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Piles and pile driving

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BY

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PREFACE

   This thesis on the subject of "Piles and
Pile Driving" has been written to fulfil one of
the requirements for the granting of the degree
of Civil Engineer by the Newark College of Engi-
neering. The material contained in this thesis
has been gleaned from many books, catalogs,
magazines and from the author's own experience.
Much still needs to be accomplished in the field
of research but this can be done only through the
cooperation of the companies who are engaged in
this work and have the equipment necessary for
making many tests under actual field conditions.

   The author wishes to acknowledge his
indebtedness to the following companies for the
information which they have supplied and also for
the illustrations, some of which are reproduced
in this thesis: - Russell Company, Charles R. Gow
Company, Mac Arthur Concrete Pile Corporation,
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valuable suggestions.

           R. W. Van Houten

Newark College of Engineering
   January, 1932

CONTENTS

CONTENTS

CONTENTS

PILES AND PILE DRIVING

CHAPTER I

History of Use of Piles

The origin of piles and pile driving is not known.
No definite date can be set as the time when the first
pile was driven but it is certain that timber piles
were known as long ago as the early lake dwellers of
Europe. Whether this was the origin of piles and pile
driving; whether they were first used in the jungles to
keep the huts off the ground and away from wild beasts;
whether they were forked branches of trees driven into
the muddy bottom of a stream to support the stringers
of a crude bridge, we cannot say. All we do know is
that piles have been used for many centuries and that
in type and method of driving there have been few
radical changes over the period from their inception
until the present time.

More is known, however, of the use of piles in
the building of ancient bridges and a brief resume of
the construction of bridge foundations will serve to
show the part that piles played in their development.
It has been determined from the study of the ruins of
ancient bridge foundations that the first piers were begun
by dumping loose stones in the water until the surface

of the river was reached. Then the masonry or wooden
bridge was constructed on that. In the arid countries
the bed often dried up for many months of the year and
the foundation could then be built without having to
contend with the stream. Another method of constructing
bridges and their foundations was to build them on dry
land adjacent to the river. After the bridge and foun-
dations were completed, the river was diverted under
the bridge and the old river bed filled in.

Following these types of bridges came the single
arch bridge which was originated by the Romans. With
the spread of civilization and the construction of more
roads the need for better bridges became apparent. The
single arch bridges of the Romans were satisfactory for
many narrow streams but some method had to be devised
for traversing the wider rivers. Several methods for
constructing piers in water came into use. Only two
of these are of special interest in a study of piles
and pile driving. First, was the method of driving
piles over the area of the foundation until the heads
were below low-water level. They were spaced at
distances apart as required by the nature of the bottom.
These piles were not driven so that the heads were at
the same level but were encased in a form of coarse
concrete such as the Romans used. This was leveled up

and on it was laid the stone for the footing course of
the pier. The second method was that of encasement.
This consisted in inclosing the space for the pier
with sheet piling, after which as much loose material
as possible was removed from within the encasement.
Stones were then dumped inside until nearly up to low
water after which the pier itself was constructed.

Of all the ancients who used piles the Romans by
far were the most proficient. The Pons Sublicuis,
which means "pile bridge," was built over the Tiber at
Rome more than six centuries before Christ. It was
attentively cared for by the high priests and endured
for at least three hundred years.

Julius Caesar during the invasion of Germany
bridged the Rhine with a pile bridge. He gave a good
description of it in his writings. The bridge was
1800 feet long and was built in ten days. When it
is taken into consideration that the builders were
harassed by enemy force all during the construction
of the bridge, it indicates that the Romans were very
familiar with that type of construction.

A more recent but equally famous example of a
bridge built on piles driven in cofferdams is the
Pont de la Concorde bridging the Seine in Paris,
built by Jean Rodolph Perronet from 1787 to 1791.
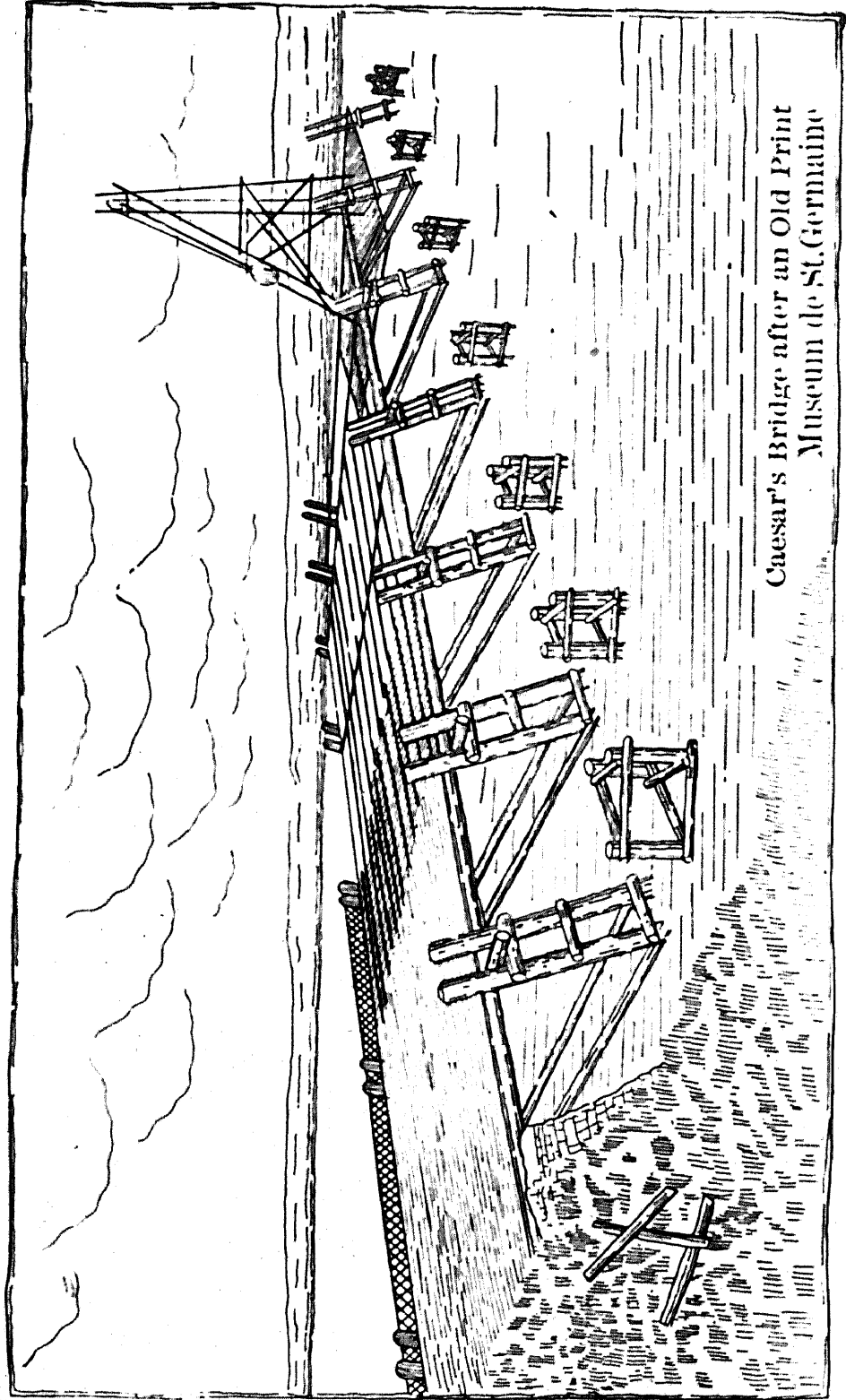
Caesar's Bridge after an Old Print
Museum de St.Germaine

This bridge still stands and is in use. The London Bridge built by Sir John Renne in 1831 was said to be "well founded" on elm piles.

Another illustration of a bridge which was built on piles but which offered special problems was the bridge constructed across the Danube at Buda Pesth. This was constructed through the efforts of Count Szcehenyi who went to England in 1832 as a member of a committee to investigate types of bridges. A suspension bridge was finally decided upon. In order to protect the two towers from the heavy ice in the Danube, which during the winter became from six to ten feet thick, it was necessary to build heavy and extraordinary cofferdams. Four of these were constructed and a total of 5224 piles were driven of which about sixteen percent had to be drawn and redriven. The piles and timber were obtained from the forests of Bavaria and Upper Austria. The first pile was set on dam number three on April 8, 1842, but owing to difficulties encountered it was not finished until April 4, 1845, three years later. No statement is made in the account of the building of the cofferdams as to whether the difficulties encountered were financial or physical. After this the work progressed more rapidly but often five to seven days were required to drive a pile to a depth of five or six feet into the clay. The average

was from twelve to fourteen days to drive one pile.
Many broke off and had to be drawn.

This gives a few of the highlights in the development of the use of piles from the earliest information available up to the century. Now I wish to touch upon the development of pile driving. This, too, is not greatly changed in the general appearance of the pile driver nor especially in the method which is similar to that used centuries ago.

CHAPTER II

Development of Pile Driving and Pile Driving Equipment

"In no department of engineering have ancient methods been more rigidly adhered to than in that of pile driving." This is a statement made by Fowler in his book "Ordinary Foundations." A study of the development of pile driving substantiates his remark without a reasonable doubt. The form of the pile-driver derrick has changed so little that a person who is but slightly familiar with pile driving would experience little difficulty in recognizing the pile driver in the illustration of Caesar's bridge.

Before derricks came into use a large wooden maul which Cresy called "a three-handed beetle" was used. It was formed from a block of hard wood bound with iron and had three handles radiating from the center. Two of these were to be used by two men to drive the pile. The third handle was shorter than the other two and was used by a third man to assist in lifting the maul.

Wooden mauls are still used in the driving of sheet piling into a soft bottom and heavy iron mauls or sledges are also used. If the bottom is too soft it is better that it be dredged and some more elaborate equipment be used to drive the piles to a harder stratum. A pneumatic

hand tool for driving sheet piling has been constructed by the Ingersoll Rand Company. It was used by the Illinois Power and Light Company in East St. Louis to drive piling 2" x 8" x 16'0" ten feet into sticky clay. It was found that it drove the piles faster and at a lower cost than the hand method.

The most primitive form of the derrick pile-driver is one which is similar to that used by Perronet at the Bridge of Orleans in 1751. It consisted of the typical type of derricks and leads with the hammer being attached to a rope while the other end of the rope was splayed. This permitted a number of men to pull down at one time. The drop of the hammer was limited by the length of the men's arms. A windlass was also included in the equipment for the purpose of raising the pile into position between the leads.

This type of derrick was later improved upon by Perronet who added a large bull-wheel to the windlass. On this was wound a rope to be pulled by a horse. As the animal moved out from the pile-driver the lead line was wound on the windlass. The illustration, which is taken from an old print, shows the horse on an embankment beside the derrick. There is no reason to assume that this was always the case. By the addition of another pulley the horse could have been on the same
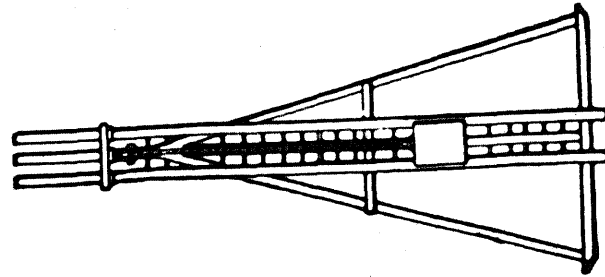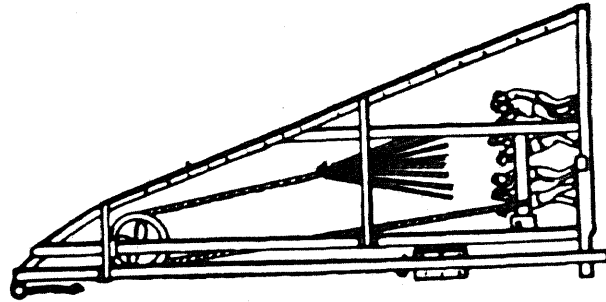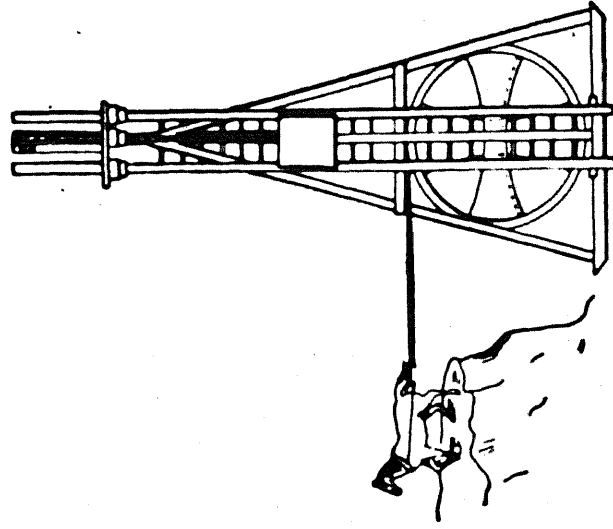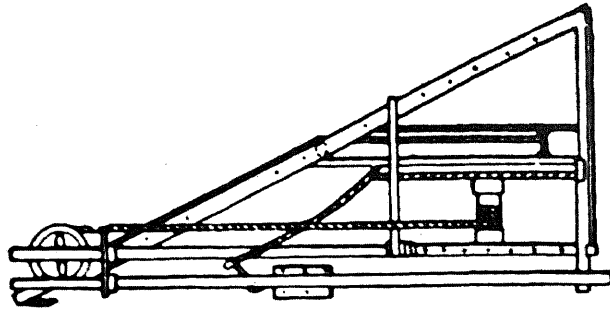
Perronet's Bull-Wheel Pile-Driver

Perronet's Pile-Driver

level as the bottom of the pile-driver. With one or
two changes this same type of apparatus has been used
down to the present time. The windlass, now installed,
is at right angles to the one shown in the sketch and
steam power has replaced man or horsepower.

Another example of the old types of pile-driver
was that used by De Cessart about 1756 at the Bridge
of Summur. He used a driver with a bull-wheel in the
periphery of which were set pins to form handles for
men to pull upon and rotate the wheel. Eight men, by
making three turns of the wheel, were able to raise
the ram, weighing 1500 pounds a distance of six feet.
Then it was unhooked and allowed to drop.

Of the more recent of the pre-steam types is one
described by Julian A. Hall in the Engineering News of
March 16, 1893. He described a simple form of pile-
driver in which the hammer was hewed out of a section
of hardwood log. Additional pieces of the log were
bolted on the sides of the hammer to hold it in the
leads. These were placed so as to give ample clearance
and avoid binding. The derrick was constructed of very
light timber, the verticals being four inch lumber and
the bottom pieces 6" x 6" timbers. The rope was passed
over the top sheave and down over steps on the back of
the driver. Men stood on these steps to pull the line

Head
Block

Rings for
Guy Ropes

Ladder

Back-Stays

Leads

Hammer
Line

Pile
Line

Steam
Hammer

Steam
Hose

Boiler

Friction
Drums

Engine

Sills

Rollers
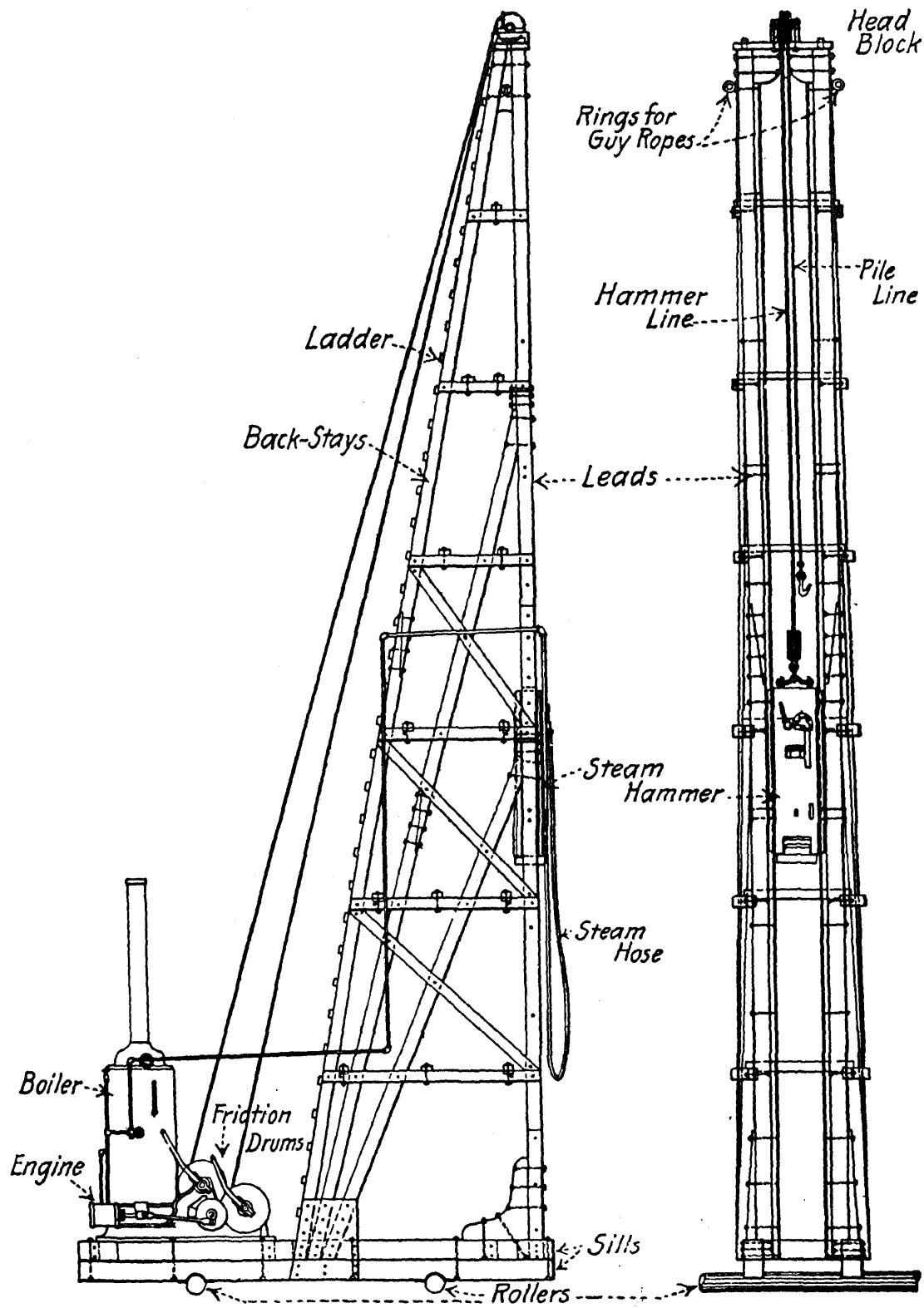
Typical Pile-Driving Rig

and operate the hammer. This was found to be a very inexpensive piece of equipment and to work well.

The foregoing gives a brief account of a few of the types of pile-drivers before the advent of the use of steam. The illustration on the previous page shows a typical pile-driver of the present day. It is apparent that the form of the modern derrick differs little from those shown in the preceding illustrations. The main differences are the boiler and engine, the drums at right angles to the old bull-wheel, the steam hammer and the rollers. The rollers permit the moving of the driver forward, backward, or sidewise. An experienced foreman can maneuver a driver around with remarkable ease and rapidity considering the bulkiness of the equipment. Some of the more efficient and modern drivers are mounted on turntables and are known as swiveling pile-drivers. These combine the ability to swing to the right or left together with the motions already listed. Other drivers are mounted on scows while a few are built for railroad service and are built to travel over rails.

The derrick of the pile-driver is now built of wood or steel with the trend being toward steel. Drivers which are to be used in excavations or on scows sometimes have rigid detachable leads which extend to the desired depth. A better method is the use of telescopic leads

which slide inside of the stationary leads and are
controlled by an extra line to a third hoisting drum.
By using some type of extension lead, piles may be
driven in deep trenches or in the bottom of cofferdams
containing a large amount of internal bracing. A few
drivers have the tower part of the derrick pivoted at
its base so that piles may be driven on a batter.
This type is expecially suited for use on railroad
trestles. Still one other type has been built to com-
bine the functions of a pile-driver and a steam-derrick
for use in the erection and maintenance of small bridges
and culverts.

The ram, or hammer, has undergone more changes
than perhaps any other part of the pile-driving equip-
ment. The hammer used in olden times was of oak, bound
with iron. For the work at Orleans, a 1200 pound hammer
was used on piles nine to twelve inches in diameter.
These were driven three to four feet on centers and about
six feet into the bed of the river. The hammer for the
sheet piles weighed only about one half as much.

With the advent of the hoisting engine the work
was reduced. The rope was left attached to the hammer
so that it was unnecessary to run the tongs down after
every drop of the hammer. This saved considerable time
and in addition a good engine man could catch the hammer

on the rebound and greatly decrease the time between
blows and, therefore, the cost of driving.

For the smaller sized hammers, from 1000 to 1500
pounds, a ten horsepower engine is generally used as it
is better to have surplus power in case of need. A
3000 pound hammer would probably use a twenty horsepower
engine as being the best and most economical. Not in-
frequently a twenty five horsepower one is used. The
cost of an outfit varies greatly. Too many variable
factors enter into the cost to give any prices for
certain sizes of engines. One thing to keep in mind
in purchasing an outfit is that with a double drum
engine the second line may be used to hoist the piles
into place without detaching the first line from the
hammer.

Another factor which has also speeded up the
driving of piles is the steam pile-hammer invented by
James Nasmyth. The principle used is that of the steam
forging-hammer which Nasmyth applied to pile-driving.
He developed this invention in 1845 and the hammers of
this class are now called Nasmyth hammers. He believed
that the drop hammer was constructed more for destruc-
tion than for useful effect. He termed it "the artillery
or cannon-ball principle." In the Nasmyth hammer, the
elastic force of steam is used in raising the ram or

driving piston. When the piston reaches its highest
point the driving-block is disengaged and its entire
weight of three tons descends on the head of the pile.
This process is repeated eighty times per minute and
the pile is driven at a remarkably more rapid rate of
speed than it is by the drop-hammer.

When Nasmyth made his first experiment with his
new type of hammer, he drove a fourteen inch pile
fifteen feet into hard ground at the rate of sixty-five
blows per minute. The saving in time was astounding.
A pile could be driven in four minutes that had pre-
viously taken a day which meant a ratio of saving in
actual driving time of about one to eighteen hundred.
Of course the time spent in hoisting the pile and
placing it was not reduced so that the total percentage
of time saved was not quite so large. It was, however,
a very much faster method than was the old drop-hammer
system.

One of the original ideas introduced by Nasmyth
was that of using the pile as the support for the piston
casing and striking block. The casing was held in the
leads but the entire weight of both it and the block
rested on the pile while it was being driven. This
method used the dead weight of the hammer as well as
the live blows struck by the steam piston. Steam was

used as a buffer in the upper part of the cylinder and had the effect of a recoil spring. This greatly enhanced the effect of the downward blow.

This hammer has been manufactured in many modified forms. One which is used to a great extent today is the Warrington-Nasmyth hammer made by the Vulcan Iron works. This is manufactured in three sizes, 550 pounds for sheet piling, 3000 pounds for general pile driving and 4800 pounds for heavy work. This hammer is provided with a positive valve-gear, a short steam passage to avoid waste of steam, a wide exhaust opening to prevent back pressure as the piston drops and a piston-head forged on the rod and channel bars on the side to allow the pile to be driven lower than the leads of the derrick. The hammer of this type is made fast to the hoist rope which is left slack when the hammer is resting on the head of the pile. The bottom of the casting is in the shape of a bonnet which encases the top of the pile and prevents brooming or splitting. When driving is to begin, the steam is turned on and the hammer delivers blows at the rate of sixty to seventy per minute. These hammers should have plenty of play in the leads and the steam pipe should extend half way up the derrick in order to save lengths of hose. Some drivers of

this type have driven as high as seventy-five to one hundred piles per day. One account gives a record of three thousand lineal feet of piling per day.

Another form of the Nasmyth hammer is the cram. This is quite simple in construction and consists of a hollow driving-head. The steam enters the hollow piston rod and causes the head or cylinder to rise on the rod. This is made in four sizes, 430 pounds, 2000 pounds, 3000 pounds, and 5500 pounds. All hammers have the same number of blows per minute. One of these hammers was used on the Passaic River and a record was established of 121 piles driven seventeen feet into a bed of sand and oyster shells in one day.

The problems encountered in driving the different types of piles will be considered when each type of pile is discussed.

CHAPTER III

The Theory of Pile Driving

Piles are used in materials that are notable to bear the weight of structures, after spreading the bases of the structure by the use of concrete or timber, either singly or combined, or where the cost of preparing the foundation in such a manner would be excessive. They are also used when the material, while being firm enough to bear the weight, is in danger of being scoured out by water. Again, piles are many times driven purely on account of convenience, expedience and economy.

From the foregoing paragraph it may be seen that the problem resolves itself into four general questions. Briefly they are these: first, the weight of the structure which must be carried by the foundation; second, the type of soil to be found and its supporting capacity; third, the number of piles to be required and how they will be grouped; fourth, the determination as to when each pile has been driven to the proper depth to develop the required supporting capacity. It is not within the scope of this thesis to discuss the determination of the loads to be imposed on the foundation by the weight of the structure. The

other three questions will be discussed, however,
and an attempt will be made to answer them in the
light of present day practice.

Test Borings

The type of soil into which the pile is to be
driven can be determined by making what are known
as test borings. Of course, until these borings are
made, the question as to whether piles are to be used
or not is not determined. The borings, however, do
have a decided effect upon the length of pile and the
number required, once the necessity for piles has been
established. It is essential that a sufficient number
of test borings be made to determine accurately the
character of the ground in question. The author has
in mind one pile-driving job where sufficient tests
were not made and great difficulties developed. Rocks
were struck, piles had to be redriven many times and
considerable time was lost. This all occurred where
the ground was supposed to be sandy. Thus, failure
to obtain accurate information may result in the loss
of thousands of dollars.

There are several methods of making soundings or
borings. Some are good and others worse than useless.
The first method to be described is one in which an

iron pipe or rod about one to one and one-half inches
in diameter is driven into the ground. The rod is
driven by constant hammering and turning and may be
made to penetrate to a depth of over thirty feet.
The information obtained by this type of test is
meagre and unsatisfactory. The character, thickness
or layers of different strata penetrated cannot be
determined. Boulders, large or small, will stop the
driving of the rod as will also logs, drifts, or
wrecks. While this method is still used, it is
strongly condemned as it leads to erroneous con-
clusions. For the construction of one bridge in
Ohio, plans were drawn and estimates and contracts
closed on the supposition that rock would be reached
shortly below the ground surface. It was later
discovered that no firm material existed under from
sixty to seventy feet below low water. Expensive
changes in the plans were thus made necessary. The
test borings had been made by the method just described.

A better and more satisfactory method of obtaining
test borings is to sink a terra cotta or iron pipe from
three to eight inches in diameter by the following pro-
cedure: The pipe is first pressed into the surface as
far as practicable. Then a long narrow bucket with a
cutting edge and a flap valve a little distance above

the cutting edge and opening outwards is dropped into
the pipe and alternately raised and dropped. This is
repeated and the pipe gradually sinks. Other sections
of the pipe are added from time to time. Sometimes it
is necessary to pour water into the pipe to aid in
cutting, and also to facilitate the flow of material
into the bucket. Great depths can be reached by this
method with fair rapidity and at no great cost. The
thickness and nature of the strata and whether they
are composed of sand, gravel and clay, is thus
determined. The main fault with this method is that
no indication is given as to the state in which the
material exists. Clay, for instance, will be brought
up as mud. For this reason a third and better method
has been developed.

The method of making test borings now to be
described, makes use of two sizes of pipe, one about
one and one-half inch in diameter, and the other about
three-quarters of an inch in diameter. The smaller
one is equipped with a chisel bottom and is lowered
inside of the larger pipe. Both are forced down,
meanwhile being turned. The smaller pipe can be
withdrawn at any time, and the material which has
been collected may be pushed out. Thus a cylindrical
specimen may be obtained which indicates the exact

condition of the material as it exists at the depth
at which the smaller pipe was withdrawn. This method,
while working better in clay, silt or mixed soils, may
be used to drill thru logs and rocks. An experienced
man can tell, when rock is encountered, whether it is
a boulder or solid rock. This may be determined by
letting the chisel drop and observing the rebound
and the sound. This outfit is cheap because any
plumber or mechanic can make it. At the same time the
results obtained are very satisfactory.

Types of Soil

After the soil has been investigated the next
problem is to determine how the piles will probably
act and how much load each one can take. Three
general possibilities exist. The soil may be such
that it is fluid or soft and the piles may be driven
thru it until a stratum of firm or practically un-
yielding material is reached. In this case the pile
receives little, if any, lateral support and therefore
acts as a column.

The second type of soil is that in which, while
no firm stratum may be reached, the earth will compact
under the pile and will also produce friction on the
surface of the pile. The strength of this condition

of piling depends upon the bearing capacity of the soil under the point of the pile, and the adhesion of the ground to the surface of the pile, or upon the compressive resistance of the material in the upper part of the pile.

The third soil condition is very similar to the second. It involves the case in which skin friction between the surface of the pile and the earth is developed, but in which the earth does not compact under the point of the pile. The piling under this condition depends solely upon the skin friction or the compressive resistance of the material in the pile.

Piles Acting as Columns

The total load coming on any one area due to the weight of the structure depends, of course, on the design of the structure under consideration. Having determined the load for any given area, the question that naturally follows is, "How many piles will be required?" If the condition is that of the first case described, the problem becomes one of determining the bearing capacity of the firm stratum and the ability of the pile to act as a column. The bearing capacity may be determined from information obtained

from test borings, and from a knowledge of the
allowable strength of the material for that particu-
lar locality. The ability of the pile to act as a
column may be determined by knowing the probable
length of the pile, its diameter, slenderness ratio
and allowable stresses. If any eccentricity is to
be caused by the loading, that also should be taken
into consideration, tho such a loading should be
avoided if at all possible.

Piles Supported by Skin Friction

In the case of skin friction a different problem
is confronted. The method of determining the allowable
stress for each pile, which is now to be discussed,
applies to cases two and three of the soil conditions
previously considered. When the earth compacts under
the point of the pile, some of the load may be carried
by the compacted ground. The amount to be carried
depends upon experience and a knowledge of how certain
material will compact under various driving conditions.
It probably varies between fifteen and twenty percent
of the total static bearing capacity. What it is
proposed to discuss now is how skin friction develops,
and how its resistance to settling may be determined.

When a pile is being driven under conditions in
which skin friction is presumed to develop, water is

usually squeezed out of the soil. This forms a slimy mud which lubricates the sides of the pile and thus reduces friction to a small value. The resistance of the pile is therefore largely due to that of the point where the pressure is high. The point causes the soil to displace and push up along the sides of the pile. Measurements have indicated that the amount of soil displacement at the surface is equal to the volume of the pile in the ground.

After a pile driven under these conditions has set for a time, the excess water is reabsorbed by the soil, by the pile, or both, causing the soil to grip the pile. When the pile is loaded there is, therefore, full friction along the sides and small comparative point resistance.

It is sometimes advocated, therefore, that the allowable load be the resistance determined by a pile-driving formula after the pile has set for some time. The pile-driving formulas are based upon the assumption that the earth is not allowed to set up around the pile during driving. What these formulas are and how they are assumed to operate will be discussed a little later in this chapter.

Frank J. Mullen relates that in driving piles for the John Hancock Mutual Life Insurance Company in Boston,

Massachusetts, it was impossible to obtain the proper penetration on the last blow during the initial driving. The piles were allowed to set until the next day and upon re-driving the desired resistance to driving was readily obtained. Later load tests substantiated the date obtained on re-driving the piles.

At the time of re-driving, if the pile has been allowed to set for at least over night, full friction along the surface of the pile will probably develop. Then when re-driving is attempted, it will be found that the soil under the point of the pile cannot readily displace upward, as it is held in place by the friction along the pile. The resistance to re-driving is, therefore, equal to the full frictional resistance plus high point resistance.

Pile driving formulae, of course, give results which are on the safe side. However, to use them indiscriminately seems, to the author, to be rather poor engineering practice. When it is known that skin friction is to be developed, the supporting capacity of the friction should be considered.

Several tests have been made upon piles under various conditions to determine the skin friction in pounds per square foot. Some of these were made by the Whangpoo Conservancy Board in Shanghai, some

by French engineers in Tunis, and still others by
Ackerman in England, who made tests on model piles.
All of these tests showed that in clays and silts the
frictional resistance per unit of pile surface in
contact is practically the same regardless of the
depth in the soil. The Shanghai tests actually
indicated somewhat smaller values for the greater
depths.

If it is possible to obtain the ultimate
frictional resistance per unit area, the bearing
value of a single pile may be easily calculated by
multiplying the resistance by the area in contact,
neglecting the point resistance, which is small.
This is the method which was adopted at Shanghai.
To obtain these friction values, it is necessary to
test the pulling resistance and the bearing capacity.
Little of such information is available but on the
following page is a table of the friction values for
soils in several localities.

It may be seen that while there are a variety
of opinions on the subject of the supporting capacity
of a pile under certain conditions, it is possible to
determine, with a reasonable degree of accuracy, just
how many piles are required in certain areas under a
structure. A careful study must be made of the soil

FRICTIONAL RESISTANCE OF PILES IN SILTS, CLAYS, ETC.

Location	Soil	Penetration (Feet)	Contact Surface (Sq. Ft.)	Ultimate Load (Pounds)	Friction per sq. ft. (Pounds)	Source of Information
Aquia Creek, Va.	Fluid mud	45-50	117	13,333	95*	Eng. News, Feb. 23, 1893
New York, foot of 17th Street, North River	Mud	50	219	33,600	130*	Proceedings Int. Eng. Cont., St. Louis 1904
Rhine Valley	Soft muck	0-35	---	------	130	Terzaghi
Rhine Valley	Soft clay	25-35	---	------	295	Terzaghi
Proctorsville, La.	Mud, sand, clay	35	144	62,500	370*	Eng. News, Feb. 23, 1893
Portland, Me.	Soft blue clay	14	58.5	50,000	740*	Fay, Spofford & Thorndike
Hull, England	Stiff blue clay	18	---	------	1,850	Terzaghi
Shanghai	Silty microscopic sand	4-50	---	------	130 to 900	Terzaghi
Tunis	Soft muddy clay	100	---	200,000	370*	Le Genie Civil Dec. 2, 1929

* Friction calculated after deducting 15% for point resistance

encountered and the allowable loads for the locality
determined before deciding on the number of piles
required.

Spacing of Piles

When more than one pile is required at any one
point, they are arranged in what are known as clusters.
In all ordinary foundations piles are usually spaced
about three feet on centers. They may be spaced more
closely, but that is the usual practice. It is also
desirable in so far as possible to spread the load by
means of the footing so that each pile will receive
practically the same load. On the following page is
an illustration of typical pile footings.

Occasionally it becomes necessary to provide
pile foundations under a retaining wall or dam, where
an unequal load distribution exists. Mr. E. P. Arneson
in the Engineering News-Record for October 9, 1919,
suggests a simple method for determining the proper
spacing of piles under such conditions. It is im-
perative that an excessive load is not caused to
exist on any one pile. Mr. Arneson's plan is to
divide the trapezoid of pressure under the cross-
section of the retaining wall or dam by vertical
lines, into several sections of equal area. The area

Typical Pile Footings

This chart gives a general idea of customary arrangement of piles in typical concrete footings.

1 Pile Footing

2 Pile Footing

3 Pile Footing

4 Pile Footing

5 Pile Footing.

6 Pile Footing

7 Pile Footing

8 Pile Footing

9 Pile Footing

10 Pile Footing

11 Pile Footing

12 Pile Footing

13 Pile Footing

14 Pile Footing

15 Pile Footing

16 Pile Footing

17 Pile Footing

18 Pile Footing

19 Pile Footing
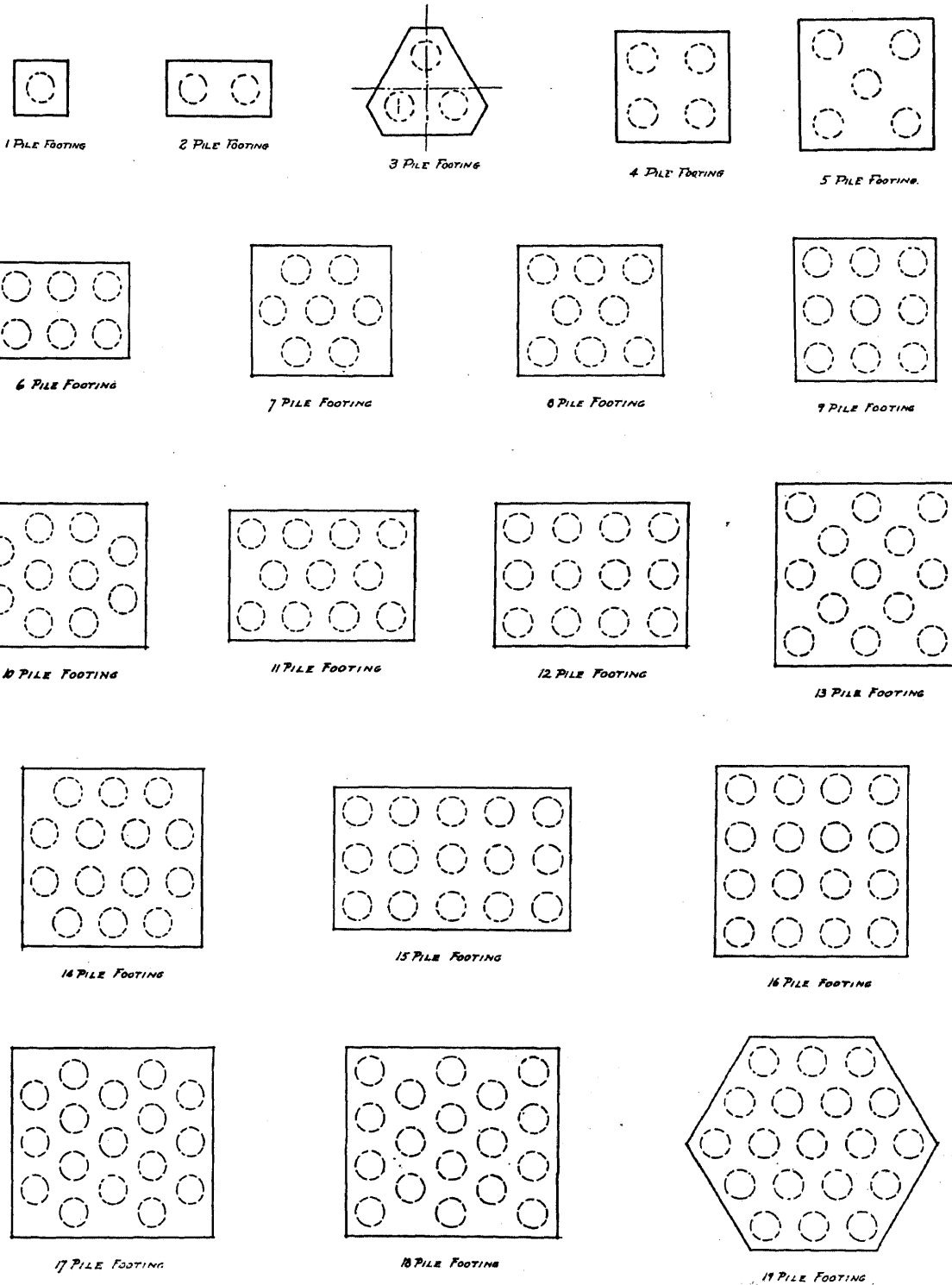
of each section is to represent the allowable load
on any one pile. The piles are then spaced at the
center of gravity of each one of these sections, thus
causing each pile to bear practically the same load.
The method is quite simple and eliminates the danger
of overloading any one pile.

Lateral Forces Acting on a Pile

Before leaving the subject of the strength of a
pile, it is necessary to touch upon the subject of
the lateral forces which may act on a pile. Bearing
piles located in streams often have to resist lateral
forces due to the impact of drift, ice, etc. As far
as possible, such forces should be provided for by
sway or lateral bracing. In the case of a retaining
wall or dam, lateral forces also may need to be
considered.

In discussing the lateral forces acting on the
piles, it will be assumed that the cross-sectional
area of the piles is large enough to offer sufficient
resistance so that, when pressure is applied against
the wall, the piles will not shear off just below the
footing course. It is also important to know the
point of zero rotation of the pile. By this is meant
the point about which the pile will tend to rotate as

a horizontal force is applied to it. Mr. Dimitri P. Krynine in the Engineering News-Record for November 26, 1931, reported on some observations which he had made. His results showed the point of zero rotation, by actual tests, to be located at a depth of 0.52 h to 0.69 h and averaging close to two thirds "h", where "h" is the length of pile in the ground. He neglected, however, to specify the points of application of the horizontal forces. Mr. Wilcoxen of Detroit, Michigan, replied to Mr. Krynine in the December 17, 1931, issue of the Engineering News-Record giving the results of his stress analysis of the problem.

Mr. Wilcoxen's report may be briefly explained as follows: It is shown that the vertical bearing power of a soil is proportional to its depth by forcing a rod vertically into a soil of uniform material. The horizontal power of a soil is then accordingly assumed to be proportional to its depth below the ground surface. Then by assuming a point of rotation at some distance "ab" below the level of the ground, Mr. Wilcoxen derives the following formula

$$A = \frac{2}{3} \frac{1 + 1.5 h}{1 + 2 h}$$

h = length of pile in the ground

a = a coefficient to be multiplied by "h" to obtain the position of the point of zero rotation below the ground surface.

1 = distance from the ground surface to the horizontal force acting on the pile. It is assumed that "1" is positive where the force acts above the ground and negative when it acts below.

Ground Surface

Horizontal Forces
Acting on a Pile
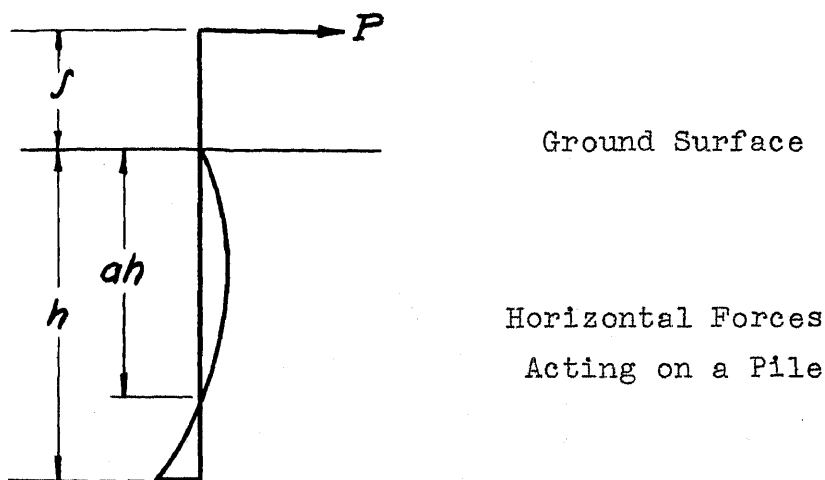
Some of the critical values are these. When 1 = -2/3 h, a = ∞ . This means that for this condition there is no tendency for the pile to rotate. When 1 = -0.50 h, a = 1.00. For this condition the point of rotation is at the bottom of the pile. When 1 = 0, a = 0.75, and as 1 increases further "a" approaches two thirds as a limit.

It will thus be seen that, when the horizontal force acting on the pile is above the ground, the

range of "a" is between 0.75 and 0.67, which compares
favorably with the values of 0.69 and 0.52 of Mr.
Krynine. Once the point of zero rotation is established,
it becomes a comparatively simple matter to calculate
the horizontal resistance to rotation which the pile
must offer. This can be determined by equating the
turning moment of the forces acting on the pile and
the resisting moment of the ground forces also acting
on the pile.

Pile-Driving Formulae

Previously in this chapter the subject of pile
driving formulae was discussed. These are necessary
in order to determine when a pile has been driven to
the proper depth to develop adequate bearing capacity.
Of course, as previously discussed, when skin friction
is to be the determining factor it is possible before
driving, to calculate how much of the pile must be in
the ground to obtain suitable surface area. Even so,
the results obtained from a pile-driving formula, when
re-driving of a pile subject to skin friction is
attempted, gives a fairly accurate conception of how
much load each pile will carry.

From the test borings it is usually possible to
estimate at what depth, if at any, a firm strata will

be reached. The depth of this strata probably varies either slightly or considerably over the area in which the piles are to be driven. Because of this and also because of the conditions in which piles depend upon the compacting of material under their point, pile-driving formulae help greatly in knowing when to stop driving.

The term "pile-driving formulae" refers to formulae based on the energy of the blow of the hammer and the penetration of the pile. Such are dynamic formulae. An exact formula of this type can only give the resistance of the pile to rapid penetration while what is desired is its static bearing capacity. The driving formula is of value, therefore, only in such cases as the dynamic resistance is some measure of the static bearing capacity. These formulae give fairly accurate results in the usual sands, gravels and other relative permeable, cohesionless soils where the resistance to rapid and slow penetration is about the same. The use of such formulae, when skin friction develops, has already been discussed.

There have been many pile-driving formulae developed. Some are very complicated and many assumptions are required in their solution. Some are interesting only from a mathematical point of view. The author intends

to discuss only one of these many formulae, but that
one is the most universally used. It is known as
the Engineering News Formula.

The Engineering News Formula was developed by
A. M. Wellington in 1888 from an almost purely
practical standpoint. The work done by the hammer
of weight "W" in falling thru a distance "h" is equal
to "W h". The useful work done upon the pile is the
product of its resistance multiplied by its penetration
under the last blow. The ratio of these two products
measures the efficiency of the hammer blow and the
proportion of the work wasted.

The energy stored in the hammer may be absorbed
in four ways: first, in brooming and washing the fibers
either at the head or the foot of the pile or at some
other part of its length; second, in bouncing and thus
striking two or more light blows instead of one heavy
one; third, in compressing elastically the material of
the pile and pile hammer; and four, in causing the pile
to penetrate against the resistance of the surrounding
earth.

Brooming, which will be considered in the next
chapter, constitutes a serious loss of energy. If
brooming occurs at the head of the pile it should be
cared for by cutting the broomed section off just

before penetration is obtained. This causes a fresh
surface of unbroken fibers to receive the final blows.

Bouncing of the hammer means waste of energy,
either because the pile has struck a solid obstacle
like a boulder, or because the hammer is too light,
or the velocity too great, or both. The presence of
a boulder can readily be detected by an experienced
man. When too light a hammer or too great a velocity
is obtained, it is impossible to get the pile in motion
before it reacts elastically with more force than the
hammer is exerting to push it down. A slight rebound,
however, is always present in good pile-driving, due to
the elasticity of the pile.

In the formula developed by Wellington, the
elastic compression of the pile and hammer is cared for
in the factor of safety which is six. Wellington's
formula for pile-driving with a drop hammer is: -

Safe load $= \dfrac{2\,W\,H}{S+1}$

W = weight of the drop hammer in pounds.

H = fall of hammer in feet.

S = average penetration in inches under the

last few blows.

The pile-driving formulae when a steam hammer is
used is similar to the one just given. The greater

efficiency of the steam hammer is due primarily to the rapidity of its blows. The Engineering News or Wellington formula for pile-driving with a steam hammer is: -

$$\text{Safe load} = \frac{2 W H}{S + 0.1}$$

Charts have been constructed for use with both of these formulae so that the safe load for any given penetration, weight of hammer and fall, can be readily obtained.

This last mentioned formula has been further modified so that for double-acting hammers it is as follows: -

$$\text{Safe load} = \frac{2 W H}{S + 0.3}$$

Later the question arose as to what influence the steam exerted in the driving of the piles. The following rule was suggested: "Ascertain as nearly as possible the foot-pounds represented by the blow delivered by the hammer. This can be done by adding to the foot-pounds represented by the free fall of the hammer, the foot-pounds obtained by multiplying the mean effective pressure by the area of the piston and the length of the stroke in feet. The result is the numerator of the formula.

In the absence of any specific data on the mean effective pressure it may be assumed as twenty five pounds per square inch.

Thus for a double acting hammer the new formula becomes: -

$$\text{Safe load} = \frac{(W + A (m.e.p.) h}{S + 0.3}$$

The safe load and W should be taken in pounds if the m.e.p. is in pounds.

Other formulae pertaining to special types of piles will be discussed when these special piles are considered in Chapters V and VI.

Test Piles

One other phase of the theory of pile driving remains to be discussed, and that is the subject of test piles. Test piles are piles which are driven under standard conditions and then loaded and the settlement observed under various loadings and over a period of time.

This method gives the most accurate results as to the actual bearing capacity of a pile. It would be ideal, of course, if these piles could be driven in various parts of the ground where a building is to be constructed before the pile foundation was designed.

This, however, is impractical both because of the time involved, the cost, and also the fact that quite accurate information can be obtained by the methods already mentioned.

It should be required, however, that a certain percentage of all of the piles driven on a job be tested by loading and the settlement noted. This has always been feasible in the case of timber and steel pile, but only in the last few years has it become practical with concrete piles, especially those which are moulded in place.

The change has been brought about by the invention of alumina or quick-setting cement. It is much more expensive than ordinary portland cement so is not feasible for use in all of the piles. It should be used, however, in those which are to be tested. The alumina cement develops its full strength in twenty four hours as against twenty eight days for ordinary portland cement. Harlan D. Miller, bridge engineer of the California Highway Commission, writes in the Engineering News-Record for February 11, 1926, that samples of alumina cement were tested forty eight hours after pouring. It was impossible to break the sample in the state testing machine which had a maximum capacity of 200,000 pounds. This indicated

a strength of greater than 5600 pounds per square inch. Thus, by using this cement in the test piles, loads may be applied as soon as twenty four hours after the concrete has been poured.

CHAPTER IV

Timber Piles

Wood Used

The kind of wood used in timber piles depends, to a great extent, upon the type of construction, the location of the piling, whether subject to alternate wetting and drying, and the permanence desired. For standard construction purposes the following woods are suggested: white, burr and post oak; longleaf pine, Douglas fir, tamarack; eastern white and red cedar; chestnut; western cedar; redwood, spruce and cypress. For less permanent construction the following types of wood are suggested: red and all other oaks, not already listed; sycamore; sweet, black and tupelo gum; maple; elm; hickory; Norway pine or, in fact, any sound timber that will stand driving. Other species which have been used to a limited extent under special conditions are beechwood, ash, and basswood; and even palmetto piles are not unknown. Each of the kinds of wood mentioned has its advantages and disadvantages. Oak is exceedingly tough and hard and will stand more hammering than any of the other species.

It has several disadvantages, the chief among them
being that oak piles cannot be obtained that are as
large, as straight or as long as those of either pine
or cypress. In certain localities oak piles are quite
expensive because of the charges for transportation.
Due to the heaviness of oak piles, any great number
of them made into a raft and carrying others are
likely to sink. In some localities where oak is
abundant, piles of this kind are used extensively.

There are two main types of pine, white pine,
found in the northern central states, and longleaf
yellow pine, found in the south. The former is soft,
white, easily worked, and possesses great strength
and durability. Since the beginning of the twentieth
century white pine has been in such demand for other
uses in building construction that it seldom has been
used as material for piles in the present day. The
longleaf yellow pine is found in abundance and is
considered to be harder and stronger than white pine.

There exists two apparently distinct species of
the longleaf yellow pine both of which present
practically the same outward appearances. One,
however, has a large proportion of sap-wood and a
small proportion of heartwood. This type should
never be used in structures unless immersed under water

at all times. The other has very little sap-wood
and long, large, straight pieces of almost clear
heartwood can be obtained. Such timber is unsur-
passed for use in structures above ground exposed
to alternate wetness and dryness. Straight trees
of this kind of pine can be obtained in any length
up to ninety or one hundred feet, and in diameters
at the butt end of from twelve to eighteen inches
or more, and from ten to twelve inches at the small
end. Pine logs can be floated in large rafts at
comparatively cheap rates. What has been stated
regarding the strength, durability, etc., of pine
piles may also be said of cypress. The main
objection to cypress is that it does not stand the
hammer as well as pine but has a tendency to split
and splinter.

Of the other kinds of wood mentioned a word or
two about several of them will suffice. Douglas fir
piles may be obtained in longer single sticks than
may any other woods. Elm is also considered good
material for piles but does not seem to be used to
any great extent. Spruce obtained from certain
localities has unusual toughness, giving the piles
increased resistance to the tendency to split.

Requirements for Good Timber Piles

The requirements for good timber piles vary in
some degree but the specifications of the American
Railway Engineering Association cover all of the main
points: "Piles shall be cut from sound trees; shall
be close-grained and solid, free from defects, such
as injurious ring shakes, large and unsound or loose
knots, decay, or other defects, which may materially
impair their strength or durability. Piles must be
cut above the ground swell and have a uniform taper from
butt to tip. Short bends will not be allowed. A line
drawn from the center of the butt to the center of the
tip shall lie within the body of the pile. Unless
otherwise allowed, piles must be cut when the sap is
down. Piles must be peeled soon after cutting. All
knots shall be trimmed close to the body of the pile.
Square piles shall show at least 80 percent heart at
each side at any cross-section of the stick, and all
round piles shall show at least a $10\frac{1}{2}$ inch diameter
of heart at the butt. Piles of the railroad false-
work grade, however, need not be peeled, and no limits
are specified as to diameter or proportion of heart."

Most engineers and authorities concur in the
greater portion of these specifications. The main

point of disagreement is the amount of permissible lateral curvature. Some engineers specify that the center of any cross section shall not depart more then one-eighth of its diameter from the straight line joining the centers of the butt and the tip. Others permit a maximum divergence of one percent of the length of the pile. When a pile bends in two directions, it is regarded as sufficient cause for rejection on first-class work.

There is one phase in the development of good piles that has not received the proper attention of engineers. That is the time of year in which timber is cut for piles. I shall quote from Foundations of Bridges and Buildings by Jacoby and Davis - "Tests made in Germany of four spruce trees, growing close together in the same soil, showed that if the strength, when cut in December, is taken as 100 percent, those cut in January, February and March had strengths of 88, 80 and 62 percent respectively. Beech timber cut in December and January gave an average mechanical life of six years, where as the same kind of timber cut in the same location in February and March gave a service of only two years."

There have been cases in this country which substantiate these reports from Germany. Some piles

of the best species of wood were cut in summer.
Decay due to fungi and worms became manifest when
the sapwood began to decay. Some of the piles
were completely eaten thru in two years.

Preparation of the Piles for Driving

After the selection of the logs for the piles,
the next step is the preparing of the logs by cutting
or sawing the large end square. The small end is
then brought to a blunt point with an axe, the bevel
being from $1\frac{1}{2}$ to 2 feet long. Finally the pile is
stripped of its bark. In soft and silty material
there is no need for pointing a pile at all, and in
fact the piles are better when left blunt. Pointed
piles on striking an obstruction will glance off and
no available power can prevent it. A blunt pile will
cut or break the obstruction. There are many illustra-
tions to justify this point of view. The large end
of the pile is chamfered for a few inches from the
end so that a wrought-iron band from 10 to 14 inches
internal diameter will just fit and will clasp the
pile uniformly and tightly with one or two light
blows of the hammer. Sometimes a ring from 1 to $1\frac{1}{2}$
inches less in diameter than the pile, is simply
placed on the top of the pile and driven into it by

light blows. This, however, is apt to split long
layers from the pile. It is imperative to put the
band on the pile before starting driving operations.
Once the pile begins to show signs of splitting then
the ring is too late to be of any advantage.

The use of the ring is not without its advantages.
Of course it would be too expensive to use a new ring
for each pile, so after the driving is completed the
ring must be removed. With ordinary tools such as
hammers and bars the work is quite difficult.   A
method has been described in Water Works and Sewerage
for January 1930 which greatly simplifies the problem
of removing the ring. A hook and lever arrangement has
been devised. The hook is caught under the edge of
the ring, and the lever extends across the top of the
pile. The hammer is allowed to drop about 6 inches
with the result that the ring is usually loosened
sufficiently to permit the removal of the ring with a
sledge. If the ring still remains wedged, the hook
may be caught under the opposite side of the ring.
A second blow of the hammer on the lever will usually
free the ring. This saves labor and prevents damaging
of the pile head.

If a ring were not used on the head of a pile,
what is known as brooming would take place, That is,

the repeated blows of the hammer would compress the
fibers until the ultimate resistance in compression
was reached. At this point failure would take place
and the fibers would yield by bending, buckling or
crushing. The adhesion to the adjacent fibers would
be destroyed and every blow of the hammer would tend
to injure the fibers further down. Wooden fibers
are more compressible when a load is applied on their
sides than on their ends and hence the broomed head
of the pile becomes more elastic. This causes it
to act like a spring or cushion and much of the
useful work of the hammer is wasted in overcoming
the cushioning effect of the broomed head of the
pile. Many times the brooming of the head is followed
by the splitting of the pile. To prevent these
failures rings should be and are generally used.

Another way in which timber piles may need pro-
tection is at the foot. As was mentioned before, it
is not necessary to sharpen or point the pile when
the driving is easy. In driving a pile with a blunt
end, a cone of compressed soil forms under it and
this acts as tho the pile were pointed. Some
authorities contend that even when driving thru hard
material the cone of earth is better than a point
would be. This is hardly true if the pointing is done

properly. When the cone of earth strikes gravel or
rock it is going to be destroyed. Then what is needed
is not a blunt end on the pile, but rather something
which will act like a wedge. To obtain a wedge-like
point the foot of the pile is cut to the shape of a
truncated pyramid, the end being from four to six
inches square. In compact material the bearing power
of the pile is practically the same, with or without
a point.

At times the driving becomes so hard that, even
tho a pile is pointed, it will be damaged in driving.
To overcome this as much as possible metal shoes are
sometimes used to replace or protect the point of the
pile. The shoes should fit tightly and preferably be
attached to the pile by straps, or some other method,
so that the shoe acts as an integral part of the pile.
Some engineers condemn the use of shoes. In most
cases it has been because of their unsatisfactory
experience with them. This was probably caused by
improperly designed shoes or by driving in ground so
hard that piles were not really necessary.

Occasionally it is necessary to use longer piles
than can be obtained in single sticks. Then it is
necessary to splice two piles together and the best

method is the fish plate splice. Four or six fish plates may be used. It may also be necessary to splice piles because of limited clearance under a bridge. Each job presents its own problems, and the solutions may vary in detail but the general remedies remain fairly constant.

Overdriving

Piles must also be protected against what is known as overdriving. This consists in driving the pile beyond the point where the desired bearing power has been obtained. This may be caused by the pile apparently penetrating the ground while it actually is splitting or crushing. It also may be caused by permitting too long an interval to occur between blows of the hammer thus permitting the earth to set up under the pile and making the driving much harder.

In Jersey City some piles were driven into the surface of a street to temporarily support a large water pipe. Later the street was excavated for the construction of a railroad. At the time of the driving it had been thought that the piles were in good condition and well driven. Upon excavation, however, it was discovered that about

Damage of Timber Piles Caused by Overdriving

half of them were ruined in driving. Some were broken off square across and the upper piece driven beside the lower piece. One of the piles struck a flat rock about 16 feet below the surface. The fibers at the tip of this pile were turned aside for a distance of about 15 feet.

The conclusion was expressed, by one contracting engineer of great experience, that "more piles are dangerously injured by improper driving than are rendered unsafe through insufficient driving." This engineer believes that much of the value of the pile is lost by overdriving and that this is due largely to the "use of drop hammers with excessive weights and undue heights of fall." He cites the case where 10 successive piles in an important foundation were driven in hard material by a 3000 pound drop hammer and a fall of 30 feet. After they had apparently reached "refusal" the heads suddenly moved several inches. The inspector assumed that the pile had penetrated a hard stratum material and ordered the driving continued until penetration took place. Later these piles were removed and it was found that every one of them had been broken off near mid-length. It is also the contention of this engineer that over driving not only injures the pile in the manner already

described but that it also "results in a degeneration of the fiber which reduces the strength of the piles acting as columns and materially hastens decay."

The Topeka and Santa Fe Railroad recently constructed a temporary underpass on piles where each pile required from 24 to 30 hours of constant driving with a large steam hammer. Later, when these piles were excavated, it was found that some of them had been compressed to one quarter their original length. In some cases where the driving had been on gravel, a coal-like substance had formed under the pile. Whether this was caused by compression or heat it was impossible to say. Probably a combination of the two caused the unusual conditions.

The Southern Pacific Railroad also had an incident occur which, while out of the ordinary, indicates some of the problems which confront an engineer in driving piles. Wood piles were driven and at a depth of forty feet, water-bearing sand was hit and the driving came to an abrupt stop. With continued driving some of the piles on an adjacent track had penetrated this stratum so the driving was resumed. One pile was driven from 10 A. M. to 12 noon when it was observed that it was brooming at the top. It was decided that the ideal thing to do

was to pull the pile and replace it by a new one
before continuing the driving. It was thought that
this would prove to be a difficult operation but at
the first strain it "popped" out. It was found to
be in good condition with the exception of the tip
which was steaming hot. A new pile was replaced
and the driving continued. Just before 5:00 P. M.
as the hammer reached the top of the leads, the
pile was suddenly blown out of the hole and was
followed by clouds of steam and sand. Eleven feet
of the pile tip was left in the hole. Examination
showed the fibers were crushed and steaming hot,
giving off the odor of charred wood. Continued
driving had generated heat due to the friction
which formed steam sufficient quantities to blow
the pile out of the hole. Incidents such as these
just described could be almost wholly eliminated if
a better study were made of the kind of ground to be
encountered when driving.

Use of the Water Jet

Piles which offer great resistance to driving
may be more easily or more quickly placed by the use
of what is known as a water jet. This consists of
a long pipe, usually about 2 inches in diameter which

discharges water under pressure at or near the foot
of the pile. It is especially useful in sandy soils
but gives good results in nearly all other types as
well with the exceptions of hardpan and rock.

The method of driving with a jet differs from
that of driving with a hammer. In the former case
one or more jets are used. The water is discharged
under pressure near the foot of the pile while the
jet is moved up and down. As the water comes up
around the sides of the pile, it carries with it
some of the material. Thus it not only serves to
excavate or loosen the soil in advance of the pile
but also tends to reduce the frictional resistance
of the earth. In some cases all that is necessary
is for the hammer to rest on the top of the pile
and it will settle due to the combined weight of the
pile and hammer. Other cases require the use of
blows with a restricted fall. In either instance,
however, the jet or jets are withdrawn just before
the pile reaches the desired penetration. The
final driving is completed by a few blows of the
hammer. The water has a puddling action and,
after the jets are withdrawn, the earth tends to
pack around the pile, thus furnishing excellent
skin friction.

One jet may be used if the driving is being
carried on in soft ground, but in most cases two
jets used on opposite sides of the pile give better
results. The pile tends to "walk" toward the side
where the jet is. The use of two jets tends to
eliminate this difficulty and the piles generally
may be more accurately placed. Sometimes three
jets are used, but whether one, two, or three are
employed, it has been shown by experience that piles
may, with the two exceptions noted, be driven by
using the jetting method at a great saving in time
and energy.

Protection against Alternate Wetting and Drying

Another problem is the protection of wood
piles when they are subject to contact with either
fresh or salt water. This has taxed the inventive
genius of hundreds of people. Wooden piles used
to support permanent structures, or in places where
they cannot readily be renewed, must be under water
at all times in order to prevent decay. This
condition may be neglected in temporary structures
or where piles can be readily replaced.

Often when wood piling is used under the
footings of a wall or piers of a building, it

becomes very expensive to excavate to a depth which
is below the permanent surface of the ground water.
In cities and towns the surface of the ground water
is often lowered several feet as new pipe-trenches
and sewers are introduced. Some foundation piles
which are well under water today may have their
tops out of water a few years from now. Because
of this, it is advisable to drive the piles so that
the cut off may be below the existing water-line
but even this does not always adequately take care
of the situation. Another problem is the protection
of the piles against marine borers, which are more
prevalent in some places than others.

History informs us that piles driven in the
first century for the bridge of Emperor Trojan
across the Danube were examined in the eighteenth
century. They were found to be in excellent condition
and petrified to a depth of $\frac{3}{4}$ of an inch. Beyond
this the timber was in its original state. This is
an unusual case, as may be seen by contrasting it
with the case in San Francisco where many of the
piles were destroyed in from 22 months to 10 years
by the work of marine borers.

First, the methods which are used at present
to counteract the ravages of decay.will be discussed.

Some of the methods used to prevent decay are also used to resist the attacks of marine borers and vice versa.

The first and most common method used is that of forcing creosote under pressure into the wood. The general procedure for accomplishing this is as follows: The material to be treated is loaded on trams and pushed into a cylinder about 8 feet in diameter and 130 feet long. The cylinder is equipped with doors at each end and it is so designed and constructed as to permit a working pressure of 225 pounds per square inch to be used inside the cylinder. After the trams are in the cylinder the doors are closed and bolted. The cylinder is then air tight. Live steam is then turned into the cylinder under a pressure of from 20 to 30 pounds. The length of the steaming depends upon the class of material being treated, and the quantity of oil to be injected. Green material to receive 12 pounds of oil per cubic foot would be steamed in the neighborhood of eight hours. Material to be treated with 24 pounds of oil per cubic foot would be steamed from 14 to 16 hours.

The material is steamed to open up the pores of the timber and heated so that the moisture can be drawn out. After the steaming process has been

completed a vacuum is created by means of vacuum pumps

designed so that the vacuum created is practically

perfect. This vacuum is maintained for from three to

four hours. This draws the sap and moisture from

the timber to be treated. In order to know when the

sap is out of the cylinder, there is a drum with a

gauge glass which shows the amount of sap at any

time contained in the drum. After the vacuum process

the cylinder is filled with coal tar creosote, and

pressure is applied to force the oil into the wood.

The pressure applied is sometimes as high as 175

pounds per square inch. When the correct amount

of oil has been injected into the timber, the oil

remaining in the cylinder is drawn back to the

working tanks from which it was originally taken.

The length of time required to get the proper and

desired penetration varies in practically every case.

To procure the proper penetration, skilled engineers

are required who make a specialty of this work. The

doors of the cylinder are then unbolted and the tram

cars pulled to the yard or dock for unloading or

loading for shipment.

It is impossible to assign any definite life

to creosoted piles but there is no question that

treated piles outlast untreated ones. There are too

many variables affecting the life of a pile to estimate the life excepting for innumerable specific conditions.

Another and more recent method used to prevent decay has been the development of what is known as the ZMA method. This means the zinc meta-arsenite method. This was developed thru the desire of engineers in telegraph companies to find a substitute for creosote. While creosote does prevent decay it has several objectionable features. It has a strong odor, an unpleasant color, will not take paint well, and has a high fire risk. Zinc meta-arsenite was finally hit upon and was obtained by the reaction zinc acetate and meta-arsenous acid to form zinc meta-arsenite and acetic acid. It was found that this new compound did not contain the objectionable features of creosote and also that it was not soluble in water but was soluble in the acid body juices of the fungii which causes decay. This, too, may be used to resist the attacks of marine borers, as well as to prevent decay. This development is so new that it is impossible to obtain any data as yet on the life of piles treated by the ZMA process. It is believed however, that the life of the pile will be long, due to the ability of zinc meta-arsenite to kill any wood-

destroying fungus.

Marine Borers

Before discussing the protections against
marine borers, it is better to explain briefly what
the more common types are and how they act.

Marine borers belong to two families, the
Crustacea and the Mollusca. The Crustacea are
composed of three genera which are destructive to
timber. These are the Limnoria, Chelura and
Sphaeroma. Limnoria resemble the ordinary wood
louse and are from 1/8 to 1/4 inch long. They
destroy piling by gnawing their interlacing branch-
ing burrows into the surface of the wood. As many as
200 to 240 burrows per square inch have been found in
heavily attacked timber. They quickly destroy the
outer layer of wood, which washes away, exposing the
next layer to attack.

Limnoria work at all levels in harbor waters
from near the mud line to the uppermost tidal level
with great facility. They are, however, most active
between tide levels, cutting off piling below mean tide
level or reducing them to an hour-glass shape.

This borer is found on both the Atlantic and Pacific
shores of the United States, north to Bering Island
and has been reported on European coasts from the

Untreated Douglas fir piling in Oakland Estuary, destroyed by *Limnoria*. Good piles shown are replacements.
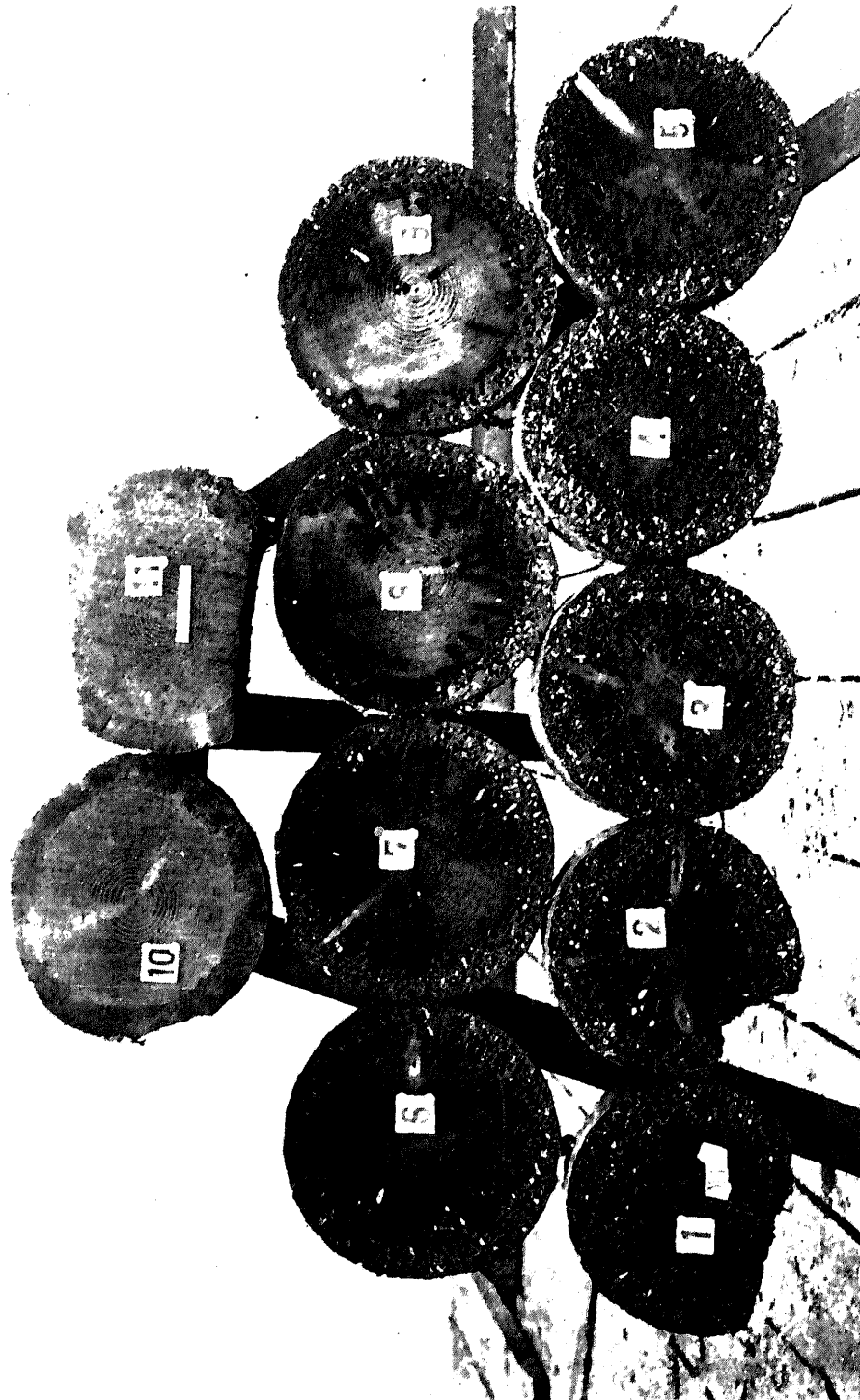
Fender pile, Shell Oil Company dock, Martinez, California. Sections three feet apart, mud-line to high water. November, 1920. Note deeper penetration on down-stream (right side) and offshore (lower) exposure.

Adriatic to Norway. It seems to thrive in sewage-laden waters but the salinity of the water also seems to have an effect. It has not been found where the salinity falls below 15 parts per thousand for any considerable length of time.

Chelura works with Limnoria in marine structures, and excavates burrows in much the same fashion. For this reason it easily may be overlooked and the necessary precautions not taken against its destructive work.

Chelura is known as a wood destroyer in European waters from Norway to the Black Sea, and on the Atlantic Coast of North America. As yet it has not appeared on the Pacific Coast, but the Panama Canal and the increase in round-the-world and interoceanic shipping will probably cause it to appear there.

Sphaeroma are larger, stouter borers than Limnoria. They are about $\frac{1}{2}$ inch long and $\frac{1}{4}$ inch wide in diameter when disturbed. They are very often found in crevices or other sheltering works outside of their burrows and are evidently foragers. They do not appear to depend upon the wood eroded from their burrows for food but seem to feed upon the minute vegetable and other growths which cover the surface of the piling.

The excavations made by the Sphaeroma are very characteristic in size, distribution and location.

They make circular openings up to nearly $\frac{1}{2}$ inch in diameter, enter the wood horizontally or turn more or less abruptly and run with the grain in the softer layers of the wood.

Sphaeroma are prevalent on the Pacific Coast from Alaska southward. They have also been known to attack piles in fresh water in St. John's River, Florida, where in eight years they reduced piles from 16 to $7\frac{1}{2}$ inches in diameter.

The other family of marine borers are the Mollusca which are bivalves and are distantly related to the clam family. The most important groups of this family are the Teredo, Baukia, and Martesia. The latter resembles a clam being wholly enclosed within a shell. The other two are like worms but have heads of shell material.

When very small the Mollusca enter timber and spend their entire life there, burrowing and enlarging their holes as they grow. Piles have been known which have only a few small holes exposed but which have been completely honeycombed on the inside. The Teredo are generally only a few inches long, while some species of the Baukia are known which have reached a length of 3 or 4 feet and a diameter of one inch. The Martesia make borings not over one inch in diameter and $2\frac{1}{2}$ inches

long.

Protection Against Marine Borers

When timber piles are not chemically treated
or mechanically protected and the waters are infested
by marine borers, the piles have a short life. The
average life of a timber pile on the coasts of the
South Atlantic, Gulf and Pacific states ranges from
about 8 months to 2 years. The development and
activity of the borers are stimulated by high
temperatures, and therefore in some of the more
northern coasts the average life may extend to three
or more years. On the other hand there are cases in
very salty water and during a hot season where piles
18 inches in diameter have been entirely honeycombed
in three years.

Many suggestions have been offered for the
protection of timber piles. Some have proved better
than others while many are utterly useless and
ridiculous. All of the useful methods in protection
of timber piles may be grouped into the following
general calssifications: - bark, chemical means, and
mechanical protection.

It is known that the bark of fir and hemlock
and of many other species are not as rapidly attacked

as the wood itself and this has naturally resulted in
many attempts to use piling with the bark on. Bark
adheres to the wood more firmly in the winter than in
spring. For this reason it is common to require that
such piles be winter cut. The objection to this method
of protection is that the bark is easily knocked off
in spots. This permits the marine borer to attack the
wood in these spots, bore their way in and destroy
the pile beneath the bark.

Of all the chemical methods of protection perhaps
the most satisfactory is that of creosoted impregnation.
The durability of creosoted piles depends on several
factors. The timber must be of good quality, free from
decay, and should have sufficient sapwood to take the
requisite amount of creosote oil. The method of im-
pregnating the pile with creosote already has been
described. Extended experience has shown that creosoted
piles may be depended upon to protect timber piles from
ten to fifteen years.

Zinc-meta-arsenite is also used as protection
against marine borers. This process also has been
described. The life of timber piles treated with zinc-
meta-arsenite has not been determined as yet. The
process is too new for any extended studies to have been
made.

Some compounds of copper sulfate and lead acetate have been tried. While they are extremely poisonous to animals life, they tend to become leached out by the action of sea-water and hence lose their toxicity.

Countless other methods of protection have been developed and are being developed all the time. It is impossible to cover all of these in this thesis. What is suggested today may be proved a failure tomorrow. The author, therefore, refers the reader to the Reports of the Committee on Wood Preservation of the American Railway Engineering Association, to the Proceedings of the American Wood Preserver's Association, and to the Engineering Index. In these publications the discussions of the subject are kept up to date, and the results of good practice are recorded.

When mechanical protection is used it is the best practice to protect the pile from a short distance above high-water level to an elevation below the mud-line. For this reason mechanical protection offers the possibility of a cheaper solution of the problem than chemical treatment which must of necessity cover the entire length of the pile. Various methods have again been suggested but the author will discuss only a few of the more feasible possibilities.

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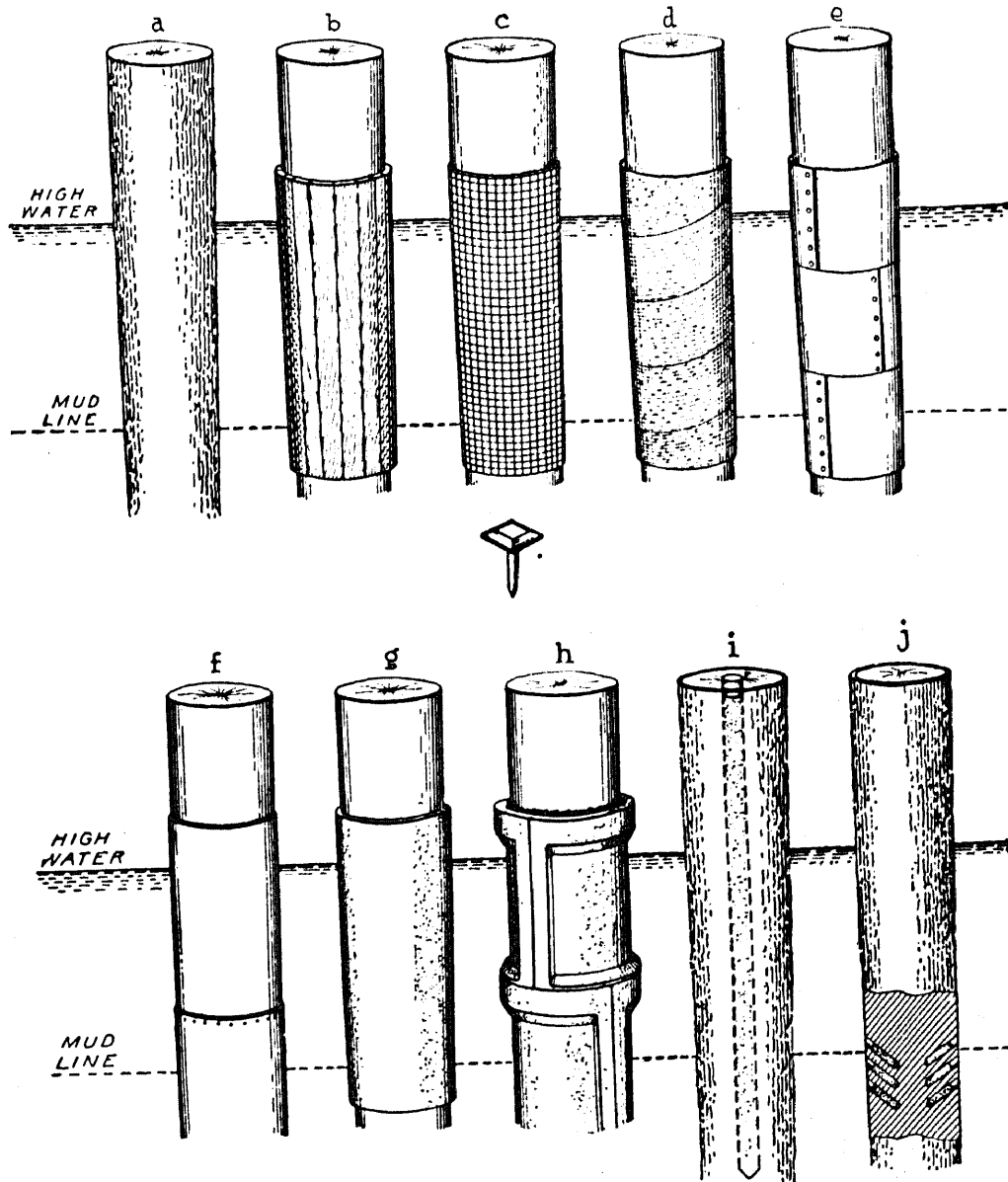
Types of Mechanical Protection

from Circular 128 of the United States Forest Service,
entitled Preservation of Piling against Marine Borers
by C. Shotwell Smith. The ten methods shown will be
briefly discussed.

Fig. "a" illustrates a pile with the bark left on.
This method of protection has already been discussed and
its advantages and disadvantages related.

Fig. "b" shows a pile sheathed with planks. This
was based on the theory that the shipworm would not
cross a crack. The Limnoria however has none of the
apparent scruples of the shipworm and bored its way on
thru the sheating and the pile. Later tar paper, felt
or other similar material was used under the sheating
and this proved to be fairly effective.

The Sante Fe Railway developed a method of pro-
tection by driving three penny and four penny nails
spaced one half inch on centers. It is not necessary
that the heads of the nails touch as protection comes
not only from the nail head but also from the rust
formed by the corrosion of the metal. The application
of strips of sheet iron with open spaces between the
strips has been tried. This has not proved so effective
as the use of nails, as the rust does not seem to pene-
trate the wood so deeply.

In Fig. "d" is illustrated a type of protection

where burlap soaked in different chemicals is used to cover the pile. Sometimes the surface of the piles is painted previous to the placing of the burlap. Quite a few of these methods are patented. One process makes use of a solution of asphalt, slaked line, rock salt, sulfur, marble dust and sand.

The use of metallic sheathing is illustrated in Figs. "e" and "f". The covering usually consists of thin sheets of iron, zinc, yellow metal or copper. Iron is susceptible to rapid corrosion. Zinc sheets of nine to fourteen gauge, prolong the life of the pile but records do not show that its use is very economical. Yellow metal, which is an alloy of copper and zinc, has been used with quite a good deal of success. Copper sheathing is expensive and its high junk value makes it likely to be stolen. Copper is an effective protective but like all metallic sheating it is subject to wear and may be easily torn by floating debris.

Fig. "g" shows a casing of cement mortar or concrete in contact with a timber pile. The design of the forms and the method of placing the concrete are the determining factors in the cost and the results obtained from this type of protection. The types of forms used vary according to the concern manufacturing them. One simple type of form consists of sheets of

steel in sections eighteen inches long and split
longitudinally. Vertical angles are riveted to the
joints so that they may be tightly clamped together
with rubber gaskets serving to make the joints tight.
The slightly reduced lower end of each section fits
into the slightly enlarged upper end of the next
lower section. Each section is filled with mortar
by a diver before the next section is fitted into
place. The lowest section is placed in an excavation
below the mud line and the sections extend up to the
mean-tide level. Above this the remainder of the pile
is painted with a wash of neat cement.

In the harbor at Seattle, Washington, and again
in the construction of bulkheads at Miami, Florida,
the following method was used with considerable
success: The untreated timber piles were wrapped with
galvanized three by three inch electro-welded mesh
and the pile then gunited to a thickness of one and
one half inches. The proportions were one to three.
The cement gun was operated between tides and the
gunite set up so quickly that no trouble was ex-
perienced from the tide. The piles used at Miami
have been in service for almost four years and still
are in excellent condition. There is no record avail-
able as to how those at Seattle are withstanding attack.

Another type of protection is illustrated
in Figure "b". This consists in fitting sections
of vitrified clay-pipe or reinforced-concrete pipe
around the pile and filling the space between the
pile and the inside of the pipe with sand. This
type of protection may be easily repaired as the
pipe is constructed with longitudinal joints for
each section. Thus a half section may be readily
and easily replaced and sand poured in at the top
to replace any sand which leaks out. Reinforced-
concrete pipe is superior to vitrified pipe as it
resists much better the accidental blows of float-
ing debris. The blows of such debris forms the
weak point in the mechanical resistance of the other
types of protection previously mentioned. Once the
sheathing is punctured the marine borers may get in
their work.

Figures "i" and "j" illustrate the protection
of piles by boring holes into them and filling the
holes with a poisonous substance. This treatment
is no longer used.

In concluding this discussion of the methods
of protecting timber pile from the attack of marine
borers, the author does not intend to infer that
these are the only methods of protection, but rather

these are the more commonly used methods of resisting
the destructive work of the marine borers.

Cutting Off and Pulling Piles

Before concluding this chapter on timber piles
the subject of cutting off and removing piles will be
briefly discussed. Several problems are present.
First, the cutting off of piles when the heads are
to be incased by a concrete footing; second, the
cutting off of piles when timber grillage or caps
are to be used; third, the removal of temporary or
old piles either by pulling or cutting them off.

When the heads of the piles are to be incased
in concrete it is not essential that they be cut off
to exactly the same level. As long as the heads
extend into the footing some distance which shall not
be less than the minimum specified, great precision
need not be used in setting the point of cut-off.
The concrete footing can be brought to the proper
elevation.

When timber grillage or caps are used, however,
to transport the load from the superstructure to the
piles, it is essential that the piles be cut off at
the exact elevation level. Concave, convex, or inclined
heads are not acceptable. The best method for making

the cut in open air is to use an ordinary cross-cut
saw set upon two straight-edge guides attached to the
piles. The method which is second best to this is to
use a circular saw mounted upon a vertical shaft which
is rigidly held in position by a movable frame.

When the elevation of cut-off is below the
surface of the water special means must be resorted
to. In general the methods used by different contractors
are the same, so only one type will be discussed here.

At Portland, Oregon, over two hundred piles for
the pivot pier of the Morrison Street bridge were cut
off close to the bed of the river. A solid falsework
was constructed upon which tracks were laid so that
a carriage might move back and forth on the tracks.
A second carriage was placed on the first one so that
it would work perpendicular to the tracks. A four-post
steel frame built of angles was suspended from the
second carriage. This frame extended down to the
required depth and upon one corner of it was attached
the shaft which drove a five-foot circular saw operated
by an electric motor. By taking proper precautions
the piles were cut off to a practically true level.

Sometimes it is impossible or impractical to
construct the falsework and carriage arrangement and
it becomes necessary to work from a scow. Then the

shaft of the saw is held in a truly vertical position
for the cut off. Remarkably accurate results have
been obtained by this method. The main requirement
being that the position of the saw be accurately
checked.

Many times piles are used for temporary construc-
tion and have to be removed after they have served
their purpose. Several methods are used depending
upon the penetration of the pile and the skin-friction
developed. If the penetration is not too large a
pile may be pulled by the pile line of the pile-driver
or by block and tackle. To reduce the initial re-
sistance the pile should be tapped by the pile-hammer
before pulling it. If water-jet equipment is avail-
able it may be used around the pile to loosen the
earth and speed up the work or removal. In tide-
water piles are sometimes fastened by a chain to a
scow at low tide and the rising tide used to pull the
pile. Care must be used to watch the action of the
pile for if the resistance of the pile to being pulled
is greater than the lifting power of the tide the scow
may be sunk. Sometimes the pile-driver is used to
pull the piles. This is accomplished by forming a
sling under the hammer, running a rope up over the
sheave wheel at the top of the rig and then down to

the pile where it is attached. As the hammer is carefully driven against the sling, the pile is pulled from the ground. The use of the water-jet materially helps here. If hard ground surrounds the pile it may be started by securely attaching a block of wood on each side of the pile and lifting by the aid of two screw-jacks.

Sometimes it is not necessary to remove a pile completely but only the part protruding above the ground. Two methods may then be used. Either the pile may be cut off as previously described or dynamite may be used. Innumerable methods of using dynamite have been developed each depending upon the difficulties encountered and the ingenuity of the man in charge.

One of the most commonly used methods has been to form a ring of telegraph wire, large enough to slip over the pile. Three sticks of dynamite are attached to this and each stick connected to a fuse long enough to reach a battery. The ring is then lowered to the proper elevation and the charge set off. The cut off is clean and the method is cheap and quick.

An improvement upon this method has been suggested by S. Standish of the Standish Engineering Corporation of Chicago, Illinois. His plan is to make a bundle

consisting of three to five sticks of dynamite
and an equal number of iron bars of approximately
the same length as the dynamite. These are bound
together and the bundle lowered to the proper point
and within three feet of the pile. The explosion
will cut the pile off clean, the bars acting much
like shrapnel.

This concludes the chapter on timber piling.
It is impossible to quote costs which would prove of
any value as too many factors enter into the cost
of the placing of piles. Only a careful study of the
conditions encountered on each particular job will
indicate the probable cost.

CHAPTER V

Concrete Piles

Advantages of Concrete Piles
Over Timber Piles

The difficulties encountered in the driving
of timber piles, the very short life they have
when subjected to alternate wetting and drying,
and the necessity for protecting them from marine
borers, prompted engineers to look for a substitute.
These difficulties coupled with the increasing cost
of timber and the decreasing cost of concrete led to
experiments with the latter which eventually brought
forth the concrete piles of today.

Hennelbique, in 1897, introduced reinforced-
concrete piles in Europe, and in America, in 1904.
Before the use of these piles in America, however,
A. A. Raymond, after many experiments, developed
what is known as the Raymond pile. He first used
these piles in 1901 in a building foundation in
Chicago. During the decade up to 1910 many other
forms were developed. Some of these were patented
while others were designed by engineers without the
use of any patented method.

The types of piles developed were of two general

classes. One group were molded to a regular form, allowed to set and cure, and then handled and driven like timber piles. These are known as pre-molded piles. They were first developed in Europe and are practically the only type used there. The second group were what are known as cast-in-place piles. These are formed in place either with or without the use of casings. The Raymond pile was one of this type and because of its use in America before the introduction of pre-molded piles, it has gained a lead which the latter type of pile, with all its advantageous features, has never been able to overcome.

It has already been noted in the previous chapter that timber piles when used in ordinary foundations must be cut off below the ground-water level. This often causes extra excavation, heavier footings, and increased cost of material and labor. Even with these precautions, the ground-water level may be lowered due to changing conditions and the pile may become rotted. This may cause expensive changes in the foundation of a structure.

It must be admitted that concrete piles cost more per pile than timber piles but it must also be remembered that the life of concrete piles is

independent of the ground-water level. This
eliminates the expensive excavations and heavy
footings that are necessary with the use of timber
piles. Furthermore, concrete piles have a greater
bearing capacity and hence fewer are needed. Roughly,
a timber may carry from ten to twenty tons while a
concrete pile will sustain from twenty to fifty tons.
Generally, concrete piles afford a saving if the tops
can be placed more than three feet above the cut-off
for the timber piles. Concrete piles also have the
advantage that they may be bonded into the concrete
grillage or cap by means of their own reinforcing
steel and the pile and cap will act together as a
monolithic structure.

Pre-molded Piles

Pre-molded piles may be divided into two classes
depending on whether they are patented or not. All
of them have certain general features. They are
always reinforced with steel bars or rods in combination
with lateral reinforcement in the form or wire hoops
or spiral wrapping. The piles may be square, hexago-
nal, octagonal or round in cross-section. It is
usually customary to chamfer the corners of square
piles. With the exception of circular piles, they are

all usually tapered from butt to tip.

It is also necessary that certain factors be considered in the design of pre-molded piles. The steel reinforcement must be ample and so placed as to resist the stresses due to handling and driving the pile as well as to aid in resisting the stresses when the pile is in its final position. The longitudinal bars receive their greatest stresses when the pile is lifted from a horizontal position. Due to the position of the cable in handling the piles before driving, the latter must be able to resist flexure due to its own weight as well as the shock or impact due to its meeting obstacles. Some designers add as much as one hundred percent to the weight of a pile to provide for shock due to handling. If proper care is used in handling, experience has shown that fifty percent is a safe and more reasonable allowance.

The lateral reinforcing bars are of two types. One type consists of a continuous spiral wrapping which varies in pitch at the head and foot of the piles. The other is composed of separate wire hoops or binders either square or circular in shape and spaced at intervals which vary along the length of the pile. The lateral reinforcement is primarily used to

increase the resistance of the concrete to compression longitudinally. It also may aid in resisting diagonal tension. The total percentage of steel in the section area of a pile varies, depending upon the design, from 0.6 to 2.8 percent. Better practice dictates that the reinforcement be not less than 1 percent.

The area of the head must be sufficient to resist in direct compression the load which the pile is to support. The unit stresses to be used should be dependent upon the quality of the concrete, the percentage of reinforcement and its arrangement, and the character of the loading. If the pile is tapered the critical section for direct compression is not at the butt but rather at some distance below the ground surface. Further, when a pile is to act as a column it must be designed to resist column action. To allow for hard driving of a concrete pile, additional section area must be provided or extra cement must be added to the batch of concrete which comprises the head of the pile.

These comprise the points of similarity of all pre-molded piles. To attempt to describe the innumerable types of unpatented piles would require an accounting of all the many varieties developed to meet special conditions. Suffice to say that they all

meet the requirements just stated and that they are in the main very successful. One noteworthy example of unpatented piles were some driven at the Port of Manilla. They were twenty four inches square and one hundred and ten feet long. They were of necessity driven by a special pile driver. When a test load of one hundred tons was applied a settlement of twenty seven sixty-fourths of an inch was observed. The application of an additional one hundred tons caused an additional settlement of twenty seven sixty-fourth of an inch. Twenty one sixty-fourths of an inch of this settlement was recovered when the loads were removed.

Corrugated Pre-molded Pile

There are several well-known types of patented piles. The first of these to be described is the corrugated pile which is hexagonal or octagonal in cross-section. It is constructed with approximately semi-cylindrical grooves on each face and with a round hole along the axis. Both the hole and the pile is tapered from butt to tip and the pile is reinforced with electrically welded wire fabric. The hole in the pile is used to permit a water-jet to pass through it, and is tapered so as not to decrease the area of the concrete at the tip as

well as to permit the plug used to cast the hole
to be readily withdrawn. The corrugations are
added to increase the surface of the pile so as
to produce greater skin friction. They also
furnish outlets for the escaping water from the
jet, thus reducing friction during driving. The
corrugations, however, are not extended along the
head or the tip so as to avoid reducing the cross-
sectional area at those points.

Cummings Pre-molded Pile

The second type of pile to be discussed is
the Cummings concrete pile. It is an octagonal
pile about fourteen inches in diameter at the head
and about nine inches at the tip. The reinforcing
consists of longitudinal rods held in position at
approximately five foot intervals by flat rings of
one quarter inch metal and a helical wrapping or
wire which performs the function of hooping and also
resists diagonal tension. The foot of the pile is
protected by a conical sheet metal point protector.
At the head there is a series of horizontal bands
closely spaced to give special lateral support to
the concrete when being driven. Each of these steel
bands in the head contains a horizontal spiral within

it to further reinforce the head. It has been
claimed that this reinforcing is so resistant
that the head of a Cummings pile has never been
broken.

Chenoweth Pre-molded Pile

The Chenoweth concrete pile is a third type
of patented pre-molded pile. It is known as a
rolled pile. The machinery used consists of a
moving platform, a number of rolls and a mechanism
for turning the tubular mandrel about which the
pile is formed. The reinforcement consists of
longitudinal bars wired to strips of wire mesh.
This mat arrangement is laid on the platform and
then ends of the wire mesh are attached by wire
clips to the mandrel. The concrete is then spread
over the mesh and by simultaneously moving the
platform and turning the mandrel, the pile is coiled
and rolled into a cylindrical form which is compacted
by means of special rollers. At the same time, the
pile is wound every six inches during the process of
rolling. After the rolling the central tube is with-
drawn and the pile is moved to a drying table. Here
a concrete point, shaped like the frustrum of a cone
and the head of the pile, is added. It is necessary

to use a very dry mix in making these piles, otherwise
the cement will be squeezed out with the water when
the rolling takes place.

Hennebique Pre-molded Pile

The fourth and last type of pre-molded patented
pile to be described is the Hennebique pile. This is
usually constructed as a square pile without taper.
The four edges are slightly bevelled and the longi-
tudinal reinforcing rods are placed near them. These
rods are bound together by wire collars or binders at
short intervals. The standard type of Hennebique pile
has a cast-steel shoe forming an integral part of the
pile.

Before leaving the subject of pre-molded piles,
a few words must be written regarding the curing of
these piles. The practice varies, but in general the
forms are removed in from twelve to eighteen hours
after which they are directly exposed to live steam
for three or more days or until sufficiently set to
be handled by a derrick. They are finally placed in the
storage yard and left there for at least thirty days
before being driven.

Cast-in-place Piles

While no record is available, it is highly probable that cast-in-place piles were first suggested by what are known as sand piles. If loamy soils are confined from moving laterally by the surrounding earth, they can be made efficient by the use of sand piles. These are formed by excavating to the proper depth and then driving wooden piles. The wooden piles are then pulled leaving holes which are filled with clear sand thoroughly tamped.

The driving of the wooden pile compresses the soil and the sand holds it in place. After the sand has been placed a test load should be applied to determine the bearing capacity of the foundation. Sometimes a conical iron weight may be used in place of the wooden pile. Holes three feet in diameter and fifty feet deep have been formed in this manner. The use of concrete instead of sand opened greater fields for the concrete pile until today it is a very essential part of foundation work.

The Raymond Pile

The pile invented by A. A. Raymond was formed

by driving a tapering sheet steel shell to refusal
by means of a collapsible steel core, by withdrawing
the core, and then, by filling the shell with concrete.
The shell is spirally reinforced with one quarter
inch wire and of sufficient thickness to retain its
shape after the core is withdrawn. The shell not
only holds the earth in position and forms a mold
for the concrete but also prevents earth and water
from mixing with the concrete. The shell is made in
varying diameters, is of conical sections about
eight feet long, to enable of easy shipment, and over-
laps tightly in telescopic fashion. The shells are
easily slipped over the core and the bottom is closed
by a section called a boot. The boot is made of
pressed steel to withstand the cutting effect of stone
and other obstacles encountered in driving the core.

After the driving of the shell and the withdrawing
of the core, it is a comparitively simple operation to
inspect the inside of the shell. This may be done by
reflecting, with a mirror, sunlight or a bright
artificial light into the shell, or by lowering a
lantern on a cord into it. The purpose of the inspection
is to locate any breaks which are admitting water. If
leaks exist because of the cutting of the shell, another
shell may be easily driven inside of the first one.
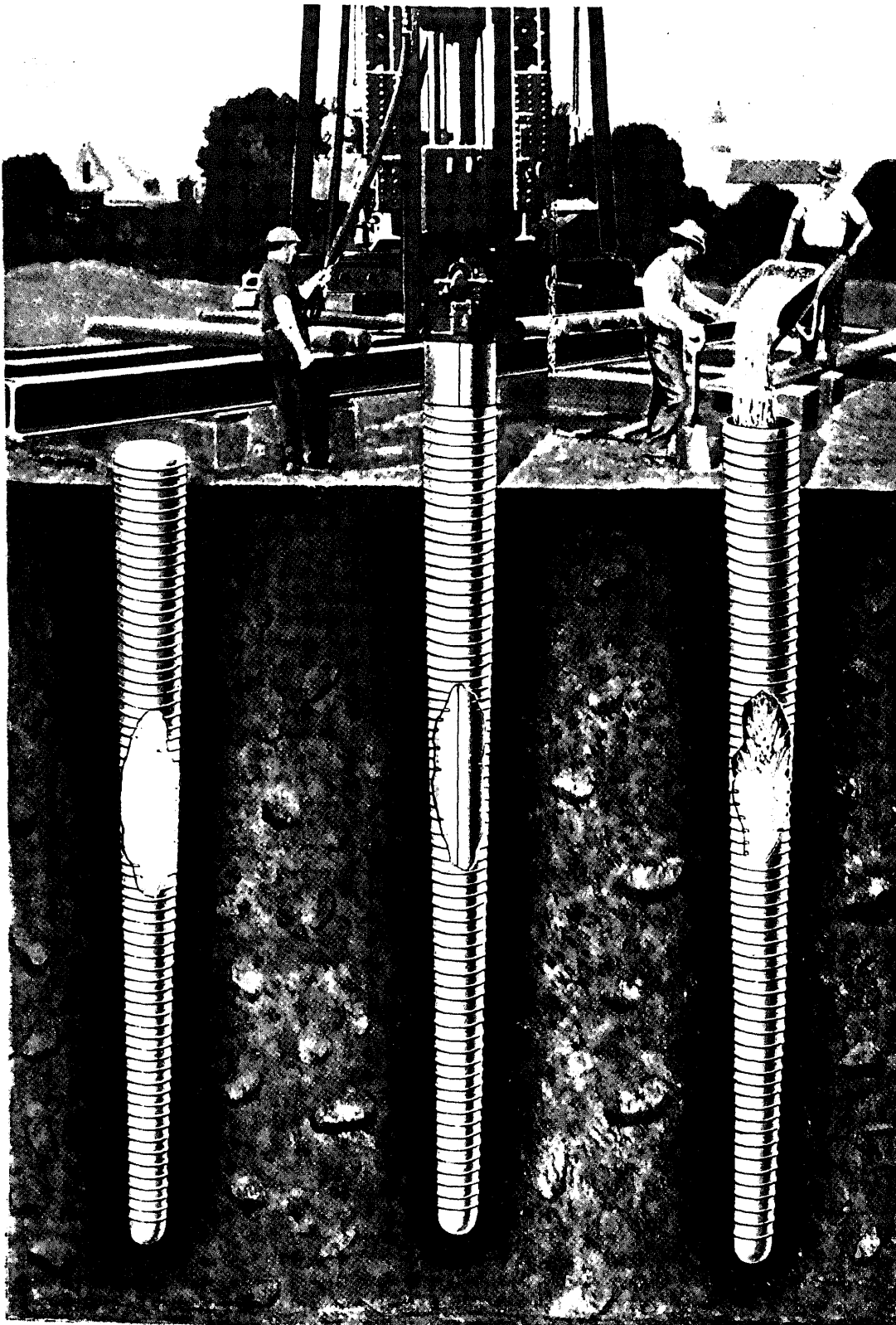
Raymond Standard Pile

This may be inspected also and it will usually be
found that the leak has been closed. It is only
occasionally that the driving of two shells is
necessary. The Raymond people claim the ability to
inspect the form before the placing of the concrete
as one of the outstanding features of their piles.

After the shell has been approved as water-
tight, the concrete is deposited in it. Either a
1-2-4 mixture using three quarter inch stones or a
1-3-5 mixture using one and one-quarter inch stones
is used. The mix is rather wet and as longitudinal
reinforcement is seldom used, the concrete may be
readily placed in the shells without voids. Bars
about three to four feet long are sometimes placed
in the concrete at the top of the pile to assist in
bonding the pile to the footing. The shell is
usually filled with concrete to a point about four
inches above the approximate cut-off. Then, after
the concrete has been allowed to set for a week, the
precise cut-off levels are established and the ex-
cessive concrete removed with a cold chisel.

The manufacturers of the Raymond pile also claim
two other advantages for their pile: The first is the
ability of the steel core to be driven through very
hard material which cannot be penetrated by any other

kind of pile at a reasonable cost, the bearing
capacity of every pile being determined by the
average penetration of the steel core under the
final blows of the hammer. The second advantage
claimed is that the taper employed on Raymond piles
greatly increases the bearing capacity over the
straight-sided or nearly straight type of pile.
This point has been much debated by engineers. The
Raymond Concrete Pile Company made a test of straight
piles and of their tapered piles. This test was
supervised by a prominent engineer who was an ardent
advocate of the straight-sided pile. Following is a
report of the tests as published in the Raymond
catalog: "Two piles each twenty feet long were driven
within a few feet of each other. One core, "Core A",
was six inches in diameter at the point and twenty
inches in diameter at the top, while the other core,
"Core C", was thirteen inches in diameter at the
point and eighteen inches in diameter at the top.
"Core C", with the large point, drove fairly hard from
the start, and required nine hundred and forty-four
blows of the steam hammer to secure a penetration of
twenty feet. "Core A", with the smaller point, started
easily and required only eight hundred and seventy-five
blows to secure twenty feet of penetration. At the

expiration of about a month, both piles were loaded
and carefully tested. The test showed that the pile
with the greater taper carried a proportionately
greater load, showing no appreciable settlement up
to sixty-five tons, whereas the straight pile showed
the same settlement with a load slightly more than
twenty tons. This result is particularly interesting,
in view of the fact that the engineer who made the
tests did so for the specific purpose of demonstrating
that a straight pile had a greater carrying capacity
than a tapered pile. The results of these tests have
been repeatedly confirmed in the course of our
experience."

It is not to be assumed that the Raymond Company
advocate tapered piles for all conditions. They do
claim, however, that they are more efficient in soils
where surface friction is to be developed. They do
advocate the straight pile when it is necessary to
penetrate to rock or hard pan through very soft or
semi-fluid material. Such piles are considered solely
as columns and as such require a very slight taper
and a large point bearing area.

Recently the author had the privilege of observing
tests made by the Raymond Company of a new type of shell.
This shell was constructed of smooth sheet steel not

spirally reinfroced. The sections were only about
three feet in length and each was lined with about
one inch of neat cement. The sections were so
arranged that the lower one overlapped the one above
it. This new type of shell was intended to be used
when it was necessary to drive through ground con-
taining many boulders. The driving of the ordinary
steel shell in such ground usually results in its
being torn and necessitates the re-driving of one or
more additional shells inside the first. Upon making
tests, however, it was found that it was faster to
drive the second or third shell than to handle the
neat-cement-lined shells. The latter were much
heavier even for the shorter section and required
great care in handling so as not to break the lining.
Thus, it took much longer to place them on the core.
In addition each section had to be held in place on
the core while the one below it was pulled into
position. This is not necessary with the ordinary
steel shell as it can be pulled up tight and is held
in place by friction. In addition it was found upon
driving and withdrawing the core that certain sections
of the lining had been jarred loose due to the vibra-
tions in driving. This type of shell may be developed
at a future date but at present it is quite impractical.

The Raymond Concrete Pile Company also drive what are known as composite piles. These are used where a long pile is necessary and the permanent water level is within a reasonable distance below the surface of the ground. In such cases wood is substituted for concrete in that portion of the pile which is permanently submerged. The main difficulty has been the development of joint of sufficient strength and rigidity, together with a method that will insure uniform and satisfactory results. This has required considerable thought and ingenuity and a long series of experiments.

The Raymond catalog lists the steps in the placing of a composite pile as follows:

"1. Driving the wood pile to ground level.

2. Fitting on to the top of the wood pile the collapsible mandrel or follower encased in a spirally reinforced steel shell.

3. Driving the combined unit to its final penetration.

4. Withdrawing the mandrel, leaving the steel shell in the ground to protect and serve as a mold for the concrete at the joint.
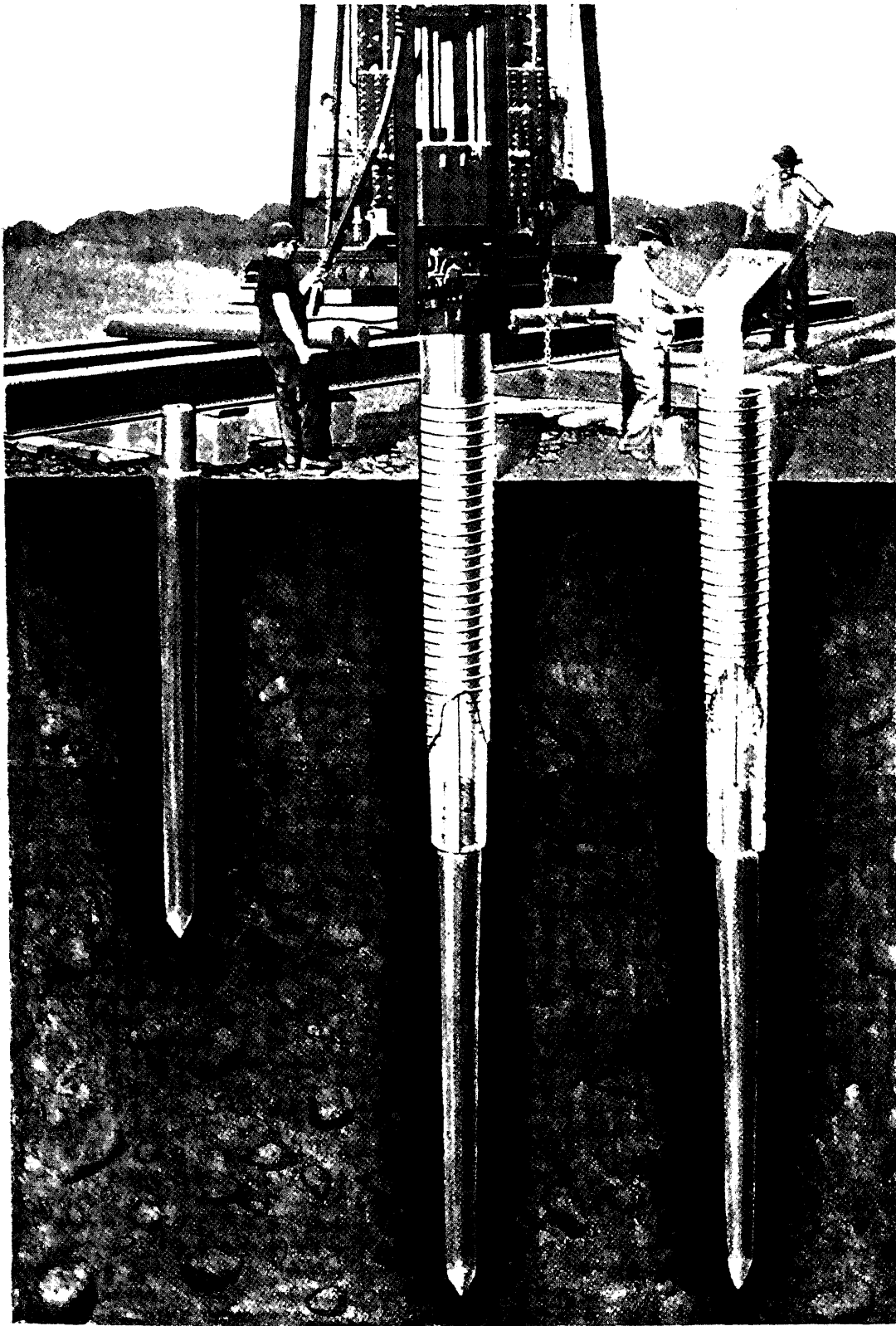
Raymond Composite Pile

5. Filling this shell with concrete."

"Before driving the wood pile, it is provided with a tenon approximately nine and one-half inches in diameter and eighteen inches long. By means of a special machine, the tenon is accurately shaped and cut square on the end. This provides perfect contact between the follower and the pile thereby avoiding any brooming or damage to the tenon during the driving. This tenon fits closely the cylindrical opening at the end of the Raymond core. A hollow boot closely encases the bottom of the steel shell on the core, and at the same time, fits tightly over the tenon of the wood pile."

Before placing the wood pile in the leads, "a hollow steel socket is embedded in the center of the tenon and secured by a seven-eighths inch steel pin extending traversely through the tenon and socket." The socket is provided with a heavy internal thread into which the threaded end of a deformed bar is screwed after the driving has been completed and the core removed. This bar provides reinforcement in the concrete and also acts as a lock between the wood and the concrete.

Simplex Piles

The second type of cast-in-place pile which is to be discussed is the Simplex pile. This was first introduced in 1903. The Simplex piles may be divided into four classes: the standard, the molded, the shell, and the composite.

The standard Simplex pile is formed in the following manner: A conical cast-iron point which is fitted loosely to the lower end of a sixteen inch diameter, three-quarter inch thick steel tube or form, is driven to suitable bearing. This is assumed to compress the soil. When the proper depth is reached soft concrete is deposited inside the tube by means of a drop bucket until the surface of the concrete reaches the desired elevation. Then the steel shell is withdrawn and the soft concrete flows laterally by its own weight thereby filling the hole. The concrete is made of a fairly wet 1-2-4 mixture using three quarter inch stone or gravel. It is possible to use reinforcement when desired. The main objections to this method are that the pipe must be extra heavy and the pile-driver must have extra strength equipment to pull out the pile. Furthermore, a new cast-iron point is required for

Simplex Standard Pile

Steel Pulling Cables
Pulling Clamp
Steel Driving Form

Standard Simplex Pile Completed

Concrete Deposited Form Partly Pulled

Form with C.I. Point Driven to Hard Pan

Simplex Composite Pile

Standard Form
Inside Follower

Permanent Water Line

Simplex Composite Pile Completed

Driven to Final Position by Form and Follower

Wood Pile Driven to First Position
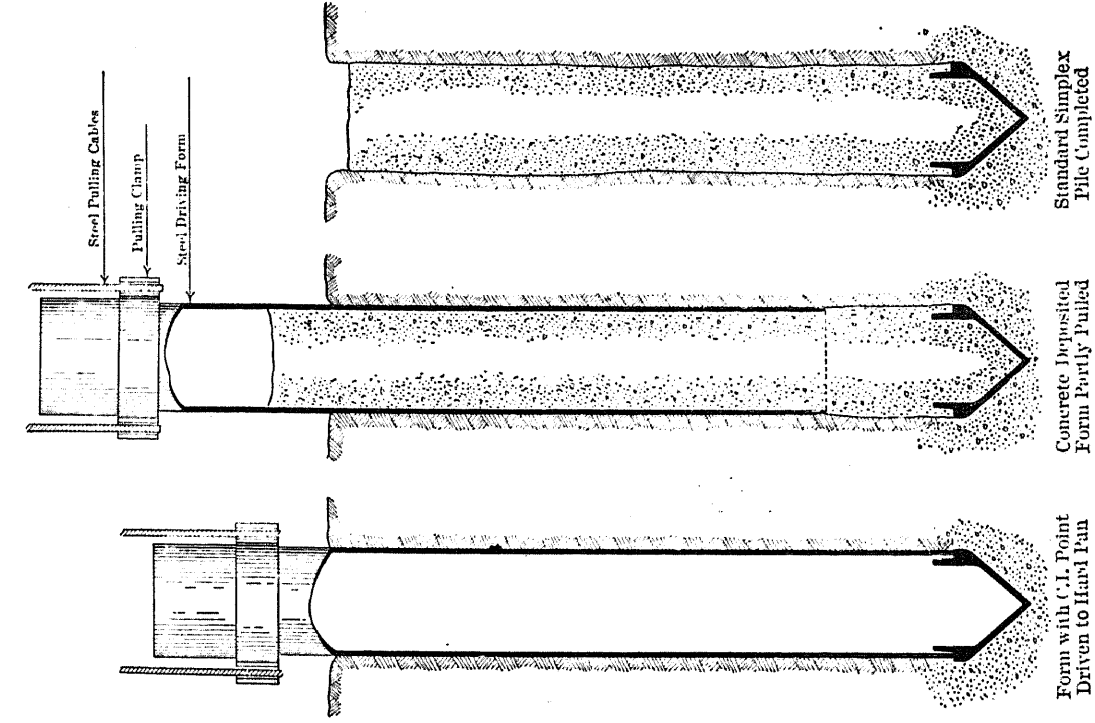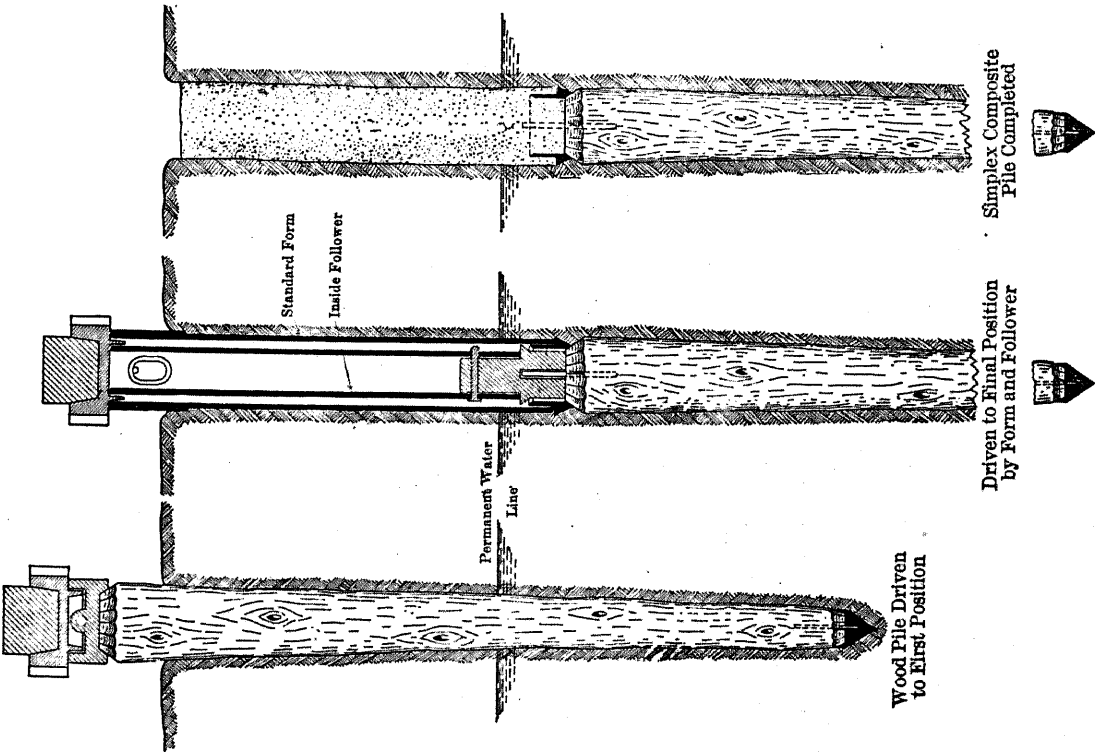
each pile as they are all left in the ground.

The Simplex molded pile is used in very soft soils. The shell and point are driven as described in the standard pile. Then a small amount of concrete is placed in the bottom of the tube and a molded concrete pile is lowered into the freshly deposited grout. The tube is next withdrawn and a thin grout is poured between the pile and the tube during with-drawal. The molded piles are thirteen inches in diameter and the metal point which is left in place is seventeen inches in diameter.

The third class of Simplex pile mentioned was the shell pile. For this construction the cast-iron point is driven as before. After the driving has been completed, a thin steel shell, slightly smaller in diameter than the inside diameter of the tube, is lowered until it rests on the cast-iron point. This shell is then filled with concrete and the driving tube withdrawn.

The reasons for driving a Simplex composite pile are the same as for driving a Raymond composite pile and the procedure is, in general, the same. The wooden pile of the proper length is driven in the usual manner. When it is down to a convenient level, the top is prepared for a heavy cast-iron ring and

dowel pin. The follower is then placed on top of
the pile and the steel tube is placed on the ring.
The combination is then driven until the top of
the wooden pile is well below the permanent surface
of the ground water. The follower is then removed
and the steel form filled with concrete and with-
drawn. In stiff, non-water-bearing, or clay soils,
where the ground has no tendency to flow, the
Simplex standard pile is claimed to be the cheapest
method of installing concrete piles.

Pedestal or Mac Arthur Pile

The pedestal or Mac Arthur pile was invented
by Hunley Abbott and may be considered as a modified
Simplex pile. The Mac Arthur pile is formed by
first driving the steel casing and core to the proper
depth. The casing is a steel pipe sixteen inches in
diameter and three eights of an inch thick with out-
side reinforcing bands at top and bottom. The core
is a smaller and longer pipe with a cast-steel point
and an enlarged cast-steel head. The core fits inside
the casing, engaging the top of the casing with the
enlarged head and the point of the core projects some
four or five feet below the bottom of the casing.
After the core and casing have been driven to the
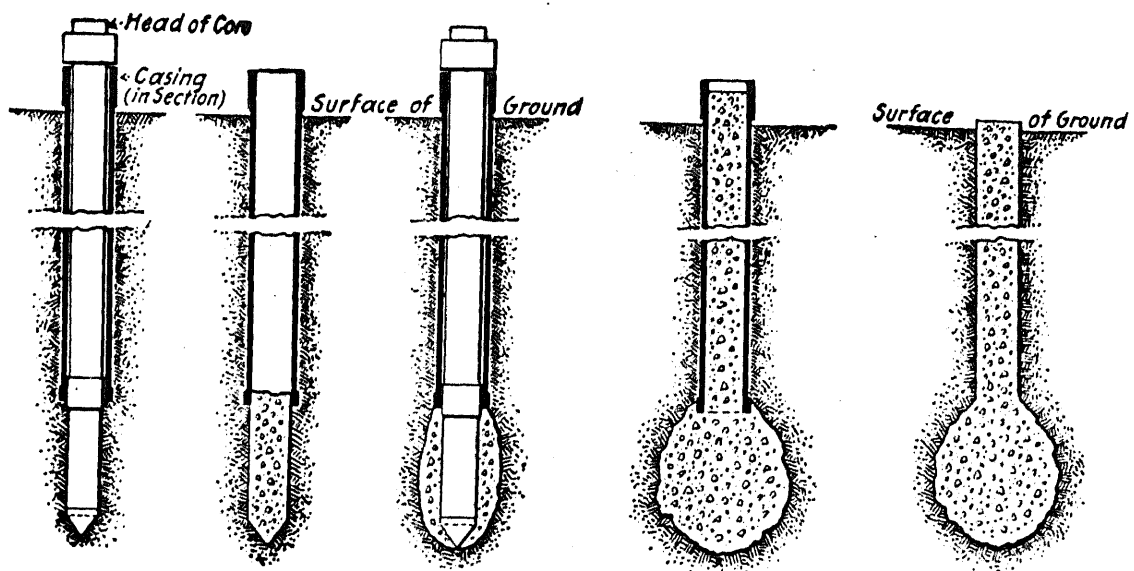
The Mac Arthur or Pedestal Pile
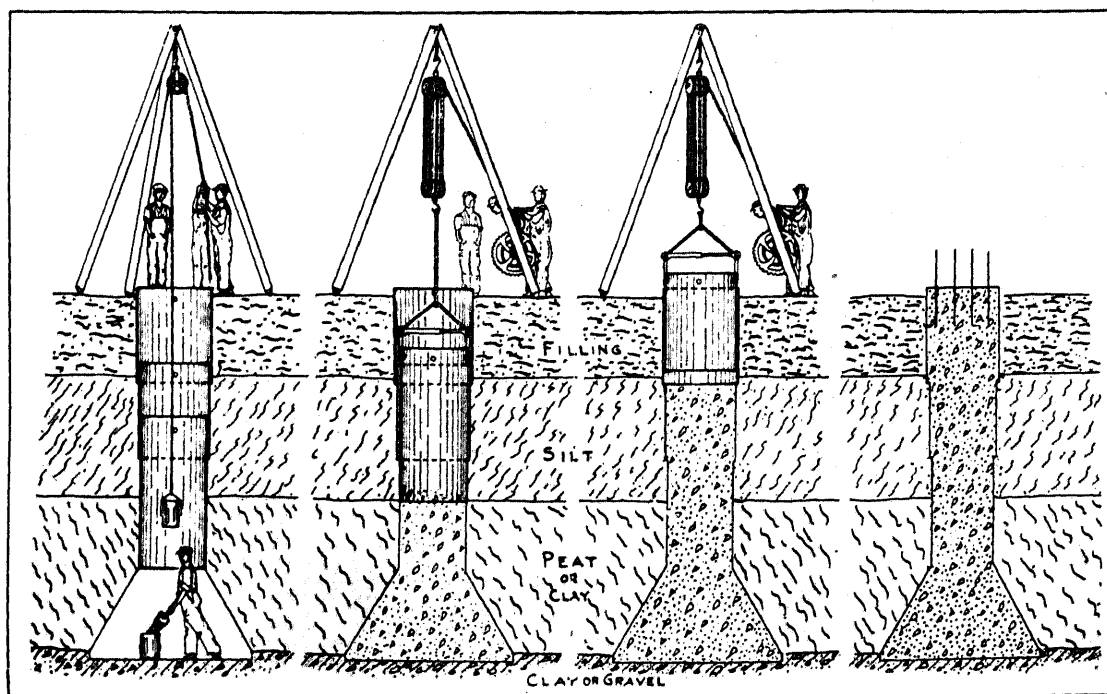
The Gow Pile

desired depth, the core is withdrawn and a batch
of concrete dropped to the bottom of the hole.
The core is then driven into this concrete forcing
it laterally into the soil. This process is re-
peated until a footing of sufficient size is
secured. Finally the core is removed and the
casing filled with concrete to the top when the
casing is slowly withdrawn. The concrete thus
flows laterally and completely fills the hole.
The original top surface of the concrete will sink
from three to six feet as the casing tube is with-
drawn.

The bulge at the bottom of the pile is assumed
to greatly increase its supporting capacity. This
of course depends upon the nature of the ground and
its homogenity. If the earth for any reason should
resist unequally on opposite sides of the hole, the
resulting form of the base would make its action
eccentric.

The Gow or Palmer Pile

The Gow or Palmer pile is to be the fourth
and last type of cast-in-place concrete pile to be
considered. This pile is formed by sinking a steel
casing or pipe into the earth by means of a water jet.

The casing consists of a series of short steel cylinders
varying slightly in diameter so as to telescope through
one another, the largest size being used as a starter.
The others are inserted in turn through those already
in place. The material is excavated by laborers and
raised to the surface in buckets. When the casing
has reached the required depth it is withdrawn a few
feet and a lozenge-shaped cutter lowered to the
bottom of the tube. By turning this tool and opening
it gradually the bottom of the pile assumes the form
of a truncated cone with its large base at the bottom.
The casing and chamber are then cleaned out, filled
with concrete and tamped, the casing being gradually
withdrawn as the concrete fills the hole. Thus a
pile having a large circular flat bottom is formed.

Precautions in Driving Cast-in-place Piles

In concluding this chapter a few words should
be included regarding the precautions to be taken in
placing cast-in-place concrete piles and some of the
objections which have not been mentioned as yet.
Care must be taken in the placing of the concrete in
the shells or casings. Wet concrete thoroughly
stirred with a rod moving up and down will obviate
a great deal of the porous structure of the concrete.

Where casings are left in the ground, and several
casings adjacent to each other are driven before
any concreting is done, each casing should be
inspected to see that it has not been injured by
the compressing of the soil due to the driving
of casings near by.

Authorities on piles and pile-driving
generally agree that when casings are to be
withdrawn, several should be driven before any
are filled with concrete. They contend that
otherwise green concrete in a pile may have its
section materially weakened by the earth being
forced into it by the adjacent casing. This
recommendation, if followed, would mean that
with certain types of piles it would be necessary
to have more than one shell or casing so that
several might be in the ground at any one time.

Occasionally concrete piles which have
been formed by casings which are withdrawn have
failed to set because of certain chemical consti-
tuents in the ground water. In still other cases,
piles have had their section areas reduced anywhere
from twenty to one hundred percent. Even if a
shell is used and left in the ground, it must be
remembered that it is highly probable that the

green concrete will be injured by the driving of adjacent piles. For this reason the practice of driving adjacent shells before filling any with concrete is recommended.

It must be understood that all of these objections do not necessarily apply to any one type of pile but that for given conditions some types are more satisfactory and cheaper than others. It again depends upon the old question of the type of ground to be encountered.

CHAPTER VI

Metal and Sheet Piles

Tubular Piles

The first metal piles were introduced
in 1901 and consisted of a heavy steel pile
filled with either plain or reinforced concrete.
This type of pile was suggested by the use of
steel pipe for underpinning the foundations of
buildings. The piles are, in general, about
twelve inches in diameter and three eights of
an inch thick but may be procured in any diameter
of which pipe and well casing are manufactured.
The ends are machined so as to be perpendicular
to the axis of the pile. This insures a true
alignment of the pile and a uniform bearing of
the metal.

The pile of this type is made in sections,
each section being provided with an inside sleeve.
The foot of the pile may or may not be protected
in driving by a hollow conical shoe of cast iron
or steel. This depends upon the soil through
which the pile must be driven. The shoes are
usually provided with a hole so that a water-jet
may be used if desired. The pipe is driven like

an ordinary pile, the top being protected by a cap.

After the driving has been completed, the pipe is filled with concrete. When reinforcing is included, the usual practice is to use four two-inch square rods placed vertically in the pile. If the pile is driven without any shoe, it is, of course, necessary to remove the material inside of the pipe before filling the pipe with concrete. The earth may be removed by an air or water-jet or by using a small orange-peel bucket.

The trade name for a casing of this type is the Simmons sectional concrete pile casing. Through experience it has been determined that if the earth surrounding the piles is undisturbed, they will last for many years. The casings, however, are subject to rapid rusting when exposed to the action of air or water. It is also possible that the action of electrolysis may damage the casing. All of these conditions must be determined before hand, if possible, and the necessary precautions taken to protect the casing.

Piles of this type have been driven to a depth of eighty five feet. It must be remembered, though, that these piles act as columns and must

be designed for such conditions.

Recently attempts have been made to use heavy H sections as piles. The process is too new and the results too inadequate for any detailed report to be given at this time. It is possible that at a later date they may be developed to the stage where they will displace some of the types used at present.

Screw and Disk Piles

Screw piles were first used in 1838. They consist of a broad-bladed screw attached to the foot of the pile. The blade is usually constructed of cast-iron or wrought metal while the stem is constructed of wood, cast-iron or steel. The diameter of the screw is from two to eight times that of the stem and has a pitch of from one sixth to one third the diameter of the screw. The pitch is always dependent upon the type of soil in which the piles are to be placed. In general there are also four types of points available for screw piles. The gimlet point is mainly used for gravel; the blunt one for sand; the hollow, conical point for use with a water-jet in gravel or sand; and the serrated point for soft rock or coral.

Screw piles are put in place by simply

screwing them into the ground by means of hand or power levers. This of course subjects the stem and blade of the pile to torsional stresses and these as well as the connections must be carefully designed so as not to fail while the pile is being placed. There are cases on record where the frictional resistance has been so great as to cause the piles to twist off. It has been also discovered, however, that by discharging water against the upper surface of the screw blade, the friction can be reduced so that the sinking of the piles may be accomplished without difficulty. It further has been determined that, by using a water-jet, only about one tenth as much power was needed to screw the piles into the ground.

The load which a screw pile will support depends primarily on the bearing capacity of the soil at the depth of the screw. The following formula has been developed for the determination of the bearing capacity of screw piles.

$$p_o = h \: w \left(\frac{1 + \sin \phi}{1 - \sin \phi} \right)^2$$

h = depth of the screw below the surface of the soil, measured in feet.

w = weight of the soil in pounds per cubic foot.

p_o = the bearing capacity of the soil in pounds
per square foot at the depth of "h".

$\emptyset$ = angle of response of the soil.

Thus by determining the bearing capacity of
the soil at the depth of the screw, and calculating
the area of the screw, the supporting capacity of
each pile may be determined.

Disk piles were developed after the screw
piles and were not used until 1856. These consist,
as the name implies, of a large disk attached to the
foot of the pile. They have been used, principally
in ocean piers and wharves, where the total penetra-
tion is not large and is subject to more or less
variation.

The disk is a casting which is composed of a
horizontal circular plate stiffened by a number of
radial ribs. The disk is connected to a pipe-like
casing, either by bolting to a flange on the pipe
or by fitting inside the pipe and being bolted in
that position. A hole is provided at the bottom
of the disk so as to permit the use of a water-jet
through it. The disk piles are placed mainly by
use of the jet but when some soil is encountered
which it is not easy to displace, the pile may be

rotated to cause the ribs to act as cutters.

The sizes of the disks and stem vary, depending upon the bearing surface desired. The diameter of the disks range from one and three-quarters to four feet, the diameter of the cast-iron pipe from eight to fourteen inches and that of steel pipe from six to ten inches.

Both the screw and disk pile are unsuitable for deep foundations where the overlying material is soft or liable to scour, since it it impossible to provide bracing of the piles below the surface. For this reason they do not play a very important part in building foundations.

Sheet Piling

Sheet piling is used to retain the sides of excavations, to prevent the lateral flow of soft earth, and in the construction of cofferdams. It is made of wood, steel, concrete or reinforced concrete, according to the purpose for which it is to be used.

In retaining the sides of excavations the sheet piling may or may not need to be driven up tightly, depending upon the type of soil to be supported. Some soil only needs supports every ten

or fifteen feet while with soft earth, which will
flow laterally, the piling needs to be driven up
tightly to prevent the soil from seeping through
the joints. In the construction of cofferdams the
problem is even more difficult. They must be water-
tight so that when the water is pumped out of the
enclosure, none will leak through the joints of the
piling. Sometimes it is necessary to drive a second
row of sheet piling, about three feet from the first,
and to fill the space between the rows with a mixture
of gravel and clay in order to make the cofferdam
water-tight. If the leaks are not bad they possibly
may be stopped by throwing bran, manure, or other
fine material into the stream so it will be drawn
into the leaks in the dam.

There are many forms of timber sheet piling,
the more general types of which are shown on the
following page. Fig. "a" shows the type constructed
of planks of considerable thickness. The planks
are usually from three to four inches thick and from
ten to twelve inches wide. In general the points of
timber sheet piling are the same. Fig. "i" shows
the points sharpened so that the piling will drive
together tightly while Fig. "j" shows the pointing
so that the piling drive straight and easy. The
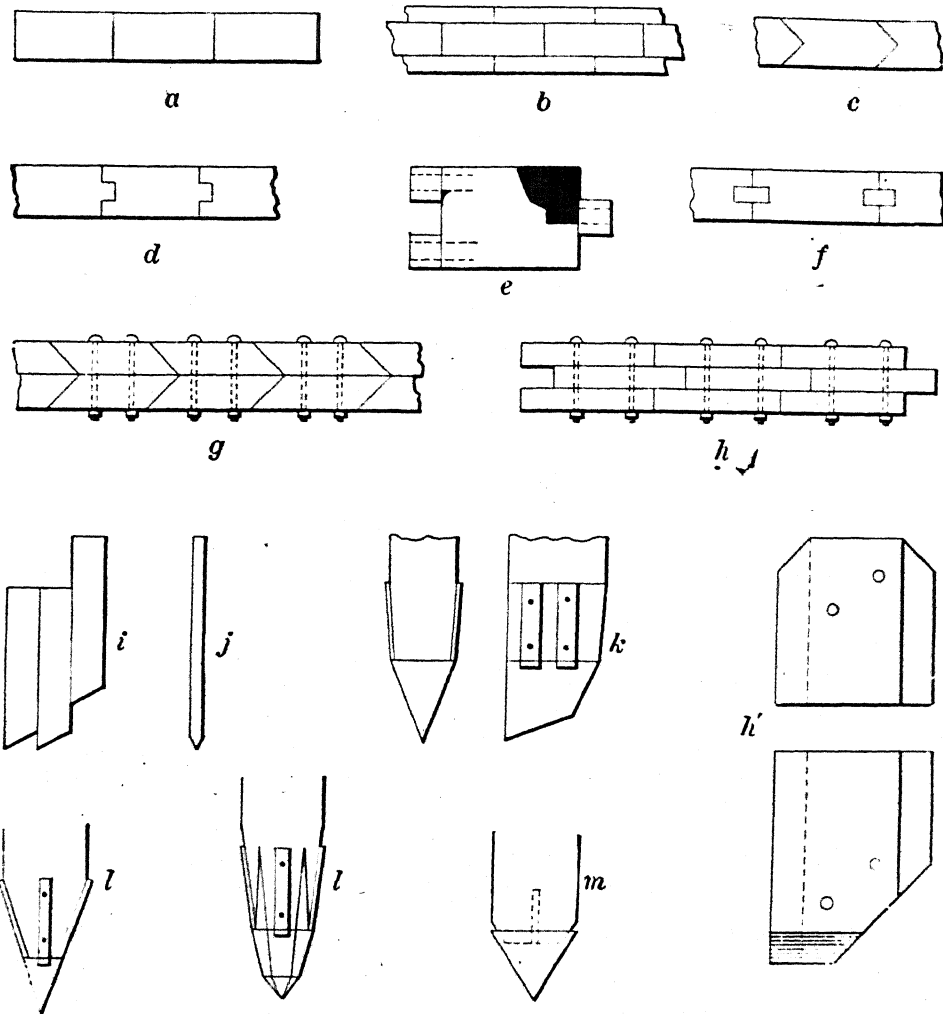
Forms of Timber Sheet Piling

same principle is embodied in the patented metal
point, shown in Fig. "k", which is used when
driving through coarse gravel. Flat planks are
also used as shown in Fig. "b". In this case a
second and third row is driven and these are used
to close the cracks in the main row. The extra
rows may be made of thinner plank so long as it
may be driven. Fig. "c" shows the V-shaped
tongue and groove piling. The ordinary tongue and
groove piling is shown in Fig. "d" but a type which
is more frequently used is that in Fig. "e". In
this type two pieces of wood forming the groove
and one piece forming the tongue are spiked to the
main piece of timber with six inch spikes which
are driven so as to slope upward. The piling shown in
Fig. "f" is seldom used. It is formed by cutting
grooves in each edge of the piling and then driving
a key into these grooves after the piles are in
place. The difficulty lies in getting the grooves
to exactly match.

Sheet piling formed of two or more planks
bolted together is being extensively used. One
type is formed, as shown in Fig. "g", by sawing
bevelled edges on two planks and then bolting them
together, thus constructing sheet piling similar to

that shown in Fig. "c". This forms a pile which
is easy to drive because of its size and which
requires supports in the shape of waling-pieces.
Fig. "h" shows the Wakefield patented sheet-piling
and Fig. "h" shows the way in which it is pointed.
It is constructed of three layers of plank from
one to four inches thick depending upon the pressure
to be sustained. The center plank must be sized so
as to keep the tongue and groove uniform. The planks
are bolted together with six bolts for each length
of from sixteen to twenty feet and two extra bolts
are added near each end. For long piles, spikes
should be driven between the bolts. The bolts vary
in diameter from three eights of an inch for one
inch planks to three quarters of an inch for four
inch planks. Figures "l" and "m" show the types
of metal points used on the ordinary round or
square piles. Fig. "l" shows a patented type of shoe.

Wooden sheet piling may be pulled and used a
second time but the expense of repairing them is
usually large and the total loss considerable.
This, coupled with the cost of pulling them, often
prompts contractors to leave the piling in the
ground where practical.

Steel sheet-piling is constructed in many

patented forms, too numerous to describe here.
The steel sheet-piling is constructed so that water
tight joints are formed and at the same time is
strong enough to withstand the earth or water
pressure against it. Steel sheet-piling possesses
the advantage over timber piling that, in most
cases, it can be withdrawn and used many times.

Concrete and reinforced concrete sheet piling
are usually rectangular and are molded and allowed
to harden before being driven. They are cast with
tongues and grooves or are provided with some form
of metal interlocking joints. This type of piling
is used to retain earth and is left in place. It
has been found especially suitable for the construction
of sea walls. Precast concrete sheet piles with
tongue and groove joints were used to protect "made"
ground in Lincoln Park, Chicago, from the attacks
of Lake Michigan and were found to be most satisfactory.

All forms of sheet piling are driven much the
same as are ordinary piles. The only suggestion being
that rapid blows driven by a hammer having a short
drop are more effective and cause the least damage
to the piling. This applies especially to piles of
considerable length. Wooden and steel sheet piling,
four to five feet in length, can be driven with mauls,

while slightly longer piling may be driven by means of the pneumatic type of hammer already mentioned in Chapter II. The water-jet has also been used with success and is very efficient in sandy soils.

No attempt has been made in this chapter to describe the types of cofferdams and the methods of bracing them. That is a study in itself involving a consideration of the type of soil and the construction problems to be met.

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