THE DESIGN AND CONSTRUCTION OF A PILE PLATFORM BULKHEAD

FOR THE

BRONX MUNICIPAL TERMINAL MARKET, BRONX, NEW YORK.

By

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Head of Department
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SUMMARY

Object

The purpose of this thesis is to make a design of a concrete bulkhead wall with a pile platform foundation for the Bronx Municipal Terminal Market, Bronx, New York City, and to give a brief description of its construction.

Method

A complete design was made of a typical section of the bulkhead wall, special attention being paid to its foundations. Only up to date methods recognized as best practice in New York City, were used. The construction was described from a point of view of a dockbuilder, special attention being paid to particular problems encountered only in this kind of work. All the necessary drawings were drawn and traced and placed in Appendix 3 at the end of this thesis. A brief description of the Bronx Market was given in the introduction.

Results:

The following results were attained:

1. A modern design of a pile platform bulkhead wall.
2. A description of the construction of that type of wall.
3. The necessary graphs, drawings and pictures.
INTRODUCTION

History of the Market

Bronx Municipal Terminal Market owes its existence to Mayor Hylan who as early as 1920 gave it his official backing. However it was not until early in 1922 that an approving resolution was passed through the Board of Estimate to establish a credit of $12,000,000 for the construction of the Market. Condemnation proceedings were issued against property holders at the future location of the Market and the first contract on the foundations of the main Market building was let to H.P. Converse & Co. of Boston. The contracts for the Main Market Building (to Newhouse Construction Co.) and the Power House (to W.W. Construction Co.) followed and finally the contract for the construction of the pile platform bulkhead wall was let again to H.P. Converse & Co. of Boston. This was early in 1926 and in May 1926 construction work on the wall was started. As this particular contract constitutes the basis of the present thesis only a very brief general description of the Market will be attempted.

Aim of the Market.

In building the Bronx Municipal Terminal Market the City had a definite purpose in view that was to give Bronx its own market and to make it possible for the retailer to buy directly from the producer thus disposing of the "intermediary" man that invariably stands in the way of the two others and exercises a very pronounced control over the prices of the different commodities.

The market situation as it stands at present is inadequate and unsatisfactory. Considering first the question of markets by itself it must be remembered that since the founding of New York all the
food products were shipped to Lower Manhattan and from there taken
to the different parts of the City. The shipping was done either by
water or by rail. Once the food products were unloaded horsecars
and recently trucks were used to carry them to their destinations.
This increased both the "traffic" problem of the City and the cost of
the food products.

Moreover the storage facilities in Lower Manhattan are very poor.
Hence the producer that is shipping his food products to New York
faces the problem of getting rid of his goods as quickly as he can. The
small retailer is not the man to be dealt with, for that would take
too much time and involve too much risk. On the other hand the time
element in case of perishable goods is very important. Hence a solu-
tion must be found.

The present solution is found in the person of the "intermediary"
man, the wholesaler that has some storage available and is also de-
pendent upon a certain constant clientele of retailers. He therefore
gets in touch with the producer and orders from him any amount of
goods that he thinks he can store or dispose of in a short time. That
evidently presents a satisfactory solution for both the producer and
the retailer, but is it just as satisfactory for the average home-
cooking citizen? Evidently it is not. The introduction of an "inter-
mediary" man between the retailer and the producer and the resulting
trucking of goods from the Market to the wholesaler's storage and
from there on to the retailer will necessarily greatly affect the cost
of food products. Furthermore not satisfied with reasonable profits
the wholesaler's acting in unison went so far as to create artificial
shortages of certain food products, forcing the population to pay
exorbitant prices, and reaping enormous profits.
These considerations forced the City Administration to take that matter in its hands and seek for an adequate solution. The present Market is the outcome of those deliberations.

Under the new plan it was decided that a new and a separate Market had to be provided for the Bronx, thus cutting down the cost of transportation. To get rid of the "third" man an ample storage space was to be provided in the very heart of the new Market, consisting of a Main Building to be used for miscellaneous food products and separate Fish and Poultry Buildings. A modern refrigerating plant had to supply the necessary ice and cooling.

The storage space is to be rented to producers only, thus allowing them to ship directly large shipments of their goods without fear of not being able to dispose of them in a reasonable time. This would also allow the retailer to deal directly with the producer, and would eventually result in a considerable decrease in prices. The danger of artificial shortage of any food products would also be eliminated.

Of course it is rather difficult to predict how this idea will work out, on account of the human element that enters into it. Yet all in all it is perfectly reasonable to expect that the idea would turn out well, and would benefit the citizens of the Bronx.

**Location of the Market.**

Those who are familiar with the ways of New York City know that both water and railway facilities exist in Bronx and have to be considered in the location of the Market. Besides, as most of the transportation from the Market is to be done by trucks, a proximity to the main thoroughfares would be of great advantage.
The site finally chosen for the Market lies at the downtown side of the Macomb's Dam Bridge and is bounded by the bridge on the north side, 151st St. on the south side, and the Harlem River and New York Central Lines on the West and East side respectively. The advantages of this site are as follows:

1) Proximity to New York Central Railroad from which a siding can be easily run into the Market.
2) Proximity to Harlem River.
3) The place is within easy reach from the Grand Concourse, Jerome Avenue, Macomb's Dam bridge, 145th St. bridge and other important public thoroughfares.

Description

If carried to completion as originally designed the Bronx Market will consist of:

1) Main Market Building (completed)
   This is a 6 story structural steel structure with a brick facing. Four tracks from the New York Central lines run into its ground floor, reducing unloading expenses to a minimum. Giant elevators provided in the building then carry the food products to any of the floors where they are to be stored. A steel viaduct level with the first floor of the building offers ample facilities for trucks services from the Market to any part of the City.

2) Poultry Building (proposed)
   This building is to be used exclusively for a poultry market.

3) Fish Building (proposed)
   To be used solely as a fish market.

4) Refrigerating Plant (completed)
   This structure designed by Major Hill, the famous refrigerating
expert is a 2-story building equipped with ammonia compressing machines, and all modern facilities for making plate ice. The power to run it is supplied by the Edison Company of New York.

5) The Viaduct.

This is a structural steel structure that forms a complete ring around the Main Market Building level with its first floor, connecting it with 151st Street on the southern side and with Exterior Avenue on the Northern side.

6) Pile platform bulkhead wall.

As this particular part of the Market is the object of this thesis the discussion of it will be taken up later.

Viewed as a whole the Market presents a wonderful engineering project and a very interesting experiment in City Market economics. A great many leading engineers have contributed to its design and the economic side of the project has been also very carefully considered. The companies in charge of the construction have performed their work under strict City supervision. It remains now for the future to show that the Bronx Municipal Terminal Market will remain a lasting monument to the foresight of the City’s administration.

Cost of the Market.

The Market as at present proposed and passed by the Board of Estimates represents an investment of $12,000,000. That includes the cost of all buildings and approaches, bulkhead wall, power house and real estate. This figure however is likely to be somewhat greater on account of certain delays in construction and real estate troubles.
DESIGN
DESIGN

Test Data

Having chosen the site for the pile platform a series of tests was ordered by the Department of Public Markets. A series of test piles were driven and a few borings were made.

The test piles are indicated on Drawing #1. It will be observed that two series of pile tests were made, one being done by the Department of Public Markets and the other by the Contracting Company. The main difference between the two series lies in the fact that the Department of Public Market's piles were driven before the required dredging was completed, while the Contracting Company's piles were driven after the dredging operations were completed. To quote the Specifications (Art. 66) "At the start of the work (after completing dredging) the Contractor will be required to drive at a location to be selected by the Commissioner or his representative, trial test piles, using 75 ft. class piles, in order to determine the proper length of piles." The results of those will be taken up later.

Only two borings were available for the design which was very inadequate. However, most of the necessary information was supplied by test piles data.

CONTRACTING COMPANY'S TEST PILES DATA.

Engineering News Formula.

\[ \text{Ex.: Safe Load} = \frac{2}{s} \cdot w \cdot h \]

where:

\[ s + 0.1 \]

Safe Load = working Load on piles, i.e. the load which it is certainly safe to place upon a pile under all conditions.
<table>
<thead>
<tr>
<th>No.</th>
<th>Length</th>
<th>Average Penetration (Contracting Company)</th>
<th>Waste</th>
<th>Remarks</th>
<th>Diam.</th>
<th>Diam. bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Penetration Last 5 blows</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>60'-0</td>
<td>1/2&quot;</td>
<td>-</td>
<td></td>
<td>'14&quot;</td>
<td>6&quot;</td>
</tr>
<tr>
<td>2</td>
<td>68'-0</td>
<td>3/4&quot; (20 blows)</td>
<td>-</td>
<td></td>
<td>in Grib</td>
<td>&quot;</td>
</tr>
<tr>
<td>3</td>
<td>60'-0</td>
<td>3&quot;</td>
<td>-</td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>4</td>
<td>60'-0</td>
<td>3&quot;</td>
<td>-</td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>5</td>
<td>75'-0</td>
<td>2&quot;</td>
<td>-</td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>6</td>
<td>59'-0</td>
<td>2-1/2&quot;</td>
<td>6'-0&quot;</td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>7</td>
<td>60'-0</td>
<td>2&quot;</td>
<td></td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>8</td>
<td>75'-0</td>
<td>1/2&quot;</td>
<td>10'-8&quot;</td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>9</td>
<td>75'-0</td>
<td>1/2&quot;</td>
<td>5'-6&quot;</td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
<tr>
<td>10</td>
<td>80'-0</td>
<td>1/2&quot;</td>
<td>5'-0&quot;</td>
<td></td>
<td>&quot;</td>
<td>&quot;</td>
</tr>
</tbody>
</table>

Steam Hammer used - 3000#

Actual Stroke - 30"
w = the weight of the hammer
L = the fall of hammer in ft.
s = set of pile under last blow in inches
l = a constant which represents the extra initial resistance of getting the pile in motion.

Pile #1.
Safe Load = A = \frac{2 \times 3000 \times 2.5}{.5 + .1} = 25000\# = 12\frac{1}{2} \text{ tons}

Pile #2
A = \frac{2 \times 300 \times 2.5}{.75 + .1} = 17640\# = 8.82 \text{ tons}

Pile #3
A = \frac{2 \times 300 \times 2.5}{3 + .1} = 4850\# = 2.425 \text{ tons}

Pile #4
A = \frac{2 \times 3000 \times 2.5}{3 + .1} = 4850\# = 2.425 \text{ tons}

Pile #5
A = \frac{15000}{2 + .1} = 7140\# = 3.57 \text{ tons}

Pile #6
A = \frac{15000}{2.5 + .1} = 5760\# = 2.88 \text{ tons}

Pile #7
A = \frac{15000}{2.5 + .1} = 7140\# = 3.57 \text{ tons}

Pile #8
A = \frac{15000}{.5 + .1} = 25000\# = 12.5 \text{ tons}

Pile #9
A = \frac{15000}{.5 + .1} = 25000\# = 12.5 \text{ tons}
Pile #10

\[ A = \frac{15000}{.5+.1} = 25000# = 12.5 \text{ tons} \]

**THEORY OF IMPACT FORMULA**

Let \( R \) = weight of hammer in lbs.

\( G \) = " pile " "

\( L \) = length " " ft.

\( F \) = area of cross-section of pile

\( E \) = modulus of elasticity of pile material

\( h \) = height of drop in ins

\( s \) = penetration due to one blow

\( u \) = coefficient of loss due to shock

\( n = 0 \) for perfectly non-elastic shock

\( u = 1 \) for " elastic "

\( Q_d \) = dynamic resistance against penetration

The Theory of Impact leads to the following formula:

\[ Q_d = \frac{F}{L} \cdot E \left[ -S^+ \sqrt{S^+ + \frac{2Rh}{E}} \cdot \frac{R + uG}{R + G} \cdot \frac{L}{F} \right] \]

Assuming \( u = .5 \) for semi-elastic shock we get the following values for safe load on test piles

**Pile #1**

Safe Load = \( A = \frac{1}{6} \left( \frac{63 \times 600,000}{60 \times 12} \left[ -0.5^+ \sqrt{\frac{2.5 + \frac{2 \times 300 \times 2.5 \times 12}{600,000}}{3000 + 2.5 \times 1325 \cdot 60 \times 12}} \right] \right) \)

\[ = 10,500 \text{ lbs} = 5.025 \text{ tons} \]

**Pile #2**

\[ A = \frac{1}{6} \left( \frac{71.2 \times 600,000}{68 \times 12} \left[ -0.75^+ // 0.56^+ \sqrt{\frac{2 \times 3000 \times 2.5 \times 12 \times 3000 \times 2.5 \times 1500 \times 68 \times 12}{600,000 \times 3000 \times 1500 \times 71.2}} \right] \right) \]

\[ = 7840 \text{ lbs} = 3.92 \text{ tons} \]

*The factor 1/6 refers to the safety factor of 6 as required in the design.*
\[
A = \frac{1}{6} \left\{ \frac{63 \times 600,000}{60 \times 12} \left[ -2 \sqrt{4 + \frac{6000 \times 2.5 \times 12 \times 3000 + 2.5 \times 1325.60 \times 12}{600000 + 3000 + 1325.63}} \right] \right\} \\
= 3680 \text{ lbs.} = 1.84 \text{ tons}
\]

File #5

\[
A = \frac{1}{6} \left\{ \frac{78.5 \times 600,000}{75 \times 12} \left[ -2 \sqrt{4 + \frac{15000 \times 12 \times 3000 + 2.5 \times 1300.75 \times 12}{600000 + 3000 + 1300}} \right] \right\} \\
= 4810 \text{ lbs.} = 2.4 \text{ tons}
\]

File #6

\[
A = \frac{1}{6} \left\{ \frac{61.8 \times 600,000}{59 \times 12} \left[ -2 \sqrt{4 + \frac{6.25 \times 15000 \times 12 \times 3000 + 2.5 \times 1300.59 \times 12}{600,000 + 3000 + 1300}} \right] \right\} \\
= 4200 \text{ lbs.} = 2.1 \text{ tons}
\]

File #7

\[
A = \frac{1}{6} \left\{ \frac{63 \times 600,000}{60 \times 12} \left[ -2 \sqrt{4 + \frac{15000 \times 12 \times 3000 + 2.5 \times 1325.60 \times 12}{600000 + 3000 + 1325}} \right] \right\} \\
= 5080 \text{ lbs.} = 2.54 \text{ tons}
\]

Piles #8, 9 & 10

\[
A = \frac{1}{6} \left\{ \frac{78.5 \times 600,000}{75 \times 12} \left[ - \sqrt{1.25 \times \frac{15000 \times 12 \times 3000 + 2.5 \times 1325.75 \times 12}{600,000 + 3000 + 1325}} \right] \right\} \\
= 13,500 \text{ lbs} = 6.75 \text{ tons}
\]

It will be observed that the values of safe loads given by the Theory of Impact Formula are very much smaller than the ones given by the Engineering News Formula. Nevertheless it can be easily shown that the Eng. News Formula is derived from the Theory of Impact Formula and therefore their results should be in much better agreement. The reasons for that difference in results reside in the following facts:

1) The Engineering News Formula takes into account the difference between steam and a drop hammer piledriving by introducing an Empirical coefficient which, though it is far from being satisfactory,
makes a noticeable difference in results.

2) The Impact Formula being, strictly speaking, the original theoretical formula fails to take into account that difference and is therefore very strongly influenced by the corresponding variations in h-drop of the hammer.

It may be further added that in Europe where the Impact Formula is much used, a factor of Safety of only 4 is required as compared with the factor of safety of 6 specified in U.S.A.

DEPT. OF PUBLIC MARKET'S TEST PILES DATA.

In preparing the preliminary plans for the bulkhead wall of the Bronx Market the Department of Markets has made a series of pile driving tests, the results of which are given in a special table. It will be noted that the tests were made with a drop hammer pile driver, the weight of which was 3800 lbs. as compared with 3000 lbs. of the steam hammer used by the Contracting Company. It also had the advantage of a much bigger drop.

Engineering News Formula

Pile #1
No computations will be made as the pile was brought up on rock (probably a big boulder.)

Pile #2
Safe Load \[ A = \frac{2 \times 3800 \times 14}{3 + 1} = 26,600 \text{ lbs.} = 13.3 \text{ tons} \]

Pile #3

\[ A = \frac{2 \times 3800 \times 14}{2.2 + 1} = 32,000 \text{ lbs.} = 16 \text{ tons} \]

Pile #4

\[ A = \frac{2 \times 3800 \times 14}{7.6 + 1} = 12,000\# = 6 \text{ tons} \]

Pile #5

\[ A = \frac{2 \times 3800 \times 14}{6 + 1} = 15,200\# = 7.6 \text{ tons} \]
<table>
<thead>
<tr>
<th>Test Pile No.</th>
<th>Length</th>
<th>Diam. of Butt</th>
<th>Point</th>
<th>Penetration under pile's weight</th>
<th>&quot; with 1st blow</th>
<th>&quot; hammer</th>
<th>Average penetration last 5 blows</th>
<th>Safe Load</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74'</td>
<td>18&quot;</td>
<td>7&quot;</td>
<td>4:0&quot;</td>
<td>1:0&quot;</td>
<td>16:0&quot;</td>
<td>6:0&quot;</td>
<td>3:6&quot;</td>
<td>1:6&quot;</td>
</tr>
<tr>
<td>2</td>
<td>84'</td>
<td>6&quot;</td>
<td>6&quot;</td>
<td>12:0&quot;</td>
<td>9:0&quot;</td>
<td>13:0&quot;</td>
<td>5:0&quot;</td>
<td>3:0&quot;</td>
<td>6:6&quot;</td>
</tr>
<tr>
<td>3</td>
<td>74'</td>
<td>7&quot;</td>
<td>7&quot;</td>
<td>10:0&quot;</td>
<td>2:0&quot;</td>
<td>2:6&quot;</td>
<td>7:6&quot;</td>
<td>6:0&quot;</td>
<td>1:9&quot;</td>
</tr>
<tr>
<td>4</td>
<td>75'</td>
<td>6&quot;</td>
<td>6&quot;</td>
<td>12:9&quot;</td>
<td>3:6&quot;</td>
<td>4:6&quot;</td>
<td>6:6&quot;</td>
<td>5:6&quot;</td>
<td>4:0&quot;</td>
</tr>
<tr>
<td>5</td>
<td>73'</td>
<td>7&quot;</td>
<td>7&quot;</td>
<td>21:0&quot;</td>
<td>2:0&quot;</td>
<td>10:0&quot;</td>
<td>10:0&quot;</td>
<td>4:0&quot;</td>
<td>5:6&quot;</td>
</tr>
<tr>
<td>6</td>
<td>81'</td>
<td>6&quot;</td>
<td>6&quot;</td>
<td>12:0&quot;</td>
<td>6:0&quot;</td>
<td>6:0&quot;</td>
<td>5:0&quot;</td>
<td>5:0&quot;</td>
<td>10:0&quot;</td>
</tr>
<tr>
<td>7</td>
<td>73'</td>
<td>7&quot;</td>
<td>7&quot;</td>
<td>21:0&quot;</td>
<td>5:0&quot;</td>
<td>8:0&quot;</td>
<td>11:0&quot;</td>
<td>7:0&quot;</td>
<td>3:0&quot;</td>
</tr>
</tbody>
</table>

Remarks:
- On rock
- Hard pulling
- April 22
- Easy
- Hard
- Easy
- Easy
- Hard
Pile #6
\[ A = \frac{2x3800x14}{4.5+1} = 14,000\# = 9 \text{ tons} \]

Pile #7
\[ A = \frac{2x3800x14}{6+1} = 66,000\# = 33 \text{ tons} \]

Theory of Impact Formula

Pile #1
computations omitted

Pile #2
\[ A = \frac{1}{6} \left( \frac{88x600,000}{84x12} \right) \left[ -3 + \sqrt{9 + \frac{2x3800x14x12}{600,000} \frac{3800+25x1655}{3800+1955} \frac{84x12}{88} } \right] \]
\[ = 19,500\# = 9.75 \text{ tons} \]

Pile #3
\[ A = \frac{1}{6} \left( \frac{77.5x600,000}{74x12} \right) \left[ -2.2 + \sqrt{4.84 + \frac{7600x14x12}{600,000} \frac{3800+25x1630}{3800+1630} \frac{74x12}{77.5} } \right] \]
\[ = 23,400\# = 11.7 \text{ tons} \]

Pile #4
\[ A = \frac{10}{6} \left( \frac{78.5x600,000}{75x12} \right) \left[ -7.6 + \sqrt{5.78 + \frac{7600x14x12}{600,000} \frac{3800+25x1653}{3800+1653} \frac{75x12}{78.5} } \right] \]
\[ = 10,100\# = 5.05 \text{ tons} \]

Pile #5
\[ A = \frac{1}{6} \left( \frac{76.5x600,000}{73x12} \right) \left[ -6 + \sqrt{36 + \frac{7600x14x12}{600,000} \frac{3800+25x1610}{3800+1610} \frac{73x12}{76.5} } \right] \]
\[ = 12,250\# = 6.125 \text{ tons} \]

Pile #6
\[ A = \frac{1}{6} \left( \frac{88x600,000}{84x12} \right) \left[ -4.5 + \sqrt{20.3 + \frac{7600x14x12}{600,000} \frac{3800+2.5x1855}{3800+1855} \frac{84x12}{88} } \right] \]
\[ = 15,050\# = 7.525 \text{ tons} \]

Pile #7
\[ A = \frac{1}{6} \left( \frac{76.5x600,000}{73x12} \right) \left[ -6 + \sqrt{36 + \frac{7600x14x12}{600,000} \frac{3800+2.5x1610}{3800+1610} \frac{73x12}{76.5} } \right] \]
\[ = 38,400\# = 19.2 \text{ tons} \]
Safe Load

Summarizing the test piles data we get the following results:

(average values)

**Dept. of Markets Tests**

Eng. News Formula \( A = 14.15 \) tons

Theory of Impact Formula \( A = 9.985 \) tons

**Contracting Company's Tests**

Eng. News Formula \( A = 7.369 \) tons

Theory of Impact Formula \( A = 3.1165 \) tons

The difference between the two series of tests lies in the fact that steam hammer pile driving does not yield itself so well to mathematical expression as drop hammer pile driving. The time element and the effect of a succession of quick blows, which does not allow the ground to regain its initial resistance to penetration once the driving is started, are supposedly taken care of by means of an empirical coefficient (Eng. News Formula) which is not very satisfactory. Hence the big difference in the final results.

The Department of Markets basing itself on its test data has taken 12 tons as a safe pile load, and made its preliminary designs accordingly. A safe load of 12 tons per pile will be adopted in this design for the following reasons:

1) Test data (with a drop hammer) are quite satisfactory

2) The factor of safety is quite large (6)

3) The soil and driving conditions are good.

While the first two reasons are evident, the third one needs an explanation. The only two existing test borings gave the following information about the soil conditions. Starting at an
elevation of +5 down

the first 20 or 30 feet - rock and cinder fill

" next 30 or 40 feet - river mud or clay

and finally, brown sand and trap rock.

These data indicate that most of the driving will have to be
done in the river mud or clay. In driving in mud and sand the
following interesting phenomenon takes place. As soon as driving
is started the water that fills the voids of the mud and sand
escapes and forms a kind of a mantle around the pile. This mantle
acts exactly like a lubricant in a machine, making the penetration
of the pile easier. Once the driving is stopped for a certain
length of time the lubricant disappears and the dynamic resistance
against renewed penetration is very considerable. However after
a little while the water film is formed again and the dynamic re-
sistance against penetration resumes its original value. Evidently
the longer the pile stays in the ground the greater becomes the
resistance to penetration. Taking all this into consideration we
feel perfectly justifiable in fixing the safe load per pile at 12 tons.

DESIGN PROPER.

General dimensions and shape of wall.

In designing the general dimensions and shape of the bulkhead
wall the following points should be considered, as having a direct
influence upon it.

1) The U.S. naval regulations and the Dept. of Docks and Ferries
regulations as to Harlem River at the place of construction.

2) The probable volume of commerce to be handled by the Market
by water.

3) The present waterfront of the river.
The first point lays down definite limits (such as the U.S. pierhead line) beyond which no waterfront structure of any kind is allowed to project itself. (See drawing #1). We will have therefore to restrict ourselves to the space between that line and the shore.

The second point will determine the length of the waterfront necessary to handle successfully the commerce coming by water. This length can be lengthened or shortened by increasing or decreasing the number of slips in the waterfront.

The third point is merely a question of economy and convenience. To keep the present waterfront of the river or to stick to it closely will reduce somewhat the cost of the bulkhead wall.

The adopted outline is shown on drawing 1. It has a total frontage of 2168 feet 4-1/8 inches and includes two slips at its southern end. Starting at the bridge the wall takes advantage of the existing lines of sheet piling and piles and runs parallel to the bridge for a length of 150 ft. This section also provides ample space for an extra car float and slip to be built when a sufficient demand for it will exist, and to extend southward along the present 280 ft. section of the bulkhead wall. The next section 55 feet in length provides a convenient location for another car float and slip (included in the present contract for the construction of the bulkhead wall) which is to extend southward along the 482 ft. section. From then on the wall follows closely the outline of the old crib wall and forms two slips capable of taking care of two barges each.
Elevations adopted

The elevation of the bulkhead wall above mean high water should be sufficient to be free from danger of flooding by waves at extreme high tides and should not be so great, as to interfere with the handling of cargo at low tides. In ordinary sheltered harbors the height is usually from 5 to 6 ft. above mean high water level. In New York City where the mean range of tide is 4.25 ft. and extreme tides have risen to 4 ft. above mean high water, the decks of nearly all piers and wharves have been placed 5 ft. above the later elevation. This value has been used for more than half a century and there seems to be no tendency to make any changes.

On account of the narrowness of the channel and other reasons taken up later the extreme tides are always apt to be higher in the Harlem River. It will be therefore wise to adopt for the top of the bulkhead wall the elevation suggested by the Specifications of +5.33 ft. above the Bronx Datum.

In fixing the elevations for the pile platform the possibilities of destruction of the timber by decay, marine borers, and fire have to be considered. Out of these three the marine borers, perhaps due to the nearness of two sewers, not found to exist in the water, while the fire danger is reduced to a minimum by the fact that a concrete platform with an earth fill on top of it are used. Undoubtedly no method of construction has been found, as yet, which would project a wooden structure from destruction by burning oil floating on the water. This danger is however minimized, as no oil pipe lines or oil storage tanks are located near the Market, and whose rupture might cause the destruction of the pier.

As far as destruction by natural decay goes, timber below
a plane located two feet above mean low water is considered safe from rot in New York City, where the mean range of tides is 4.25 ft. as previously mentioned. The pile cut off for brace piles will be therefore fixed at -3.08 according to the Bronx Datum, and that for vertical foundation piles at -2.21. This cut-off allowing 12 inches for the caps and 2" for planking gives an elevation of -1.08 for the top of the pile platform.

PILE PLATFORM

Spacing of Piles.

As mentioned in the summary only a typical section of the bulkhead wall will be designed. This section, as indicated on drawing #1, includes a part of the 280 ft. section, the 55 foot section, the main 480 ft. section, and a small part of the section at the north side of slip #1. The pile platform will be designed for sections A-A, B-B, and C-C, as indicated on the drawings.

Section B-B.

This section located on the side of the car float slip will have to withstand the heaviest loading on the wall consisting of freight cars and locomotives, as well as the dead load of the structure itself. The most possible care would evidently consist of a combination of:

1) Dead load of the structure
2) Locomotive load on one track
3) Uniform car load on the other track.

Cooper's E 40 loading will be chosen as live load, for it is not likely that heavier locomotives will be used for shifting freight cars.

The fill will be taken at 100 lbs. per cu. ft.

Concrete " " " 150 " " "

The weight of the lumber will be neglected.

The procedure will be as follows: first a section will be
assumed according to the Specifications supplied by the Dept. of Markets. Then a computation of the loading will be made, assuming the train load as a uniform load acting on an area at 45° from the top of the rails. The total load will be assumed as acting on the surface of the concrete slab on top of the pile caps. (see sketches).

**Longitudinal spacing**

The longitudinal spacing will be taken as 5 ft. for all rows except the two front rows. This is an assumed trial spacing which can be changed, if the computed spacing at right angle to it will prove unsatisfactory. An effort will however be made to keep the same longitudinal spacing throughout the whole design to make it simpler.

**Crosswise spacing**

The section is indicated on a sketch. Due to the fact that a certain grade is given to the track, the elevation of the base of rail will vary from +4.75 to +3.75 thus changing somewhat the distribution of load on the concrete slab. It will be observed that the heaviest loading on this section will be obtained at the place where the two live loads overlap. Evidently an El +4.75 will cause a greater overlapping and will be therefore considered in this design.

Distance from base of tie to slab - 4'-6"

Spread of Live Load on Slab - 17'-0"

" " Double live Load Slab - 5'-0"

Then Live Load:

Locomotive load per ft. (long.spacing = 5'-0"

\[
\frac{42000}{17} = 2350 \text{ lbs. per ft.}^2
\]

Train load per ft. (long.spacing = 5'-0"

\[
\frac{20000}{17} = 1175 \text{ lbs. per ft.}^2
\]

Total Live Load per ft. of overlapping section 3525 lbs. per ft.²
Dead Load
Concrete $150 \times 1.5 \times 5 = 1125$ lbs. per ft.
Fill $100 \times 3 \times 5 = 1500$ " " "
Track $2 \times (150 \times 5) = 1500$ " " "

Total Dead Load per ft. of overlapping section $= 4125$ " " "

Total Load per ft. of overlapping section: $= 3525 + 4125 = 7650$ lbs. per ft.

The Total load acting on the overlapping section will be: $7650 \times 5 = 37250$ lbs.

Hence the number of piles required: $37250 / 24000 = 1.55$

Spacing of piles required: $5 / 1.55 \approx 3.23$ ft. $= 3' - 3''$

Spacing of Piles under single live load:

Live Load (Locomotive) $= 2350$# / ft.
Dead " $= 3375$# / ft.

Total Load $= 5725$# / ft.

The total Load on Slab due to single live load: $5725 \times 17 = 97200$

Number of piles required: $97200 / 24000 = 4.05$

Spacing of piles required: $17 / 4.05 \approx 4.2$ ft. $= 4' - 2\frac{1}{2}''$

Spacing of End Piles

The last two or three piles are evidently subjected to dead load only. Taking this dead load as being the weight of the concrete wall we have:

Dead Load: $150 \times 6.21 \times 2.5 = 2335$#/ft.

Total Load acting on section under concrete bulkhead: $2335 \times 5 = 11675$ lbs.

Number of piles required: $11675 / 24000 = .486$ piles

Spacing required: $5 / .486 = 10.3$ ft.

Spacing Adopted:

The adopted spacing is indicated on sketch. 10 piles are provided to carry out the load. The first seven piles that stand
under the tracks are spaced at 3'-6". This is bigger than the
spacing required for the overlapping section and smaller than
the one under single live load. It stands to reason that the
overlapping section is too small (5 ft. only) to present any danger
to the structure. We can therefore safely increase its spacing,
relying on the beam action of the caps and the adjoining piles
not loaded to capacity. The spacing for the 8th pile is 4 ft., while
the last two piles have a spacing of 5 ft. No spacing greater than
5 ft. has been used in order to give the structure the required
stiffness.

Section A-A

The design of this section is essentially the same as that of
section B-B, except for the fact that only one track will have to
be considered. The dimensions and the Live Load (E 40) being the
same in the two sections no new computations for spacing of piles
will be necessary. We have therefore:

**Longitudinal spacing**

5 ft. c. to c. of all pile rows except the two front ones, where
a 2'-6" spacing will be used.

**Spacing under the Live Load Section**

4'-2" c. to c. as a maximum

**Spacing of End Piles**

10'-0" c. to c. as a maximum.

**Spacing adopted**

The Dept. of Market's Specifications call for a 25'-3" width
of platform, with 26'-0" supporting caps. Using the suggested
number of piles, we will space the front piles at 5'-0", the next
5 piles at 3'-9", and the last two at 3'-8", leaving 1'-6" as the
distance from the last pile to the sheet piling. (For details see Drawing #4 and sketch of section).

Section C-C

This section of the wall on the north side of slip #1 is subjected only to the live load of unloaded foot products plus its own dead weight.

Longitudinal Spacing

Same as in sections A-A and B-B.

Crosswise Spacing

Live Load.
The live load will be taken at 500#/ft.
Live load per ft. : 500 x 5 = 2500#/ft.

Dead Load
Concrete 150 x 1.5 x 5 = 1125#/ft.
Cinder Fill 40 x 4 x 5 = 800#/ft.

Total Dead Load = 1925#/ft.

Total Load per ft. = 1925 + 2500 = 4425#/ft.

Taking an arbitrary section 10 feet long we get as a total load on it: 4425 x 10 = 44250 lbs.

Number of piles required 44250 / 24000 = 1.83 piles
Spacing of piles required 10 / 1.83 = 5.2' or 5'-2½"

Adopted Spacing

The Dept. of Markets' Specifications call for a platform width of 36'-6" with a cap of 37'-0". Using the suggested number of 8 piles we will space them at 5'-0" c. to c. with 1'-6" left between the center of the last pile and the sheet piling. For details see Drawing #4 and sketch of section.
Brace Piles

To protect the vertical piles against the action of lateral forces brace piles will be provided in the pile platform.

Assuming a batter of 1:2 the brace piles will be driven with a steam hammer of same weight as used in driving bearing piles. The penetration must be such as to develop the safe axial bearing value of 12 tons. Then the vertical component will be about 21,400 lbs. and the horizontal 10,700 lbs. The pile then is capable of resisting safely a horizontal thrust of 10,700 lbs if, and herein lies the difficulty, - the head of the pile is held down by a force equal to the vertical component 21,400 lbs.

In our case this downward resistance to the upward thrust of the brace pile will be furnished by the weight of the fill on the platform, and by the resistance to pulling of a vertical pile to which the brace pile is attached. In order to insure against any possible failure of connections between the bearing and brace piles, a timber running across the bent cap and called the brace or batter cup will be provided, to transmit the upthrust to one of the bearing piles of the bent through pair of strap bolts. As it is hard to bore two holes in a pile only one 7/8 inch bolt through the pile from strap to strap will be used.

**Section B-B:** 3 rows of brace piles at 3'-6" c.to c. Slope 1:2

**Section A-A:** 2 " " " " 3'-8" " " " 1:2

**Section C-C:** 2 " " " " 5'-0" " " " 1:2

Omission of Brace Piles

Brace piles will be omitted in the inside and outside corners of the pile platform. The corners are the stiffest points of the structure and the omission of a few brace piles would not impair their
strength. This would also greatly facilitate the driving of the inside corners.

**SHEET PILING**

**Horizontal Thrusts**

Let \( W_a \) = weight per ft.\(^3\) in air
\( W_w \) = " " " " water

\( K_a \) = angle of repose in air
\( K_w \) = angle of repose in water

For gravel, sand, and clay these quantities are:

\( W_a = 100 \text{ lbs.} \quad K_a = 36^\circ 53' \)
\( W_w = 65 \text{ lbs.} \quad K_w = 18^\circ 26' \)

Then:

\[
p = \frac{1}{2} \cdot \theta^2 \tan^2 (45^\circ - \frac{1}{2}K)
\]

which assumes that, were the dike to be removed the backing would fail by parting along a plane of rupture at an angle of \((45^\circ - \frac{1}{2}K)\) with the vertical.

Then:

\[
45 - \frac{1}{2} K_a = 45 - \frac{36^\circ 53'}{2} = 26^\circ 34'
\]
\[
45 - \frac{1}{2} K_w = 45 - \frac{18^\circ 26'}{2} = 35^\circ 47'
\]

The weight of the sliding wedge is made up of three parts:

(see sketch)

1) Area (a.b.c.) in sq. ft. \( \times W_w \)
2) " (bdefc) in sq. ft. \( \times W_a \)
3) the length (df) in ft \( \times 600 \)

Hence the total weight of the composite wedge is:

**Submerged stratum:** \( = \frac{65\frac{1}{2}}{2} (14.72 \times 0.721) = 5060\# \)

**Dry Stratum:** \( = 100 (10.6 \times 10.04) \left( \frac{10.04 \times 500}{2} \right) = 13164 \)

**Live Load:** \( = 500 (10.6 \times 5.02) = 7630 \)

**Total weight =** \( W = 25854\# \)
Then: $P = W \tan (45^\circ - \frac{1}{2} K)$

$= 25,854 \times .721 = 18,675 \text{ lbs.}$

This represents the net thrust, as the water pressure has already been deducted by reason of the fact, that the quantities used for the submerged stratum were submerged quantities.

Hence the pressure to be resisted by the sheet piling is: 18,675#.

**Design of Sheet Piling**

The problem of the design is to determine the stresses in the sheet piling and the proportion of the thrust transmitted thereby to the water structure. The most convenient treatment is by the method of equivalent fluid pressure, i.e., the determination of the weight of a hypothetical fluid which will produce the same thrust $P$ both in magnitude and point of application. Resultant earth pressure acts as a point somewhere between one-third and one-half the height of the wall from the bottom. There the live load surcharge is considerable, the point of application may be safely taken at 0.4 the height.*

In our case: $0.4 \times h = 0.4 \times 24.74 = 9.896 \text{ ft.}$
or 9.896 feet from the bottom.

Hydrostatic resultant pressures, however, act at one-third of the height. The head of the so-called equivalent fluid will in our case be: $h = 3 \times 9.896 = 29.688 \text{ ft.}$

and the resultant pressure: $\frac{\#wh^2}{2} = \frac{w 880}{2} = 440w$

Equating this to the above value of $P$ and solving for $w$, we find that a fluid weighing 42.4 lbs. per cubic foot will exert an equivalent thrust.

The unit pressure at the base of the wall is:

$wh = 42.4 \times 29.688 = 1259 \text{ lbs.}$

*(see next pg.)
Considering now our case we can readily see that the sheeting is in reality a vertical beam fixed at the lower end at A and supported at the top B. The point A will be a short distance below the mud line, depending upon the resistant qualities of the material comprising the bottom. For a mixture of gravel, sand and clay, we shall assume a value of 2 feet.

The beam A.B. is resisting the trapezoid of pressure abdc and the problem is to find the relations at A and B and the bending moment in the sheeting. To this end we shall consider a beam loading in two parts:

1st, the uniform load, bdfa, and

2nd, the uniformly varying load 0 to fc, pictured by the triangle def.

Then we shall ascertain, independently, the end reactions, the movement and shears in the beam due to each load. Finally by combining the two, the critical stresses in the sheeting will be found. Special sketches give the diagrams for the uniform load abdf and for the variable load, def.

From mechanics of a beam of length l fixed at one end and supported at the other carrying a total load, w,l, (where w,= bd=af) varying uniformly from 0 at the supported end to 2w (twice the average load per ft.) at the fixed end we get the following:

\[ R_1 = \text{the reaction at the supported end} = \frac{1}{15} w l \]
\[ R_2 = \text{W (total Load)} - R_1 \]

\[ \text{Max. positive moment } M = 0.059 \frac{w l^2}{15} \]
\[ \text{" negative " } M = - \frac{2}{15} \frac{w l^2}{15} \]

* (from preceding pg.) For large important sea walls an investigation of the location of the point is necessary. See Mr. Hoag's paper in Proced. Municipal Eng. 1905.
Loading  Shear  Moment  Elastic Curve
From the mechanics of the same beam but only carrying a total load \( w_2 l \) (where \( w_2 = \frac{1}{2} f_c \)) and of a uniform intensity throughout the whole length of the beam we get:

\[
R_1 = \text{the reaction at the supported end} = \frac{3}{8} w_2 l
\]

\[
R_2 = \text{total Load} - R_1
\]

Max. positive moment \( M = +9 \frac{w_2 l^2}{128} \)

" negative " \( M = -\frac{w_2 l^2}{8} \)

Now combining the two loadings we get:

Reaction at the supported end:

\[
R_s = \frac{3}{8} w_2 l + \frac{1}{5} w_1 l
\]

\[
= \frac{3}{8} \times 359.5 \times 21.2 + \frac{1}{5} \times 899.5 \times 21.2 = 6668 \text{ lbs.}
\]

Reaction at the fixed end:

\[
R_f = \frac{5}{8} w_2 l + \frac{4}{5} w_1 l
\]

\[
= \frac{5}{8} \times 359.5 \times 21.2 + \frac{4}{5} \times 899.5 \times 21.2 = 20,010 \text{ lbs.}
\]

Max. negative Bending Moment:

\[
M_n = \frac{1}{8} \frac{w_2 l^2}{15} + \frac{2}{15} w_1 l^2
\]

\[
= \frac{1}{8} \times 359.5 \times \frac{21.2^2}{15} + \frac{2}{15} \times 899.5 \times \frac{21.2^2}{15} = -74,100 \text{ ft.lbs.}
\]

Max. positive Bending Moment:

\[
M_p = \frac{9}{128} w_2 l^2 + 0.06 w_1 l^2
\]

\[
= \frac{9}{128} \times 359.5 \times \frac{21.2^2}{15} + 0.06 \times 899.5 \times \frac{21.2^2}{15} = 13,793 \text{ ft.lbs.}
\]

* The last formula is not absolutely true, due to the fact that the point of Max. pos. B.M. is not coincident in the two cases. However, it is sufficiently accurate to be consistent with the other assumptions, and the error is on the side of safety.
The total pressure to be resisted by the bulkhead structure is the sum of the reaction at B as above plus the triangle b.c.d. (see sketch). Using a rectangular section for the sheet piling and an allowable unit stress of \( f = 100 \) lbs., we have:

\[
\frac{bh^2}{T} = \frac{6M}{6 \times 74100} = 4446 \text{ ins}^2
\]

A \((6 \times 12)\) sheet piling will give for \(bh^2\): \(12 \times 6^2 = 432 \text{ ins}^2\)

This is a little bit smaller than the required section. It will however be adopted as the average length of the sheet piling is much smaller than the one assumed in the design.

**Remark:**

According to the City specifications the sheet piling was to be driven 9' and 8' below the minimum dredge line, as specified on plans. This however was later changed when the trial piledriving has shown the impossibility to obtain good results by driving sheet piling in a ground full of boulders and old timber crib work. It was therefore decided to drive the sheet piling until it would hit some obstacle and bolt it to the back wale. A fill of riprap on the outer side of the sheet piling would provide it with the necessary stability.

**Concrete wall and slab**

The dimensions used in the mass concrete wall were adopted from similar structures built in New York City. Drawing #4 illustrates all the necessary details.

A 9 inch concrete slab will be placed on the platform to carry the load between the pile caps, the decking being considered as a permanent forming. As a reinforcement 5/8 inch rods will be used spaced at 7 inches c.to c. The design was made for a maximum loading of 5725 lbs. per foot.
CONSTRUCTION
GENERAL CONSIDERATIONS

Tides

In any kind of marine construction work such as the one under consideration the question of tides plays a predominant role. Indeed for any man endowed with sane common sense it is quite hard to conceive of the low water work (that is, work to be done at elevations below mean sea level) being done under several feet of water. Evidently that kind of work has to be performed at low tides and the whole work to be planned accordingly. It will therefore be necessary to start the construction considerations with a description of the tides at the place of construction.

Number of Tides

There are usually two high and two low tides in a day. However tides follow the moon more closely than they do the sun, and the lunar or tidal day is nearly an hour longer than the solar day. This causes the time of tide to advance from day to day, and a tide which has occurred near the end of one calendar day will be followed by a corresponding tide that may skip the next day and occur in the early morning of the third day. Thus on certain days of each month only a single high or a single low tide occurs. At some stations, during portions of each month, the tide becomes diurnal - that is, only one high and one low water will occur during the period of a lunar day.

Datum

The tides must evidently be reckoned from some well defined datum. The datum used in each case is the same as that used on the charts of that locality. Thus the datum for the Atlantic Coast
of the United States is mean low water. By mean low water we mean the average value of the minimum heights reached by each falling tide. In the Bronx where the Bronx Terminal Municipal Public Market is located the so-called Bronx datum is used, whose elevation reckoned from the mean low water standard is +4'71. This figure can be explained as an effort to fix the Bronx Datum at mean high water instead of mean low water as the tide range around Bronx is between 4'25 and 4'75. The mean high water for New York (Governor's Island) is fixed at +4'60.

Variations in Tides

The variations in tides can be divided into two general classes.

1) Those due to the average annual inequality or variations in mean sea level and,

2) Those due to physical conditions such as narrow channels, etc.

The variations in mean sea level are the result of meteorological conditions, and have the effect of making the heights of high and low waters higher than the average at certain times of the year and correspondingly lower at other times. At the ocean coast the variation in mean sea level due to this inequality is usually less than half a foot. At places situated on tidal rivers the average seasonal inequality in mean river level may be considerably more than a foot.

The variations in tides due to physical conditions are usually the result of the narrowness of river channels, landlocked harbors, tidal rivers and winds. The influence of those factors on the tides is oftentimes very baffling and no general rules can be laid
down as to their exact effect.

**Conditions in Harlem River.**

Harlem River on which the Bronx Municipal Terminal Market is located is essentially a tidal river, the direction of flow being determined mainly by the tides of the Atlantic Ocean. It joins the Hudson River with the East River, completing the water ring around the island of Manhattan. Those familiar with the map of New York City will probably remember its course, about six miles long; its average depth is around 20 feet.

A few observations of the direction of the flow will disclose the following facts:

1) At incoming low water the current is uptown.

2) At incoming of high water it is downtown.

These peculiarities are easily understood if one considers for a moment the huge volume of water that moves uptown and downtown in the Hudson River where Harlem River has its intake, and in the East River into which Harlem River opens. However the Hudson River rises and lowers its level more quickly than the East River due to greater depth and width, therefore causing a corresponding uptown and downtown current in the Harlem River. The comparative narrowness of the river channel causes the tides in the Harlem to rise and fall much more quickly, at the same time greatly increasing the heights of the two tides.

Of some interest is also the influence of winds, a northwestern wind having a lowering effect on the tide, while a southeastern wind causing it to rise considerably higher above the expected elevation. As a rule a favorable wind always meant
longer low tides and shorter high tides, thus in many cases facilitating the work of the contractor.

It is perhaps interesting to note that on February 20, 1927 while the construction operations were in full swing a sleet and snow storm accompanied by a strong south western wind caused the tide to rise to a record level of +4.10 above the Bronx Datum, an elevation not exceeded in 50 years, causing a great deal of damage in and around New York City. The damage done on the construction, however, has been slight, proper precautions being always taken to have everything tied securely to the temporary fender piles of the pile platform. This was the only occurrence of its kind during the construction, the tide generally behaving itself without any eccentricities.

Method of Procedure.

The heading of the specifications for the contract under consideration reads as follows:

"Specifications for the removal of present timber crib bulkheads, and the construction of foundations for the Bronx Municipal Terminal Market..."

If we were to analyze this contract we would probably divide it into the following items:

1) Dredging: including the removal of the old crib bulkheads and dredging.

2) Piling: including the driving of all piles required on the job.

3) Timber work: including low water work on the pile platform and the racks.
4) Sheet piling: including the driving of the required sheet piling.

5) Concreting: including form making, steel laying, form erecting, and pouring of concrete.

6) Back filling to the proper elevations.

Out of these items the hardest one to do and also the slowest is undoubtedly the timber work. Not only is the work of straightening out and pulling piles slow and disagreeable, but all of it together with sawing off piles, coping and finally decking the platform must and can be done only at low water. Estimating the approximate amount of time required for the completion of this particular item we can safely say that at least 30% of the total construction time has to be spent on timber work, leaving the remaining 70% for the rest of the items.

This figure may not be exact, yet it impresses the fact that no low tides should be wasted on work which can be just as well done at high water. Having that in mind the Contracting Company has procured from the Department of Commerce, U.S. Coast and Geodetic Survey tide and current tables for the Atlantic Coast. With the aid of those tables it was possible to predict with a reasonable degree of accuracy the time of the future tides. A Special Tide Calendar was made with a form shown on pg. As will be observed, the Calendar gives for each day of the month

* "Tide Tables, Atlantic Coast North America for the year 1926" "Current Tables, Atlantic Coast North America for the years 1926,1927". Both published by the U.S.Coast and Geodetic Survey, Washington,D.C. 1925.
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the start and finish of each low tide, the length of the working day (not computed) and the minimum height reached by the low water according to the Bronx Datum. This calendar proved to be very useful during the first months of construction work. Its usefulness however gradually decreased as one became acquainted with the peculiarities of the tides and was able to predict them without recurrence to any tables and calendars.

The general procedure followed on the construction was the same as the arrangement of the main items given on a previous page. That is: dredging, piling, timber work, sheet piling, concreting and back filling. However, in order to make full use of all the low water available, an overlapping of timber work and piling was made necessary. Piling was done in sections, so that as soon as one of them was completed, timber work was started on it at low water and driving continued at high water on the next section. The scheme worked very well.

CONSTRUCTION PROPER.

Layout of the Work

The first step in starting the construction operations was to establish the base lines and benchmarks necessary for the execution of the work. As specified in Art. 11 and 12 of the Specifications, a base line and a bench mark were provided by the Commissioner (that is, by the City Engineering Department) to be used as a reference.

Basing ourselves on that base line a series of base lines was laid out parallel to the future front line of the bulkhead wall. Starting with Stake #1 located at the northern end of the contract under the Macomb's Dam Bridge, and ending with Stake #43 on the
southern side of Slip #2 (see Drawing #1) these stakes gave a basis for a complete network of base lines from which all the necessary measurements and settings could be easily obtained. The following points were taken into consideration in setting these stakes for the base lines:

1) the base lines should be parallel to the front line of the bulkhead wall,

2) they should always be double, thus allowing the use of ranges in piledriving,

3) they should give the directions for all the outside and inside lines of the pile platform,

4) the front base line should be located at about 40 ft. from the back side of the pile platform, thus allowing the use of a tape in piledriving, when ranges could be put up only in one direction.

Besides that a special line of stakes spaced about 25 ft. in line with the future 6 inches sheet piling was added to these base lines. This indicated the limit to which the dredging operations should be carried out.

A series of benchmarks was also established at convenient locations all along the shore of the Harlem River within the limits of the contract. The leveling was done from the fixed bench mark provided by the City engineers, located on the west side footwalk of the main Market Building.

These base lines and benchmarks were frequently checked due to the fact that as soon as the dredging operations were completed a decided movement of the ground toward the river was observed. In checking only those stakes and benchmarks were used whose location
left no doubt as to their stability. Although in some cases the movement of the ground was as large as 5 or 7 inches, by making the necessary corrections a good and efficient service was obtained from all the stakes, with the final results checking as close as half an inch in a distance of 400 ft. or more.

**Dredging.**

In referring to dredging the Specifications state the following: "The Contractor shall... in a good, substantial and workman-like manner dredge the areas outlined on the plans, to the depth called for." It was not, however, the privilege of the author to be present during this operation as his connection with the Contracting Company began on June 27th and dredging operations were completed early in June. A rather brief description of this phase of construction will therefore be given here, the author having to rely on others for his information.

The dredging part of the contract was sublet by the contracting company to the Great Lakes Dredging Company, that started work on April 10th, 1926. As a preliminary work for dredging, stakes were put in all along the shore spaced at 25 feet, the line followed by the stakes being the same as the line of the future sheet piling driven behind the pile platform. (See Drawing #4.) Soundings and elevations over the area to be dredged were indicated on plans provided by the Department of Public Markets. However, as those plans were a little out of date new plans were made by the Company that agreed quite closely with the original plans.

The dredging done under the subcontract embraced the removal of structures, and materials of every description required to pro-
vide the slips indicated on the plans (see Drawing #1) and to permit the construction of the proposed bulkhead. This was accomplished by dredging the slips to the required depth of 14 feet at mean low water (or to an elevation of -18'71 according to the Bronx Datum) and deepening the bed of the river adjacent to the bulkhead line to a depth of 16 feet at mean low water (elevation -20'71 by the Bronx Datum). The banks of the slips and on the river front were also dredged to the stake line, care being taken to provide the required slope of five horizontal to one vertical (1:5). The latter requirement was found to be quite difficult to be exactly adhered to, on account of the mechanical peculiarities of the dredging buckets that did not give them the desired motion. It was however expected that the natural movement and disintegration of the banks during construction will make the dredged slope to conform more closely to the Specifications requirements.

Two dredges were used by the Great Lakes Dredging Company with a bucket capacity of 6½ yards and 3 yards respectively. The work was carried out very quickly and efficiently with an average daily haul of 4000 tons.

The dredging operations were completed on June 10th, 1926.

PILE DRIVING

General Conditions.

Piledriving operations were started on June 4th, 1926 and were carried out throughout the whole construction, the last fender pile being driven in June 1927. This included the driving of about 6500 foundation piles, and a few hundreds of fender and
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cluster piles, a total of about seven thousand piles. A complete list of all the piles driven on the construction is given on pg. 36a.

The piles were brought to the place of construction on special pile-barges, and as soon as measured and accepted loaded by means of a floating derrick on catamarans* drawn alongside of the pile barge. As much as 200 piles were placed on a single catamaran. When filled to capacity the catamarans were pulled alongside of the pile drivers and the piles hoisted from them into the leads of the pile drivers.

The piles used had to conform to the following specifications (Arts. 63 and 64).

1) All piles (excluding fender piles, described later) shall be of Yellow Pine, Norway pine or cypress.

2) They 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 will impair their strength or durability.

3) Piles must be butt cut above the ground swell and have a uniform taper from butt to tip. No piles with bell butts will be allowed. Short bends will not be allowed. A straight line drawn from the center of the butt to the center of the tip shall not lie outside the pile more than one one-thousandth the length of the pile. All limbs and knots shall be trimmed close to the body of the pile.

*Catamarans or "caddies" are special rafts made out of old white pine timber with strong posts at the corners and along the sides, used for the purpose of carrying piles with the pile drivers. Most of the piles being unseasoned and oftentimes soaked with water are liable to sink unless supported by catamarans.
4) Piles shall be of sufficient length to bring up in driving. All piles shall have a minimum diameter of 14 inches at two feet from the butt for all piles above 45 foot class and at least 12 inches for piles up to and including 45 foot class. All piles of whatever nature shall have a point of not less than 6 inches in diameter for piles up to and including 74 feet in length and of not less than 5 inches for longer piles. (Dimensions noted are exclusive of bark.)

Floating piledrivers in which the leads similar to those used on land are mounted on scows were used on the construction. Besides their special driving function, they were of great general usefulness. Equipped with a cable on which is placed a trolley, from the top of the ways to some convenient point, they were used for "telegphasing" or transferring piles and timber. A boom with its lower end fitted into a socket in a drop hammer converts the pile driver into a fairly efficient derrick boat. Besides all of them were equipped with air compressors for operating wood boring tools. For manoeuvring the scow and the rapid and efficient handling of piles, special engines were provided, differing from the ordinary machine for use on land, in that they are equipped with two or more pairs of extra winch heads. The later also proved indispensable in staylathing and pulling of the piles.

A total number of seven pile drivers was used on the construction, the greatest number working at one time being four. Out of those two were steam hammer piledrivers and the rest had drop hammers. While the drop hammer pile drivers were of the ordinary type, with scows measuring 23' x 46' feet on the outside (See pictures), the steam hammer pile drivers presented some interesting
Steam Hammer Piledriver
and unusual features. Belonging to the contracting company they were built in Boston by bracing two ordinary scows with 12" x 12" inch timber and 1-1/2 inch bolts. On those scows were now placed a small power house with the necessary equipment and a steel boom held in place by a bull's wheel framed into a strong wooden A bracing. (See pictures) The steel hammer ways or guides were hung on a pivot at the top of the boom, with movable bracing sills at the bottom. This arrangement gave unusual mobility to the leads of the piledrivers that not only could be easily inclined at any desired angle with the vertical, but could be also turned about 60 degrees either way from their ordinary position. The outside dimensions of these drivers were 38 x 75 feet.

The crews used on each pile driver numbered from 9 to 11 men depending upon the kind of driver, the number of men being determined by the dockbuilder's union. Their respective occupations were as follows:

Steam piledriver

1 foreman
1 fireman
1 engineer
8 men of which:
2 were on the catamaran
2 were on the leads
2 on the winch heads
2 helping the others

* The crew of 11 men always seemed to the author to be too great and his estimation could have been easily reduced by one or two men on each machine.
In driving, the pile is first hooked on the catamaran and hoisted up into the leads of the piledriver. The next step is to place it correctly in the leads, this being of special importance in steam pile drivers where the head of the pile should enter into the base of the hammer. This usually requires the turning of the pile in the leads and calls for quite a bit of skill on the part of the workmen using ropes and small p.v.'s. Finally the head of the pile being in the right place the hammer is lowered and allowed to settle down with the pile. The pile is then driven into the required elevation.

Piles were located by means of lines of ranges placed on the shore parallel to the base lines. Now it was only necessary to sight through the leads of the piledriver first in one direction than in the other and move the piledriver accordingly. It was however found desirable to offset most of the ranges on the shore by 11 inches to the left, and to do the sighting using the outside or the right inside face of the leads, which permitted a check of the location of the pile when it was placed in the leads. In cases where only one set of ranges could be provided on the shore, a cloth tape was used from the nearest range line.

The order of driving did not present any intricate problems. As already mentioned before, the driving was performed in sections, each machine working on a separate section. The rows of piles were driven in their natural order, always leaving out two or three piles at both ends in order to facilitate future driving. Some difficulties were experienced in the inside corners where considerable turning of the machine and stepping out of pile rows was made necessary before those sections were completed. On account of the rela-
tively small space available between the rows and the nearness of the banks only steam pile drivers with turning leads were used for that work.

The number of piles driven per day varied with every machine and every crew, showing however a marked increase as the time went on. Starting with an average of about 20 piles per day per machine, it steadily increased to about 30 piles a day. The maximum number of piles driven per day (8 working hours) was 45 piles for a steam hammer and 38 piles for a drop hammer. The seeming advantage of the steam hammer is nevertheless somewhat offset by increased cost of equipment and rather frequent breakdowns of the different parts of the hammer.

The piles driven on the construction included vertical foundation or bearing piles, brace or batter piles, and fender piles. The brace piles with an inclination of 6 inches horizontal to one foot vertical were all driven by the steam hammer pile drivers. No ranges were put up for the location of brace piles as they were driven after the vertical piles were already in. As a matter of precaution they were placed half way between the vertical piles and sufficiently far ahead from the row to which they had to belong, in order not to destroy their function.

The fender piles driven all along the bulkhead wall and the racks had to conform to the following specifications (Art. 74):

"Fender piles shall be of sound and straight mixed oak, not less than 14 inches in diameter two feet from the butt, and not less than 5 inches in diameter at the point. Except where otherwise noted on plans fender piles shall be 60 foot class piles."

These rigid requirements were later reduced to 12 inches in diameter,
two feet from the butt, the length being also reduced to 50 foot
class piles. A drop hammer pile driver was used in driving fender
piles as it obviously fits that work better than a steam hammer
pile driver.

Observations and Plots.

The author, being in charge of the piles, was fortunate to
observe and to collect a number of interesting data on actual pile-
driving. With the aid of those he was able to draw penetration curves
of a great many piles. The present paragraph represents a brief
summation of his results and observations.

The vertical foundation piles driven on the construction can
be divided into two main classes, namely those driven in a ground
relatively free from any obstacles, such as boulders, etc., and
those driven in the ground with obstacles. Two main kinds of ob-
stacles were observed:

1) the old crib wall that until very recently performed the
function of a river front wall, and whose outline follows quite
closely the outline of the present bulkhead wall being built for
the Bronx Municipal Terminal Market, (See drawing #1)

2) big boulders that came from the subway excavation nearby
at the time when the river banks were being filled in.

The ground itself as shown by the few borings and by actual driving,
proved to be a satisfactory soil, for what one calls "good driving."
The ground was mostly fill underlined with mud and clay with rock
beneath them. No piles were driven to bed rock on account of its
deepth, the necessary resistance being provided by the mud and clay
layers.

Example 5 shows a typical penetration curve for a pile driven
Example 1
Batter Pile
Length - 25'0"
Location - South Side Slip 1
Piledriver - 1 (Steam Hammer)
Example 2
Batter Pile
Length - 30'-0"
Location: South Side Slip +
Piledriver * (Steam Hammer)
Example 3
Batter Pile
Length - 28' 0"
Location - South Side Slip 1
Didedriver 1 (Steam Hammer)
Example

Battered pile
Length: 30'-0"
Location: South side of slip +1
Piledriver: +1 (Steam Hammer)
Example 5
Test Pile
Length - 74.0'
Location - near bridge
Drop Hammer
in "free" ground. As we observe it is resembling a parabola with its vertex at the point where further driving would produce no more penetration. The curve starts with a slope that is almost vertical and gradually changes to a horizontal one. In our case with the bed rock at too great a depth a horizontal slope was not striven after, the Specifications stating (Art.67) that "piles shall be driven until the last 10 blows will not drive them more than 1 foot, except under special conditions of bottom where the driving is different from the general run."

Coming to the driving in the ground with obstacles, it will be necessary to look over a few plots carefully selected by the author as representative of a great many others. The first three of these plots, Examples 1, 2 and 3 are typical penetration curves of piles driven in the old crib work, while Example 4 is a case of meeting a big boulder. Each of these curves tells the story of the driving and shows the striking deformations of its ordinary shape (Example 5) by obstacles.

Example 3 illustrates a typical case of driving in a crib, and a late encounter of a serious obstacle. From the very beginning the curve is very irregular, the pile penetrating with a startling irregularity (Notice the large penetration after the second blow). Then the penetration becomes more regular until the 8th blow when comes on some firm obstacle in the crib work, presumably a piece of timber which causes a decided retardation in its penetration for five successive blows. A little easing up comes after that, which however does not warrant the continuation of driving. The total penetration is around 12 feet.

Example 2 gives a striking illustration of an early encounter
of a serious obstacle. Already after the third blow the pile seems to be set firmly on something through which it cannot possibly penetrate. Repeated driving evidently does not materially improve the situation, causing its discontinuance at the 20th blow with a total penetration of only 5½ feet. In many similar cases the penetration was hardly sufficient to hold the pile in the ground necessitating their redriving a few feet from their true location.

Example 1 shows a case of driving in crib with a repeated encounter of different obstacles. The curve is very irregular with two main turning points. It is also interesting to note the considerable easing up in driving once the obstacle is passed.

Example 4 which is essentially the same as example 2 is a case when a big boulder is the obstacle. The interesting point about it is the fact that for 12 consecutive blows no visible penetration of the pile could be observed. Slight penetrations were observed after the 16th blow, the total penetration for 32 blows being only 4 feet.

The conclusions to which the author came after watching the driving of several thousands of piles are given below:

1) It is impossible to foretell the required length of the piles driven in a ground with obstacles. This is due to the wide variations in penetrations of piles spaced oftentimes only a few feet apart. Hence piles with a length greater than the average length required for that particular section had to be used throughout that section with the result that about 30% of them were left sticking out of the ground by 10 or 20 feet.
2) If a drop hammer is used in driving a better and greater penetration is secured but the pile is invariably out of alignment. This is due to the greater impact that can be recorded with a drop hammer by increasing the fall of the hammer.

3) In case if a steam hammer is used the penetrations are as a rule smaller and the time consumed in driving much greater. On the other hand the pile is usually in a fairly good alignment, as the leads give it less freedom in choosing its own way through the obstacles.

4) As a rule no exact alignment of piles is possible in driving through crib work or coarse fill.

5) When the obstacle against which the pile is brought up is lumber (such as crib work timber) a very characteristic up and down movement of the pile may be observed, following each blow of the hammer. This peculiar rebound is helpful in determining the nature of the obstacle.

6) When this obstacle is a big boulder no such rebound is observed, the downward penetration being merely minimized until the obstacle is passed.

LOW WATER WORK

Methods Used.

The term low water work as used in this thesis means work that has to be done at low tides on account of the water interfering with it at high tides. This work includes the straightening, staylathing, and cutting to grade of piles, as well as caping those piles and decking the pile platform.

The low water work was started at the inner corner of the 55-
foot section, which happened to be the first section where the driving was completed on the job. From there the work proceeded towards the Slip #1. As soon as other sections were completed low water work was started there too, until finally every machine had a place of its own where to fall back on low water work during the low tides. This arrangement was found to be advantageous and more efficient than the mixing together of the different gangs of workmen, which invariably led to quarrels between them.

While the methods used by different gangs (at the discretion of its foreman) had much in common and the final result was always the same, three general methods of attack could be distinguished:

1) Stay-lathing and straightening method.

In this method the first two (or three, if that happened to be the case) rows of vertical foundation piles that had brace piles driven between them were pulled to the required distance apart and stay-lathed to a three inch board that ran over four or five piles. This being done straighteners were introduced on each side of the remaining vertical piles in each successive row, and the piles straightened or pulled into their proper positions. Next the batter piles were pulled in place, cut to grade and capped. Finally the vertical piles were cut off and also capped. (For arrangement of caps on piles see Drawing 4.)

2) Complete straightening method.

Straighteners are introduced between the rows from the very beginning inclosing all the piles in a row and leaving the batter piles in between. The piles are now pulled into their proper positions between the straighteners by pulling straighteners and cross-
tying them with wire or chains, until all the piles are in a practically straight line and can be capped without any further pulling. Then the batter piles are pulled and capped, the vertical piles' caps being placed next.

3) Incomplete Straightening.

This method, though applicable to any cases, is of special advantage when the piledriving was done well and the piles are practically in place before the straightening is started. A few straighteners are introduced between the rows mainly in order to facilitate walking between the piles and to mark the consecutive rows. The batter piles are then pulled and capped. The vertical foundation piles are also cut to grade and the caps placed on them and bolted to those piles that happen to be in line and under it. The remaining piles are then pulled under the cap and bolted to it.

Considering these three methods of attack from the standpoint of efficiency and good workmanship the first one, although somewhat slow, is perhaps the best one of the three, especially if done in the proper order. It insures good accuracy in the results and allows an early start in work (as soon as the first two rows are driven). In fact, it is by far the commonest and best method used in New York. The second one is rather slow and unless the piles are already well in place and easy to pull it often becomes cumbersome and unsatisfactory. The third method is the quickest of the three and should be used if the time at one's disposal is limited and the specifications not too rigid. It does not give very accurate results, as doubtless one cannot expect piles pulled under the cap to give a perfect fit. It therefore offers a somewhat
Low water work
inferior workmanship in return for greater speed and amount of work accomplished.

The main features of low water work are straightening, pulling, sawing off and capping. The tools and machinery used in that operation are quite crude and consist mainly of axes, adzes, mallets, levels, ropes and steel cables or "lines" from the piledrivers, pv's chains, hooks and wire. Of those the most important are the lines from the driving machines, as they provide the necessary power for pulling and straightening. A clever use of those will govern the speed and efficiency of the work, and the ability of a foreman to do good work will be measured by his ability to handle those lines. Once pulled in place piles are tied to some other piles near by by means of wire, care being taken to tie them below the cutting grade. In case of batter piles a 12 x 12 inches timber was often used at the back of the first row of vertical piles, and the piles tied to it. The timber was moved along as the work progressed.

In conclusion one may say that low water work of the character described above will always depend on the way the piles are driven. The nearer they are to their true positions the less trouble it will present. One should therefore pay considerable attention to the way the preliminary driving is done, as it certainly pays to have less piles driven per day and better placed, than to strive after quantity and afterwards lose twice that time on low water work. The idea of making each piledriver work in the section where he is driving is also to be commended, as it naturally makes the workmen more careful in driving, to reduce the troublesome and often unpleasant labor of low water.
The low water work on the pile platform was completed by placing the 4 x 12 and 2 x 12 inches decoking and front and back wales, the line being given from one of the base line stakes on the shore.

Winter vs. Summer Work

The low water work was started on July 29th, 1926 and continued till March 1927. A great deal of it in fact the most important part was done during the winter of 1927. The summer work did not present any difficulties except perhaps for the fact that sun rays, by their decomposing action, caused a very strong generation of ill smelling gases, with a big percent of H₂S. These gases were generated by a mud layer formed on the bottom and banks of the Harlem River, by sediments whose content was supplied by two sewers opening at close proximity to the place of construction. Moreover that sediment settling with surprising rapidity on the pile platform already completed, presented a very slippery, treacherous surface, making walking difficult.

The conditions in winter were much more trying on account of the low t°. The cold caused the platform and piles to be covered with a layer of ice thus greatly hampering the speed of construction. Two or three times during the winter the pipe lines carrying water to the piledrivers were frozen in spite of the efforts to keep the main pipe in manure to prevent them from freezing.

On the whole the winter of 1926-27 has been a very mild one, the t° staying most of the time around 30° F. Only one working day was lost on account of extreme cold weather, the t° going down to -2° F.
METHOD PROPOSED.

As designed in the first part of this thesis a continuous row of sheet piling of 6 x 12 inch tongued and yellow pine shall be driven along the rear face of the deck platform. The tops of the sheet piles had to be protected against the blows of the hammer in driving and their lower ends cut diagonally so as to drive toward each other. The sheet piling was to be driven to fit closely, with tongues setting throughly in the grooves. It also had to be of sufficient length to give a minimum of 9 feet penetration below the minimum dredge line specified on the plans and where the bottom was below this line it had to be driven 8 feet into the actually existing bottom. When driven in place its top had to come flush with the wale piece and each piece had to be fastened to the deck with two 1/2 x 10 inch dock spikes. (See Drawing 4.)

The specification also required (Art. 83) that: "Any sheet piling driven out of proper position shall be pulled out and re-driven and any that may be damaged in driving shall be replaced with others."

In accordance with this requirement a trial section of sheet piling was driven in and the result shown to the City's engineers. As it might have been expected the driving of sheet piling in the old crib work proved to be a hopeless proposition. The successive sheet piles were driven out of their proper position and inclined at all possible angles to each other and to the vertical. A new method therefore had to be adopted.
Method Used.

It was proposed by the Contracting Company and accepted by the Department of Public Markets that the sheet piling will be set by hand at its proper place and allowed to be gently driven in until it would come upon some obstruction, no attempts being made to drive it any further for fear of getting it out of place. To make up for the insufficient penetration (in many cases only a few feet) 5 feet of a rip rap fill was provided on the outside of the sheet piling, thus giving it the necessary stability. The rip rap had to be quite a good sized stone to prevent possible erosion due to the waves of the many tugs and pleasure boats going up and down the Harlem River.

The scheme worked out quite well, the sheet piling offering an almost perfect fit and being set in with great care and speed. The rip rap coming on scows was unloaded by one of the ex pile-drivers with the leads and hammer removed and a bucket suspended at the end of the boom.

CONCRETE WORK

Forms used.

The last important step in the construction of the bulkhead wall was the concrete work. This consisted of a wall of mass concrete and a reinforced concrete deck of the shape and dimensions shown on Drawing 4. The work was started by constructing the forms for the wall. The wall as required by the specifications was constructed in separate sections of an average length of about 30 feet. The forms were accordingly made of an average length of 10 feet, except at the corners, with the waterfront partitions centered over the pile rows. They consisted of a front
and back form with crossbracings spaced about 9 ft. As all the front forms had the bolt holes already bored in them, special care was exercised in getting the proper forms in the proper place. Vertical construction joints of tongue and groove Section were formed in the wall at intervals of 30 feet.

Pouring of Concrete.

As indicated on Drawing #4 a 1:2:4 mixture was used on the construction as required by the Specifications (Art.92). All proportioning was done by volume. A machine mixer of the Batch type was used for all concrete.

No water was allowed in the forms when the concrete was deposited therein, the work of depositing being kept well ahead of the tide so that there was no danger of entrance of water into the forms until the concrete was sufficiently hardened. Once the concrete work was started, the pouring was carried continuously until an entire section was completed. To insure greater rapidity of work small Ford trucks with 1 yard buckets were used, one carrying the ingredients to the mixer and the other taking care of the ready concrete. Special portable runaways were provided for the trucks all over the pile platform, that could be easily shifted from one section of the wall to another. The wall was poured in alternate sections to insure good expansion joints.

Special care was taken in setting the anchor bolts to place them at a right angle to the forms. In order to allow for the future timber or piles that they will have to hold, the bolts were set out of the wall by 8 inches for the chocks and 9 inches for the fender piles and guard logs. Special templets were used in setting bolts for cleats, bitts and mooring ports.
Filling operations
The concrete work was started on May 7th, 1927 and completed early in July.

**Filling.**

The filling called for on the plans (see Drawing 4) consisted of a rip rap fill on the inside of the sheet piling to an elevation of -1.21, and a fill on the platform to an Elevation of +5'00. As this operation did not call for any engineering knowledge its description will be omitted.

The filling operations completed the construction of the bulkhead wall for the Bronx Municipal Terminal Market.

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APPENDICES
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SPECIFICATIONS

Warrington-Vulcan Steam Pile Hammer #2, Standard Base, used on the construction

Distance between Jaws 19 inch.

Width of Jaws 7\(\frac{1}{2}\) inch

Length of Hammer 11\(\frac{1}{2}\) ft.

Net weight 6300 lbs.

Weight of Ram (striking parts) 3000 lbs.

Bore of Cylinder 10\(\frac{1}{2}\) inch

Normal Stroke of Ram 3 ft.

Actual Stroke of Ram (as used) 70

Strokes per minute (minimum) 9000

Ft. lbs. of Energy per Blow

Size of Hose 1\(\frac{1}{2}\)

Number of Plies in Hose 6

Standard Length of Hose 35

Boiler H.P. Required 25

Heating Surface in Boiler 300 sq. ft.

Grate Surface in Boiler 10 sq. ft.

Largest Diam. of Round Wood Piling 14 inch

" " " Concrete " 14 "

" Section of Sheet Piling 14 "