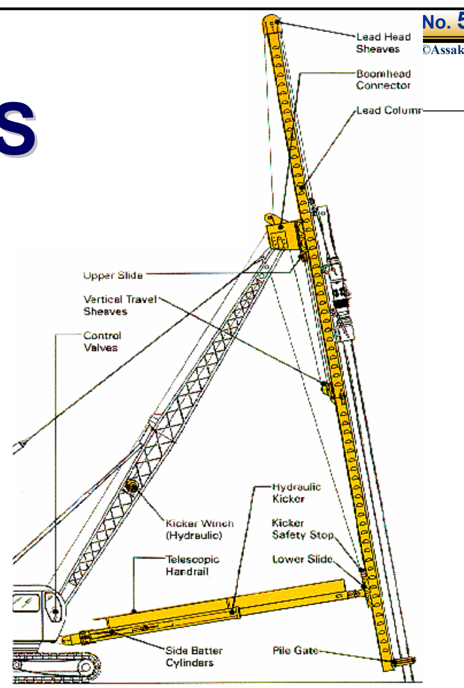
- To control pile position, hydraulic leads utilize a system of hydraulic cylinders connected between the bottom of the leads and the driving rig.
- This system allows the operator to <u>position the pile very quickly</u> and accurately.

HYDRAULIC LEADS

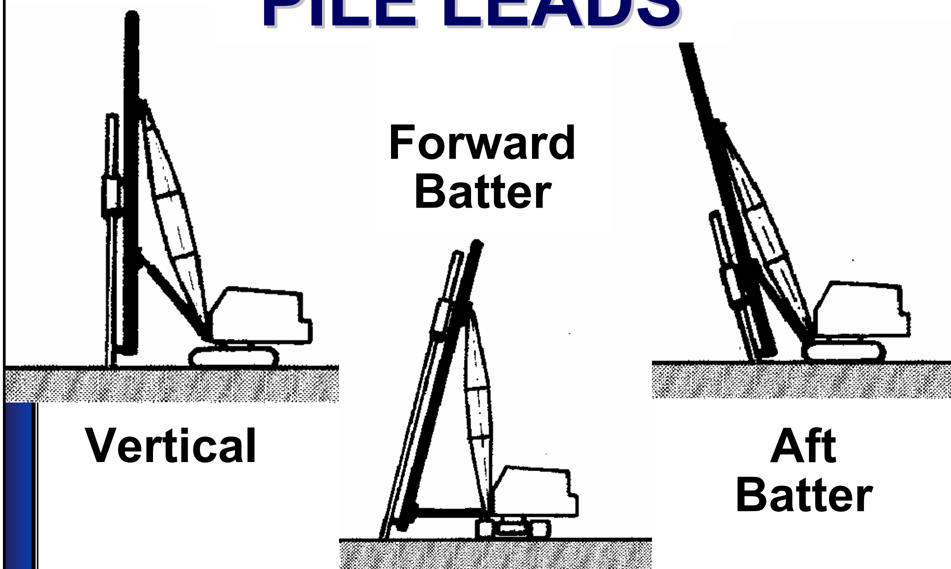


Vertical travel leads (hydraulic) attached to a crawler crane. (*Berminghammer Corporation Limited.*)

PILE LEADS



PILE LEADS



HYDRAULIC LEADS

- Hydraulic leads are extremely useful in driving batter piles since the system can rapidly and easily adjust the angle of the leads for the required batter.
- The system is more costly than standard fixed leads but that dollar difference is quickly recovered by any contractor who is regularly involved in pile-driving operations.

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:

PILE DRIVING EQUATIONS

– For a drop hammer:

$$\boxed{R = \frac{2WH}{S + 1.0}} \qquad (1)$$

where

R = safe load on a pile, lb

W = weight of a falling mass, lb

H = height of free fall for mass W, ft

E = total energy of ram at the bottom of its downward stroke, ft-lb

S = average penetration per blow for last 5 or 10 blows, in.

PILE DRIVING EQUATIONS

- ✓For a single-acting steam hammer:

$$R = \frac{2WH}{S + 0.1} \qquad (2)$$

- ✓For a double- and differential-acting steam hammer:

$$R = \frac{2E}{S + 0.1} \qquad (3)$$

Example 1

The falling ram of a drop hammer used to drive a timber pile is 6,500 lb. The free-fall height during driving was 19 in, and the average penetration for the last eight blows was 0.5 in per blow. What is the safe rated load?

From Eq. 1:

$$\text{Safe Rated Load, } R = \frac{2WH}{S + 1.0} = \frac{2(6{,}500)\left(\frac{20}{12}\right)}{0.5 + 1.0} = \underline{14{,}444 \text{ lb}}$$

SELECTING A PILE-DRIVING HAMMER

- Selecting the most suitable pile-driving hammer for a given project involves a study of several factors, such as:
  - ✓The size and type of piles
  - ✓The number of piles
  - ✓The character of the soil
  - ✓The location of the project
  - ✓The topography of the site
  - ✓The type of rig available, whether driving will be done on land or in water, etc.

SELECTING A PILE-DRIVING HAMMER

- A pile-driving contractor is usually concerned with selecting a hammer that will drive the piles for a project at the <u>lowest practical cost</u>
- <u>As most contractors must limit their ownership to a few representative sizes and types of hammers, a selection should be made from hammers already owned unless conditions are such that it is economical or necessary to secure an additional size or type.</u>

SELECTING A PILE-DRIVING HAMMER

- The function of a pile hammer is to provide the energy needed to drive a pile. This energy is supplied by a weight which is raised and permitted to drop onto the top of the pile, under the effect of gravity alone or with steam/air acting during the downward stroke.
- The theoretical energy per blow will equal the product of the weight times the equivalent free fall.

SELECTING A PILE-DRIVING HAMMER

- Since some of this energy is lost in friction as the weight travels downward, the net energy per blow will be less than the theoretical energy
- The actual amount of energy depends on the efficiency of the particular hammer. The efficiency ranges from 50 to 100%.
- The following table (Table 1, Table 19-3, Text) gives recommended sizes of hammers for different types and sizes of piles and driving resistances.

SELECTING A PILE-DRIVING HAMMER

Table 1. Recommended Sizes of Hammer for Driving Various Types of Piles† (Table 19-4, Text)

Length of piles (ft)	Depth of penetration	Steel Sheet‡ 20	Steel Sheet‡ 30	Steel Sheet‡ 40	Timber 30	Timber 60	Concrete 150	Concrete 400
Driving through ordinary earth, moist clay, and loose gravel, normal frictional resistance								
25	$\frac{1}{2}$	2,000	2,000	3,600	3,600	7,000	7,500	15,000
	Full	3,600	3,600	6,000	3,600	7,000	7,500	15,000
50	$\frac{1}{2}$	6,000	6,000	7,000	7,000	7,500	15,000	20,000
	Full	7,000	7,000	7,500	7,500	12,000	15,000	20,000
75	$\frac{1}{2}$	—	7,000	7,500	—	15,000	—	30,000
	Full	—	—	12,000	—	15,000	—	30,000
Driving through stiff clay, compacted sand, and gravel, high frictional resistance								
25	$\frac{1}{2}$	3,600	3,600	3,600	7,500	7,500	7,500	15,000
	Full	3,600	7,000	7,000	7,500	7,500	12,000	15,000
50	$\frac{1}{2}$	7,000	7,500	7,500	12,000	12,000	15,000	25,000
	Full	—	7,500	7,500	—	15,000	—	30,000
75	$\frac{1}{2}$	—	7,500	12,000	—	15,000	—	36,000
	Full	—	—	15,000	—	20,000	—	50,000

(Weight of various types of piles (lb/lin ft))

† Size expressed in foot-pounds of energy per blow.

‡ The indicated energy is based on driving two steel sheet piles simultaneously. In driving single piles, use approximately two-thirds the indicated energy.

HAMMER SPEC'S

WORKING SPECIFICATIONS

Rated energy .... 42,000 ft-lbs (5807 kg-m)

Minimum energy .... 16,000 ft-lbs (2212 kg-m)

Stroke at rated energy .... 10'-3" (312 cm)

Maximum obtainable stroke .... 10'-5" (318 cm)

Speed (blows per minute) 37-55

Bearing based on EN formula .... 210 tons (190 tons)

WEIGHTS Bare hammer .... 7,610 lbs (3452 kg)

Ram .... 4,088 lbs (1854 kg)

Anvil .... 545 lbs (247 kg)

Typical operating weight with cap .... 8,710 lbs (3950 kg)

HAMMER SPEC'S

DIMENSIONS OF HAMMER

Width (side to side)	20" (508 cm)
Depth	29" (737 cm)
Centerline to front	13 3/4" (349 mm)
Centerline to rear	15 1/4" (387 mm)
Length (hammer only)	16'-1" (490 cm)
Operating length (top of ram to top of pile)	27'-9" (846 cm)