THESIS

A STUDY OF THE METHODS OF CONSTRUCTING FOUNDATIONS FOR HIGH OFFICE BUILDINGS IN BOSTON, MASSACHUSETTS

BY

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COURSE I-3

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Cambridge, Massachusetts,

May 19, 1930.

Professor A. L. Merrill,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

Herewith is submitted a thesis entitled "A Study of the Methods of Constructing Foundations for High Office Buildings in Boston, Massachusetts," fulfilling in part the requirements for a degree of Bachelor of Science from the Massachusetts Institute of Technology.

Respectfully submitted,

Signature redacted

Joseph D. Guertin.

ACKNOWLEDGMENT

The author wishes to take this opportunity to acknowledge his indebtedness to Rodney Hand of The Gow Company, Steven Burke and George Tuttle of Coleman Brothers, Harry Bastow of Thompson Starrett Company and Professor Charles M. Spofford of the Civil Engineering Department of Massachusetts Institute of Technology, under whose supervision this thesis has been prepared and whose suggestions have been very helpful.

SUMMARY

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PURPOSE.

This thesis has for its purpose the study of the methods of constructing foundations under high buildings in Boston, Massachusetts which are at present under construction.

SCOPE.

The study was confined to the Tower Building, 75 Federal Street, and to the Edison Central Heating Plant, corner of Kneeland and South Streets. At the Tower Building job open Gow caissons were used, with the exception of the underpining of the adjoining building where shafts were excavated and wood sheeting used. At the Edison job pre-cast caissons were used mainly, with the exception of a few small open Gow caissons.

METHOD OF STUDY.

A detailed study of each job will be presented, first of the Federal Street job and then of the Kneeland Street job.

THE STUDY

Sub-Surface Investigations of 75 Federal Street.

Current engineering practice recognizes the necessity of obtaining accurate advance information respecting the strata and characteristics of the soil underlying the site of all contemplated structures.

Untold millions of dollars have been lost or wasted in the past because of ignorance of the probable behavior of various sub-soils which have been relied upon to support heavy loadings. Expensive and elaborate structures have been destroyed or seriously damaged so as to necessitate extensive repairs merely because competent and intelligent inquiry has not been made as to the value of the supporting medium.

There are a number of methods of determining to a more or less accurate degree the soil stratification at any given location. The oldest and best method, of course, is by the actual excavation in test pits into the earth, which was used as the main source of information on this job. By this method the stratification is exposed for examination and the conditions to be met in actual building operations are seen in their true relations. The firmness of the material, its water content, its tendency to run or cave and the extent to which sheeting and bracing of banks will be necessary become evident as the excavation in the pit progresses.

This test pit was made the same as an ordinary Gow caisson pile. The pit was 64 feet deep and an accurate determination of the soil was made. A diagramatic sketch of the pit and the listing of the materials are shown in Figure 1. In addition to the pit seven borings were made at various points on the lot. The results of these checked up with the pit fairly well. However, they also indicated that the hard pan, which on this job was a mixture of hard gray sand, blue clay and stone, and the bed rock had a pitch of nearly 1 in 10. The direction of the pitch was southeast, that is the hard pan was deepest near the corner of Devonshire and Franklin Streets and it rose diagonally across the lot, the highest point being at Federal Street. It is interesting to note here that following in this southeast direction the hard pan continues to rise and that at the site of the present United Shoe and Machinery Building, which is southeast from this job, the hard pan and bed rock are only about 15 to 20 feet below the street. As a result, in the foundation of the United Shoe and Machinery Building spread footing was used and the cost of the foundation was greatly reduced in proportion to that of the Tower Building. The explanation of this is that the general vicinity of the United Shoe and Machinery Building is where Corn Hill used to be.

Figure No. 1

TEST PIT.

Elevation.	Kind of soil.
0'-0"	Old basement grade = -15'-0"
-5'-7"	Fill.
-8'-0"	Hard blue-yellow clay.
-9'-0"	Hard blue clay.
-11'-6"	Medium blue clay.
-13'-7½"	Yellow and gray sand.
-15'-9"	Soft blue clay.
-17'-6"	Fine gray sand.
-22'-10½"	Soft blue clay.
-24'-6"	Muddy gray sand (fine).
-27'-5"	Gray sand.
-48'-6"	Medium soft blue clay.
-49'-3"	Medium blue clay. Veins of fine gray sand.
-51'-8"	Muddy gray sand.
-52'-9"	Medium blue clay.
-53'-2"	Gray sand (laminated).
-54'-2"	Medium blue clay (laminated).
-55'-6"	Medium clay.
-56'-9"	Gray sand (fine).
-59'-6"	Medium blue clay (laminated).
-60'-6"	Quicksand (traces of clay).
-63'-6"	Soft mixture of gray sand, blue clay, and small stone.
-64'-0"	Blue clay, sand, and stone.

Underpinning and Shoring.

The character of the sub-soil of the lot having been determined and the buildings removed, the next step in the work is the underpinning of the adjoining building, which is necessary in all building construction to avoid any settlement of them due to the new operations.

Since additional supports were required during the underpinning, shores were used. These were long wooden 12"x12" posts placed in an inclined position against the wall of the building in suitable niches in the masonry and were ádequately supported at the bottom by a wooden crib. The head of these shores were placed opposite the second floor line and they made an angle of approximately 70 degrees with the horizontal. The steeper these shores are, the more stress they can take. However, it should be remembered that they relieve the foundation of only that part of the load above their heads. Therefore, when the main underpinning was started sections not over ten feet, and generally five to seven feet, were excavated. In a length of 200 feet, not over three of these sections would be in operation.

The adjoining building was supported by granite blocks, about six-foot square. Beneath these granite blocks fifteen pits were dug and spaced advantageously along the wall. These pits varied in size but were approximately six-foot square, and went down to the hard pan which was about 40 to 45 feet below the granite blocks, and the blocks in turn were about 8 feet below the street. It is along this section that the hard pan has its highest grade, which was fortunate since these pits were dug by hand. As the excavation progressed the pit was sheeted with three-inch planking and this in turn was reinforced with rangers and cross bracing. The clay was taken out of the pit by means of a bucket and then removed in wheelbarrows. When the excavation was completed, the pit was filled with concrete, leaving all sheeting and bracing in, to within four feet of the granite blocks. After it had set a day the remaining four feet was bricked up.

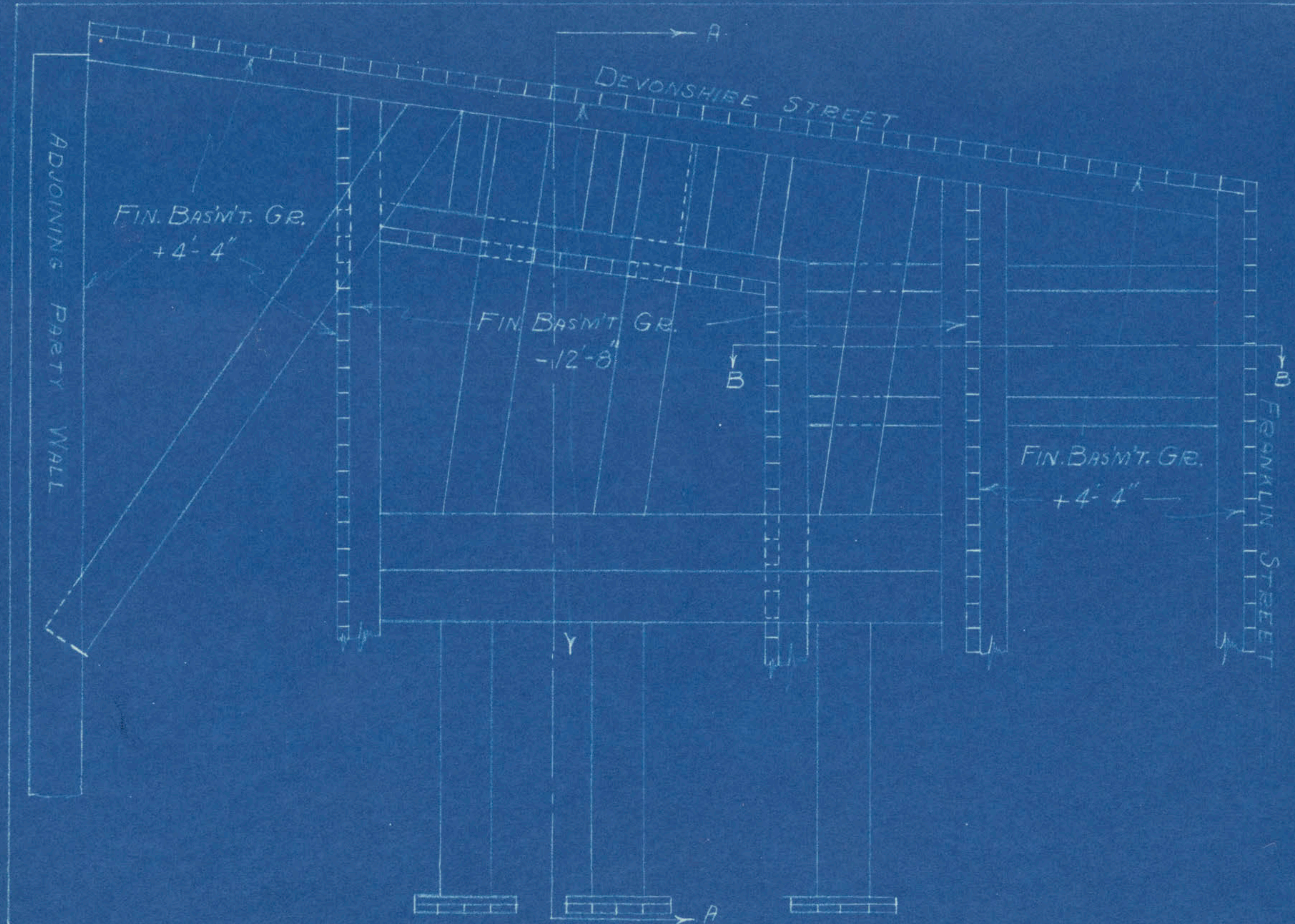
Since the basement of the new building was lower than that of the adjoining building, lintel walls, two-foot thick, were constructed between the underpinning pits. The same care was exercised in opening up the sections for the lintel walls as for the pits. When the wall between the pits was in excess of ten feet, the concrete was poured in sections to prevent cracking or dislodging of the granite blocks. In some instances the blocks were braced whenever there was any question of their being disturbed.

Up to this period of construction the general excavation of the lot had not begun, as this is one feature of the Gow Caisson Piles, and since there was only the street to hold in place, no shoring was done on the other three sides of the job, which were already supported by the old building walls. However, a small amount of support was used to keep the sidewalk in place. This general underpinning and shoring was sufficient until approximately 90 per cent. of the caisson work was completed. It was here that a great many difficulties were encountered.

Along Devonshire Street the general basement level was -13'-4", which is approximately 35 feet below Devonshire Street. The excavation was started and it was agreed that the slope of the bank next to the street would be stable if left as a 1:1 slope. On this basis the work was carried on until a grade of +4'-0" was reached. The following night it rained heavily and, as a result, the greater part of this bank slid down. The sidewalk pulled six inches away from the street and, due to the movement of the soil under the street, the gas pipes under the street were broken. It might be noted here that had the men in charge of this work reminisced back a few years they would have profited by the accident, similar to this one, which occurred on the First National Bank location, only a block away, when Devonshire Street caved in on the job.

The following morning all possible precautions were taken to prevent further sliding. The concrete mixing plant and piles of sand, gravel and cement, which were setting on the street directly over where the movement occurred, were removed. Sheeting was driven down and the excavating in this section was stopped until all the sheeting had been driven. First, a row of wooden sheeting was driven about two feet beyond the property line, so as to leave room for the whalers and rangers supporting the sheeting and not interfere with the outside face of the forms for the basement wall. Since this deep section extended only about half the length on Devonshire Street, sheeting was driven on the north and south boundary lines of this deep section. See plate No. 2 and No. 3. With this sheeting driven, a secondary row about ten feet into the lot was driven, which extended from the south row of sheeting along Devonshire Street and then parallel to the north row of sheeting. The second row was driven to act as a support to the first as the excavation progressed. The ten-foot section between the sheeting was excavated by hand. Buckets were lowered and raised between the braces by means of a derrick which was set on Devonshire Street. As the excavation progressed, braces were added. Due to the great pressure behind the sheeting, these braces were placed wherever there was room. When this ten-foot section, or trench, was first brought down to grade it appeared that where the clay was removed nearly an equal volume of wood braces had been substituted.

There are several facts which lead to this system of bracing, if it can be termed a system. The main thoughts in the minds of the men were to keep Devonshire Street intact; second, to get the concrete wall along the street in place as soon as possible; and third, these men were being pressed by the general contractor to get the work done as quickly as possible. It can be said that they held the street, but that is all. As soon as the excavation had been completed, work on the wall forms was commenced. This was a slow operation



A
DEVONSHIRE STREET
ADJOINING PARTY WALL
FIN. BAS'M'T. GR.
+4'-4"
FIN. BAS'M'T. GR.
-12'-8"
B
B
FRANKLIN STREET
FIN. BAS'M'T. GR.
+4'-4"
Y
A

Plate No. 2

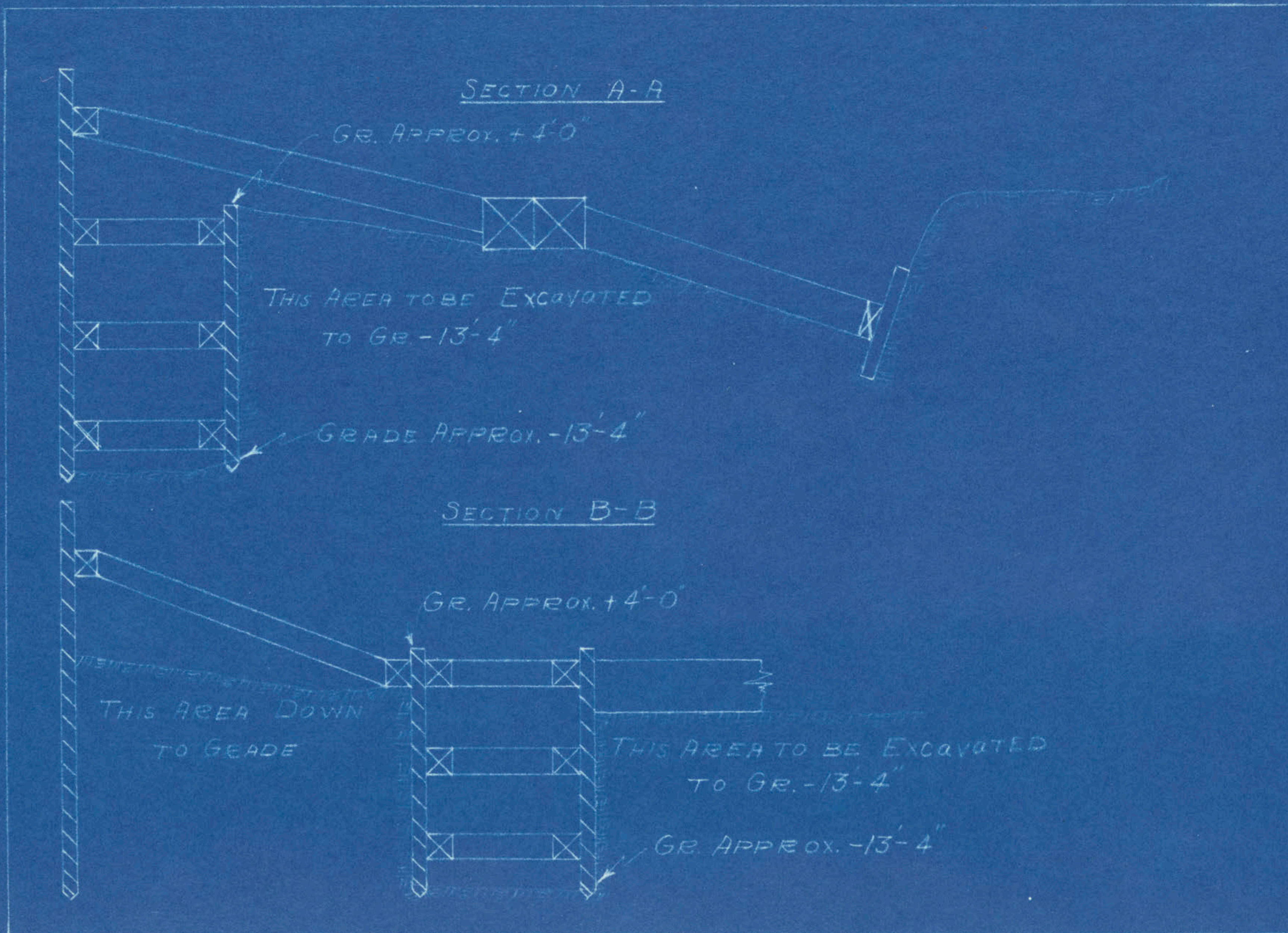

SECTION A-A
GR. APPROX. +4'-0"
THIS AREA TO BE EXCAVATED
TO GR. -13'-4"
GRADE APPROX. -13'-4"
SECTION B-B
GR. APPROX. +4'-0"
THIS AREA DOWN
TO GRADE
THIS AREA TO BE EXCAVATED
TO GR. -13'-4"
GR. APPROX. -13'-4"

Plate No. 5

as a great deal of cutting was necessary due to the braces. The forms were finally completed and the iron workers had started to set the reinforcing steel when trouble was encountered. Most of the vertical steel could be set, but it was impossible to place the horizontal steel because of the braces. This meant tearing down the forms and resetting the braces, and this is precisely what was done. An authority on shoring was called in and he simplified the matter by bracing mainly as I have previously explained and have illustrated in plates No. 2 and No. 3.

Digressing momentarily from the purely technical view of this study, it might truly be said that it was the lack of management and foresight which caused much of the delay and trouble. Had the men in charge given a little more thought much time would have been saved. It might also be said that there was no coordination among the contractors. They neither trusted nor helped one another. I firmly believe that these were the most serious and retarding obstacles with which they had to contend.

As was indicated, the concrete walls had to be built with the braces in place. After the forms were pierced by the braces they were boxed around leaving about one-half inch between the brace and the box, which, needless to say, was insufficient clearance, for when the brace was to be removed it was concreted into the wall and had to be sawed off. In order to remove the section of the brace in the wall, it was necessary to burn it out with a kerosene pressure pump torch, such as is used to heat concrete in a mixer, for jack hammers were ineffective on old hickory beams which had been used for the braces.

I believe that the abuse the wall took in removing these stubs caused it to be weaker after the job was completed than it would have been had the stubs been left in the wall, for, due to the jack hammer, much of the reinforcing steel in the concrete was bared because it became necessary to remove concrete from the stub. The wall was also subjected to a terrific heat from the torches, and it might be of interest to know that the wood sheeting behind the wall caught fire several times and as it was partially backfilled the blaze was not easily extinguished.

Gow Caisson Piles.

While the underpinning and shoring were in progress the work in the caisson was going on simultaneously.

The Gow System of Caisson foundations was designed to meet the need for an efficient, expeditious and economical method of carrying the supporting columns of buildings and other structures through underlying strata of unsuitable soil to form bearing material capable of safely sustaining the superimposed load. Wherever underground conditions permit the adoption of this method of foundation construction, there will usually result a marked saving of time and inconvenience as well as a substantial reduction in cost of installation over any of the alternatives available. This was so at the 75 Federal Street job, for the foundations of this building were originally designed for steel shell concrete piles with a steel grillage cap. The Gow Company bid a lower figure to do the job with their method and consequently were awarded the contract.

With this system, a single cylindrical concrete shaft of sufficient cross sectional area to carry the concentrated load of the building column is sunk through any unsuitable upper layers of soil to a satisfactory bearing material, upon which the load is distributed by an enlargement of the section in the form of a conical frustrum, so as not to exceed the safe unit supporting capacity of the particular soil selected for the purpose.

This type of construction is capable of supplanting the use of large clusters of piles with their necessary capping of concrete, or the sinking of sheeted open pits to considerable depths and the consequent building therein of a formed concrete pier resting upon a spread footing of a plain or reinforced concrete.

The particular feature of the Gow System which has mostly appealed to engineers and architects is its extreme simplicity. Any number of footings may be worked upon simultaneously according to the progress that may be desired. Pier locations inaccessible to pile drivers or derricks offer no obstacles to the use of this method.

Only a minimum volume of excavation is removed equal in form and amount to the required displacement of the concrete shaft and base to be installed therein, so that the walls of the excavation serve as forms for the concrete when it is poured.

Ready access may be had at all stages of the work for the purpose of inspecting the various strata of soil encountered or for checking the dimensions of the work. Similarly the bearing soil may be examined for approval just as in the case of any open pit. The concrete is visible during all the stages of depositing the same and there need be no uncertainty as to its character or sufficiency.

The method used in constructing Gow Caissons consists essentially in sinking a series of short steel cylinders varying slightly in their several diameters so as to telescope through one another, the largest size being used as a starter and the others in turn inserted successively through those already in place. In this manner a circular form of opening of the desired cross section area is maintained and ample protection is afforded at all times to the workmen employed in the process of excavating and subsequently in the placing of the concrete.

When the cylindrical excavation has reached the desired depth and has encountered the bearing soil selected as the supporting medium, the bottom of the opening is enlarged in the form of a truncated cone, having a base of sufficient cross section area upon which to impose the entire load carried by the particular column without danger of overloading the underlying soil.

When the bottom excavation has been completed to its proper dimensions and the bearing soil has been inspected and approved, concrete of suitable materials and proportions is deposited in the opening thus prepared so as to entirely fill the same, the several steel cylinders being successively withdrawn as the concrete work progresses. The final result is a cylindrical concrete column resting upon a suitable spread base all of sufficient dimensions to carry safely the superimposed loading and to transfer the same to a satisfactory stratum of sub-soil.

The steel cylinders employed in this process serve not only to retain the soil in place during the period of excavation, but also act as cofferdams to exclude the ground water from the openings until the entire operation has been completed. When inflowing water is encountered in the underlying bearing stratum itself, it is handled by a special method which has been devised for this purpose and which prevents it from rising into the openings while the depositing of the fresh concrete is under way.

Due to the meagre amount of head room required for the installation of these footings it is entirely practicable to work in very restricted places, such as basements of existing buildings or under walls and footings of structures requiring either strengthening or underpinning. It is only necessary to make a comparatively small opening under such a wall or footing of sufficient depth and area merely to admit the placing of a single cylinder. In the case of a continuous wall footing this will not usually be of sufficient size to necessitate shoring the wall during the construction period.

In many instances it is entirely possible to install footings of this type on sites covered with water, a cylinder of sufficient length being employed as a starter so as to act as an ordinary cofferdam with its lower end embedded in the underlying mud while its upper end extends above the water level.

In those situations requiring the building of footings close to property lines, the Gow Caisson method is frequently found to be of especial value. Whereas the center of a cluster of piles is bound to be at a substantial distance from the line thus necessitating expensive cantilever construction for the carrying of the outside columns, the caisson type of construction permits a minimum of eccentricity of loading because the shaft may be sunk directly against the property line while the eccentricity induced by reason of the base being off center may be compensated for by reinforcing bars properly placed to prevent bending in the vertical shaft.

Another distinct advantage possessed by this type of foundation lies in the minimum depth of construction required. Wherever ordinary piles are employed for such purposes, it is necessary to drive them not only to good supporting stratum but also into the same for a distance of several feet in order to secure adequate resistance, whereas it is only necessary to carry caissons to the top surface of the bearing stratum. This consideration is frequently of great importance when the supporting stratum grows softer at increasing depths, a condition which is not at all uncommon. In all such cases, the hard top crust of the material acts as a distributing blanket to spread the load over a much greater area of the underlying softer soil.

It has frequently been found advantageous to employ Gow Caisson when for purposes of progress it was desirable to proceed with the foundation construction in advance of the general excavation. Under these circumstances the cylinders are sunk from the original ground surface while the concrete is stopped at the upper sub-grade elevation. The additional depth of excavation required in such cases is comparatively inexpensive and where time is an important factor may be easily justified. Plates No. 4 and No. 5 illustrate typical construction work on a job where the Gow System of Caisson Piles is employed.

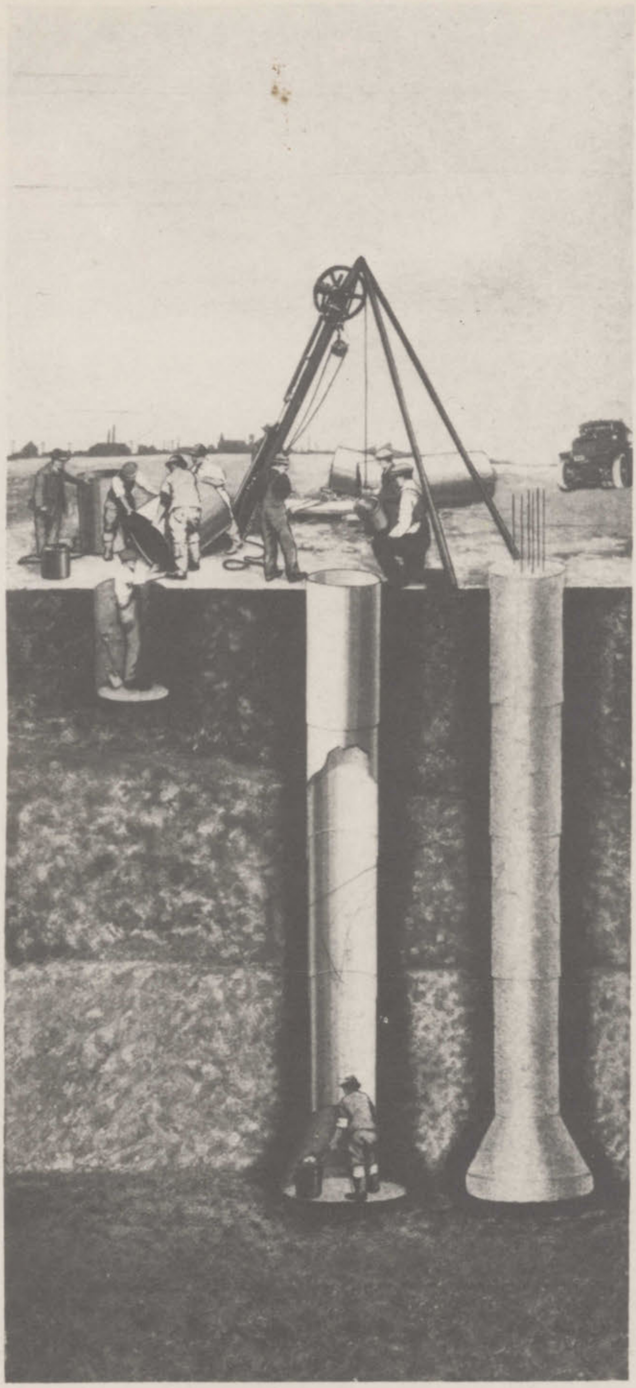
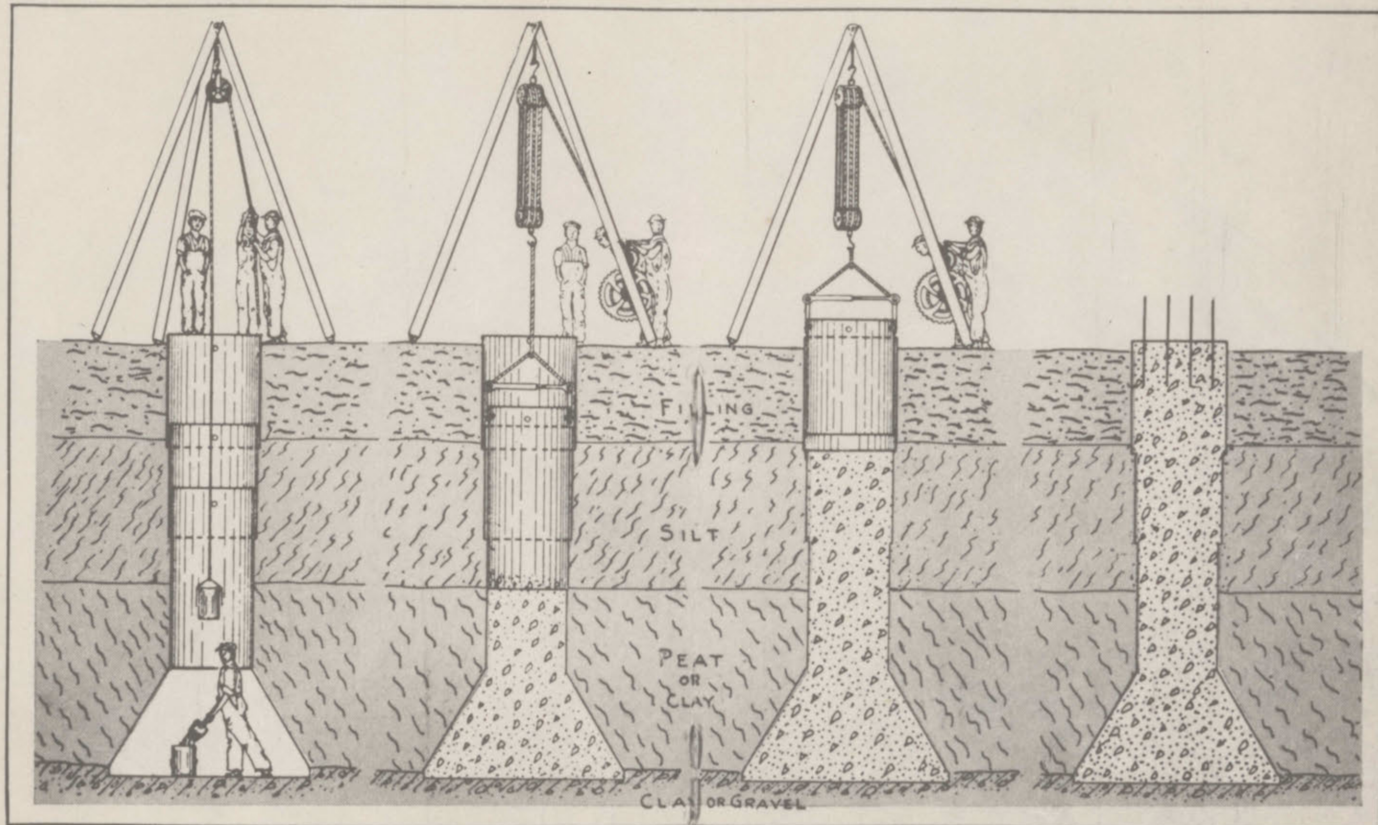


Plate No. 4



These four views represent graphically the process of placing Gow System Caisson Piles. In the first sketch the cylinders have been placed in position and the man at the bottom is excavating the bell, thereby spreading the load over the greater area. The second sketch shows some of the concrete in place and the lowest of the three cylinders being withdrawn. The third sketch shows the concrete as nearing completion and the center cylinder being withdrawn. Note that the cylinder is not withdrawn until the concrete is in place. The fourth sketch shows the concreting as having been completed and the reinforcing steel in place ready to receive the column.

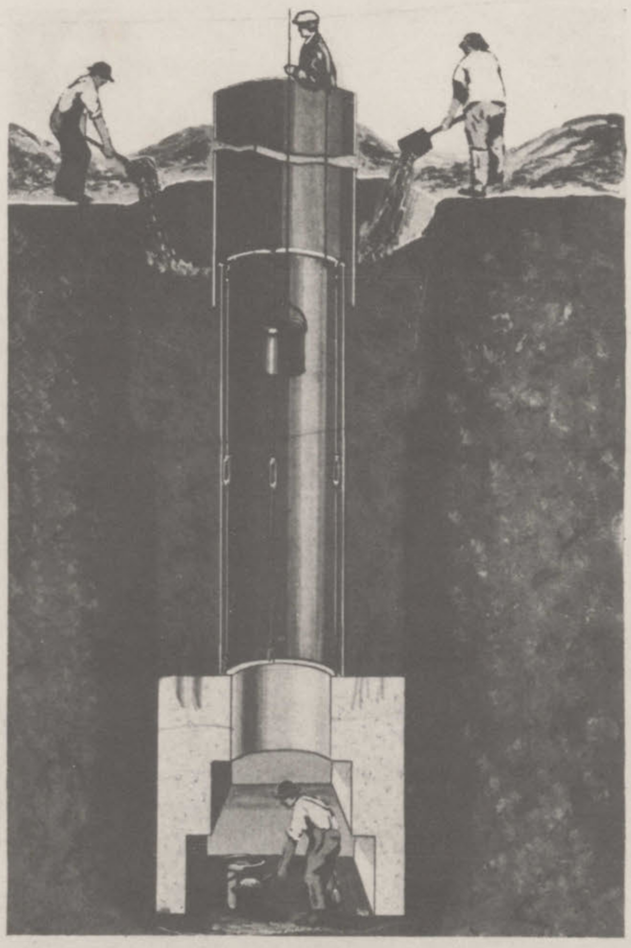
Plate No. 5

It is obvious that the method just described is applicable only when the soil at or immediately above the bearing stratum is of such a nature as to permit undercutting the excavation in order to form the conically shaped bell which distributes the load upon the supporting medium. This consideration requires that it shall possess a considerable degree of cohesiveness as in the case of clay, silt, peat or cemented sand or gravel. In the event that a material possessing suitable characteristics for belling purposes is not encountered at the desired depth, an alternative method, which may be used, has been provided to meet this situation.

This alternative method provides for the utilization of a precast bell or footing (see Plate No. 6), which is formed with vertical sides which act as guides during the subsequent operation of sinking the same to its final position. It is built with a hollow interior in which working men may be employed for the purpose of removing the excavation, thus allowing the bell to settle as the removal of soil progresses until the selected bearing stratum is reached. As the sinking process proceeds, vertical steel cylinders are attached to the top of the pre-cast bells and are drawn down as the latter settles. Meanwhile, a portion of the excavated material is used to backfill the annular space outside of the cylinder, thus preventing any tendency for displacement of the surrounding soil.

When the pre-cast bell has been sunk to a satisfactory bearing material, it is only necessary to concrete the interior of the working chamber and to fill and withdraw the steel cylinders in the usual manner in order to obtain the desired result.

In cases where a large shaft is called for by reason of the great load to be carried, a pre-cast hollow concrete cylinder may be substituted for the temporary steel cylinder and made ultimately an integral part of the completed structure.

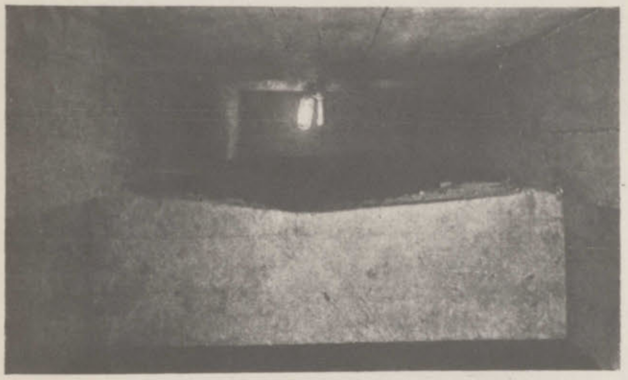


This shows a method whereby the bell is pre-cast to provide a working chamber and is followed down by the customary steel casing. The working chamber and column are then concreted; the steel casing withdrawn, in the customary manner, resulting in a completed Gow Caisson Pile.

Plate No. 6

Occasionally a sub-strata condition is found where it is impossible to make a bell by the usual method. Therefore the pre-cast bell method is frequently used, the general scheme of which is more clearly indicated above.

This shows the top or exit from a pre-cast bell method. Upon the completion of the excavation the whole interior of this caisson is filled with concrete.



The inside of a rectangular pre-cast bell caisson ten feet in width and thirty-two feet in length carrying two column shafts. In this instance excavation has been completed and the caisson is now ready to receive its concrete filling.

Plate No. 7

Gow Caisson Piles at the Tower Building.

The character of the sub-soil of the lot having been determined and the buildings removed, the next step in the work was the sinking of the Gow Caisson Piles.

It was obvious that the soil immediately above the bearing stratum was not of such a nature as to permit undercutting the excavation in order to form the conically-shaped bell which distributes the load upon the supporting medium. This consideration requires that it shall possess a considerable degree of cohesiveness, and as this condition did not exist, as was shown by the test pit and borings, it was decided to use compressed air to hold this material in place.

The sinking of the caisson was accomplished by excavating a round hole, the size of which depends upon the size of the caisson pile. When a depth of about seven feet was reached, a steel shell was placed in. On top of this first shell was placed another shell an inch greater in diameter than the previous shell. This one overlapped the former by a foot. On the upper edge of this shell was a flange three inches wide, with holes in it, to which the air lock was bolted. In Appendix A, Figure No. 1, some of the shells are shown protruding from the ground. Before the air lock was set on this special shell, the excavation was continued until the water level was reached, when a pulsometer pump was lowered into the hole to handle the water. As the work progressed new shells, seven feet in length, were lowered into the hole. Each new shell was two inches in diamater smaller than the one previously set.

In this manner the excavation was carried on until a depth was reached at which the bell was to be formed. Here, work was temporarily stopped while the air lock was placed on the special shell. Six of these air locks are shown in Appendix A, Figure No. 1. The air lock consists of a cylindrical chamber with a sliding door in its side and another door which is in reality the floor of the lock. This door is raised and lowered by levers from outside the lock and it permits the men to enter or leave the caisson. The next step taken was to grout the spaces between the shells to make them as air tight as possible and also to hold out any ground water. The material was excavated by shovels and picks and was put into cylindrical buckets lowered down through the air lock and shaft. On the cable there was a stuffing box which set on top of the lock. This allowed the cable to be raised or lowered through the lock while they are closed without leakage of air.

The air lock was operated by two men, one of whom had charge of the valves and signals and was held accountable for the lives of the men in the caisson below. The only means of signalling used was a code of raps made on the air shaft. This may appear primitive, but the metal of the shaft is a good sound conductor and the raps made by the men inside are easily heard at some distance from the caisson.

During this operation of belling trouble developed. The strata at this depth was such that not only would it stand by itself but it was of such a nature that it would not hold the air.

so that a pressure could be built up sufficient to hold back the material.

After attempts had been made to bell out about seven or eight of the shafts with this method, it was decided that the time necessary to complete the job would be far greater than the contract time would allow. As a solution of this problem, it was agreed to take the compressed air off the job entirely and build the piers of such a size that the diameter of the shaft at the bearing strata would be equivalent to the diameter of the base of the proposed bell. This necessitated much more excavation and consequently a great deal more concrete , since the diameter of the shaft had to be materially increased in the absence of bells.

The Gow Company realized this added expense and, wishing to decrease this necessary evil as much as possible, questioned the allowable bearing value of the hard pan, on which the piers were to be sunk, which had been set at ten tons per square foot. This necessitated a test to be carried out to demonstrate the feasibility of increasing this ten-ton-per-square-foot allowable bearing value. In one of the underpinning pits which had been excavated down to the hard pan, the test was carried out. See Plate No. 8. On the hard pan in the pit there was formed a truncaded prism of concrete with the base 14" x 14" and the top 13" x 13". In the top of the concrete was set a 12" x 12" x ½" steel plate on which rested a 12" x 12" wooden timber that was carried on up to within three feet of the bottom of the foundation of the building which was being underpinned. This 12" x 12"

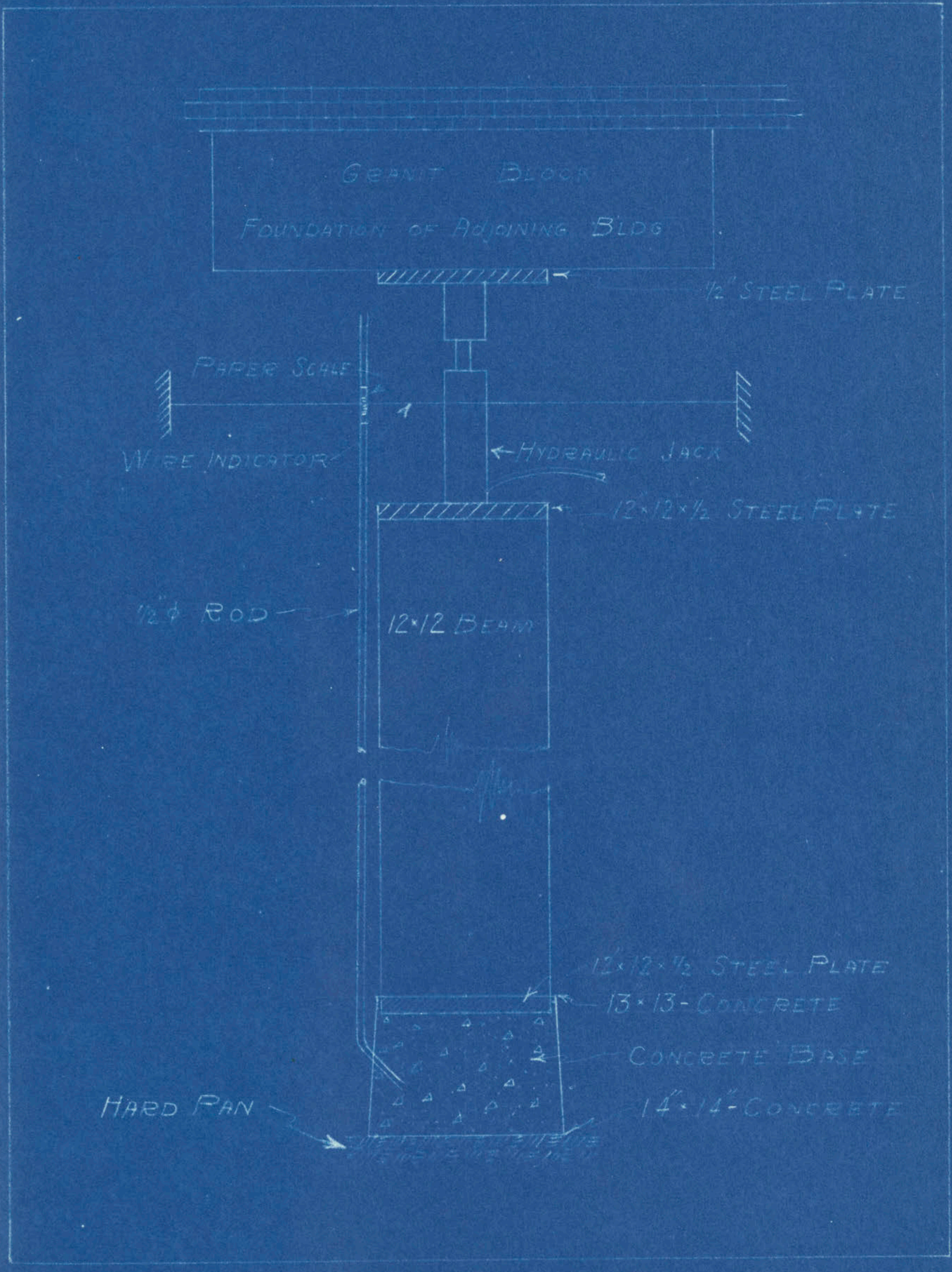

GRANIT BLOCK
FOUNDATION OF ADJOINING BLDG
½" STEEL PLATE
PAPER SCALE
WIRE INDICATOR
HYDRAULIC JACK
12×12×½ STEEL PLATE
½"φ ROD
12×12 BEAM
12×12×½ STEEL PLATE
13×13-CONCRETE
CONCRETE BASE
HARD PAN
14"×14"-CONCRETE

Plate No. 8

was guided and plumbed the entire depth of the pit to assure stability. Between the top of the 12" x 12" timber and the granite foundation of the adjoining building was placed a hydraulic jack. Embedded in the concrete at the bottom of the pit was a half-inch round pipe that was also guided and plumbed the entire depth of the pit. On this pipe at the top was pasted a piece of paper graduated into sixteenths of an inch. A wire was stretched across the pit so that its height was identical with that of the paper scale fixed on the pipe. As was stated at the time the test was performed, the ideal worst conditions were present for the material labelled hardpan in the bottom of the pit was loose coarse gravel and stone. It was the poorest hardpan found on the job. The load was applied in five-ton increments and no settlement occurred until twenty tons had been applied, when only a slight settlement occurred. The load was held at twenty ton and there was no further settlement. From then on the load was applied in five-ton increments with ten-minute periods between the application of the additional five-ton increments. This process was carried on until thirty-five tons plus one ton dead load had been applied. At this point the total settlement reached three-sixteenths of an inch.

The results of the test were as would be expected for hardpan, for settlement only occurred during the application of the load; whereas, if the hardpan had been clay a settlement would have occurred during the intervals between the application of the loads. As a result of the test the Gow Company benefited materially, for the allowable bearing of the hardpan was increased from ten ton per square foot to eighteen ton per square foot, which meant that the area of the shaft could be decreased or a leaner mixture of concrete might be substituted.

When these caissons are not in a corner or up against a wall, they are excavated by a machine built by the Marion Company, but for which the Gow Company hold the patents. The main portion of the outfit is similar to any derrick mounted on caterpillars. It is a gas-electric machine and has a boom which mades an angle of about eighty degrees with the horizontal. Hanging from the boom is a round bar twenty-five feet long, to which is connected rigidly at the bottom a cylindrical bucket three feet in diameter with a base that is similar to the first tooth of an auger. The bar has four keys set at ninety degrees to one another and extend the full length of the bar. The digging is accomplished by lowering the bar and bucket through a guide which extends out from the bottom of the boom. The keys on the bar pass down through four corresponding grooves and rotate the bar and the bucket. This motion causes the auger base to dig into the ground and the material is sent through the base into the bucket, which when full is withdrawn, and swings away from the hole being dug. The base of the bucket, which is in two parts, opens downwardly and the material is dumped either in a pile or into a truck.

The steps taken in excavating the foundation holes are illustrated on Plate No. 9. The first step is to locate on the lot a shell of the correct size. The shell is then swung into a position which will enable the digger, which has a cable running

1. Swinging Caisson To Position

2. Placing Caisson

3. Picking Up Caisson Hammer

4. Adjusting Hammer To Caisson Diameter

5. Hammer Down On Caisson

6. Lowering Auger

7. Dumping Auger

8. Placing Concrete

9. Pulling Caisson As Concrete Is Cast

Plate No. 9

from the top of its boom, to pick up the caisson with its cable and place it in position in the hole. As might be expected, due to the rough handling on the job, these caissonsare not true round cylinders, and as a result will not fit true in the hole. A caisson hammer, as shown in Figure No. 3 on Plate No. 9, is used to force the caisson down into place. The lower portion of the hammer has two jaws, which can be adjusted to fit any size caisson. The hammer is operated by the cable from the digger. With the jaws fixed on the caisson edge, the weight which runs between two leads composing the top of the hammer is raised and dropped until the caisson is down in place. With this operation finished, the hammer is then brought out of the hole and the digger, or auger, commences to dig another seven feet before the following caisson is placed. A truck is backed up to the digger, and, when the auger is full, it, in turn, is raised and the digger swung around until the auger is over the truck, when the collapsible bottom of the auger is opened and its contents dumped into the truck.

When the hole is completed, the concrete is brought to it in buggies and dropped into pipes through which it is carried into the hole. The apparatus for pulling the caissons is shown in Figure No. 9, Plate No. 9.

Always where this type of foundation is used the top of the pier is larger than three feet, which is the capacity of the bucket. To overcome this difficulty, two cutting edges, which are adjustable in length, are bolted on to the top of the bucket at 180 degrees from each other and extend from the top of the bucket radially to the distance desired. As soon as the bucket has excavated to its own depth, the cutting edges come into action. The material cut by the edges falls into the bucket and as soon as a hole is excavated about seven feet in depth and the diameter set by the cutting edges, a shell is put down to brace the material on the sides and keep it from caving in. After the first shell has been set, the bucket is withdrawn and the cutting edges shortened one inch, since the next shell to be placed is two inches smaller than the previous one. This operation is repeated and it is possible with the machine to excavate down to a depth of seventy-five feet, the twenty-five-foot bar at the top of the bucket being telescopic in form. This bar is in reality a shell in which there are two more shells twenty-five feet in length, so that as soon as a greater depth than twenty-five feet is reached the second shell starts to slide out of the first. A similar situation takes place at a depth just over fifty feet.

When hardpan or ledge rock is reached the bucket commences to jump and ceases to dig any further. This is one of the limitations of the outfit, since the only force by which the bucket is lowered is the dead weight of the bucket and bar, and when it comes in contact with a material strong enough to resist this force, it is of no further use. Another limitation of the bucket is that it can only be used in fine and cohessive materials, such as clay or peat, for the bottom has an opening of three inches through which the uncohessive materials fall as it is being raised, and if the materials contain segments larger than three inches in size they cannot enter through the bottom of the bucket.

However, where it is possible to use this machine, it more than demonstrates it value, because it is able to excavate one foot of ground and place one foot of cylindrical shell with four men in ten minutes, whereas it takes five men with a derrick all in place approximately one hour to accomplish the same result. This means a six to one saving in time, which is well worth consideration. See the Marion Type 450 machine in Appendix A, Figures Nos. 2 and 3.

As soon as the last shell has been set the machine starts work on another hole, just previously laid out by the engineers. Over the former hole is placed either a tripod or an A frame and a pulsometer pump is connected up and lowered into the hole to take care of any ground water which may enter. Following this operation a small bell is dug if the cross section area of the last shell is not sufficient to accommodate the load which the pier will have to sustain. The bell is concreted as soon as completed to prevent collapsing of its sides. In a few cases it was difficult to dig even these small bells, which were not over two feet in diamater greater than that of the shaft, and it became necessary to lower bags of cement into the hole. As soon as a pocket large enough for a bag was excavated, it was plugged with the bag of cement to prevent further caving. The rest of the bottom of the shaft was then poured and dowels placed to anchor the bell to the shaft when the latter was poured, which often was not for a day or two.

The shaft was poured by shooting the concrete through lengths of six inch pipe which extended down to within approximately a foot of the concrete in the shaft. As the shaft began to fill the pipe was raised and when the concrete surface was within a foot of the bottom shell, it, in turn, was raised enough to keep the bottom of it about one and one-half feet below the concrete surface. This was done to prevent the ground water from coming in on the surface of the concrete, which would have occurred if the shell had been entirely removed. The remainder of the concreting is clearly illustrated and described on Plate No. 5.

Often it was impossible to pull even one shell at a time, due to the enormous friction on its sides. In a few cases on this job two derrick, besides the derrick on the A frame directly over the shaft, were hooked on to the shell, but with no result except the breaking of the wire cable. Due to this friction, about sixty shells were lost, at a cost of about five thousand dollars.

A shaft should never be poured when extremely close to another which is open, for, as the shells are removed, the concrete exerts a pressure of 150 pounds per cubic foot and it requires considerable resistance to hold it in place. This point was overlooked on this job in one instance where there were two shafts within a foot of each other. One was being poured while the other was being belled. The pouring was going on in the usual way and the cylinders were being pulled when suddenly the pressure exerted by the concrete overcame that of the foot of earth between the shafts, and the concrete, forcing out the earth, worked between the laps of the shells in the nearby shaft and partially filled it, seriously injuring two men who were doing the belling.

When the air was taken off the job there were several shafts which had been carried down with the smaller shells of the original design, but due to the difficulties in belling it became impossible to obtain a cross-section area large enough to withstand the superimposed loads. In these cases it became necessary to excavate two more shafts, one on each side of the old one. These were started of such a size that on reaching the hardpan their combined area was capable of safely sustaining the load. The three concrete piers were then capped with a reinforced concrete beam.

The piers along the wall of the adjoining property were in pairs and capped with a reinforced concrete beam of a cantilever design to take care of the eccentric loading caused by the steel columns of the superimposed structure.

General Excavation

The general excavation of this job proved to be a very expensive and troublesome operation and was not finally completed until twelve stories of steel had been erected. There are two main basement levels in this building, one at elevation +4'-4" and the other at -13'-4".

With the caisson work completed, a steam shovel was put to work excavating the general lot down to the grade +4'-4". The material excavated was directly dumped into trucks and carried off to a barge at the water front, to be deposited in the harbor.

By the time this excavation had been done the anchor bolts and billet plates on top of the piers had been set and consequently the erecting of the steel began, necessitating the removal of the shovel from the lot. As the steel derrick was set on cribbing built upon ground whose elevation was +4'-4" and which was the only section to be excavated to grade -13'-4", the general excavation was stopped until the derrick had been jumped to its new level on the second floor, for any digging in the section around the derrick would have undermined it.

With two floors of steel completed the derrick was jumped and the excavation resumed to bring this section down to its final grade. A derrick mounted on caterpillars, with a short boom, was brought in on the first floor on the Franklin Street side and another derrick of a similar design was set on the Devonshire Street side. By means of these derricks buckets were raised and lowered between the steel beams. All this work was done by gangs of laborers with picks and shovels. The section immediately in the vicinity under the derrick was brought down to grade. As the excavation progressed away from this section, a system of narrow-gauge tracks were laid. On these tracks were pushed by the men flat cars large enough to accommodate one bucket. In this manner the excavation was finally completed.

COSTS

The cost data listed below is incomplete, due to the reluctance of the Gow Company and Thompson Starrett Company to volunteer any information of this type. Through other sources, however the following was obtained:

General Excavation	12,000 c.y.	@ $2.50	$30,000
Bank "	2,000 c.y.	@ 3.00	6,000
Trench "	200 c.y.	@ 4.00	800
Masonry Wall Excavation	600 c.y.	@ 3.00	1,800
Sheeting - 4" left in place	50 M.	@ 1.00	5,000
Braces and Rangers	50 M.	@ 1.00	5,000
Cinder Concrete - fill	180 c.y.	@ 10.00	1,800
Fence	400 ft.	@ 1.50	600

The unit price for the general excavation was obtained by estimating the total excavation to various grades at corresponding unit prices and then an average unit price for the excavation in general was set. Following is the method used for obtaining the general unit price for the excavation:

From existing basement	to grade +2'-10"	9,000 c.y.	@ 2.00	$18,000
From grade +2'-10"	to grade -7'-8"	1,000 c.y.	@ 3.00	3,000
From grade -7'-8"	to grade -13'-10"	2,000 c.y.	@ 4.00	8,000
Total Yardage		12,000 c.y.		
Total Cost				$29,000

The figures were rounded off and $2.50 per c.y. was bid and accepted.

The charge for trucking the materials excavated by The Gow Company from the caissons was based on a time rate of $3.00 per hour. In general, it took a truck between forty-five and sixty minutes to be loaded, make the trip to the barge, be unloaded and return.

The major part of the concrete used was purchased from the Rapid Transit Ready-Mix Concrete Company of Roslindale. This method of using concrete which is mixed in the specially-constructed trucks while in transit to the job is a marked improvement over mixing the concrete at a plant located on the job. This concrete was purchased at $8.25 per cubic yard for a 1:2:4 mix, which is much cheaper than it could have been made by a plant located on the lot. This concrete from the Ready-Mix Company tested 30 per cent. more in compression than was required.

As was stated, no information could be obtained from The Gow Company in regard to the costs of construction, but it is known that it requires five men at $0.85 per hour to excavate four cubic yards out of a hole per eight hours; and that with the digging machine and four men: an operator at $1.65 per hour, a mechanic at $1.35 per hour, and two laborers at $0.90 per hour, it is possible to dig about fifty cubic yards in eight hours.

The general payroll for the job was $125,000. This included only the wages received by men working directly under The Gow Company.

Foundations for the Edison Central Heating Plant.

Although this job may appear to be off at a tangent to the title of this study, which would limit it to high office buildings, it is an excellent example of the pre-cast compressed air caisson that is frequently used in the construction of the foundations for high office buildings. Therefore, a short detailed study of this job will be presented to bring out the features of this type of foundation construction.

As on the other job, a number of borings were made on the lot, since it is necessary to obtain a knowledge of the strata underlying the building site before the engineer can decide on the type of foundation to be used. These borings indicated that it would be necessary to excavate from one hundred to one hundred twenty-five feet below the street level before a firm bearing strata could be reached. The location of the job is such that it is only about 250 yards from the water front and to excavate to the necessary depths which are below low water indicated that compressed air would have to be used to keep out the water. Therefore, it was agreed to use the pre-cast caisson to accomplish this result.

When the caisson work commences before the general excavation of the lot it necessitates the digging of a pit sufficiently large to accommodate the construction of a pier which is to be sunk at that point. The next step after the pit has been excavated is to dig a cylindrical hole four inches in diameter larger than the shaft of the pier and about five to six feet deep.

Into the hole is accurately set the cutting edge, which is at the bottom of the pier-to-be. The edge is made up of a steel cylinder of 5/8 inch plate, 7 feet long. See Plate No. 10. At the top of the cutting edge are eight gusset plates which support a 1-inch circular disc with a 3-foot hole cut in the center to allow entrance for a man or a bucket. Piercing through the disc are eight anchor bolts which act as a bond between the concrete shell that is formed on top. Below each gusset plate, or knee brace, are two angles, placed vertically, that act as stiffeners for the 5/8 inch plate. These vertical angles are cut off one foot from the bottom of the 5/8 inch plate. Here, another plate of the same size is riveted to the former. The total thickness of the last foot of the cutting edge is 1 1/4 inches. Between the vertical stiffener angles are placed three horizontal angles, the first one directly under the gusset plate, the next 3 1/2 feet down and the third at the bottom of the vertical angles. These horizontal stiffeners are not continuous, but extend from one set of vertical angles to another.

The following step is the construction of the forms for the concrete shell, the thickness of which is determined by the diameter of the pier required. As the majority of the piers on the job were 8 feet, the thickness of the shell was 30 inches, as a 3-foot opening is always allowed for passage of either a bucket or a man. This shell was built in 10-foot lengths with dowels in the top to act as anchors for the next section which would be built on top of it.

The sinking of the caisson was accomplished by excavating the material underlying the caisson continuously with picks and

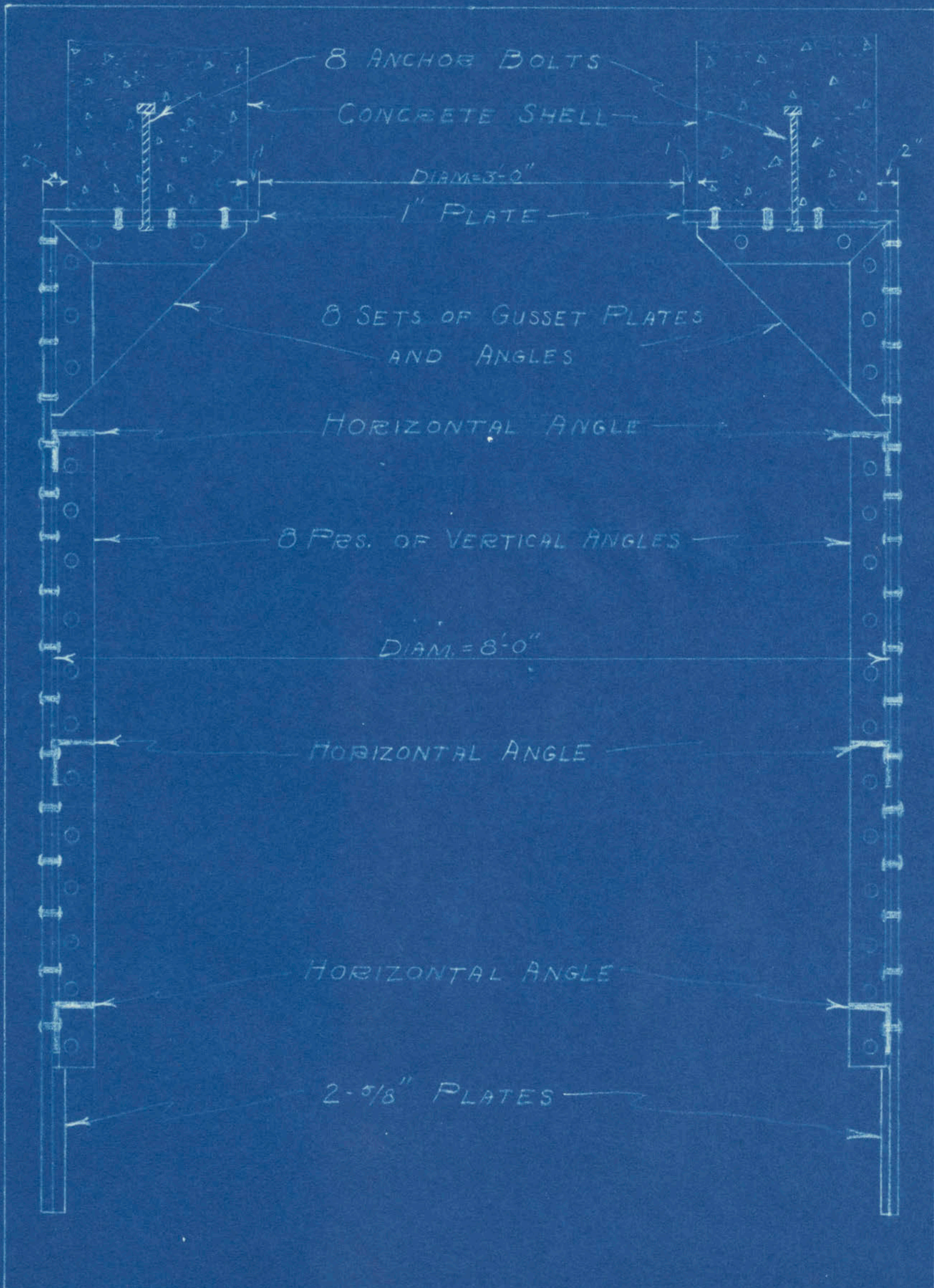

8 ANCHOR BOLTS
CONCRETE SHELL
2"
1"
DIAM.=3'-0"
1"
2"
1" PLATE
8 SETS OF GUSSET PLATES AND ANGLES
HORIZONTAL ANGLE
8 PRS. OF VERTICAL ANGLES
DIAM.=8'-0"
HORIZONTAL ANGLE
HORIZONTAL ANGLE
2-5/8" PLATES

Plate No. 10

shovels, the weight of the concrete mass on top, together with the 2-inch setback of the concrete over the cutting edge, sufficing to force it down. Where caissons are left still for several days after being started, the skin friction on the sides is very great, and in order to overcome this a number of ton slugs are placed on the caisson, and these, with the dead weight, suffice to push it down. However, when the caisson reaches a depth of from sixty to seventy feet, it requires a load of slugs amounting to 198 tons to sink the pier, and, for fear of crushing the concrete with the greater load which is required as the depth increases to sink the caisson, an alternate method is used, which will be described later. When the process of loading the caisson to sink it is used, great care must be taken in starting the caisson to see that it is vertical and to keep it so, which is accomplished by bracing the concrete.

The concrete shells were sunk down to a depth of about sixty-five feet before it became possible to control the ground water by means of pulsometer pumps. At approximately this depth the water got out of control and flooded the caissons. Centrifugal pumps of a larger capacity than the pulsometer were brought, but even with continued pumping for a week there was no appreciable lowering of the water level. As other caissons approached this depth, attempts were made to pressure grout the underlying strata, but this failed also. Every attempt was made to complete the work without introducing compressed air, but all failed, and the work continued from this stage under compressed air.

Steel sheeting was then driven around the whole lot to prevent as much as possible the material from flowing into the lot from the outside. When a caisson was put under air no further attempts were made to sink it. The alternate method used, which was spoken of in the preceding section, was to employ steel plates, which were used to line the shaft as the excavation progressed. These plates had flanges on all four sides and were butted against each other and bolted. To reduce the leakage of air as much as possible, a red clay imported from New Jersey was used to pack behind the plates, so that there would be no pockets for air to enter. Over all the joints of the plates the clay was also packed to prevent leakage. This clay, due to its cohesiveness, clings firmly to the plates and does not become hard or brittle, like the Boston blue clay. However, even with this precaution, there was considerable leakage of air.

As soon as the caisson had reached the hard pan or slate, which was used mainly as the bearing strata, the shaft was filled with concrete up to the concrete shell. The air lock was then removed and the concreting carried on under atmospheric pressure. This was just to make the process easier, as concrete sets as well in compressed air as under ordinary conditions.

As has been previously stated, the air lock is operated by two men, one of whom has charge of the valves and signals given by a code of raps made on the air lock. As the caisson increases in depth more air pressure is required to keep out the ground water. The maximum pressure needed on this job was forty pounds per square inch. The extra amount needed is fed in by the lock man, who knows from signals which is required.

Men under compressed air work with greater speed than they could outside. The compressed air seems to make them artificially lively and, as a result, great care should be taken in handling them, both in regard to the amount of time required to work and the time taken to change from the pressure under which they have been working to the atmospheric pressure. To guard against attacks of the bends, The Gow Company have a hospital lock where the men can be treated. A warm dressing room is also provided for the caisson workers after coming from the warm compressed air to the cooler atmospheric air to guard against colds. If care is taken to allow a long time in passing through the air lock, little danger will result from working under the greater pressure.

An interesting incident which occurred on this job was due to the compressed air. It was deemed necessary to have a small Gow Open Caisson constructed at a corner of the lot to support two intersecting concrete walls. At a depth of twenty feet below grade, there was a layer of hard cemented sand, gravel and clay, which, it was believed, would safely withstand the dead weight of a concrete pier four foot in diamater and twenty foot long, plus the weight of the two walls. A caisson of this type was constructed and filled with concrete. When the time came to build the forms for the walls over the caisson, the area in this section was cleaned out, but the caisson had disappeared. Soundings were made for it and it was located about twenty feet below its original elevation. The reason was that much of the fine strata below the layer of cemented sand and gravel had been blown or carried up to the elevation of the lot by the air which excaped from the main caissons. This is one of the main reasons for driving the metal sheet piling to prevent ground outside the lot from being disturbed and thereby endangering the neighboring buildings. The sheeting undoubtedly did reduce this condition but not one hundred per cent., for on Shawmut Avenue, which is two blocks away, a spring bubbled up in the middle of the Avenue, and it was traced back to this job. To take the place of the caisson which slumped down, sixty-five foot piles were driven around it and capped.

APPENDIX A


COLUMBIAN NATIONAL LIFE BUILDING
The GOW COMPANY
GOW CO. INC.
The Gow Co Inc
Job G551
Aug. 20-1924
F.A.George
99 Br'dw'y-Boston

Figure No. 1


FOR RENT
CROSS & BROWN CO.
COFFIN & TABER
W.H. DOLBEN
MARION
TYPE
430
MARION
ERIE STEAM SHOVEL CO
THE GOW CO. INC. JOB G-551- 9/21/29 - 3.30 P.M.

Figure No. 2

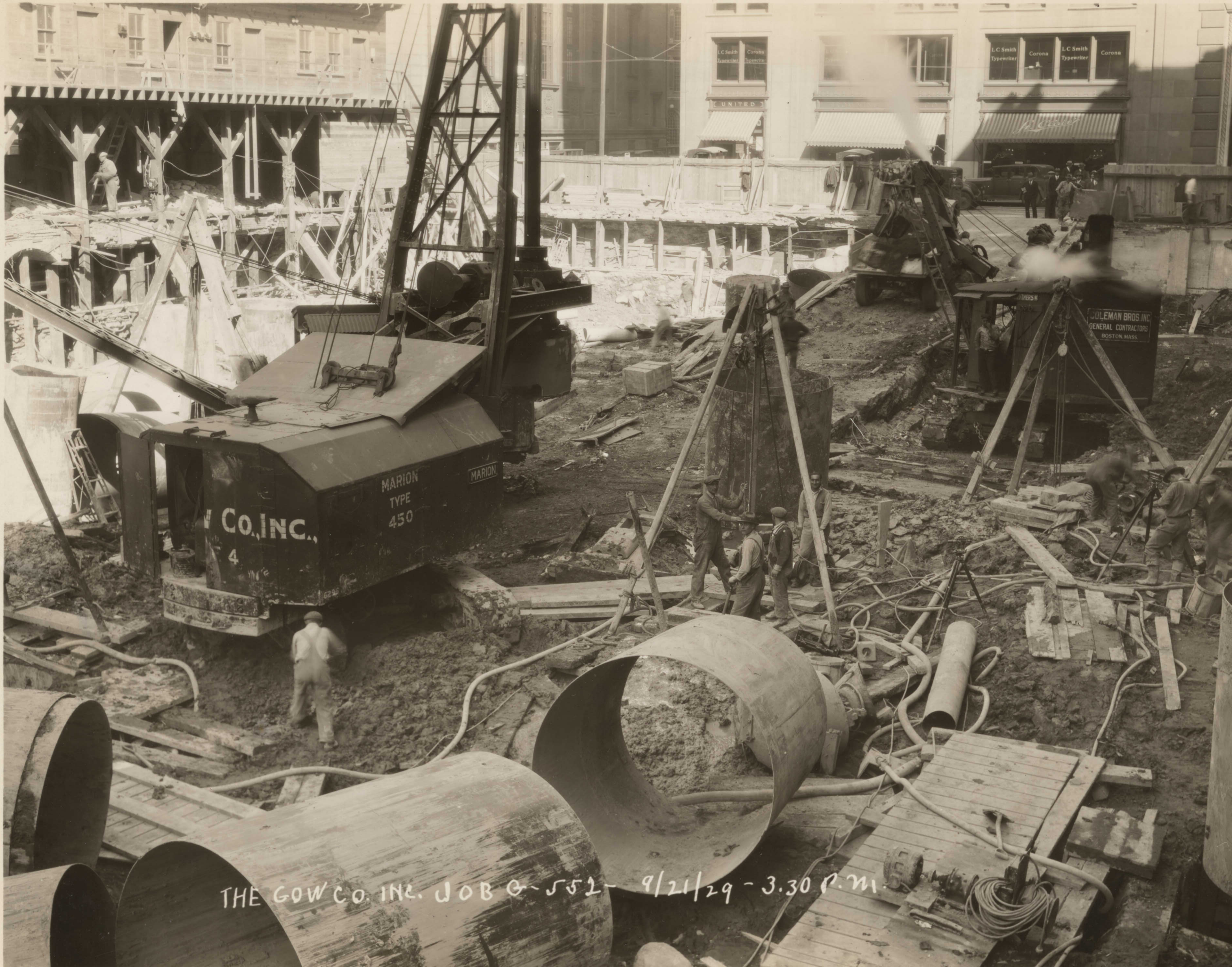

THE GOW CO. INC. JOB G-552- 9/21/29 - 3.30 P.M.
MARION
TYPE
450
MARION
CO. INC.
COLEMAN BROS. INC
GENERAL CONTRACTORS
BOSTON, MASS.
L C Smith
Typewriter
Corona
UNITED

Figure No. 3