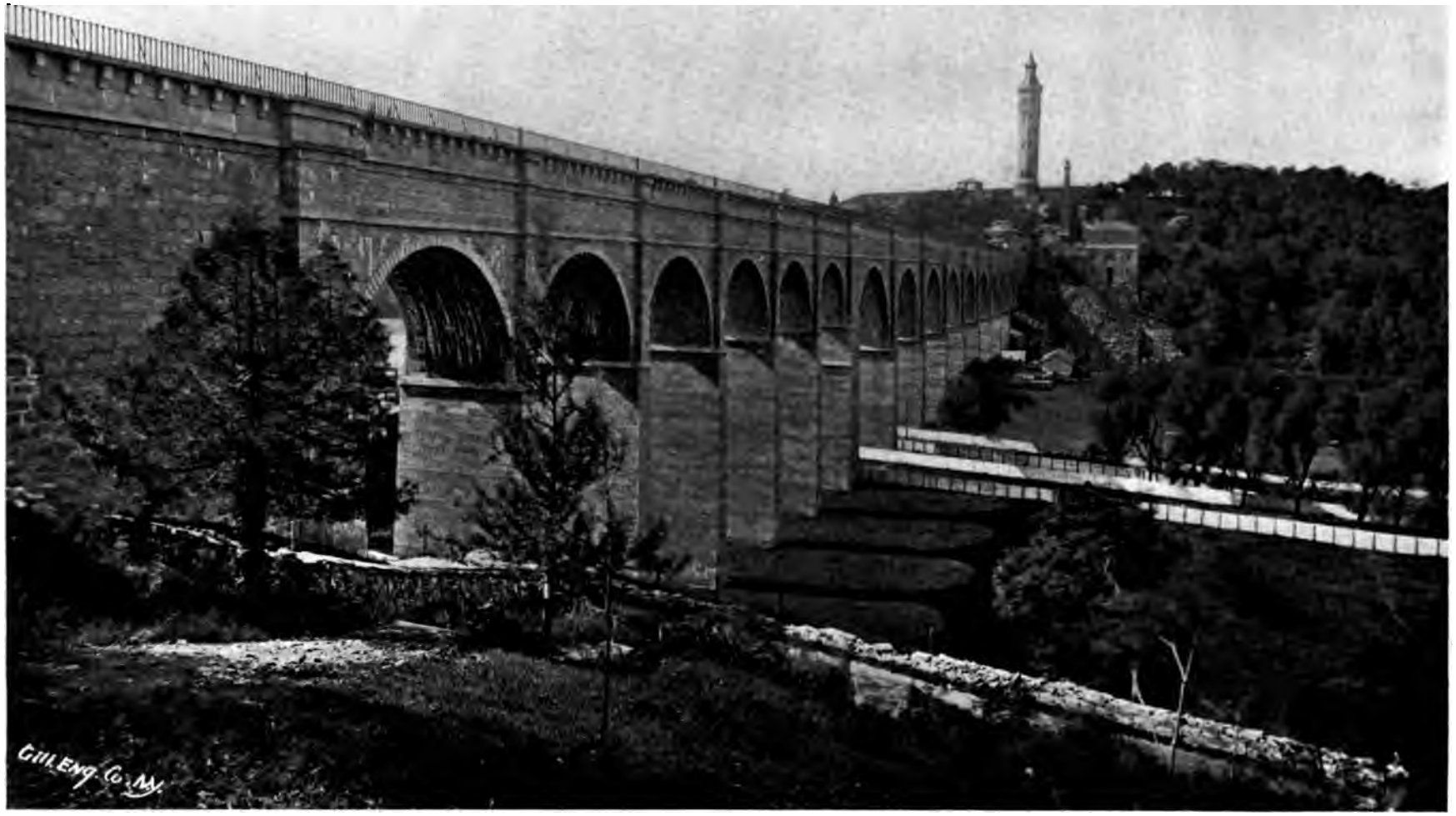

PLATE 1.—HIGH BRIDGE ACROSS HARLEM RIVER.

THE WATER-SUPPLY

OF THE

CITY OF NEW YORK.

1658-1895.

BY

EDWARD WEGMANN, C.E.,

M. Am. Soc. C.E.,

Author of "The Design and Construction of Masonry Dams."

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FIRST THOUSAND.

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PREFACE.

THE citizens of New York celebrated in October 1842 the completion of their first water-works of importance. By building a dam across the valley of the Croton River a storage reservoir had been formed, from which an aqueduct, about forty-one miles long, conveyed a copious supply of pure water to the city. This conduit was designed to have a maximum discharging capacity of about 72,000,000 U. S. gallons per day, a quantity of water which was not expected to be required for many years to come. The growth of New York was, however, so much more rapid than had been anticipated, that within thirty years of its completion the Croton aqueduct had to be strained to its utmost capacity to satisfy the consumption. By allowing the water to rise within twelve and a half inches of the crown of the arch (thirty-two inches higher than had been originally intended) the aqueduct was made to discharge 95,000,000 U. S. gallons per day.

In 1884 a daily supply of 15–20 million gallons was obtained from the Bronx River, but this small addition was not sufficient for the steadily increasing demand. New works on a large scale had become an imperative necessity.

An Act passed by the Legislature of 1883 gave the city the necessary power to construct additional works under the direction of a Board of Aqueduct Commissioners. In accordance with the provisions of this Act a new aqueduct, having a discharging capacity of 302,000,000 gallons per day, has been built from the Croton valley to the city. Large storage reservoirs have been constructed in the Croton watershed, and others are being formed.

The capacity of the three conduits supplying the city of New York at present is as follows:

Name.	When Built.	Maximum Discharge in 24 hours.
Old Croton aqueduct....	1837–1843	95,000,000
Bronx River conduit.....	1880–1885	28,000,000
New Croton aqueduct.....	1884–1893	302,000,000
Total.....		425,000,000

The reservoirs already constructed, including those within the limits of the city, store about 27,000,000,000 U. S. gallons. To this will be added by the completion of the works now in construction 48,000,000,000 gallons, making the total storage of the Croton and Bronx works, including the reservoirs in the city, amount to about 75,000,000,000 gallons. When this storage has been obtained it is estimated that a minimum supply of 280,000,000 gallons per day may be relied upon even in the driest year. As the average daily consumption was 183,000,000 gallons in 1894 (about 100 gallons per capita), the present water-supply will provide for the wants of the community for some years to come.

Works of the magnitude of those mentioned above should be a matter of just pride for the citizens who have paid for their construction, and a subject of special interest to engineers. Full information about the water-works of New York is, however, not easily obtained. The books describing the Old Croton Aqueduct * are now out of print and very scarce. From 1846 to 1887 the only information published about the water-supply of the city is that contained in official reports, which are nowhere to be found collected. The Aqueduct Commissioners have issued two valuable reports, illustrated by photographs and plans, describing the important works executed under their direction; but these documents cannot reach the public at large, owing to the limited number of copies printed, nor could they include many details of the works, having only a technical interest. Under these circumstances a book giving a full description of the water-supply of the city of New York is much needed.

The writer has undertaken the somewhat arduous task of preparing such a volume with a twofold object:

1st. To give, for the general reader, the history of the water-works from the sinking of the first public well in 1658 in front of the old fort at Bowling Green to the present time.

2d. To present such technical details of the important new works as may be of interest to civil engineers, keeping such matter as much as possible in special chapters (as Chapters III, VII, VIII).

To the people of the present generation the Croton watershed may seem the only proper source of a water-supply for New York. Opinions differed, however, very much about this subject sixty to seventy years ago. The numerous projects proposed for the purpose are all discussed in this work. Some of them, seriously considered at the time, would scarcely be entertained now, as, for instance, the proposition to build a dam across the Hudson River at Christopher Street (see page 32). The argument of the Water Commissioners of 1833 against the use of *forty-two* steam-engines within the limits of the city (see page 31) is amusing reading in these days of elevated railroads.

In glancing through this work the reader will realize how little the wonderful growth of the city of New York was anticipated when the old Croton works were begun. One of the prominent engineers reporting in 1833 on the best source for supplying the city of New York with water predicted that Manhattan Island would be inhabited by a million souls within sixty years of that time (see page 21); on the other hand, an equally distinguished engineer expressed the opinion that such a population would not be reached until "after the revolutions of a few centuries" (see page 26). That the latter was not alone in his belief may be judged from the statement of the Water Commissioners of 1840 that Ninety-sixth Street and some other streets in that vicinity would probably not be opened "for a century or two" (see page 43).

The welfare and growth of a community are intimately connected with its water-supply. Before the old Croton works were constructed, the citizens of New York suffered at frequent

* Memoir of the Construction, Cost, and Capacity of the Croton Aqueduct by Charles King, New York, 1843. Illustrations of the Croton Aqueduct by F. B. Tower, New York, 1843. Description of the New York Croton Aqueduct by T. Schramke, New York, 1846.

intervals from the ravages of cholera and yellow fever. Since an abundant supply of pure water has been introduced these diseases have almost disappeared from the city.

The losses of life and property from fires—formerly very great—have been much reduced since water-mains have been laid in all streets. Works that have brought such improvements must be of interest to all citizens.

A large part of the book is devoted to giving, for the benefit of engineers and contractors, full details of the new works executed during the past ten years. The manner in which the new aqueduct was designed, the distribution of the "available head," the formulæ used in estimating the flow, and the results obtained by gaugings after the aqueduct was completed, etc., etc., are given in Chapter VIII.

In excavating the great aqueduct tunnel—the longest tunnel driven thus far—all kinds of material were met with: solid rock, decomposed rock, sand, gravel, and liquid mud. The ordinary methods of tunnelling adopted, and the ways in which the difficulties encountered were overcome are described in Chapter VII.

Plans, specifications, and contract prices are given for almost every detail of water-works construction—from a fish-screen to a high masonry dam. Considering the prominent engineers who have been connected with the water-supply of the city of New York, the book may be stated to give standard plans for water-works construction as practised in the Eastern States.

The preparation of this volume has involved much labor and expense. In describing the new works, the writer, having been engaged on their construction from the beginning, has been able to speak largely from his own observation and experience. The information about the older works had to be obtained from official reports, now scattered in the different libraries of the city, and in bookstores. After much searching, copies of all reports of any importance that have been issued in connection with the water-supply of New York were found. It was no easy matter, however, to present the mass of disconnected facts, thus collected, in readable form.

Great pains have been taken to insure accuracy in this work. Whenever possible, the facts stated have been taken from the original sources of information—the records of the Common Council of New York, official reports, etc.

The different portions of the book have been submitted to the engineers who had charge of the works described. In this connection the writer wishes to express his thanks to Gen. Geo. S. Greene; Mr. J. J. R. Croes; Mr. Geo. W. Birdsall, Chief Engineer of the Croton Aqueduct, and his assistants; Mr. A. Fteley, Chief Engineer of the Aqueduct Commission, and the engineers under him on the new works; and especially to the Aqueduct Commissioners, who have given the writer full privilege to reproduce in this book such photographs, plans, tables, etc., contained in their reports as might be required for his purposes.

In offering the volume to the public it is hoped that it may be of some interest to the citizens of New York, whose water-works surpass all others in magnitude, and that it may be of practical value to engineers and contractors engaged on similar constructions.

E. W.

NEW YORK, December 2, 1895.

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THE WATER-SUPPLY OF THE CITY OF NEW YORK.

CHAPTER I.

EARLY WORKS AND PROJECTS.

THE city of New York, the metropolis of the Western Continent, is situated at the head of a large bay, in latitude 40° 42′ 43″ north and longitude 74° 0′ 3″ west from Greenwich, about eighteen miles from the Atlantic Ocean (see Plate 54). It lies mainly on Manhattan Island, which is bounded on the east and south by the East River (a narrow strait opening into Long Island Sound), on the west by the Hudson River, and on the north by Spuyten Duyvil Creek and the Harlem River, two narrow tideways separating it from the mainland. The island has a length of 13½ miles, an average width of 1⅔ miles, and an area of about 22 square miles. The city includes, also, an extension on the mainland known as the "Annexed District" and several small islands in the East River and Bay. It covers in all about 41½ square miles.

The Bay of New York is believed to have been entered in 1524 by Jean Verrazani, an Italian navigator, who was exploring the coast of America in the interests of Francis I. of France. The practical discovery of Manhattan Island and the surrounding country was not made, however, until 1609, when Henry Hudson undertook a voyage of exploration for the Dutch East India Company in the "Half Moon," a vessel of eighty tons burden.

Hudson's primary object was to find a north passage to the East Indies. Entering the Bay of New York in September 1609, he passed up the river, now bearing his name, to the head of navigation near the present site of Albany. Although he did not succeed in finding the desired passage, the glowing account he made, on his return to the Netherlands, of the land he had discovered and of the fine furs in the possession of the natives, induced the Dutch merchants to dispatch, in 1610, another vessel to America to open a trade with the Indians inhabiting Manhattan Island and the surrounding country. The fur traffic proving very profitable, a regular commerce was soon established. Manhattan Island was made the chief depot for this trade. A company was formed in the Netherlands for carrying on the traffic. Hendrick Christiænsen, the first agent the company sent to America, built in 1613 a redoubt and several small houses where now stands No. 39 Broadway, and laid thus the foundation for the future city of New York. The first buildings of importance were erected in 1621, near the southern extremity of Manhattan Island. In 1626 Peter Minuit

bought the whole island from the Manhattan Indians for sixty guilders (twenty-four dollars) for the Dutch West India Company.

The Dutch named their colonies in America "the New Netherlands," and the settlement on Manhattan Island, New Amsterdam. These names were changed by the English, who obtained possession of the Dutch Colonies in 1664, the town on Manhattan Island being called New York, in honor of the Duke of York, the brother of Charles II., who had obtained a grant of all the land from the west side of the Connecticut River to the east side of Delaware Bay.

From the simple trading post established by the Dutch, the settlement grew steadily, at first slowly and then with rapid strides, and ranks now among the largest cities of the world. The growth of the population of the city of New York is shown by the following table, the population from 1790 to 1890 being taken from the records of the United States Census Bureau:

POPULATION OF THE CITY OF NEW YORK.

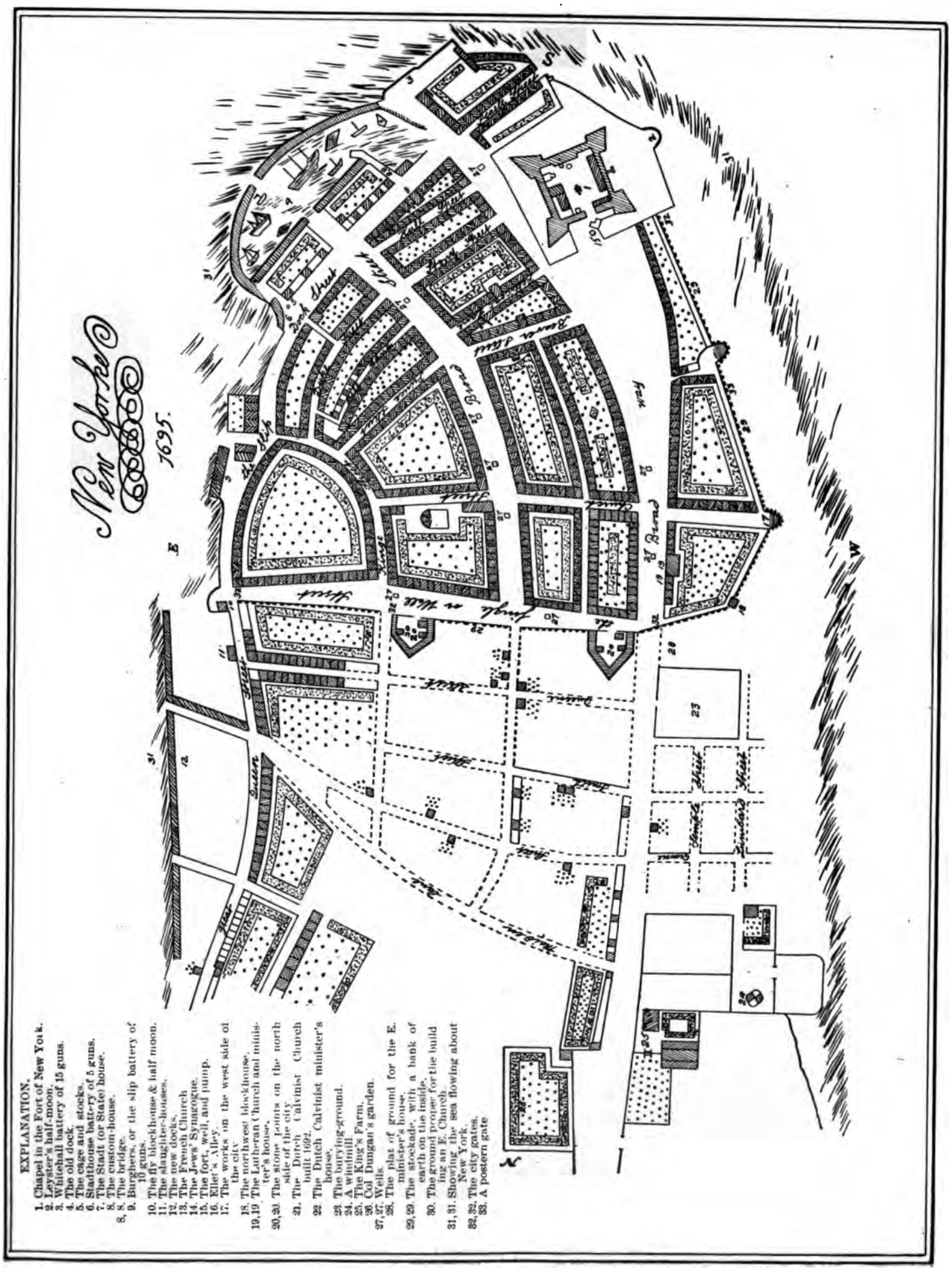
Year.	Population.	Year.	Population.
1664	1,500	1830	197,112
1697	4,302	1840	312,710
1756	13,040	1850	515,547
1790	33,131	1860	805,658
1800	60,489	1870	942,292
1810	96,373	1880	1,206,299
1820	123,706	1890	1,515,301

Manhattan Island and the neighboring mainland are formed principally of gneiss and mica-schist rock. When the island was discovered by the Dutch, the southern part consisted of wood-crowned hills, grassy valleys, and a chain of swamps extending from the Hudson to the East River. Wild fruit and flowers grew in abundance in the fields; the brooks were full of fish, and the woods of game. A deep fresh-water pond, fed by numerous springs, occupied the space where now stand the Tombs and the surrounding buildings (see Plate 3). The Dutch called this pond Kalch-Hook (Shell-Point), a name originally applied to a point of land on the shore of the pond, containing about forty-eight acres, which was the site of an old Indian village. The name owed its origin to the large quantity of decomposed shells found there. It was corrupted by the English into "Collect." Most of the early projects of furnishing the city of New York with water involved this pond as the source of supply.

The northern part of the island was rocky and covered with dense forests. It rose to a height of 238 feet above the Hudson River.

The early settlers of Manhattan Island obtained water for domestic purposes from shallow wells, by means of buckets, raised by ropes and pulleys, or by long balance-poles. The water thus procured was generally found to be soft and sweet, except near the shores of the island, where it was rendered brackish by salt water percolating through the ground. The

PLATE 2.


New Yorke
1695.
EXPLANATION.
1. Chapel in the Fort of New York.
2. Leyster's half-moon.
3. Whitehall battery of 15 guns.
4. The old dock.
5. The cage and stocks.
6. Stadthouse battery of 5 guns.
7. The Stadt (or State) house.
8, 8. The custom-house.
9. The bridge.
9. Burghers, or the slip battery of 10 guns.
10. The fly blockhouse & half moon.
11. The slaughter-houses.
12. The new docks.
13. The French Church
14. The Jews' Synagogue.
15. The fort, well, and pump.
16. Eliet's Alley.
17. The works on the west side of the city.
18. The northwest blockhouse.
19, 19. The Lutheran Church and minister's house.
20, 20. The stone joints on the north side of the city.
21. The Dutch Calvinist Church built 1692.
22. The Dutch Calvinist minister's house.
23. The burying-ground.
24. A windmill.
25. The King's Farm.
26. Col. Dongan's garden.
27, 27. Wells.
28. The plat of ground for the E. minister's house.
29, 29. The stockade, with a bank of earth on the inside.
30. The ground proper for the building an E. Church.
31, 31. Showing the sea flowing about New York.
32, 32. The city gates.
33. A postern gate

first wells were constructed entirely by individual enterprise. A few years after the city of New Amsterdam (New York) was incorporated public wells were sunk in the middle of the most important streets and furnished water for domestic use and for extinguishing fires.

The first step to obtain a public well was taken by Burgomasters Oloff Stevensen Van Cortlandt and Paulus Leendersten Van der Grist, on July 11, 1658, when, according to the city records:

"The Burgomasters resolved to communicate with the Herr General relative to having a public well made in the Heere Straat" (the gentlemen's street, the present Broadway).

No further reference to this matter occurs in the Records. It appears, however, that a public well was dug about this time (probably in accordance with the above request) in front of the old fort, which was situated just south of the present Bowling Green. This was the only public well until 1677, when, on February 27th, the Burgomasters and Schepens "Ordered that several wells be made in the places hereafter mentioned (for the public good of the city) by the inhabitants of each street where said wells shall be made, viz.—[Here follows the description of the location of six wells]—and that the several inhabitants take notice of this order and put the same in execution with all possible speed, as they will answer the contrary at their peril." The location of these wells, of two others constructed later, and of the one in front of the fort is shown on the map on Plate 2.

Additional public wells were sunk from time to time, as required, the city bearing part of the expense, and the balance being assessed on the property benefited. The later wells were dug, however, at the street-corners instead of in the centre of the street. Pumps gradually replaced the primitive buckets. The charge of all the public wells of each Ward was given to its Alderman and Common Councilman.

As the population of the city increased, the well-water became much polluted by organic matter and insufficient in quantity. This was especially the case in the densely populated districts. In order to obtain pure water, in those days, the citizens sent often to a great distance to wells reputed to furnish water of superior quality. One of the most famous wells, situated in a hollow near the junction of the present Chatham and Roosevelt streets,* was known as "the Old Tea-water Pump." The first mention of this well is found in the diary of a traveller, who wrote in 1748 about New York: "There is no good water in the town itself, but at a little distance there is a large spring of good water, which the inhabitants take for their tea, and for the uses of the kitchen. Those, however, who are less delicate on this point make use of the water from the wells in town, though it be very bad."

Shortly before the Revolution, a pump was placed over this famous spring and ornamental grounds laid out. The "Tea-water Pump Garden" became soon a famous resort where tea and stronger beverages could be obtained. The street in the vicinity of the pump became so much obstructed by the water-carts of rich and fastidious persons, waiting for their turn at the pump, that the Common Council ordered in June 1797 that the spout of the pump be sufficiently raised and lengthened to permit pedestrians to pass under it.

The water from the wells in the densely populated districts became so bad that it was sickening to strangers. As it deteriorated rapidly when stored in tanks, the supply for the

* See Plate 3.

ships in the harbor was generally obtained from creeks on the neighboring mainland. Hogsheads of water from such sources were brought to the city as a profitable cargo.

Besides being objectionable in quality the water obtained from wells was found to be insufficient in quantity for the growing wants of the community and the citizens sought, therefore, more ample sources of supply.

As early as 1774, when New York had a population of only 22,000, Christopher Colles,* an English civil engineer, made to the Common Council a proposal for constructing water-works. His proposition was to construct a large reservoir on Manhattan Island, into which water was to be pumped from wells by means of a steam-engine, and to distribute the water from the reservoir by pipes laid in the principal streets.

The Common Council accepted Mr. Colles' proposal in July 1774, and on the 8th of August passed the following resolution:

"Ordered, That the northerly part of the property of Augustus Van Cortlandt and Frederick Van Cortlandt, fronting on Great George Street, [now Broadway] be purchased at £600 per acre, for a reservoir, provided, that on sinking a well there, good water be found. If not, the well to be filled up by the Corporation."

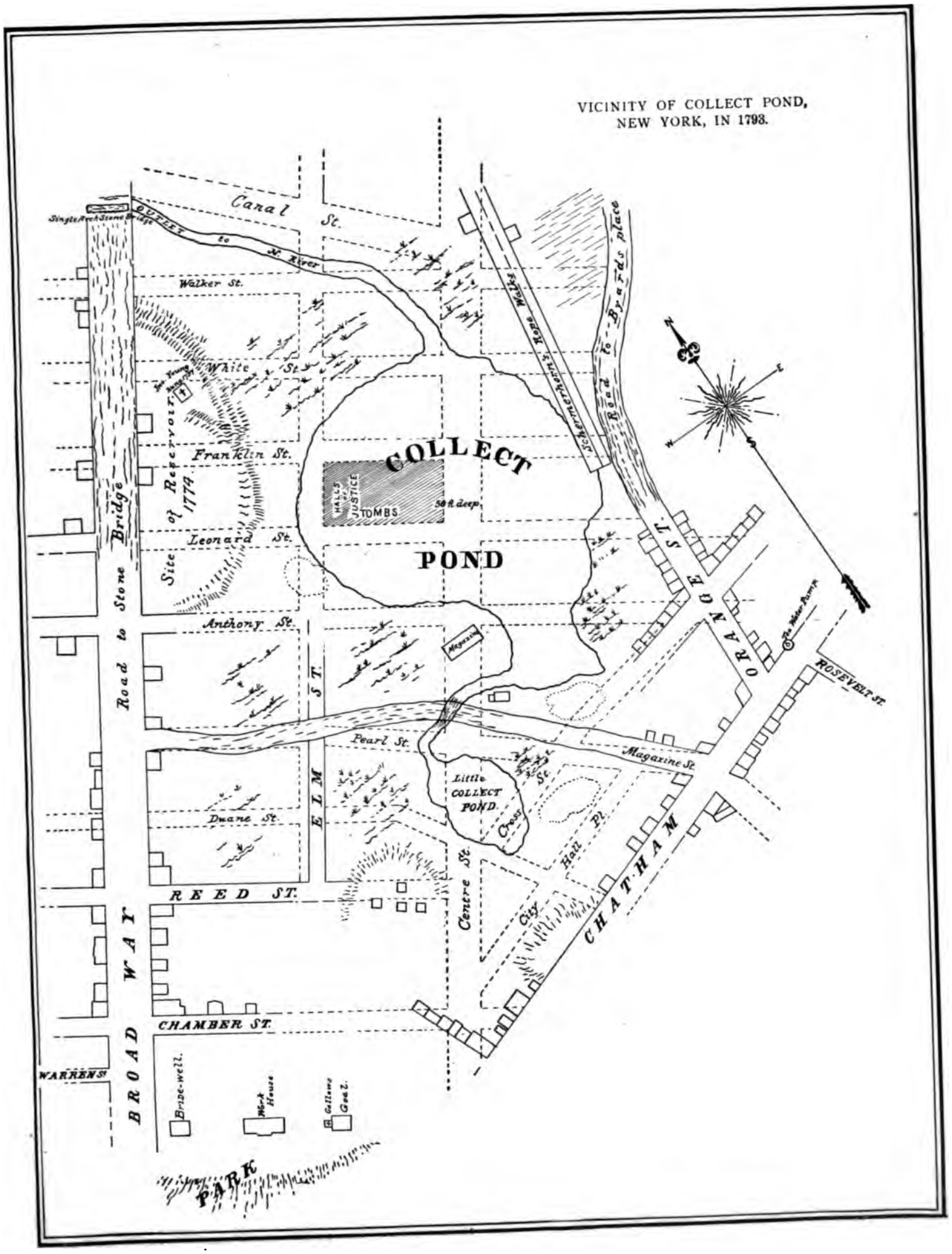
The quality of the water proving satisfactory, 1¾ acres of land were bought of the Van Cortlandts for £1050, the deeds being signed on October 8, 1774. A spacious reservoir was constructed on this property on the east side of Broadway (see Plate 3) between the present Pearl and White streets. A large well was sunk near the "Collect," a fresh-water lake fifty feet deep. Additional wells were dug subsequently and some water was pumped directly from the "Collect."

To defray the expenses of the work and to pay for the land purchased, bonds bearing 5% interest and paper bills, denominated Water Works Money, were issued to the amount of £11,400. From the fac-simile of one of these paper notes, given on page 5, some idea can be formed of the kind of machinery which Mr. Colles intended to employ for the pumping. The engine shown on the back of the note represented undoubtedly one of Newcomen's Atmospheric Engines, a machine that had been largely used in Europe, from the beginning of the century, for pumping water from mines. One of these engines had been imported in 1760 by the owners of the old copper mines near Belleville, New Jersey.

In 1776 the works were put in operation, Mr. Colles being made the Superintendent. The water was distributed through hollow logs, laid in the principal streets. Owing, however, to the insufficient supply furnished, and the confusion caused by the Revolution, the whole enterprise was soon abandoned.

Soon after the restoration of peace, the citizens of New York agitated again the question of obtaining an adequate water-supply. Various plans were proposed for this purpose from 1785 to 1798, most of them involving the "Collect" as the source of the supply. The

* Christopher Colles, an accomplished civil engineer, linguist, and man of science, was born in Ireland of English parentage in 1738. He came to America in 1765; lectured on canal navigation in 1772, published a series of sectional road maps, assisted almanac-makers in their calculations, and engaged in manufacturing printer's colors and paper boxes. Although highly esteemed by men of science and at one time Actuary of the Academy of Fine Arts, he died in comparative obscurity in New York in 1821.


VICINITY OF COLLECT POND,
NEW YORK, IN 1793.
Canal St.
OUTLET to N. River
Single Arch Stone Bridge
Walker St.
White St.
Franklin St.
Site of Reservoir 1774
Leonard St.
Anthony St.
Road to Stone Bridge
COLLECT
POND
HALLS OF JUSTICE
TOMBS
50 ft. deep
Magazine
Pearl St.
Little COLLECT POND
Cross St.
Hall Pl.
City
Centre St.
Duane St.
ELM ST.
REED ST.
CHAMBER ST.
WARREN St.
BROAD WAY
CHATHAM
ORANGE
ROSEVELT St.
Magazine St.
Road to Bayards place
Schermerhorn's Hook Walks
Bridewell.
Work House
Gallows
Gaol.
PARK

records of the Common Council show that Samuel Ogden made proposals to the Corporation for constructing water-works in April 1785, and that Hon. R. R. Livingston made a similar proposition in January 1786. The Common Council considered these projects in February 1786, and finally decided to advertise for proposals for supplying the city with water. This was done, and in April three sealed bids for the above object were received. It would seem,

FIG. 1.

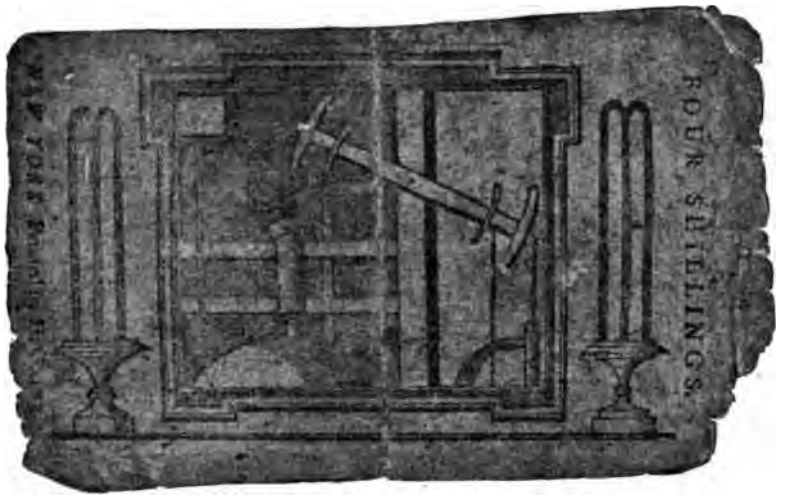


FIG. 2.

PAPER MONEY ISSUED FOR WATER-WORKS OF 1774.

however, that some of the citizens must have manifested a strong opposition to the idea of having the water-supply furnished by private parties, for we find that the Common Council adopted the following resolution:

"Ordered, That the proposals remain unopened with the clerk until the further order of the Board, or that they be returned at the option of the parties offering them.

"Ordered further, That the Aldermen and Assistants be requested to set on foot, in their respective Wards, representations to this Board, in writing, and subscribed by the citizens, in

order, more fully, to ascertain their sense, whether the Corporation ought to grant to individuals, the privilege of supplying the City with water, or whether the same ought to be undertaken by the Corporation, and that the moneys necessary for the purpose should be raised by tax on the citizens."

What the results of these proceedings were does not appear in the records, nor can we find any details of the plans mentioned above.

In February 1788 a petition signed by a great many citizens complaining of the insufficiency of the water-supply and requesting that either the plan of Mr. Colles or some other scheme be adopted was presented to the Common Council, but led to no practical results.

In January 1789 a committee of the Rumseian Society of Philadelphia informed the Common Council that Mr. Rumsey was perfecting an engine especially adapted for supplying towns with water. This company was invited by the Board to make a proper proposal to the city of New York for furnishing the water-supply, but does not appear to have done so.

After various additional propositions had been made to the city—viz., by Zebina Curtis in February 1794, by Amos Porter in March 1795, by Benjamin Taylor in April 1795, and by Sayrs Crane, who proposed, in March 1795, to lead water from the "Tea-water Pump" through Roosevelt Street, a committee of the Common Council was directed on February 1, 1796, to advertise for sealed proposals for supplying the city with water. This was done in January 1797, and, in response, seven different offers were received in the following May, one being from Christopher Colles, the constructor of the works of 1774. Some additional proposals were received later and, also, a "Memoir of the utility and means of furnishing the city with water from the river Bronx," by Dr. Joseph Browne, dated July 2, 1798.

Dr. Browne argued forcibly that the water to be obtained on Manhattan Island was entirely inadequate in quantity for the growing wants of the community, and that it was, moreover, so much contaminated by organic matter as to cause many contagious diseases, including the yellow fever from the ravages of which the inhabitants had just recovered. As the presence of carbonic acid from decaying matter made the water sparkling and palatable, it was very difficult to convince the citizens that this water contained the germs of diseases. With reference to the "Collect" Dr. Browne stated:

"The large stagnating, filthy pond, commonly called the Collect, which now is, or soon will be, the centre of the city, has been looked to by some of the people as a fund from whence an adequate supply might be obtained, by means of a steam-engine, for the purposes already spoken of. I cannot undertake to say that this source would at present be incompetent to all the preceding purposes for which a supply of water is wanted; but if the quantity naturally discharged from this pond be the whole that is furnished by its springs, then I might say with propriety, it is infinitely too small for those uses. But admitting that at present it might be competent, the time will come, and that very shortly, from the growth of the city, when this source will most certainly be very inadequate to the demand. And again, supposing the pond to contain and furnish enough, it is a consideration well deserving attention, whether a pond, into which the filth from many of the streets must, without very great

expense and care, be constantly discharged, and to which the contents of vaults, etc., will continually drain, is a desirable source from whence we should like to take water for drinking, cooking, etc., without taking into account its noxious qualities, medically considered; although it may be laid down as a general rule that the health of a city depends more on its water than on all the rest of the eatables and drinkables put together."

Dr. Browne recommended the Bronx River as the proper source of the water-supply of the city. The manner in which he proposed to obtain the supply was as follows:

To construct a dam, five feet high, across the Bronx at West Farms (see Plate 30) about half a mile below Williamsbridge, whereby the whole water of this river might be turned through a canal, 400 yards long, into Morrisania Creek and thus into the Harlem River, at a point eight miles distant from the old City Hall (in Wall Street). Here part of the water was to be used to turn a water-wheel twenty feet in diameter, working four 6-inch force-pumps. By this arrangement 362,800 gallons were to be pumped daily through a cast-iron pipe to a reservoir on Manhattan Island, to be located about five miles from the city. The surface of the reservoir was to be about eighty feet above high tide. The water was to be conveyed to the city through a line of 6-inch cast-iron pipes.

Dr. Browne estimated the total cost of the necessary works, including twenty miles of distributing pipes and two public fountains, at $200,000. He considered a daily supply of 300,000 gallons ample for the wants of the city at the time, and estimated that the minimum flow in the Bronx at the site of the proposed dam amounted to about ten million gallons per day.

On December 12, 1798, the Common Council received two additional propositions for supplying the city with water, one from Nicholas S. Roosevelt and the other from Judge Cooper, of Otsego. The committee to which the various proposals received had been referred reported to the Common Council on December 17, 1798, as follows:

"The Committee appointed to investigate the subject of supplying the city with water report

"That being impressed with the importance of the subject, they have considered it with all the care and attention in their power, and incline to the opinion that the Bronx River will afford a copious supply of pure and wholesome water. They incline also to think that the plan suggested by Dr. Jos. Browne, for conveying the waters of that river, is, with some few variations, the most eligible that can be adopted. But as any mistakes in the plan or conduct of the business, may be attended with incalculable mischief, they would recommend that Mr. Weston,* who has been the engineer of the Canal Companies in this State, and whose abilities are well known, be requested to examine that river, with the situation of the grounds to be employed in the aqueduct, and such other matters incident to the supply of the city with pure and wholesome water from that or any other source, as he may think proper, and that he be requested to report his opinion to the Corporation, with the requisite plans and estimates, as soon as may be practicable.

* A British engineer, who had been in charge, in 1792, of the improvements around Little Falls, in the Mohawk Valley, for the Western Inland Lock Navigation Company.

"Your Committee further report, That they have considered the several matters which have been suggested for the execution, either by individuals or by the Corporation, of the plan that may be finally adopted. They are sensible that each of these methods is attended with difficulties, but considering the immense importance of the subject to the comfort and health of their fellow citizens, that it will not be undertaken by a company unless with the prospect of considerable gain, and that such gain must be acquired at the expense of the city, your Committee have at length agreed that the undertaking ought to be pursued by, and under the control of, the Corporation, as the immediate representatives of the citizens in general.

"Under this impression, and to avoid any further delays which may arise, unless measures are taken to prevent pecuniary embarrassments, and other difficulties in the course of the business, your committee would recommend that an act be prepared and presented to the Legislature, investing the Corporation with the powers necessary to effect the great end they have in view, and granting them the moneys arising from the tax upon the sales at auction, in said city, with such further aid as the Legislature may think proper, to enable them by the reception thereof, or by loans founded thereon, to defray the expenses incident to the undertaking.

"New York, December 17, 1798."

"JNO. B. COLES,
"GABRIEL FURMAN,
"JNO. BOGART,
"JACOB DE LA MONTAGNE."

This report was accepted, a bill embodying its recommendations was prepared for the Legislature, and 500 copies of the proceedings of the Board and of Dr. Browne's project of water-supply were ordered to be printed in pamphlet form. Mr. William Weston, the civil engineer mentioned in the report, was engaged by the Mayor and proceeded at once to study the proposed plan of water-works. It seemed indeed as though the problem of securing a proper water-supply for the city would receive at last a practical solution.

On March 16, 1799, Mr. Weston presented to the Mayor a written report of his conclusions with reference to a water-supply for the city.

The first question considered was the probable quantity of water required daily for all purposes, including the sprinkling of the streets. As the engineer in those days had no published statistics to guide him in this matter, the manner in which Mr. Weston estimated the amount of water to be delivered may be of interest. We quote from his report as follows:

"I have endeavored to calculate as near as the want of sufficient data would enable me, the minimum quantity necessary to be introduced in twenty-four hours. Though conclusions deduced from hydraulic principles of the discharge of water issuing from pipes of given diameters, placed on the summits of the several streets, would have been much preferable to vague guesses; yet the infinite variety of cases, arising from different degrees of depression

below and distance from the principal reservoir, would have rendered the operation a very laborious one; and from a variety of causes, the result very uncertain. Indeed, every mode with which I am acquainted may be objected to on the latter principle; but though it is perhaps impossible to ascertain the exact truth, we must endeavor to approximate as near thereto as possible. Conceiving it to be the intentions of the gentlemen who have recommended the measure of washing the streets, as essential to the health of the citizens, to have a regular and plentiful current of water running at least twelve hours every day through all the streets, by means of pipes placed at the respective summits, producing an effect similar to what we may observe to be done by a moderate shower of rain of the same duration; calculating, therefore, the area of the city, the quantity of water usually descending in the time above mentioned, and making due allowance for such parts of the general surface as are pervious to water, we shall obtain a result that perhaps, on the whole, will be as near the truth as can be done by any other mode, and sufficient to answer every purpose required. I find that the area of the city bounded by the East and North rivers and the intersection of them by Grand Street is upwards of 750 acres; and making an allowance of 350 for public squares, gardens, and other unpaved surfaces, we have a remainder of 400 acres; which being impenetrable to the rain, all that falls on that surface must be discharged by means of the channels of the different streets into the adjacent rivers. I have made various inquiries, but have not as yet received any correct information of the quantity of water produced by a moderate shower of twelve hours' continuance. I am, therefore, under the necessity of assuming, as a fact, what may hereafter be proved to be erroneous; though I have reason to believe that my calculations will not be found to be overrated. Fixing, therefore, the depth, as shown by the rain-gauge, at one fourth of an inch, we shall find the total amount to be 363,000 cubic feet, or 2,221,560 ale gallons; and adding to this 778,440 gallons, as an adequate supply for domestic consumption, we shall have 3,000,000 of gallons to be introduced into the reservoir every twenty-four hours."

Having arrived at the quantity of water to be delivered daily, Mr. Weston considered next whence it was to be obtained. Only two of the various sources of supply that had been suggested seemed to him worthy of attention, viz., the Collect and the Bronx River. Public opinion favored the former on account of the superior coolness of its water and its proximity to the city, but Mr. Weston considered the water that might be obtained from this source as insufficient in quantity, its quality doubtful and sure to deteriorate in the future. The plan of supplying a city with water from a pond in its centre seemed to him very objectionable.

As regards the Bronx River, Mr. Weston felt confident that it could be depended upon, even in the driest seasons, to furnish an ample quantity of pure water by gravity alone. The plan recommended for obtaining this supply was as follows:

1st. To convert the two Rye Ponds (see Plate 30), the principal sources of the Bronx River, into a storage reservoir, having an area of about 600 acres and a storage capacity of about 960,000,000 gallons, by dams which would raise the surface of the ponds six feet. Some of this water would be required for the city's supply during dry seasons, and the balance

could be allowed to flow to the mills, reducing thus the damages to be paid for the water rights.

2d. To construct a dam across the Bronx River a short distance above Mr. Lorillard's snuff-mill, diverting thus a portion of the water flowing in the Bronx. It was to be conveyed to the Harlem River in an open canal having a grade of six inches per mile and a cross-section of about 10 square feet. This canal was estimated to deliver about six cubic feet of water per second into a small reservoir to be constructed at the Harlem River. From here the water was to be conveyed through an inverted siphon, formed of cast-iron pipes, two feet in diameter, to a reservoir on Manhattan Island. Eight feet head was to be allowed to force the water through this siphon.

3d. The water was to be filtered in the last-mentioned reservoir and then to be conducted, part of the distance in open canal and part in cast-iron pipes, to a distributing reservoir near the city. The total length of the conduit from the dam across the Bronx to the distributing reservoir was to be about 14 miles.

As no accurate surveys had been made for the proposed works, no estimate of the probable cost was presented in the report.

The Common Council adopted Mr. Weston's plans and appointed a committee to investigate the subject more fully. It also had two bills prepared and submitted to the Legislature: one granting the city of New York the necessary powers for constructing waterworks; and the other establishing regulations for improving the sanitary condition of the city. A strong opposition to the former bill arose at once, partly from prominent citizens such as Alexander Hamilton and Gulian Verplank, who thought the city ought not to engage in any enterprise the revenue of which was uncertain, partly from Aaron Burr and other influential gentlemen, who wished to profit by the situation by advancing a scheme of their own.

On February 25, 1799, the Mayor, Richard Varick, informed the Common Council that Aaron Burr, a member of the Assembly, John Murray, President of the Chamber of Commerce, Gulian Verplank, President of the New York Office of Discount and Deposit of the Bank of the United States, Peter H. Wendover, President of the Mechanics Society, Major-General Alexander Hamilton, and John Broome, had called on him, according to an appointment made by Mr. Burr, and had stated to him, in the presence of the Recorder, that great difficulties had arisen in the minds of members of the Legislature, regarding the powers requested to be vested in the Common Council by the proposed bill for supplying the city with water, and also by the bill investing this Board with adequate powers in relation to certain important sanitary matters, and that it was doubtful whether those bills would pass in the proposed form. Under these circumstances Mr. Burr and the gentlemen accompanying him suggested the propriety of the Common Council requesting the Legislature, in case the above-mentioned bills were not deemed proper in form, to make such provisions on the several subjects thereof as should appear desirable.

The conversation reported by the Mayor having been of an informal nature, the Common Council passed resolutions requesting Mr. Burr, General Hamilton, and their associates to

submit a written statement of the difficulties which had arisen in the Legislature with reference to the two bills in question and of such propositions as they wished to submit in this connection. In response to this request General Hamilton sent the Common Council, on February 26th, a lengthy written communication on the subject of the two bills, in which he recommended, on account of the uncertain profits which might result from introducing water in the city, that a private corporation be chartered for the purpose, the city being granted the privilege of subscribing for one third of the capital stock of said company.

The effect of the opposition of the prominent citizens, mentioned above, to the city's constructing water-works was that the Common Council passed on February 28th a resolution requesting the Legislature to make such laws as might be deemed proper for accomplishing the introduction of an ample water-supply and the improvement of the sanitary condition of the city. This removed the chief obstacle in the way of Aaron Burr's scheme, which was to obtain a charter for a new bank. At that time there were only two institutions of this character in the city, viz., the Bank of New York, and a branch of the United States Bank. Both were under the control of the Federalists, and it was charged that they were influenced in making discounts, to a considerable degree by politics. Burr determined to found a bank for the Republican (i.e. Democratic) party. The great prejudice against banks existing then, and the opposition of the Federalists in the Legislature, made it, however, almost impossible to obtain a charter for a new bank. Aaron Burr succeeded nevertheless, by using his influence as a member of the Assembly, in obtaining a perpetual charter for a bank, disguised as a water company. He accomplished his purpose by an adroit use of the pressing need of a better water-supply for the city of New York, which had been brought into prominence by the ravages of the yellow fever.

On April 2, 1799, the Legislature passed "An Act for supplying the city of New York with pure and wholesome water," whereby Daniel Ludlow, John B. Church, Aaron Burr, and several other citizens were incorporated as the Manhattan Company (known now as the Manhattan Bank). The capital stock of the company was not to exceed two million dollars divided into shares of fifty dollars each. The city of New York was permitted to subscribe for two thousand shares of the capital stock and availed itself of this privilege. The water was to be introduced into the city within ten years of the passage of the Act. The water-rates were to be agreed upon between the Manhattan Company and the water-consumers.

The eighth clause of the charter, which attracted but little attention at the time, was really the most important one. It reads as follows:

"And be it further enacted that it shall and may be lawful for the said company to employ all such surplus capital as may belong or accrue to the said company in the purchase of public or other stock, or in any other moneyed transactions or operations not inconsistent with the constitution and laws of this State or of the United States, for the sole benefit of the said company."

Availing itself of the powers conveyed by the above clause, the Manhattan Company formed a powerful bank, the real object of the incorporators. Only enough was done in introducing water to maintain the charter.

That the Legislature expected the Manhattan Company to obtain an ample water-supply from the Bronx River or some other stream is evident from the wording of the charter, which granted said company the right "to erect any dams or other works across or upon any stream or streams of water, river or rivers, or any other place or places, where they shall judge proper for the purpose of raising such stream or streams, or turning the course thereof, or of making use of such streams, rivers, or places for constructing or working of any necessary engines, and to construct, dig, or cause to be opened any canals or trenches whatsoever for conducting of such stream or streams or any other quantity of water from any source or sources that they may see fit."

Instead of obtaining an ample supply from the Bronx or some other stream, the Manhattan Company sunk a large well, twenty-five feet in diameter, at the corner of the present Reade and Centre streets,* in a thickly populated part of the city, and pumped water into a

FIG. 3.—CHAMBERS STREET RESERVOIR.

reservoir on Chambers Street (see Plate 4 and Fig. 3). From here the water was distributed through hollow logs.

Figs. 4, 5, and 6, taken from an old work on hydraulics, show the manner in which the wooden pipes were usually joined.

Among the valuable grants obtained by the company was the ground on which stood the reservoir constructed by Christopher Colles in 1774. How little was done towards

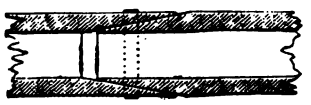


FIG. 4.

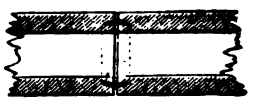


FIG. 5.

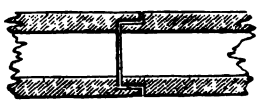


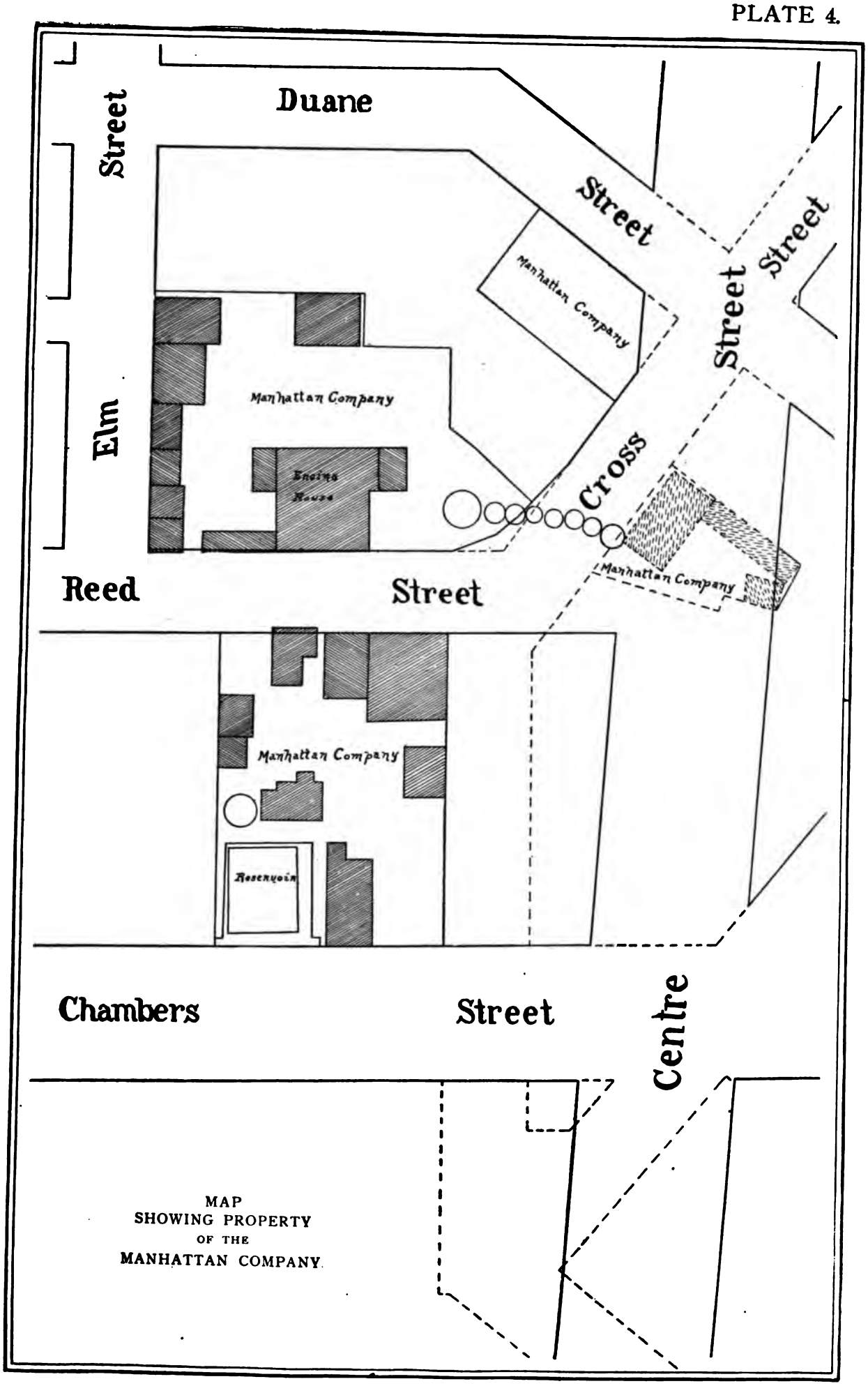
FIG. 6.

WOODEN PIPES.

furnishing an ample water-supply is shown by a circular signed by John Lozier, Esq., in 1823, from which it appears that up to that time the Manhattan Company had only laid twenty-three miles of water-pipes, mostly of wood. Its works consisted of the large well mentioned above, from which two steam-engines, of eighteen horse-power each, pumped 691,200 gallons per day into the Chambers Street reservoir, which had a capacity of about 550,000 gallons. The pumps were operated only sixteen hours each day.

* To maintain its charter the Manhattan Company is still pumping water from this well into a stone reservoir about fifty feet in diameter, located at the northwest corner of Reade and Centre streets.

PLATE 4.



MAP
SHOWING PROPERTY
OF THE
MANHATTAN COMPANY.

For more than thirty years the citizens of New York submitted patiently to the unsatisfactory water-supply furnished by the Manhattan Company. Some more projects were proposed and considered, and the Common Council took some steps in 1807 to get the Manhattan Company to cede its works and privileges for supplying water to the city, and appointed in 1816 a committee "to consider and report upon the propriety of making an application to the Legislature at their present session, to invest the Mayor, Aldermen, and Commonalty of the city with all necessary powers and authority to supply the city with water"; but all these efforts led to no practical results.

In August of 1819 Robert Macomb presented to the Common Council a memorial in which he made a proposal for furnishing the city with water from the Bronx River, and asked that a committee be appointed to confer with him on this subject. This request was granted, and after a proper investigation Mr. Macomb and his associates were given the privilege, under certain restrictions, of bringing water from the Bronx River to a reservoir on Manhattan Island, and to lay the necessary pipes in the streets and roads of the city for distributing the same. Mr. Macomb's plan contemplated taking water from the Bronx River at its junction with Mill Brook, conducting it through this brook and then through a deep cut to the valley of the Morrisania Creek, and down this creek to the Harlem River at Macomb's Dam,* where the water was to be pumped to a reservoir on Manhattan Island. For reasons which do not appear in the records this project was never carried out.

In December 1821 the question of water-supply was again considered by the Common Council, and a committee, having the Mayor, Stephen Allen, as chairman, was appointed to inquire into the best means of obtaining water for the city, with authority to spend $200 in procuring plans and estimates. After making a general examination of the Bronx River and the surrounding country, the committee reported on April 1, 1822, the results of its observations, and recommended that $500 be appropriated for a survey and estimates of cost for a water-supply from the Bronx River to be made by a competent engineer. This suggestion was approved by the Common Council, and Mr. Canvass White † was selected as the engineer for the above purposes. Before he had completed his investigations, some new water schemes turned public attention from the Bronx River project and produced new delays.

It was proposed, namely, to construct from the Housatonic River to the City of New York, a canal which should serve for navigation and also for supplying the city with water. An Act of Incorporation was obtained by some citizens of Connecticut for this enterprise, but the project was soon superseded by another scheme consisting in the construction of a similar canal from the Oblong River at Sharon, in the State of Connecticut, to New York. This canal was to be fifty miles long and was to reach the Harlem River at an elevation of ninety-seven feet above high water. The citizens of Dutchess, Putnam, and Westchester counties, in the State of New York, and those of the western part of Connecticut were

* Macomb's Dam was constructed across the Harlem River near Eighth Avenue, in accordance with an Act of the Legislature of 1813. The action of the tides was utilized by means of this dam to drive water-wheels. An opening in the dam was to be maintained for navigation, but this matter was neglected and the dam was finally removed.

† For biographical sketch see page 235.

greatly interested in this project. The plan was submitted to the Corporation of New York by General Ward, of Westchester County, on March 10, 1823, and was approved by the Common Council, which sent a memorial to the Legislature, asking that the projectors be given a charter. This was granted; but, owing to an expensive lawsuit, to the difficulty in raising the necessary means, and to mismanagement, this project, like so many preceding ones, was abandoned.

In January 1824 Mr. Canvass White presented to the Mayor and Common Council a written report of his investigations of the feasibility of obtaining a water-supply for the city from the Bronx River. He stated that he was fully convinced that a minimum daily supply of 3,000,000 gallons could be obtained directly from the Bronx, and that this quantity could be increased to 6,600,000 gallons if storage reservoirs were constructed. For this purpose he recommended that a dam be built across the outlet of the two Rye Ponds, converting them into a large reservoir.

Assuming a daily supply of 27 gallons per capita as ample for all purposes, including manufactures and street-sprinkling (as shown by experience in Philadelphia), Mr. White concluded that the city could be fully supplied with water from the Bronx River for many years. When this source should become insufficient, an additional supply could be obtained by conducting part of the water of the Byram River through a canal and tunnel to the Rye Ponds, or by leading some of the water of the Sawmill River through an open cut, having a maximum depth of eight feet, to the Bronx. Mr. White tried to find some means of connecting the Croton with the Sawmill River, but in this he was unsuccessful, and concluded that the only way of using the Croton River for the water-supply of New York was by building an aqueduct along the Hudson River.

Four plans for obtaining a supply from the Bronx were presented in the report. For the first two a dam was to be built across the Bronx River near Williamsbridge, and part of the water flowing in this stream was to be conveyed by an open canal to a small reservoir, to be constructed near the Harlem River, at Macomb's Dam. Here the water was to be pumped, by utilizing the action of the tides, to a receiving reservoir on Manhattan Island, whence it was to be conducted through a line of 30-inch cast-iron pipes to a distributing reservoir near the city. Between the receiving and distributing reservoir on Manhattan Island two others were to be constructed to insure a greater amount of head on the pipe-line.

The difference between Plans No. 1 and No. 2 was principally in the location of the canal to the Harlem River and in the height to which the water had to be pumped.

Plans No. 3 and No. 4 were for a gravity supply, the water being taken from the Bronx at the Pond of the Westchester Cotton Factory (see Plate 30), which by means of a dam was to be raised six feet, to an elevation of 62 feet above the park at the City Hall.

One of the requirements given to Mr. White was to deliver the water at this park with a head of 30 feet. There were, therefore, 32 feet of "available head" for Plans No. 3 and No. 4. In the former, the water was to be conveyed to the Harlem River in a brick conduit having a diameter of about five feet; in the latter, in an open canal. The distance from the

"intake" at the pond to the Harlem River was about twelve miles on the locations adopted for Plans Nos. 3 and 4. One foot grade per mile was allowed both for the brick conduit and for the open canal. The water was to be conveyed across the Harlem River and to a distributing reservoir near the city substantially as in Plans Nos. 1 and 2. A line of iron pipe was to connect the distributing reservoir with the reservoir of the Manhattan Company in Chambers Street.

The estimates presented for the cost of constructing the proposed works were:

Plan No. 1	$953,011 95
" " 2	921,711 00
" " 3	1,949,542 65
" " 4	987,535 95

Mr. White recommended decidedly that one of the plans for a gravity supply be adopted. Another civil engineer, Mr. Benjamin Wright, who was consulted by the Mayor and Common Council with reference to the supply from the Bronx. presented at the same time a report agreeing with the views of Mr. White.

The New York Water-works Company was incorporated in 1825 to carry out Mr. White's plan, this gentleman being appointed its chief engineer. It appeared, however, very soon that the charter of the company was very defective and conflicted with those of the Sharon Canal Company and of the Manhattan Company. The Water-works Company was therefore finally dissolved in 1827.

As all the attempts to bring water from distant sources had thus far failed, the Common Council looked once more nearer home for a supply, and appointed in March 1826 a committee to inquire whether "water of the best quality, and in quantity sufficient to supply the wants of the city, could not be obtained from wells sunk, or to be sunk, on Harlem Heights." A fourth water company, called the New York Well Company, was incorporated by the legislature in 1827 to procure water on the high ground of Manhattan Island; but the company soon became satisfied by borings that water could not be obtained in this manner in sufficient quantity, and abandoned the undertaking.

About this time Levi Disbrow had been very successful in sinking artesian wells, for which work he had invented and patented improved tools. One boring, made by him for the Manhattan Company at the corner of Broadway and Bleecker Street (eight inches in diameter and 442 feet deep, lined with pipes from the top to the bottom in order to exclude impure water near the surface), is said to have yielded 120,000 gallons per 24 hours, but in some other cases the results were not so satisfactory.

Mr. Disbrow offered to supply the city with water from artesian wells, located in the different wards; but although the Corporation had some wells bored in the public markets and in Jacob Street, in the Swamp,—where at a depth of 128 feet a mineral water unfit for domestic use, but supposed at the time to possess good medicinal qualities, was obtained,—the proposal was rejected as unpractical, it being estimated that about two hundred artesian wells would be required for the city's supply, which would have to be obtained entirely by the expensive operation of pumping.

While all these schemes were being discussed the scarcity of water was making itself

felt, not only as an inconvenience, but as a serious danger in cases of fire. During the year 1828 about $600,000 worth of property was destroyed by fire. Salt water was used, where obtainable, to extinguish the flames, but was found to injure the goods and the fire-engines.

In March, 1829, Alderman Samuel Stevens (afterwards Chairman of the Water Commissioners) presented to the Common Council a strong report from the Committee on Fire and Water, urging that the city build a reservoir for fire purposes on the high ground at Broadway and Thirteenth Street, sink a well for filling the same, and lay two lines of 12-inch iron pipe, one down the Bowery to Chatham Square, and the other through Broadway and Canal Street. It appears from this report that as the Manhattan Company found it unprofitable to lay pipes in the upper part of the city, owing to the fact that the inhabitants there preferred the water from their comparatively pure wells to the supply furnished by that company from its down-town wells, but few water-pipes had been laid up-town. The Corporation had built forty public cisterns (each containing about 100 hogsheads and costing, on an average, $600) for supplying water in cases of fire. It was estimated that a wooden reservoir, containing 2000 hogsheads, could be constructed at a cost of about $1500.

The Common Council approved and carried out, though somewhat reluctantly, the plans suggested in this report. A reservoir was constructed at Thirteenth Street and Broadway (see Figs. 7 and 8) and filled from a well, by means of a steam-engine. This was the beginning of the public water-works of the city of New York.

FIG. 7.

The well from which the water was pumped had an inner diameter of 16 feet and a depth of 112 feet, 98 feet of which was excavated through solid rock. The elevation of the bottom of the well was 62 feet below high tide. Within 12 feet of the bottom of the well a gallery, six feet high, four feet wide, and seventy-five feet long, was driven on the east side. A similar gallery, having a branch 25 feet long, was excavated on the west side, the object of these galleries being to obtain more water and to furnish additional storage capacity in the well. The water rose ordinarily within 12 feet of the surface of the ground, the well and its galleries containing 175,150 gallons. The daily yield of the well amounted to 21,000 gallons. It is stated that the water in the well was originally soft, but became hard and unfit for domestic use when the horizontal galleries were excavated.

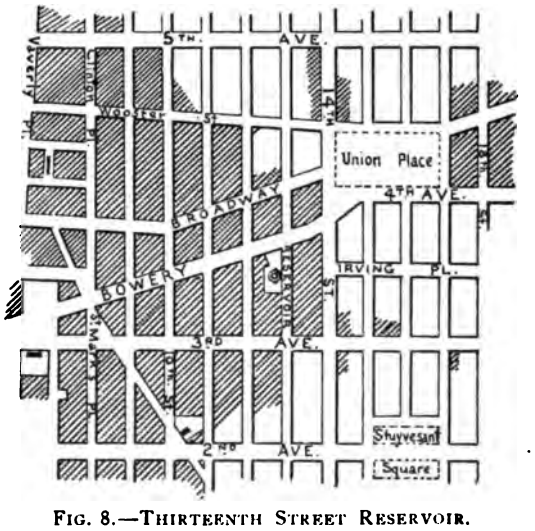


FIG. 8.—THIRTEENTH STREET RESERVOIR.

The water was pumped by a 12-H.P. steam-engine into a cast-iron tank, enclosed by an octagonal stone building having a height of 27 feet above the surface of the street. (See Fig. 7.) The tank had a diameter of 43 feet, a height of 20½ feet, and a capacity of 233,169 gallons. The bottom of the tank was

at an elevation of 83½ feet above tide. The water was conducted from the tank to the mains by curved pipes, 20 inches in diameter. The cost of the reservoir and well, including the steam-engine and the buildings, was $42,233. The operating and maintaining of the works cost about $3,165 per annum.

By the end of 1832 a line of 12-inch mains, having branches 10″ and 6″ diameter at various points, had been laid from the reservoir through 13th street, Third Avenue, Bowery, Chatham, Pearl, and William streets, and most of the pipes were delivered for a line of mains down Broadway.

The extent to which the city had carried on the pipe-laying up to January 1, 1833, was as follows:

CAST-IRON PIPES LAID AND DELIVERED UP TO JANUARY 1, 1833.

Size of Pipes.	Lineal Feet of Pipes Laid.	Lineal Feet of Pipes Delivered.
12-inch	20,194	9,464
10-inch	10,232	2,201
6-inch	4,220	775
Total	34,646	12,440

The pipes were cast in lengths of nine feet and had hubs 6 inches deep.

The cost of laying the pipes was as follows:

	Diameter of Pipes. 6 in.	10 in.	12 in.
Cost per lineal foot	$1.00	$1.70	$2.15

Early in 1830 a motion was made in the Common Council to request the Legislature to grant the city the necessary authority for constructing water-works and for raising $2,000,000 for defraying the cost of the same. This motion was lost, but had the effect of drawing public attention again to the important question of water-supply, and was thus the cause for new proposals for this object being presented to the Board. Among these we find a memorial from Mr. Francis B. Phelps, dated May 17, 1830, in which he suggests four sources of supply and gives estimates of the cost of conducting the water to the city, viz.:

1st. From Rye Ponds by means of a 28-inch iron pipe for the whole distance,—cost $2,600,000.

2d. From the Croton River (which seems here to have been proposed for the first time as the source of supply) by an open canal,—cost $1,834,000; or by iron pipes at a cost of $3,060,000.

3d. From the Passaic River, taking the water from above the falls at Paterson, and conducting it in iron pipes across the Hudson River,—cost $1,932,000.

4th. A preferred plan, which is not explained but seems to have involved wells on Manhattan Island,—cost $792,000.

None of these estimates were based upon actual surveys

In August 1830 Mr. John L. Sullivan, a well-known civil engineer, advocated, in a pamphlet addressed to the inhabitants of New York and presented to the Mayor, a plan for a water-supply from the Passaic River in New Jersey. Mr. Sullivan drew attention to the

great improvement in the healthfulness of the city of Philadelphia since an ample water-supply, amounting to two million gallons per day, had been introduced from the Schuylkill River. He stated that while, prior to this event, five thousand lives had been lost in 1793 in that city by the yellow fever, which raged from July to November, causing almost a total suspension of business, no difficulty had been experienced in keeping this epidemic within narrow bounds since an ample supply of water had been introduced.

New York, on the contrary, had suffered severely within a few years of 1830 from this dread disease, the money loss resulting in one summer from the stagnation in business on account of the yellow fever being probably greater than the amount required for constructing water-works for the city.

Mr. Sullivan dwelt, also, upon the possibility of New York being surpassed by its rival city, Philadelphia, which was making rapid strides in securing the trade of the middle and western states.

To accomplish the two objects of introducing an abundant supply of pure water, at a moderate cost, into New York and of furnishing this city also with a valuable means of communication, by which a large share of the western business might be secured, Mr. Sullivan proposed to construct a large ship canal from the falls of the Passaic River at Paterson to the Powles Hook Ferries at Hoboken. This canal was to cross the Hackensack River by means of an "aqueduct draw-bridge," of 60 feet span, a novelty in engineering, and to be brought through Bergen Hill by a tunnel a mile long. At Hoboken the canal was to terminate in one or two reservoirs, having their surface about 30 feet above tide-water.

Mr. Sullivan left it an open question whether all this water was to be conveyed to Manhattan Island, or whether part of it was to be used, to pump the balance of the water by means of turbine wheels, to a high reservoir at Weehawken, whence the water would flow to another basin on the New York side.

In either case the crossing of the Hudson River was to be effected in the same manner. The water was to be conveyed across the river by two lines of iron pipes, cast in lengths of ten feet, which were to be placed, at the bed of the river, on a pile foundation. Bents, each of two piles, were to be placed at regular intervals, the piles being sawed off by men working in a diving-bell, and capped with timbers which had been cut out to fit the roundness of the pipes. Four pipes were to be joined together on the deck of a twin boat and then lowered to their foundation, where they were to be moved to the proper position by men in a diving-bell. To enable these men to lead the joints, Mr. Sullivan invented a device which he had called a "coffre," and described as follows:

"The coffre is made in two halves, open at the top, divided lengthwise in the direction of the line of pipes. Its two opposite sides when brought together enclose the joint of the pipe in the coffre. The scallops of its ends form two circular holes which fit the pipe and their edges, and the joinings are made water-tight by leathers or other means, when the two halves are drawn together by their screw-bolt fastenings.

"The coffre is deep enough to reach sufficiently above the surface of the water in the diving-bell to be pumped out by hand-pumps, or by one above on deck, having a long

flexible tube from the pump to the coffre; which when thus emptied permits the men in the bell to reach the joint dry, and apply and hammer in the lead, and even with some precautions to cast it in.

"Thus may the pipes be laid secure and tight; and the same method permits of their being examined at any time should occasion arise."

From Paterson, where the canal was to terminate in a large basin, navigation was to be continued up the Passaic River and its branches. A connection was to be made with the Morris Canal and also with the Hudson and Delaware Canal. A railroad was to be constructed through Warren County, N. J., to Belvidere or to the Water Gap to meet the termination of the railroad chartered by Pennsylvania. By means of these connections a valuable communication with the greater part of Pennsylvania and with the West was to be obtained. The owners of the Passaic Falls were interested with Mr. Sullivan in this project, and no legal difficulties appear to have been apprehended about diverting water from one State for use in another. We have described this project fully (although it was never carried out), as it involved many interesting features which were not proposed by some enthusiastic schemer, but by an engineer of high standing in his profession.

In September 1830 the Common Council received proposals for supplying the city with water from Mr. Benjamin Wright. About the same time a paper, in which the inadequacy and impurity of the supply furnished by the Manhattan Company was pointed out, was presented to the Common Council.

As the result of this renewed agitation of the question of the water-supply, we find Alderman Samuel Stevens, whose forcible report in 1829 had led to the construction of the reservoir at Thirteenth Street, proposing the following resolution to the Board:

"Resolved, That the counsel of the Board prepare a memorial to the Legislature, setting forth the wants of the city in relation to a full and ample supply of water, as necessary for the safety of the city against fire, and to be of a pure and wholesome quality, as necessary for the preservation of the health and lives of our fellow citizens, and further setting forth that the Manhattan Company, although chartered in the year 1799, for the express and apparently sole purpose of furnishing the city with these inestimable blessings, have not, in the opinion of the Common Council, complied with the conditions of their charter, and stating that, under the circumstances, it has become necessary for the Corporation to do that which the Manhattan Company has failed to perform, and that the Common Council, finding that there exist powers in the acts relating to this company authorizing them to take by process of law all streams of water, and to divert watercourses from their natural channels, and also in like manner to possess themselves of other property, which, however, the Manhattan Company have wholly failed to use, therefore asking a repeal of the said powers now vested in said company, and the vesting exclusively all such powers for the purpose aforesaid in the Corporation of the City of New York, and further enabling the Corporation to raise by loans a sum not exceeding $2,000,000, for introducing an ample supply of pure and wholesome water."

This resolution was debated at the meeting of the Common Council held on February

28, 1831, but was lost, although the Board had received a petition signed by many brewers, complaining of the impurity of the Manhattan Company's water, and also a lengthy report from the Lyceum of Natural History in New York, in which it was clearly shown that a sufficient supply of water could not be found on Manhattan Island, and that the well-water which was then being used had become much polluted by organic matter.

The necessity of securing a proper water-supply for the city had become too pressing to be ignored much longer. Mr. Samuel Stevens, on behalf of the Committee on Fire and Water, in December 1831 presented to the Common Council a report in which all the suggestions for a water-supply received thus far were reviewed, and the conclusion finally reached that the source which united the most advantages was the Bronx River, which according to the gauging of engineer Canvass White could furnish, after the Rye Ponds had been dammed, 6,600,000 gallons per twenty-four hours.

The committee discussed in their report three ways of conveying the water to the city; viz., by an open canal, by an arched brick conduit, and by iron pipes. The first plan was not considered to protect the water sufficiently from contamination; the last plan was thought to be too expensive; so that a brick conduit was recommended as the best construction for the water-channel. It was estimated that in this manner an ample supply of water could be delivered, at a cost of $400,000, at the Harlem River, where the action of the tides was to be utilized to pump the water to a reservoir on Manhattan Island, located 120 feet above high tide. From here the water was to be conducted to the city by three lines of 12-inch iron pipes. The whole cost of the works, including the necessary land, was estimated by the committee, assisted by engineers Canvass White and Benjamin Wright, at $2,000,000.

The committee showed that the revenue which might be easily derived from the water-works would more than pay the interest on the money invested. As the membership of the Common Council was changing every year, the committee advised that the construction of the water-works be intrusted to a Board of Water Commissioners, who should be paid for their services. In conclusion the committee presented the draft of a bill for the Legislature, embodying the views they had expressed.

While the above report favored decidedly a supply from the Bronx River, we find appended to it a letter from Mr. Cyrus Swan, President of the New York and Sharon Canal Company, addressed to the Corporation, in which it was asserted that "a supply which shall be adequate to the present and future wants of the city" could only be obtained from the Croton River.

The Common Council approved the report and sent the proposed bill to the Legislature, but it failed to become a law, principally because the latter body was not willing to authorize the expenditure of what then seemed a very large amount of money until the practicability and probable cost of the project had been fully demonstrated. The proposed method of pumping by the action of the tides was considered especially objectionable, as being somewhat of an experiment.

Although the Common Council had again been unsuccessful in its efforts to secure a sufficient water-supply for the city, the investigations for this object were not allowed to

stop. The frightful ravages of the cholera from which the inhabitants suffered during the summer of 1832 gave new interest to the subject. By order of the Common Council the reports of Dr. Browne and engineer Weston, in which the insufficiency and dangerous character of the water-supply derived on Manhattan Island were pointed out as early as 1798, were reprinted and distributed among the people. The Board spent one thousand dollars more in testing again the possibility of securing an abundant water-supply on Manhattan Island, but without satisfactory results.

On November 10, 1832, the Joint Committee of the Common Council on Fire and Water engaged Col. DeWitt Clinton to examine the various sources and routes of water-supply which had thus far been suggested. Soon afterwards, on December 22d, Col. Clinton made a very complete report on this subject, laying stress on the point that in obtaining a water-supply for the city not only the immediate wants of the community were to be considered, but that reasonable provision should also be made for the future. Col. Clinton seems to have had a truer conception of the probable growth of the city of New York than most persons at that time, as will be seen from the following extract from his report:

"It is evident that if our prosperity as a nation and a state should continue uninterrupted, and our country augmenting in wealth and population, in the same ratio as during the last fifty years, sixty years will not elapse from this period before this island will be inhabited by one million souls. This remark will not appear exaggerated when we reflect that in 1697 this city contained but 4302 persons; that Philadelphia in 1800 exceeded it fifteen thousand; and at this time its population is more than 220,000; that the value of all kinds of property on the island has increased within the last year over twenty millions of dollars; and that it is now assessed at one hundred and forty-five millions of dollars; and that it is only since 1800 that New York has been ranked the first commercial emporium of the country.

"If this city has been so eminently prosperous in the last few years what greater augmentation of her wealth and extent may not be reasonably anticipated from the enterprise of her merchants, the skill of her mariners, the ingenuity of her manufacturers, the industry, patriotism, and economy of her citizens; and also from the facilities, cheapness, and dispatch which the various avenues of intercommunication, natural and artificial, in the different states have opened to her, and in the completion of new channels of communication, many of them in progress, and others in contemplation, tending to unite her more permanently and more advantageously with all parts of our improving and diversified country.

"With such evidence of an augmenting and multiplying wealth and population in the increase of her ships, her manufactories, and the permanency and splendor of her public and private dwellings; and with the most conclusive evidence from her geographical position, and her proximity to the ocean, and the security of her harbor, that she must be to this country what London is to England, it must not only be a matter of surprise and of profound regret that she is destitute of a supply of good and wholesome water, and that there should exist any hesitation to grant her power to obtain an element so essentially connected with the prosperity, health, and comfort of her citizens."

Col. Clinton accounted for the long delay in securing a satisfactory water-supply for the city partly by the great difference of opinion among the citizens as to what source of supply should be selected, and partly by the quiet but powerful opposition of the Manhattan Company.

After reviewing briefly the efforts of the various companies which had been chartered to supply the city with water, Col. Clinton considered fully the proposal of Mr. Levi Disbrow to sink artesian wells for this purpose, excluding the bad water near the surface by tubing. The conclusions at which he arrived were: that this method of securing a supply would involve a very doubtful experiment both as regards the quantity and the quality of the water to be obtained; that the first cost for wells, pumps, tanks, and buildings would be very large, and the operation of the works expensive, as all of the water would have to be pumped. In this connection Col. Clinton gave some interesting statistics of the amount of pure water sold in New York at the time, owing to the deterioration of the water of the shallow wells in the thickly-populated wards of the city. We quote from his report:

"Many parts of the city are now supplied with water brought from the upper wards. On the East and the North River, in some instances, it is pure, and in others its goodness is but little better than the present well-water. The tables of the wealthy are supplied from this source, while our poorer classes have to resort to such wells or pumps as are in their neighborhood. I therefore consider it important to ascertain what the present supply is; careful and minute inquiries were made, and the result was that there is now daily brought to the city by drays or water-carts six hundred hogsheads, for which there is paid one dollar and twenty-five cents (or about two cents per gallon) for each hogshead, or $750 per day, or $273,750 per annum, for water from that source. There is also much inconvenience in obtaining the above supply, which frequently leads to an increased expense, and difficulties in procuring it. The sum paid for water is also annually increasing, owing to wells and springs which are now pure losing their goodness. It is also proper to remark that our city as it augments in population, the source from which it is now supplied will also become impregnated with foreign matter, which will render it necessary to resort to more distant springs, which must very much increase the expense of providing water.

"Many of our large hotels at this time pay from $200 to $450 annually for water, and our smaller classes of boarding and private houses pay from fifteen to fifty dollars for the same.

"I am informed that our shipping is now principally supplied with water procured on Long Island at Brooklyn, and in a small quantity from the Jersey shore and from Staten Island, and some of the steamboats and small coasting vessels from the Manhattan Works and the pumps and springs on the island. Other coasting vessels and foreign packets and ships provide themselves with a sufficient quantity abroad to serve them for the trip, and to avoid the expense and detention of obtaining it in our harbor. The daily average supply, as ascertained from careful inquiries, from Brooklyn for 313 days (no water is delivered on Sunday) is equal to 375 hogsheads (or 23,625 gallons). On this there are two prices. The

first is thirty-one cents per hogshead, when the water is delivered opposite the city; the second is fifty cents, when it is carried to vessels lying at the Quarantine. It is stated that two thirds of the quantity is delivered opposite to the harbor, and the balance, one third, is taken to Quarantine. To the above quantity is to be added the supplies delivered at our piers and wharves. This is supposed to be, from the best information I can obtain, equal to forty hogsheads per day, and is probably below the true amount. The following table will show the actual quantity and cost of the same for a year."

TABLE.

Hogsheads delivered per Day.	Gallons per Day.	Hogsheads delivered per Year.	Gallons per Year.	Cost of Hogsheads. Cents.	Amount Paid per Day. Dollars.	Amouut Paid per Year. Dollars.
250	15,750	78,250	4,929,750	31	$77 50	$24,257 50
125	7,749	39,125	2,464,875	50	62 50	19,562 50
40	2,520	12,520	788,760	50	20 00	6,260 00
415	26,019	129,895	8,183,385		$160 00	$50,080 00

Having rejected artesian wells on Manhattan Island as a source of supply, Col. Clinton considered next, at great length, all the various streams which had been suggested for that purpose. He thought it unadvisable to obtain the supply from the Passaic River or from any other stream in New Jersey, owing to the difficulty of effecting and maintaining the crossing of the Hudson River, the doubtful purity of the source, and the objection to taking water from another state. The choice was therefore limited, in his opinion, to the streams of Westchester County. The engineers who had preceded him in investigating this subject had recommended the Bronx River as the best source of supply. As the consumption increased, an additional quantity of water was to be obtained by constructing storage-reservoirs and feeders from the Byram and Sawmill rivers. From the gaugings that had been made Col. Clinton concluded that no water could be diverted from the Sawmill River in dry seasons, and that the minimum supply which might be obtained from the Bronx and Byram rivers would not exceed 12,000,000 gallons per day. This would probably be sufficient for the next 25 to 28 years, but ultimately the city would have to resort to the Croton River.

Surveys had been made to connect this stream with the Bronx system by means of a canal, but had been unsuccessful. As the future water-supply would have to be derived from the Croton, in which more water was flowing, even in the driest season, than what could be obtained from the Bronx with the proposed reservoirs and feeders, Col. Clinton reached the conclusion that it was advisable to lead the Croton water at once directly to the city.

This being the first time that a competent engineer recommended the Croton River as the proper source of the water-supply of New York, and outlined the plans of an aqueduct from the Croton Valley to the city, it may be of interest to quote his own words:

"In the Croton River, at Pine's Bridge, there is never less than 20,000,000 gallons of water passing in every twenty-four hours. The river at this point is therefore capable of supplying one million of people, allowing a consumption of twenty gallons to each person.

This supply can be augmented by constructing reservoirs; and we have seen by Mr. Dewey's statement that one reservoir could be constructed which would supply more than seven millions of gallons per day within a few miles of Pine's Bridge. But if it were necessary, more than seven thousand acres could be ponded, and the water raised from six to sixteen feet on it; and also other supplies could be obtained, as I have before stated in alluding to the Sharon Canal route and the east branch of the Croton River. This supply may therefore be considered as inexhaustible, as it is not at all probable that the city will ever require more than it can provide. The character of the waters at Pine's Bridge, I have no hesitation in saying, is equal to the Bronx at Underhill's Bridge.

"The elevation at Pine's Bridge, by Mr. Cartwright's measurement, is 183 feet above tide. I would propose at this point to sink the bottom of the works below the bed of the stream, to avoid the risk of a dam, and more fully to command the whole volume of water if necessary. Sluices with gates should be provided, and also other contrivances to prevent any impurities from the stream passing into the works.

"From Pine's Bridge the route would follow the elevated and broken banks of the Croton until it intersected the bank of the Hudson River. It would continue on the rugged slope of the lands in the vicinity of that stream to Tarrytown, about eleven miles from the point of commencement. In this distance it would be necessary to cross the valley of Sleepy Hollow and several considerable ravines and gulfs formed by springs and brooks. The route would have to be conducted meanderingly round them; or they may be crossed in a straight line by embankments, pipes, or aqueducts. From Tarrytown the ground may be considered favorable, although principally a steep side-hill to the mouth of the Sawmill River, a total distance of twenty miles. From the Sawmill River the route could either follow the northern bank of the stream to Danger's Mill, a distance of one and a quarter miles, and continue on, or in the vicinity of the route surveyed to Macomb's Dam by Mr. White, a distance of nine miles, and there cross the Harlem River: or it would cross near the mouth of the Sawmill River and follow the bank of the Hudson to the Harlem River, and cross that stream a short distance above its mouth, and reach on the opposite side very rocky, narrow, and elevated ground lying directly on the banks of the Hudson River. This ridge is broken in a short distance in its continuation south by a ravine or hollow which crosses the road to King's Bridge, near Crawford's Tavern. The line would be forced to pass over it to reach the elevated lands in the vicinity of Fort Washington; and the first reservoir on the island would be constructed near Madame Jumel's. The other reservoirs ought to be placed on the elevated ground on different parts of the island. The distance from the Sawmill to the Harlem River is about six miles, and from that stream to the reservoir is four miles, making the whole length of the route thirty miles to Madame Jumel's, and the one to Macomb's Dam is thirty miles and a quarter.

"I must say that the routes present great, but not insurmountable, impediments. In some places the works may be very expensive, and in others very cheap; and I have seen nothing in the character of the routes but what perseverance and skill can overcome. It will, however, be necessary that a minute and careful survey should be made, to determine

fully the difficulties of construction. The expense of the work will also, in a great degree, depend on the plan of crossing the valleys, some of which are wide and deep. Many modes ought to be examined; such as stone, wood, and iron arches, supporting pipes or elevated and open aqueducts; low and high embankments supporting pipes, or the embankments being sufficiently elevated to conduct the works over, without depressing them more than the required fall; and also carrying the works circuitously around the valleys, and other matters connected with the construction of the works.

"The elevation of the Croton at Pine's Bridge being 183 feet, and the bottom of the work being sunk six feet below the bed of the river, it leaves 177 feet; and if the line from that point should descend uniformly one and a half feet in the mile, the Sawmill River, on the first route, would be crossed at Danger's Mill, at an elevation of 42¼ feet above that stream. On the lower route it would require, at the mouth of the Sawmill River, a work 147 feet high; at the Harlem River, on either of the routes an aqueduct 138 feet high and 1000 feet long; and over the low ravine at Crawford's Tavern, a work 115 feet in height. It is apparent that these elevations could be reduced by resorting to pipes sustained on low arches, instead of the open aqueduct. This plan would, however, much depress the heights of the reservoirs on the island, on account of the friction of the pipes. It is true a higher starting-point on the Croton could be obtained, which would, perhaps, obviate all fears on that subject. But it remains to be seen if that would be the most economical plan. These facts cannot be settled, and the height that the water from the Croton can be delivered on the island must remain in some doubt until after an actual survey. I have, however, strong confidence in the practicability of delivering it at 138 feet above tide, and it would admit of the bottom of the reservoir being 120 feet, provided it was 18 feet in depth."

The correctness of the conclusions of Col. Clinton just stated have been proved by subsequent experience. The manner in which he proposed to convey the water to the city was in an open canal having a deep cross-section and a grade of eighteen inches to the mile. He thought that all contamination of the supply could be prevented by proper care, that the depth of the canal would eliminate any trouble resulting from the formation of ice, and that such an open canal could be constructed much more economically than a covered channel. He estimated the expense of introducing the Croton water into the city at $850,000 and the total cost of the work, including the reservoirs and the distribution on Manhattan Island, at $2,500,000. Considering all the advantages resulting from an abundant supply of pure water, Col. Clinton calculated that it would be profitable for the city to build the Croton works even if the cost of construction amounted to $11,000,000.

The arguments of Col. Clinton against obtaining a water-supply from artesian wells, located in the different wards of the city, were attacked by Mr. John L. Sullivan (the proposer of the Passaic River scheme mentioned on page 18), who had become a joint owner with Mr. Levi Disbrow in various patents for improved tools and methods for driving deep wells. In a pamphlet of 40 pages, addressed in March 1833 to the Mayor, Aldermen, and inhabitants of New York, Mr. Sullivan advanced a lengthy argument in favor of a water-supply from artesian wells and asked that he and his associates be given the necessary

authority for forming "A Rock Water Company," which was to have the same banking privileges as those accorded to the Manhattan Company. He also made a proposal for supplying the latter company with rock water from deep artesian wells.

In dilating on the advantages of obtaining pure water from the very rocks upon which the city was built, Mr. Sullivan quotes an esteemed friend as saying: "By thus supplying the inhabitants with fine pure rock water it will remove the popular pretext for using alcohol to correct the impurities of the water now in general use, and will be the most effectual means of promoting the great and noble cause of temperance in this city." He asks, in another place, whether to fail to use the water in the rocks "will not be to reject a beneficent gift of nature."

With reference to a supply from the Bronx or the Croton, Mr. Sullivan reached, in his pamphlet, the following conclusions: "The obvious and principal difficulties in supplying the city from the Bronx or the Croton consist in the distance, the deficiency of water, the intervening elevation of the ground, its expensive character, consisting generally of rock, the waste of water that must attend its transmission in our climate, the moderate quantity to be relied on without recourse to reservoirs, and their dubious value at such distant positions, flowing a long way in shallow channels."

Mr. Sullivan criticised Col. Clinton for contemplating, notwithstanding the above-mentioned difficulties, "the preliminary of a plan of supply commensurate with the probable numbers here, after the revolution of a few centuries, when New York, like London, shall contain a million of inhabitants," and urged that it was best to let posterity take care of its own water-supply.

This was written in 1833, when the population of New York amounted to 225,000, and the property, real and personal, was valued at only one hundred and fifty million dollars.

Mr. Sullivan mentions in his pamphlet a great many artesian wells (70 to 130 feet deep) which Mr. Disbrow had bored for corporations or private parties since 1825, when he obtained his first patent for improved boring machinery, and which had furnished good water. He claimed that while the public well at Thirteenth Street, 16 feet in diameter (described on page 16), yielded on an average 10,428 gallons a day, a quantity sufficient for 260 families, the artesian well bored for the Manhattan Company at Bleecker Street and Broadway (see page 15) had supplied 129,600 gallons a day, enough for 3200 families, which had been pumped out of this well by a six-horse-power engine, during a long trial in the summer of 1832.

Mr. Sullivan estimated the cost of the land, boring, pump, building, and cistern for one artesian well at $10,000, and the cost of operating it at $2670 per annum. He thought that such a well would supply 80,000 to 130,000 gallons a day, a quantity sufficient for 1600 to 3000 families, allowing 8 gallons daily per person, which was double that used at Hudson, N. Y. Mr. Sullivan proposed to have such wells bored in the different wards of the city.

This project was never carried out, as the citizens of New York determined within two years to obtain their water-supply from the Croton River. We have given the above facts

to show how opinions on the question of the best source of the city's water-supply differed even among prominent professional engineers.*

While Col. Clinton was exploring a route to the Croton River, Timothy Dewey and Wm. Sewell were examining again the Bronx River project, under the directions of the Street Commissioner, Benj. Wright. They found it impossible to deliver water from this river on Manhattan Island, at an elevation of 120 feet above high tide, by gravity alone (which had been one of the objects they had tried to accomplish), but nevertheless reported in favor of the Bronx and against the Croton River, stating "that a canal or tunnel on high level is not the best or safest mode of obtaining water, and that it should not be attempted;" also, "that the Croton cannot be brought in by this route, and cannot ever be needed, seeing that the quantity which can be obtained at a moderate cost through the valley of the Bronx will be sufficient for all city purposes." An analysis of the Bronx water, made by three different chemists, showed it to be very pure, the foreign matter amounting to only about two grains in a gallon. In this respect, however, the Croton water was found to be equally desirable.

The choice of the source of the water-supply seemed now practically limited to the Croton and Bronx rivers, as the other available streams which had been suggested had the undesirable feature of being partly or wholly outside of the State. Recognizing the fact that the final selection of the water-supply could only be made intelligently by means of accurate surveys, the Common Council applied in January, 1833, to the Legislature to have the Governor and Senate appoint five Commissioners, "who should be invested with full power to examine the plans hitherto proposed, to cause actual surveys to be made, to have the water tested, to estimate the probable expense, and generally to do whatever in their judgment may be necessary to arrive at a right conclusion in the premises."

A bill embodying the request of the Common Council was passed by the Legislature on

* The amount of water obtained from artesian wells bored in recent years by the Manhattan Railway Company are given in the following table, which has been furnished by Mr. John Waterhouse, chief engineer of the Manhattan Railway Company.

ARTESIAN WELLS OF THE MANHATTAN RAILWAY COMPANY.

Location.	Diam.	Depth in Feet	Gallons per Minute.	Material Drilled through	Approximate Cost.
Morris and Greenwich Streets	8"	700	0	Rock	$7,000 00
Morris and Greenwich Streets	8"	625	0	"	
Sixty-seventh Street Yard, Second Avenue	8"	1502	0	"	13,000 00
Sixty-seventh Street Yard, Third Avenue	8"	1504	7	"	13,000 00
Ninety-eighth Street Yard, Third Avenue	8"	609	0	"	15,000 00
Ninety-eighth Street Yard, Third Avenue	8"	1505	11	"	
One Hundred and Twenty-eighth Street Yard, Second Avenue	6½"	253	0	"	
One Hundred and Twenty-eighth Street Yard, Second Avenue	6½"	237	0	"	9,000 00
One Hundred and Twenty-eighth Street Yard, Second Avenue	6½"	251	0	"	
One Hundred and Forty-fifth Street Yard, Eighth Avenue	8"	1035	60	"	10,000 00

The water in the wells stands from 10 to 20 feet below the surface and has to be pumped. The wells are not cased through the rock.

February 26, 1833, and was to be in force one year. The Governor appointed accordingly, with the consent of the Senate, the following gentlemen as Commissioners: Stephen Allen, B. M. Brown, S. Dusenberry, S. Alley, and W. W. Fox.

The Common Council having appropriated $5000 for the necessary surveys and investigations, the Water Commissioners entered upon their duties at once and engaged Canvass White and Major D. B. Douglass,* who had been Professor of Engineering at the United States Military Academy, as their engineers. Owing to important professional duties on the Raritan and Delaware Canal, the former gentleman, who had already investigated the Bronx River project, could not accept the appointment, so that the whole task of making the examinations devolved on Major Douglass. As the law under which the Commission had been created was to be in force only for one year, and required the Commissioners to report the result of their investigations to the Common Council by November 1st and to the Legislature by the succeeding January 1st, but very little time could be devoted to the surveys. Nevertheless Major Douglas, with the assistance of a small engineer corps, consisting of one traverser, one leveller, one rodman, eight chainmen, etc., and one draughtsman, succeeded, from June 20th to September 4th, in running lines up all the branches and tributaries of the Croton River, in determining two feasible routes for a conduit from the Croton River to New York, and also in locating a route to the Rye Ponds at the head of the Bronx River.† He also gauged the streams surveyed, and investigated the power which might be obtained from the Harlem River for pumping water to a high reservoir on Manhattan Island.

The report of Major Douglass, which was submitted to the Commissioners on November 1, 1833, seems to have determined finally that the only proper source of a water-supply for the city of New York, within a reasonable distance, was the Croton River. According to the gaugings made and the information gathered regarding the driest season within the memory of the inhabitants (viz., in 1816) Major Douglass estimated the minimum flow of the Croton River and its tributaries at Mechanicsville,‡ about twelve miles above its mouth, at 26,000,000 imperial gallons per twenty-four hours. As stated in the report, however, this quantity could be much increased by drawing on the large amount of water stored in the numerous lakes in the Croton Valley, and, when this should be insufficient, by constructing storage reservoirs.

After exploring all the low passes in the hills south of the Croton Valley, Major Douglass concluded that there were only two routes for an aqueduct from the Croton River to New York which were worthy of consideration, viz., an inland route by way of the Sawmill River Valley, and a river route along the slopes of the Hudson.

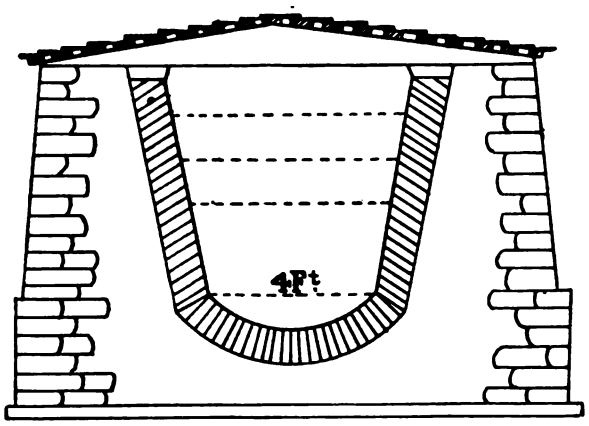
For the inland route the water of the branches and tributaries of the Croton River was to be collected by means of iron feed-pipes in a small confluent reservoir, located in a natural basin of solid rock near Mechanicsville (see Plate 30). The surface of this reservoir was to be about an acre in area and about 270 feet above low tide in the Hudson River. From this small reservoir the water was to be conveyed in a masonry conduit, covered either by a

* For biographical sketch see page 235.

† See Plate 30. ‡ Now Katonah.

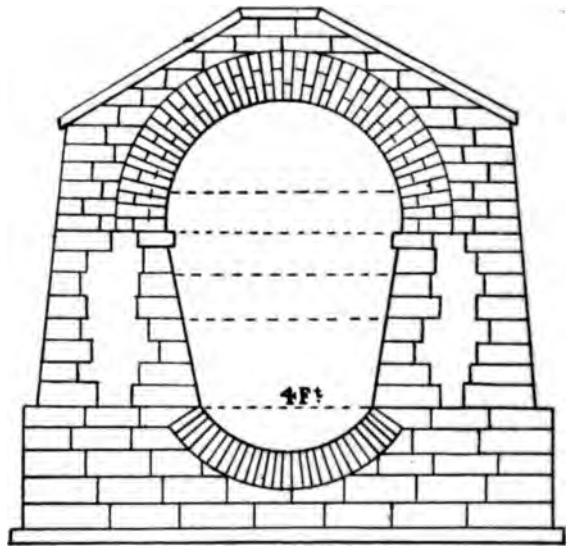
PLATE 5.

ORDINARY CUTTING.



1.

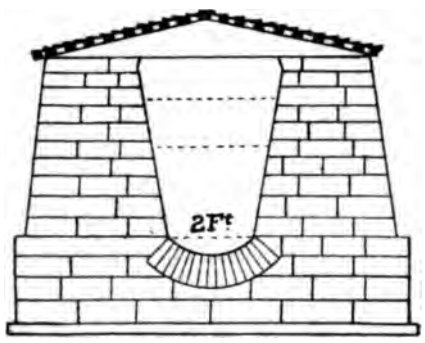
DEEP CUTTING.



2.

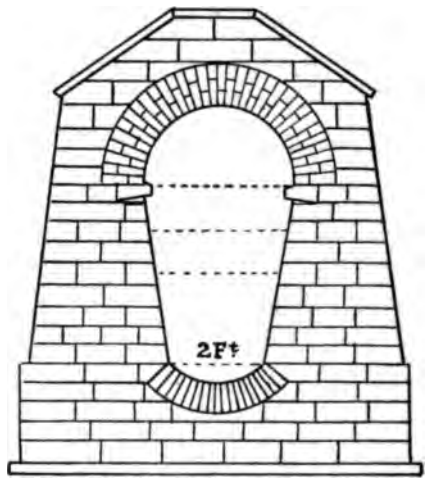
PROFILES OF THE AQUEDUCT ON THE HUDSON RIVER ROUTE.

ORDINARY CUTTING.



3

DEEP CUTTING.



4

PROFILES OF THE AQUEDUCT ON THE INLAND ROUTE.

SECTIONS OF THE AQUEDUCT PROPOSED BY MAJ. D. B. DOUGLASS.

brick arch or by a shingle roof, as circumstances might require (see Plate 5), to a receiving reservoir on Manhattan Island, for which a suitable location was suggested between Ninth and Tenth avenues, from One Hundred and Thirty-third to One Hundred and Thirty-seventh Street. The area of this basin was to be about eight acres, and the elevation of its surface about 123 feet above low tide.

The route surveyed for the conduit from the confluent reservoir to New York (see Plate 30) followed first the Beaver Dam River, then Muddy Brook, then the west branch of the Cisco. From the valley of this stream that of the Sawmill River was to be reached by a cut three miles long, having an average depth of 38 feet. It was suggested in the report that for the deepest part of this cut, which required an excavation 55 feet deep, a tunnel might be advantageously substituted.

After reaching the valley of the Sawmill River the line followed this stream until it turned west near Yonkers. The aqueduct location was continued south along Tibbit's Brook to the Harlem River, which was the only formidable obstacle encountered. Major Douglass proposed to cross this river by an aqueduct bridge, 1188 feet long and 126 feet high above low water, which was to carry the aqueduct to Manhattan Island. After having turned around a steep bluff the conduit was to be continued down Tenth Avenue to the receiving reservoir at One Hundred and Thirty-third Street, mentioned above. From this basin the water was to be conveyed, either by a masonry conduit or by iron pipes, to a distributing reservoir on Fifth Avenue, between Thirty-eighth and Fortieth streets, that was to have an area of about eight acres and a capacity of 52,000,000 gallons, the high-water mark being at an elevation of 117 feet above low tide.

Two intermediate equalizing reservoirs were to be constructed on the line of the conduit between the receiving and distributing reservoirs, viz., one on One Hundred and Fifth Street, between Eighth and Ninth avenues, and the other on Sixty-ninth Street, east of Eighth Avenue. The object of these small reservoirs was to enable the distributing reservoir to recover quickly its ordinary pressure when drawn down by any cause. In such a case this reservoir would draw on the nearer equalizing reservoir, and this, in its turn, on the further one, an increased flow being produced by the abnormal differences in head between these basins, until the usual condition was restored.

Major Douglass located a large storage reservoir in the Sawmill Valley, and indicated other sites where similar basins could be constructed when it should become necessary.

For the Hudson River route the plans proposed were as follows: To form a fountain reservoir by constructing a dam, about 13 feet high, across the Croton River at Muscoot Hill, a mile down stream from Mechanicsville. The surface of this basin was to be about 80 acres, and its elevation above low tide about 175 feet. From this reservoir the water was to be conveyed to the city in a masonry conduit, similar to the one shown on Plate 5. The proposed location followed the Croton River nearly to its mouth, and then the Hudson River to a point near Tarrytown. From here the line was deflected to the east until it joined the inland route in the Sawmill Valley. The two locations remained identical

from this point to the distributing reservoir at Thirty-eighth Street. The lengths of the two routes and the corresponding estimates of the cost of construction were given as follows:

Inland route, length about 43 miles	Cost $4,550,237
Hudson River route, length about 47 miles	" 4,718,197

The above estimates were for a conduit having a capacity of over 30,000,000 imperial gallons per day for a grade of 1 foot per mile. The minimum amount of running water which was to be obtained on the inland route was calculated to be 16,000,000 gallons per day. The whole supply was to be furnished by gravity, on either of the suggested routes. Which of the two locations for the aqueduct was to be finally accepted was to be determined by more detailed surveys.

We have already stated that Major Douglass made some investigations of a water-supply to be derived from the Bronx River. According to the gaugings made he calculated that even if the Rye Ponds were raised three feet and utilized as storage reservoirs, not over 5,750,000 imperial gallons per day could be depended on from the Bronx River. The water was to be taken below the Underhill Mill and Tuckahoe Cotton Factory and to be delivered at 50 feet above low tide at the Harlem River, the power of which was to be utilized to pump the water 73 feet higher to a reservoir on Manhattan Island. Careful investigations showed, however, that not over 5,000,000 gallons per day could be pumped in this manner.

As at the point where it was to be dammed, the Bronx River could only furnish sufficient water for the immediate requirements of the city, all of which would have to be pumped, and as the surveys and chemical analyses had proved that a much greater quantity of equally pure water could be obtained entirely by gravity from the Croton River, Major Douglass recommended strongly that the latter be selected as the source of the water-supply even though it was at a somewhat greater distance from the city than the former.

On November 1, 1833, the Water Commissioners presented a report of their investigations to the Common Council, as required by law. In estimating the quantity of water which should be delivered at once, the Commissioners assumed that the population of the city on the completion of the work would be about 300,000. Taking as the quantity of water to be delivered for each person per day 22 imperial gallons, which was the average of the quantities supplied at the time in London, Edinburgh, and Philadelphia, the required supply was calculated to be 6,600,000 gallons. The investigations of Major Douglass had shown that this quantity could not be obtained advantageously from the Bronx River. The only other available sources within a reasonable distance of the city and within the State were the Croton River or deep wells on Manhattan Island. Leaving the question of the quality of the water aside, the Commissioners stated in their report that from the best information at hand they calculated that forty-two wells, each having a pump and a reservoir, would be required in the city in order to furnish the desired amount of water from the latter source.

The Commissioners estimated that the expense of pumping from these wells would cost $100,000 more per annum than a 5% interest on the estimated cost of constructing the

works for a supply from the Croton River. But the Commissioners advanced still another objection against a supply from wells. They stated, namely, in their report:

"Now if we were satisfied (which we are not) that by the operation of boring, a sufficient supply of water could be obtained, in each of the wards, to employ these *forty-two* steam-engines in filling as many reservoirs with good water, and that the expense would not exceed the bringing it from a distance, a strong objection would still arise to placing *forty-two* steam-engines in the densely settled parts of the city, to annoy and disturb a neighborhood with the unceasing noise and clatter of the machinery, the constant smoke of the furnaces and the incessant discharge of steam; thus depreciating the value of property for a distance around, and driving from their vicinity every citizen whose means would permit him to seek for more peaceful and comfortable quarters."

The arguments stated above and the certainty that all the water on Manhattan Island would become eventually more or less polluted by the extension of the city, decided the Commissioners to reject a supply from wells. They therefore recommended that the only remaining adequate source of supply, the Croton River, be selected for the water-supply of the city.

The Common Council approved the recommendations of the Commissioners and applied on February 6, 1834, to the Legislature to have a law passed authorizing the city to raise $2,500,000 for constructing the water-works.

As the law of the preceding year under which the Water Commissioners had been appointed had expired, the Legislature passed on May 2, 1834, an Act forming a permanent Water Commission of five persons, who were to be appointed by the Governor, with the consent of the Senate, and providing for the raising of the necessary money for constructing the works. Under this law, which was entitled "An Act to provide for supplying the City of New York with pure and wholesome water," the Commissioners were required to mature a plan of water-supply for the city, making all the needful surveys for the same, also to investigate what revenue might be derived from the works, and to make a full report on these matters to the Common Council on or before January 1, 1836. Should this body approve of the plan proposed by the Commissioners, the question whether it should be executed or not was to be submitted to a popular vote. Should this be decided affirmatively, the Common Council was authorized to issue "Water Stock of the City of New York," bearing 5% interest, to the extent of $2,500,000 for constructing the works.

Under this Act the Governor reappointed the Commissioners of the preceding year, who entered upon their duties at once and were able to submit to the Common Council, in February 1835, a report of their investigations. In compliance with a resolution passed by the Common Council the Commissioners had again examined how much water might be obtained within the county, but had become fully convinced that a supply derived from springs and wells on Manhattan Island would be insufficient for the growing wants of the city and also very uncertain.

They mention in this connection that the yield of a number of the wells in the city was rapidly diminishing.

The Commissioners reported also on various schemes for water-supply which had been communicated to the Common Council, all of which were more or less visionary and impracticable. To one of these projects, however, the Commissioners appear to have devoted considerable attention on account of the great advantages which were claimed for it. We refer to a plan for a water-supply for the city which was submitted by Mr. Bradford Seymour, of Utica, in a communication dated November 21, 1834. This gentleman proposed to build a dam across the Hudson River from a point near the foot of the present Christopher Street to the Jersey shore, so as to raise the water on the upstream side of the dam 18 to 24 inches above high tide. A sufficient number of locks were to be constructed in the dam to permit vessels to pass. The advantages which Mr. Seymour claimed to obtain by this construction were stated by the Commissioners in their report as follows:

"1st. That the waters of the Hudson, coming from the highlands around the Sacondago and Mohawk rivers, are the purest in the United States.

"2d. That a hydraulic power equal to 30,000 horses may be thus obtained, 27,000 of which may be employed for manufacturing purposes and 3000 used for elevating the water to the reservoir for supplying the city.

"3d. That by raising the water in the river above said dam, to the height proposed, all overslaughs and bars will be removed by the down current, and any vessel capable of entering the harbor of New York may proceed to Albany and Troy without obstruction.

"4th. That an easy and safe communication between this city and Albany on the ice for three months in the year may be effected.

"5th. That no injury will be caused to the land on the banks of the Hudson, as the water within the dam will never be higher than it now is in high tides and freshets. Another of the advantages is that solid and pure ice may be obtained at small expense."

In a subsequent communication of November 29th Mr. Seymour offered to build the dam for $1,500,000, the locks for $150,000 each, and the coffer-dam needed for constructing the dam for $200,000. He agreed to finish the work on August 1, 1839.

The Commissioners appear to have considered this rather startling project carefully and to have consulted Mr. Frederick Graff, the Superintendent of the Fairmount Water-works of Philadelphia, in reference thereto. This gentleman was of the opinion that a dam 24 inches above high water would not answer for the desired purposes. He stated that although the dam across the Schuylkill River for the Philadelphia Water-works was 6½ feet above high tide, the water-wheel could only work from 7 to 9 hours in 24. Such a raising of the water of the Hudson River he considered, however, to be out of the question on account of the great value of the land which would thus be submerged. Mr. Graff thought that even if the advantages claimed for Mr. Seymour's plan could be trebled, they would not compensate for the injury done thereby to navigation. These arguments, and others of more or less weight, induced the Commissioners to report adversely on Mr. Seymour's project and to repeat their former recommendation that the Croton River be selected as the source of the water-supply of the city.

Shortly after they had been reappointed the Commissioners directed Major Douglass

to examine carefully once more his surveys and estimates with a view of reducing the expenses wherever possible. They engaged, also, Mr. John Martineau and Mr. George W. Cartwright, civil engineers, to make some investigations, independently of Major Douglass, for the best site for a dam in the Croton Valley and the best location for the conduit to the city.

Based upon the reports made by these gentlemen, the Commissioners recommended to the Common Council that a dam be constructed across the Croton River either at Garretson's Mill, 5½ miles below the site of the proposed Muscoot Dam (see page 29), or further down stream at Halman's Mill, near the mouth of the river, and that the water be conveyed to the city in a covered masonry conduit, to be located substantially on the Hudson River route mentioned in the report of 1833. The cost of the whole work was estimated at $5,500,000.

As we shall describe the old Croton Aqueduct in Chapter III as actually constructed, we will not discuss here the minor differences in the plans submitted by the Commissioners in the above report from what they recommended in 1833.

Mr. D. S. Rhodes had offered to bring 6,000,000 gallons of water per day from the Croton River to the city in iron pipes. In connection with his plan he proposed to construct a dam 45 feet high across the Croton River at the Quaker Bridge, or to build a dam, 32 feet high, four miles further up stream. The details of Mr. Rhodes's project were very defective and his estimates were based upon wrong data. The Commissioners directed their engineers, however, to investigate whether it would be advantageous to construct the proposed dam across the Croton River further down stream than the Muscoot site, suggested originally by Major Douglass in 1833, reducing thus the length of the aqueduct.

As the result of the examinations made, Major Douglass reported that a saving of about $92,000 on the original estimates could be effected by constructing the dam at Garretson's Mill, about 5½ miles down stream from the Muscoot site. The valley was found to be very much contracted at this place and to present steep slopes of solid rock against which the dam would abut. The advantages of this site were already reported in 1832 by Col. DeWitt Clinton. According to the plans of Major Douglass the dam at Garretson's Mill was to be 33 feet high above the bed of the river, and to form a reservoir having a surface of about 200 acres at an elevation of 155.5 feet above tide-water.

Mr. Martineau, who also examined the Croton Valley to find the most advantageous site for the proposed dam, reached the conclusion that the best location was at the mouth of the river, near Halman's Mill. He proposed to construct here a masonry dam, 130 to 150 feet high, which would form a reservoir of 700 acres of surface, having an elevation of 150 feet above high tide. The advantages claimed for this site were that the land flooded would be of much less value than that further up stream, that the length of the aqueduct would be considerably reduced, and that the mill rights destroyed would be more than offset by selling the surplus water for power at the high dam near the mouth of the river. According to the estimates given by Mr. Martineau the construction of the high dam at the mouth of the river and the resulting reduction of the length of the aqueduct would have effected a saving of $200,000 in the cost of the works.

The unusual height of the dam at Halman's Mill, which was to be 130 or 150 feet, according to which of two suitable locations, one above and the other below the mill, was selected, did not seem objectionable to Mr. Martineau. He proposed to construct it of good "hydraulic masonry, laid compactly, well bonded, and grouted throughout." The waste-weir was to be 100 feet long. The cross-section of the dam through this weir was to have a top width of 24 feet, a vertical up-stream face, and a down-stream face on an angle of 60°. The masonry dam on either side of the waste-weir was to have a top width of 20 feet, elevated 6 feet above the top of the weir. The wings of the dam were to be formed of earth embankments. The total length of the dam was to be 500 to 700 feet, according to which site was selected.

The dam proposed by Mr. Martineau, which we have described from the scanty details contained in his report, is of interest as being the first project for a dam near the mouth of the Croton River, being thus the precursor of the famous project for the Quaker Bridge Dam which has excited so much discussion of late years in connection with the New Croton Aqueduct.

The Water Commissioners had not decided when they reported to the Common Council whether the Croton Dam ought to be constructed at Garretson's Mill or at Halman's. In either case the location of the aqueduct was to follow substantially the Hudson River route proposed in 1833, with such modifications as the grade finally established might require.

The important crossing of the Harlem River was carefully re-examined by the Commissioners' engineers. Three plans were proposed for carrying the aqueduct across the river:

Major Douglass still advocated his original plan for an aqueduct bridge, 126 feet high above tide-water, formed of semicircular arches. Mr. Martineau reported in favor of conveying the water across the valley of the Harlem River by an inverted siphon, formed of a wrought-iron pipe 8 feet in diameter, made of plates ½ inch thick. This pipe was to be laid in a rock embankment 30 feet high above tide-water, which was to close the Harlem River except at the channel, where a semi-elliptical arch of 60 feet span, having its springing-line near the surface of the water, was to form an opening for the river to flow through. The Commissioners reported in favor of the last-named plan.

Another point of importance was the crossing of the Manhattan Valley. Major Douglass proposed to construct here an aqueduct bridge similar to the one designed for the Harlem River crossing. Mr. Martineau recommended, however, to convey the water from the receiving reservoir on the north side of Manhattan Valley to the distributing reservoir at Thirty-eighth Street and Fifth Avenue through a line of cast-iron pipes 6 feet in diameter. This plan was found to be more expensive than the one recommended by Major Douglass, and was consequently not adopted by the Commissioners, especially as there appeared to be much doubt whether pipes of that size could be cast successfully at that time. The expense of conveying the water-supply from the Croton River to the city through one or more lines of 30-inch cast-iron pipes was also investigated and found to be much greater than the cost of a masonry conduit of equal capacity.

While the Commissioners had not decided on all the details of a water-supply from the Croton River when they reported to the Common Council, yet the investigations and estimates made by different engineers convinced this body of the feasibility of this project and of its advantages above all others that had been proposed. The inquiries made by the Commissioners with reference to what revenue might be derived by the city from its water-works showed that it would more than cover the interest on the cost of construction.

The Common Council adopted, therefore, the plan recommended by the Commissioners on March 2, 1835, and ordered that the question whether the proposed works should be constructed or not be submitted to popular vote at the next election, which occurred on the following 14th, 15th, and 16th of April. The result was decidedly in favor of the construction of the water-works, 17,330 affirmative against 5963 negative votes being cast. It is interesting to note that the only three wards in which the negative vote preponderated were the poorest of the city, where consequently the least taxes would have to be paid in support of the works.

CHAPTER II.

THE CONSTRUCTION OF THE OLD CROTON AQUEDUCT.

THE people having decided in favor of carrying out the plans submitted by the Water Commissioners, the Common Council ordered these gentlemen on May 7th to proceed to construct the works, and authorized a loan of $2,500,000 at 5% interest to defray the expenses. A subsequent ordinance, passed May 15th, fixed the salary of the Chairman of the Water Commissioners at $1500 per annum and that of the other members at $1000 each.

Major Douglass was reappointed, on June 2d, Chief Engineer of the Commissioners, at a salary of $5000 per annum. On July 6th he took the field with a corps of seventeen engineers and helpers to stake out the final location of the aqueduct and to survey the lands required for its construction. This survey of the line of the aqueduct, the fourth made by Major Douglass, resulted in some important revisions, whereby the distances were shortened and some of the curves lessened. By the 15th of June 1836 the surveys were completed and all the required land maps were prepared.

Many delays occurred, however, before the city could acquire the necessary property, owing to the great opposition manifested by the land-owners in Westchester County to the construction of the aqueduct. Public meetings were held, at which hostile resolutions were passed, memorials were sent to the Legislature, and all possible obstruction was made to the condemnation proceedings.

The chief propositions submitted to the Legislature in the memorials were:

1st. That the legal possession and use of the land bought by the city of New York for the construction of the aqueduct should remain with the original owners.

2d. That any land not used for the purposes of the aqueduct should revert to the original owners.

3d. That the persons through whose land the aqueduct passed should have the right to use the water by paying a reasonable compensation.

4th. That some provision should be made to prevent trespassing on the land near the aqueduct.

5th. That all appraisements should be made by the judges of the county courts, instead of by the Commissioners appointed by the Vice-Chancellor.

Much of the opposition to the construction of the aqueduct arose from the cupidity of some of the land-owners who expected to profit by delay. Another reason was the dread people felt of the annoyance that would be caused, during the construction of the work, by the army of laborers which would have to be employed.

The Legislature refused to take any action on the unreasonable memorials of the excited land-owners, but, in order to allay some of their apprehensions, pased on May 25, 1836, an Act in which it was provided that the Corporation of the City of New York could only acquire, in connection with the aqueduct, such lands as were needed for the purposes of introducing water into the city of New York; that the Corporation should erect and maintain convenient passes across or under the aqueduct, wherever the aqueduct should pass through a piece of land belonging to one or more individuals; and that the Corporation should erect and maintain fences along the aqueduct where needed.

This law did not satisfy the complainants, who threatened at a public meeting in Tarrytown to carry their case to the Supreme Court of the United States and to test the constitutionality of the laws under which the property required for the aqueduct was being condemned.

The result of this opposition was that, with the exception of some of the land needed for the Croton Reservoir, all the required property in Westchester County had to be obtained by appraisement. Great delays occurred in the slow condemnation proceedings and the still slower process of having the awards confirmed by the Chancery Court.

By the fall of 1836 the plans for the construction of the aqueduct were well matured, and the only serious difficulty in commencing the work was the delay experienced in obtaining possession of the required property.

In their semi-annual report, dated January 9, 1837, the Water Commissioners dwell upon this matter and also complain of a "lack of energy in the operations of their engineer department," which induced them to appoint on Oct. 11, 1836, Mr. J. B. Jervis * Chief Engineer, in the place of Major Douglass. The large amount of work which had been accomplished by Major Douglass with the assistance of a small corps of engineers is an ample refutation of the above charge. His admirable reports in which he outlined the construction of the whole aqueduct substantially as afterwards carried out prove his ability as an engineer. The real trouble seems to have been some differences of opinion between Major Douglass and Mr. Stephen Allen, the Chairman of the Water Commission. Although Mr. Jervis proved himself in every way worthy of conducting the construction of the aqueduct, and designed all the structures as actually built, one cannot help regretting that the engineer who had prepared all the preliminary plans was not permitted to superintend the work to its successful completion.

The advertisements for proposals for constructing the first twenty-three sections of the aqueduct (including the Croton Dam), about ten miles in length, were published on Feb. 28, 1837, in newspapers in New York, Albany, Utica, Hartford, and Philadelphia.

The bids received were opened on April 26th. They were found to be considerably above the preliminary estimates. For financial reasons, the Commissioners awarded, at the time, only the contracts for thirteen sections, selecting those for which the proposals seemed the most satisfactory. Three year's time was allowed for performing the work. Ground was broken in May, 1837.

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* For biographical sketch see page 236.

Before active operations commenced, the line of the aqueduct was divided into four divisions, each being placed in the charge of a resident engineer, who was assisted by two or three assistant engineers.

The divisions were as follows:

Division.	Length in Miles.	Description.	Resident Engineer.
1	10.177	Croton Dam to three miles south of Sing Sing	Edmund French
2	10.732	End of Division 1 to Hastings	Henry T. Anthony
3	9.669	Hastings to 2 miles from Harlem River	Peter Hastie (temporarily)
4	9.984	End of Division 3 to the distributing reservoir at Forty-second Street	Peter Hastie
	40.562		

NOTE.—Mr. William Jervis later on was given charge of the 3d Division as Resident Engineer. Mr. Horatio Allen* was appointed Principal Assistant Engineer in 1838.

In the autumn of 1837 the ten sections of the first division for which bids had been received at the first letting, but rejected, were put under contract, and also the twenty-seven sections of the second division. By the end of 1837 the construction had commenced on the first twenty-one miles of the aqueduct, which were to cost according to the bids received $2,823,691.

Based upon the prices at which the work on the first two divisions had been let, the Water Commisioners estimated, in their semi-annual report for the second half of 1837, the cost of the aqueduct and reservoirs, not including the distributing pipes, at $8,464,033.

The "Act to provide for supplying the City of New York with pure and wholesome water," passed May 2, 1834, authorized only an expenditure of $2,500,000 for this purpose. The estimates of the cost of the aqueduct and reservoirs, made in 1835 by Major Douglas and Mr. John Martineau, independently of each other, were respectively $4,786,637 and $4,225,814, the difference in their estimates being chiefly due to the fact that the latter engineer proposed to cross the Harlem River by a siphon of iron pipes placed in a rock fill, instead of by the high bridge planned by the former. The great differences between the preliminary and revised estimates were explained by the Commissioners "by the fact that the engineers originally employed did not possess the means of testing their calculations by the actual contract prices, as the Commissioners had been able to do."

To enable the Commissioners to complete the great work, the Legislature passed, at the request of the Common Council of New York, on March 29, 1838, a law anthorizing the Corporation to raise three million dollars more, at a rate of interest not exceeding 6%, for defraying the cost of the construction. Another Act, passed on March 24, 1838, provided that the cost of procuring and laying all the necessary distributing pipes should be paid out of the Water Fund.

During 1838 the contracts were let for all the remaining work, including the crossing of

* For biographical sketch see page 238.

the Harlem River and the reservoirs in the city, all of which was to be completed by the end of 1841.

The most difficult and expensive construction on the line of the aqueduct was involved in the crossing of the Harlem River. At the place selected for this purpose the width of the river is 620 feet at high water and 1450 feet at the grade of the aqueduct. The preliminary borings showed that the bed-rock was 20 feet below high water on the north bank and 32 feet on the south bank.

As has been stated, Major Douglass proposed to construct an aqueduct bridge, 126 feet high above tide-water, across the Harlem River, while Mr. Martineau recommended that the Croton water should be conveyed across the river by a siphon of iron pipes which were to be placed in a rock fill, having an 80-ft. arch at the channel of the river. The celebrated Charles Ellet, then quite a young engineer, submitted a plan for effecting the crossing by means of a suspension bridge upon which iron pipes were to be laid. A wooden arch bridge seems also to have been proposed.

Only the first two of the above plans were taken into consideration by the Water Commissioners, who ordered the Chief Engineer, Mr. Jervis, to prepare detailed estimates of the cost of crossing the Harlem River by a high bridge, at the grade of the aqueduct, and also by means of a siphon of iron pipes, placed in a rock fill.

The estimates made by Chief Engineer Jervis were as follows:

1. Cost of the high bridge	$935,745
2. Cost of the siphon of iron pipes placed in a rock fill	426,027
Difference in favor of the siphon	$509,718

The great difference of cost in favor of the siphon, and the fact that it would require much less time to construct than the high bridge, decided the Chief Engineer to give the preference to that plan. In their semi-annual report for the second half of 1837 the Water Commissioners presented the estimates given above and indorsed fully the conclusions of the Chief Engineer. At the same time they admitted that the high bridge would produce a fine architectural effect, which some of the citizens seemed to desire, and stated that they were willing to construct such a bridge if the Mayor and the Common Council would express their approval of this project by passing an ordinance to that effect.

The Common Council took no formal action in this matter, although the Board of Assistant Aldermen passed the following resolution on July 9, 1838:

Resolved, "That it is inexpedient to adopt the plan proposed by the Water Commissioners for crossing the Harlem River by means of a low bridge or siphon, and that the plan of the high bridge referred to in the report of the Commissioners should be adopted as submitted to, and approved by, the electors of the city and county of New York."

Under these circumstances the Water Commissioners felt justified in following their own judgment by crossing the river by the cheaper plan, namely, the siphon of iron pipes. The manner in which this was to be effected was as follows:

The aqueduct was to terminate on the high ground of the north bank in an influent pipe-chamber, from which eventually four lines of 36-inch pipes were to be laid across the Harlem Valley to an effluent pipe-chamber at the beginning of the aqueduct on the south bank. These four lines of 36-in. pipes were calculated to have a discharging capacity of about 50,000,000 imperial gallons per day, which was very nearly equal to the maximum capacity of the aqueduct, viz., 60,000,000 gallons per day. As that quantity of water was not then required, only two lines of pipes were to be laid at first, but all the embankments, pipe-chambers, etc., were to be constructed sufficiently large for four lines of pipe.

From the influent chamber, on the north bank, to the river, the pipes were to be laid about four feet below the surface of the ground. They were to be laid across the river in a rock fill to the channel, near Manhattan Island, and then on an arcade of semi-circular arches to the south bank. The arch across the channel was to have a span of 80 feet and a clear height, at the crown, of 50 feet above high tide. It was to be supported by abutment piers. From the channel span the south bank was to be reached by three arches having respectively spans of 35, 30, and 25 feet. From the last of these arches a foundation-wall for the pipes was to be built up the slope of the abrupt bank to the effluent chamber. This wall was to be formed of dry masonry except the upper two feet and the faces of the wall to a depth of two feet, which were to be laid in cement. The rock fill mentioned above was to have a height of four feet above flood tide except near the channel, where it was to form an incline to the top of the channel arch. The pipes laid on the rock fill and on the foundation-wall on the south bank were to be covered with four feet of earth, which was to be retained by suitable parapet walls.

The contract for crossing the Harlem River as described above was let in 1838. Great opposition against this plan arose from the owners of land in the vicinity of the crossing and from people who were interested in the navigation of the river. Memorials were sent by the complainants to the Legislature, which on May 3, 1839, passed an Act compelling the Commissioners to abandon the proposed siphon, and to substitute for it either a high bridge crossing the channel of the river with arches having at least 80 feet span and a clear height at the crown of not less than 100 feet above high tide, or a tunnel placed below the bed of the river.

In order to compare the relative merits of the two plans between which the choice had to be made, the Water Commissioners ordered the Chief Engineer to prepare detailed plans and estimates for a high bridge and for a tunnel, conforming to the conditions contained in the law of May 3, 1839. They also asked him to investigate the practicability of substituting for both the above plans a timber arch bridge.

In compliance with these orders, Chief Engineer Jervis presented to the Commissioners on June 1, 1839, a detailed report, in which he reviewed the question of crossing the Harlem River very fully. All the former plans for a high bridge had contemplated constructing the bridge to the grade of the line of the aqueduct, which made the distance from the inside of the arches at the crown to high water about 112 feet. The masonry water-channel on the bridge was to have a lining of cast iron, similar to what was used in the aqueduct bridge

across the Sing Sing Kill (see Plate 35). As Mr. Jervis considered it, however, preferable to convey the water across the bridge in cast-iron pipes instead of in a masonry channel as described, he prepared his plans for a high bridge, supporting four lines of 36-inch water-pipe. By forming a siphon of these pipes he was enabled to reduce the height of the bridge 12 feet from that of the former plans, and still had a distance from the soffit of the arch, at the crown, to high water of 100 feet, the minimum required by the law. The bridge became thus somewhat of a compromise between the high aqueduct bridge proposed by Major Douglass and the siphon advocated by Mr. Martineau. The saving effected by the above changes in the plans for the high bridge was estimated at about $100,000.

The plans for constructing a tunnel under the channel of the river, which has a width of three hundred feet on the line of the aqueduct, were as follows:

The tunnel was to consist of two arched masonry vaults, placed side by side, each being 12 feet wide and 8 feet high at the crown of the arch. The masonry was to be founded on a bed of concrete. The side walls and centre wall (between the two vaults) were to be 4 feet thick.—The top wall and invert brick arches were to be respectively 16 inches and 12 inches thick. The whole structure, top and sides, was to be covered with a stone pavement (12 inches thick, set in hydraulic mortar), which was to be kept 24 feet below low water. Each vault was to be arranged for two lines of 36-inch water-pipes, which were to rest on suitable supports and to be covered by a roof to keep any salt water, percolating through the masonry, from corroding the pipes. The tunnel was to terminate at each end in a masonry abutment through which the pipes were to rise to the level of rock fills placed on either side of the channel. The pipes were to be laid in these fills, in the manner originally proposed for the low bridge, and to be continued on shore to the pipe-chambers at the level of the aqueduct.

As water was sure to find its way into the tunnel, vertical wells were to be constructed in the abutments through which the water percolating into the tunnel could be pumped out. At the level of the river blow-offs were to be provided, but as any deposits which might collect in the bottoms of the siphons could not be discharged in this way, manhole plates were to be placed in the pipes, at suitable distances in the tunnel, through which the pipes might be entered and cleaned.

The space required for the tunnel and abutments, 400 feet by 40 feet, was to be enclosed by coffer-dams, the excavation being thus made in open trench. The work in connection with this coffer-dam was considered by Mr. Jervis to be very hazardous.

The cost of the high bridge and of the tunnel was estimated by Mr. Jervis as follows:

Cost of the high bridge.....	$836,613
Cost of the tunnel.....	636,738
Difference in favor of the tunnel.....	$199,875

The time required for constructing the bridge and for the tunnel was estimated respectively at five and four years.

Although 50% had been added in the above estimate for contingencies for the

tunnel and only 10% for the bridge, the many uncertainties involved in the former construction and the subsequent cost of maintenance decided Mr. Jervis to recommend the construction of the high bridge as the more satisfactory plan of the two. As regards a timber arch bridge, the conclusions arrived at by Mr. Jervis were that a wooden bridge could be constructed much more cheaply than either the high bridge of masonry or the tunnel, but would not be permanent, would be exposed to decay and danger from fire, and entirely out of keeping with the rest of the aqueduct, which was all built as durable as possible.

The Water Commissioners accepted the views of their Chief Engineer, and advertised on June 15, 1839, for proposals for building the high bridge of masonry. The construction was commenced in August 1839.

The work of constructing the aqueduct was prosecuted energetically with a force of 3500 to 3800 men. The total amount disbursed up to December 31, 1838, was very nearly two millions of dollars.

During the summer of 1838 an unusual drought prevailed. This occasion was utilized to make some new gaugings of the minimum flow in the Croton River above the proposed lake. On August 16th Mr. Horatio Allen, Principal Assistant Engineer, gauged the stream at two different places, obtaining for the flow per 24 hours respectively 26,386,560 and 28,738,000 imperial gallons, or an average of 27,584,780 gallons. This was considered to be about three times the quantity of water which the city would consume. The smallest gaugings obtained previous to this had been 51,522,486 gallons by Major Douglass on September 5, 1833, and 50,074,044 gallons by Mr. Stein on September 26, 1833.

A strike for higher wages which occurred early in 1838 retarded the work somewhat between Croton Dam and Sing Sing. It was followed soon by a much more serious disturbance. The Commissioners had inserted in all the contracts the condition "that the contractors should not themselves, nor their agents, give or sell any ardent spirits to their workmen, or any person at or near the line of the aqueduct, or allow any to be brought on the works by laborers, or any other person, and would do all in their power to discountenance its use in the vicinity of the work by persons in their employ." This precaution did not prevent the men from obtaining liquor without difficulty. Grog-shops of the worst kind were soon established in neighboring farm-houses and in shanties erected for the purpose, and led to much disorder. During a drunken frolic in April, 1838, a desperate fight occurred among the Irish laborers, who grouped themselves as Corkites and Fermanaghs. One man was killed on this occasion and many were severely wounded.

The work on the aqueduct progressed rapidly during 1839, 3000 to 4000 laborers being employed on the line. The expenditures for construction during this year amounted to $2,300,438. By the end of 1839 only 14 miles of the 41 miles of aqueduct and pipe-line from Croton Lake to the distributing reservoir remained unfinished. Much difficult and expensive work had, however, still to be performed on Manhattan Island, where, for a distance of only seven miles, the work was estimated to cost three million dollars. The bridge across the Harlem River had scarcely been commenced, and but little progress had been

made on the two city reservoirs and at the expensive crossings at Manhattanville and at the Clendining Valley.

To provide the iron pipes required to be laid across High Bridge, across Manhattan Valley, and between the receiving and the distributing reservoirs, the Commissioners invited, in May 1838, iron-masters in England and in the United States to bid for this work. In all, four to five thousand tons of pipes, 30 inches and 36 inches in diameter, varying in thickness from 1 in. to 1¼ in., were needed. The offers received (three from England and seven from the United States) were opened on October 1, 1838. The contract was awarded to the West Point Foundry Association, whose bid was found to be a trifle below the others.

On March 20, 1840, owing to a change in politics, the Commissioners who had been in charge of the enterprise of supplying the city of New York "with pure and wholesome water" from 1833 were superseded by a new Board, consisting of Samuel Stevens, Benj. Birdsall, John D. Ward, Zebedee Ring, and Samuel B. Childs. Mr. Stevens, who had formerly labored earnestly for the introduction of water-works (see page 16) was elected Chairman of the Commission. No changes were made in the engineer department. The old Board submitted its final report to the Common Council on March 30, 1840.

The first difficulty the new Commission had to meet was a lack of money. This embarrassment was soon relieved by the Legislature passing, on April 27, 1840, upon application of the Common Council, a law authorizing the corporation to raise $3,000,000 more, at a rate of interest not exceeding 6%, for the construction of the water-works.

The new Commissioners made some changes in the plans for crossing Clendining Valley. The former Board had decided to close three of the streets which were crossed by the aqueduct in this valley and to build arched openings for six adjacent ones (viz., Ninety-sixth to One Hundred and First Street, inclusive), the expenses of this work being estimated at $154,543. The new Board considered these openings unnecessary, as the streets in question were not graded nor likely to be for many years. The arches for three of the streets were too far advanced to be abandoned, but for the other three (viz., Ninety-sixth, Ninety-seventh, and One Hundred and First streets) the Commissioners decided to omit the openings, as a saving of $52,820 was thereby effected in the construction. This change was approved by the Common Council, but opposed by the Mayor. In answering the latter's objections the Commissioners state, in their semi-annual report of December 31, 1840:

"The abandoning three arches does not require any street to be closed, and does not shut up any street, properly so called, *no street or road ever having been required, opened, or made* on any of these lands where the arches were contemplated; straight lines are drawn on paper for the streets, if the public interest require them—yet *no tribunal but the Corporation is authorized to decide whether these streets shall be ever opened or not.* If not opened, as they probably will not be, for a century or two to come, they will of course remain fee-simple property, as they now are."

This was written in 1840. New York has now (1895) passed beyond Two Hundred and Thirtieth Street.

A long and somewhat acrimonious dispute arose during the year 1840 between the Water Commissioners and the Common Council with reference to which Board should have charge of the laying of the distributing pipes. The former Water Commissioners had considered that their work terminated at the Murray Hill distributing reservoir. The new Board claimed the right to lay the distributing pipes, as the expense of this work was to be defrayed, according to the law of March 24, 1838, out of the Water Fund and as the law of April 27, 1840, provided "that no item of expenditure should be charged against the Water Stock Fund, except the same is approved by the Water Commissioners and the Comptroller." The Water Commissioners asserted further that the practice adopted by the Common Council of laying the pipes by day's work was very expensive; and that this work was progressing very slowly, only 35 miles of the 165, required early in 1842, having been laid up to May, 1840.

The Common Council claimed, on the other hand, that the plans of the water-works submitted to the voters in April 1835 did not extend beyond the Murray Hill reservoir, where the responsibilities of the Water Board consequently terminated, and asserted its authority to lay the distributing pipes by passing in August 1840 an ordinance organizing "the Croton Aqueduct Department," which was to have charge of this work. The Department was to be composed of:

1st. The Croton Aqueduct Committee, consisting of three members from each of the two boards of the Common Council, which was to have charge of all expenditures, and was authorized to make the necessary contracts for laying the pipes. The Committee was to report monthly to the Common Council.

2d. An Aqueduct Commissioner, who was given charge of all the work and records of the Department. He was to make quarterly reports to the Common Council, giving details of the expenditures, the number of pipes laid and on hand, etc. He was to receive a salary of $1000 per annum, and to give a bond for $5000.

3d. A Water Purveyor, who was to be subject to the direction of the Committee and of the Commissioner.

On September 24, 1840, the Common Council passed another ordinance to settle the questions in dispute between it and the Water Board. An Act authorizing the Corporation to raise more funds for the construction of the aqueduct, passed by the Legislature on July 26, 1841, settled the question at issue, about the laying of the distributing pipes, by giving the Common Council charge of all of the work south of the Murray Hill reservoir. The above Act provided additional means for completing the water-works by authorizing the Common Council to raise three and one-half million dollars more.

An extensive strike for higher wages occurred in April 1840. The civil authorities proved unable to restrain the violence of the mob. The militia had to be ordered out, and soon put an end to the rioting.

The first serious loss during the construction of the aqueduct occurred on the night

of January 7–8, 1841, when a severe freshet washed away the earthen bank of the Croton Dam. It was caused by a heavy rain falling continuously for 48 hours, at a time when the ground was covered with 18 inches of snow and the temperature was warm. The overflow-weir proved to be insufficient to discharge the large volume of water flowing in the river, although the waste culvert was kept open and part of the water was discharged through the aqueduct to the waste-weir at Mill River, fifteen miles from the dam. During the night the water rose in Croton Lake, which has a surface of about 400 acres, at the rate of 14 inches per hour. The earthen bank stood well until the water nearly reached its top, when it flowed between the frozen and unfrozen earth, about 20 inches below the crest of the bank, and formed a breach which was soon widened. The large masses of ice in the river demolished the protection wall and the whole enbankment was washed away. At the time when the accident occurred, 4.30 A.M. on January 8th, the water flowing over the weir had a depth of 15 feet. The masonry of the abutment and overflow-weir sustained but little injury.

All the bridges on the Croton River, both above and below the dam, were destroyed by this freshet. Some small buildings below the dam were washed away and three persons were drowned. The total amount of damage done for which the city was responsible was estimated at about $75,000.*

No other part of the aqueduct was injured during this rain-storm, all the culverts and other structures proving to be well designed.

A new contract at higher prices was made for reconstructing the Croton Dam. The masonry overflow-weir had been but little injured. It was determined to fill the gap made by the freshet—about two hundred feet wide—with a masonry structure, making the total length of the masonry overflow-weir 180 feet, instead of 90 feet as originally designed. The rainy weather which prevailed in the spring of 1841 retarded the work of reconstructing the dam.

By the summer of 1842 the work on the whole aqueduct had progressed sufficiently to enable the Commissioners to allow the Croton water to flow, for the first time, from the Croton Lake to the distributing reservoir on Murray Hill. The high bridge across the Harlem River was not completed, but a 36-inch iron pipe for conveying the water had been laid on the earthen bank which had been formed on the line of the coffer-dams across the whole river.

On June 8 and 9, 1842, the Commissioners, accompanied by their engineers, made a final inspection of the aqueduct, walking through the conduit from the Croton Lake to the Harlem River, a distance of thirty-three miles. The whole structure being found to be in good condition, orders were given to close the "weepers" in the tunnels, through which the ground-water had been led into the aqueduct.

The Croton Dam being sufficiently raised, 18 inches of water was admitted into the aqueduct on June 22d at 5 A.M.

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* For some details of the destruction caused by the great freshet of January 7–8, 1841, see page 232.

The Croton Maid, a boat large enough for four persons, was placed in the current and arrived almost simultaneously with the first water at the Harlem River on Thursday, June 23d. During this strange voyage, which was watched with much interest, different persons took turns in navigating the boat. The velocity with which the current flowed was found to be about a mile in 40 minutes, which exceeded the expectations of the engineers. For a depth of two feet the flow was found to be at a rate of a mile in 36 minutes, and it was estimated that with a depth of water of four feet the velocity would probably amount to nearly two miles per hour.

On Monday, June 27th, the water was admitted at 4 P.M. into the north division of the receiving reservoir. A large assemblage of people, including the Governor, the Lieutenant-Governor, the Mayor, and many other distinguished persons was present. A salute of thirty-eight guns was fired on this occasion by a detachment of artillery, and the Croton Maid, which appeared soon afterwards, was greeted with much enthusiasm by the assembled citizens. The boat was presented by the President of the Water Commission, in an appropriate speech, to the Fire Department of the city.

The water was not allowed to flow into the distributing reservoir until July 4th, at 5 A.M. Invitations had been issued to the Mayor, to the members of the Common Council, and to other important persons to witness this event; but owing to the early hour only few persons were present. The Mayor arrived soon afterwards, and at his request the water was admitted to the distributing pipes which led to the tanks at Thirteenth Street (constructed for extinguishing fires, see page 16), which were at the time completely empty. Owing to the manner in which the pipes had been laid it took nearly the whole day to rid them of air, before the water flowed regularly to the lower part of the city.

The introduction of a copious supply of pure water from the Croton River into New York, an event of the utmost importance for the welfare of the city, was celebrated by the citizens on October 14, 1842, by a grand military and civic procession and by other appropriate festivities. New York has seldom witnessed a finer celebration. The Governor and Lieutenant-Governor of the State, the Mayors and Common Councils of New York and neighboring cities, officers of the army and navy, the clergy, judges, scientific and philanthropic societies, the different trades, the militia, the firemen, with their engines decorated, etc., etc., took part in the procession. At the request of the Corporation of the City of New York, George P. Morris wrote for the occasion an ode which was sung by the members of the New York Sacred Music Society in front of the fountain in the City Hall Park. The Common Council had a silver medal (see Figs. 10 and 11) struck to record the event, and voted to have a memoir of the work prepared. It was written by Mr. Charles King and published in 1843. For a full account of the celebration of October 14, 1842, we must refer the reader to that memoir.

The flow through the aqueduct was maintained without interruption until November 8, 1842, when the conduit was emptied for inspection. Some small leaks were discovered and stopped from the inside, and some slight settling of the conduit was noticed at some places. Upon the whole the work appeared to be in good condition.

Fig. 9.—Badge worn in Procession of October 14, 1842.

Fig. 10.—Silver Medal.

Fig. 11.—Silver Medal.

Although the Croton Works were sufficiently advanced by the summer of 1842 to be put into operation, they were not entirely finished for some time. By January 1, 1844, all the work was completed with the exception of High Bridge, which was not finished until November, 1848. The total cost of the Croton Aqueduct, including land, interest on water stock, etc., amounted to about $12,000,000 (see page 311).

While the works were being finished the Water Commissioners took charge of their maintenance. Semi-annual inspections of the interior of the aqueduct were made, as recommended by the Chief Engineer, and led generally to the discovery on embankments of some small cracks in the masonry, which were repaired. The exterior of the works was constantly inspected, six stations for the "keepers" being established in 1843.

In November, 1846, one of the 36-inch pipes in the line from the receiving to the distributing reservoir burst, which was attributed to careless laying in 1841. With this exception all the work which had been constructed under the supervision of the Water Commissioners proved to be well done.

Another change in politics having occurred, the Water Commissioners were superseded on February 8, 1843, by the former Board whom they had succeeded in 1840. The different changes in the Board of Water Commissioners made fortunately no difference in the engineer department, at the head of which J. B. Jervis remained. The original Board of Commissioners continued in office, with the exception of the year 1848 (when they were superseded by Philip Hone, John H. Williams, Nathaniel Weed, M. O. Roberts, and J. H. Hobart Hawes), until the Croton Aqueduct Department was organized under the law of April 11, 1849.

While the Water Commissioners were finishing the Croton Works the Croton Aqueduct Department (called also the Croton Aqueduct Board) formed by the Common Council (see page 44) continued the work of laying the distributing mains. By Feb. 1, 1844, 150 miles of pipes (6 inches to 36 inches in diameter) had been laid south of the Forty-second Street reservoir. The total amount of pipe laid by this Board previous to July 1849, when the Croton Aqueduct Department was formed, was about 194 miles.

A matter which soon forced itself upon the attention of the Water Commissioners was the great waste of water that was taking place. When the Croton water was first introduced the hydrants were free. The result may be readily imagined. The Water Commissioners tried various measures for stopping the waste, but without much success.

As early as 1846 the Commissioners foresaw the need of another large reservoir in the city and submitted the question to the Common Council in several reports. During thirteen days in 1846, when the aqueduct was shut off from the city for inspection and repairs, the receiving and distributing reservoirs were lowered respectively about 14 and 22 feet, although at that time there were only 12,000 water-takers.

The work of the Water Commissioners was terminated by the Act of the Legislature of April 11, 1849, which organized the "Croton Aqueduct Department," transferring to it all the work which had thus far been performed by the Water Commissioners and by the Croton Aqueduct Board.

PLATE 6.

OLD CROTON DAM.

AQUEDUCT-BRIDGE ACROSS HIGHWAY NEAR TARRYTOWN.

CHAPTER III.

DESCRIPTION OF THE OLD CROTON AQUEDUCT.

WE shall describe in this chapter the old Croton Aqueduct, as originally constructed.* Modifications and improvements which were made subsequently will be published later.

Croton Lake (Plate 54), the "Fountain Reservoir" which supplies the Croton Aqueduct, was formed by constructing a dam across the Croton River, about six miles above its mouth. The lake is four miles long and has a width of about one eighth to one fourth of a mile. Its area contains four hundred acres, and its storage capacity for a depth of six feet (namely, to the level at which a daily flow of 36,000,000 U. S. gallons can be maintained in the aqueduct) amounts to 600,000,000 U. S. gallons.

The Croton Dam (Plate 31) was constructed across the Croton River at a point where the channel was 120 feet wide, the average depth of water being about four feet. During floods the depth of water increased to a maximum of about ten feet. At the site of the dam the left bank of the river consists of abrupt rocks, while the right bank is formed of a sandy table-land, about three feet higher than the ordinary level of the river, extending back eighty feet to a hill of sand, having a slope of about forty-five degrees.

Major Douglass located the dam originally four hundred feet further up stream, but his successor, Chief Engineer Jervis, in making the final examinations, changed the location to the site we have described in order to obtain a better foundation for the dam. At the place selected the dam had to be raised forty feet above low water (equal to fifty-five feet above its rock foundation) in order to obtain the desired amount of head. By locating the dam further up stream a site might have been found where the dam would have required only sufficient height to deflect the water into the aqueduct, but this would have lengthened the costly masonry conduit and would have rendered several important tributaries of the Croton unavailable for the city's water-supply.

On the location selected for the dam a rock foundation could only be obtained near the south bank. It was, therefore, determined to form the dam of earth, with the exception of the overflow-weir, which was to be constructed of masonry and to be located at the southern extremity of the dam. On the down-stream slope of the earthen bank a protection wall was to be built.

According to the original plans the overflow-weir was to be one hundred feet long, and to be flanked by abutments rising eight feet above its crest, but, owing to the short distance that the rock extended into the river, the length of the weir was reduced to an average of

* Plates 30 to 49, referred to in our text, are copies of the original drawings for the old Croton Aqueduct, reproduced from T. Schramke's "Description of the Croton Aqueduct," published in 1846.

ninety feet, part of it being obtained by excavating the rock on the south bank. Only the north abutment had to be constructed, the one on the south being formed by the rock. As the length of the weir had been reduced, the north abutment was raised so as to be fifteen feet above the crest of the weir on the up-stream and twelve feet on the down-stream side. The rock descended so rapidly in the river that an artificial foundation had to be prepared for part of the north abutment.

A waste-culvert, 5 feet by 6 feet, having two sets of suitable gates, operated from a small house on top, was constructed in the abutment, to make it possible to draw down the reservoir whenever it should be required, for repairs or other purposes. A small foot-bridge, placed across the waste-weir, gives access to the gate-house.

Before the earthen dam had been quite completed it was washed away by a freshet, without precedent, which occurred during the night of January 7–8, 1841 (see page 45). The gap made by the destruction of the earthen dam was about 200 feet wide. It was decided to fill it up by extending the masonry overflow-weir 180 feet across the channel of the river to a point where it would join the earthen dam near the north bank. As no rock foundation could be obtained for the extension of the masonry structure, an artificial one had to be prepared. The method adopted was as follows (see Plate 31):

The bottom of the river was cleared of mud and boulders where the masonry was to be built. The space to be occupied by the structure was then enclosed by coffer-dams, formed of heavy cribs which were left in the foundations. The cribs *C* and *D* were first sunk, and covered on top by white-pine planks, six inches deep. On top of these cribs two others were placed, and connected together near the top by cross-ties. While the cribs were being carried up, the space between them, *E*, was filled with concrete. In front of *D*, a small crib, *H*, having square timbers only on its down-stream face, was constructed and securely anchored by timber ties to *D*. The cribs just described formed a coffer-dam on the up-stream side of the foundation. As a protection against the water on the down-stream side the cribs and *J*, *K*, and *L* were placed, the crib *J* being filled with concrete and the others with loose stones. On top of these cribs an apron of elm-timber was constructed. The square timbers in all the cribs were 12-in. × 12-in. hemlock. The cross-ties were of oak and were spaced 6–10 feet apart. They were dovetailed into the square timbers and secured by treenails one inch in diameter. The crib timbers were fastened together by treenails 2 "to 2½" in diameter, by thirty inches long, placed about three feet apart. The planking of the apron was secured to the square timbers on which it rested by one-inch locust treenails.

After the coffer-dams had been completed the space enclosed by them was excavated to a hardpan foundation and filled with concrete and masonry as shown on Plate 31. Against the up-stream face of the dam an earthen bank having a slope of 5 in 1, and extending on the bottom to a width of 275 feet, was constructed. Near the top, the earth bank was paved with stone. Three hundred feet down stream from the Croton Dam, a secondary dam was constructed of cribs of round timber, filled with stone, the object being

to back up the water so as to form a pool to break the force of the water flowing over the weir of the main dam and, also, to keep its cribs and apron constantly under water.

The Location of the Aqueduct is shown on Plate 54. The aqueduct begins at Croton Lake, follows the Croton River to a point near its mouth, and then the Hudson River to Yonkers. Here it crosses the valleys of the Sawmill River and Tibbit's Brook and follows the ridge on the east side of the latter and then the summit of the land lying between the Hudson and East rivers to the Harlem River. A fine masonry bridge, about 1450 feet long, known as "High Bridge," carries the aqueduct across the valley of the Harlem River to Manhattan Island, which at this place is about one hundred feet higher than the grade of the aqueduct, the bank of the river being very steep. The aqueduct avoids this high ground, being constructed at a suitable elevation on the slope, and turns then westerly to Tenth Avenue, which it reaches at One Hundred and Fifty-first Street. The location follows the line of Tenth Avenue to One Hundred and Eighth Street. Here it turned originally into a line parallel with and 100 feet west of Ninth Avenue, which it followed to Eighty-ninth Street. It then curved to the east and passed through Eighty-fifth Street to the receiving reservoir, in Central Park. From here two lines of 36-inch cast-iron mains were laid through Eightieth Street and in Fifth Avenue to convey the water to the distributing reservoir at Forty-second Street.

From Croton Lake to the receiving reservoir the aqueduct was constructed as a masonry conduit with the exception of the crossing of the Harlem and Manhattan valleys, where two lines of 36-inch pipe were substituted for the masonry water-channel.

On the location described above very little ground was found that was favorable for the construction of the aqueduct. In following the valleys of the Croton and Hudson rivers, many spurs of ridges and deep ravines increased the difficulties and expense of construction, the former involving frequent tunnels or deep cuts, and the latter high embankments.

Sixteen tunnels, 160 to 1263 feet long, aggregating 6841 feet, had to be driven. About 400,000 cubic yards of rock were excavated for the whole aqueduct. Table-land was rarely found at the required elevation.

The formation of rock encountered was generally gneiss, but in a few cases marble was met in the excavation, viz., at a point about two miles from the Croton Dam, in a tunnel near the State Prison at Sing Sing, at Dobbs Ferry, at Hastings, and in the foundation of two of the piers of the bridge across the Harlem River. The surface soil was generally a sandy loam, beneath which gravel, sand, and boulders were found, and also hard-pan to a considerable extent.

Grade-line of the Aqueduct.—According to the original plans, the masonry conduit was to commence at Croton Dam with the crown of the soffit of the arch at the elevation of the overflow-weir of the Croton Dam (166.2 feet above the datum plane, for which mean tide in the Hudson River at the mouth of the Croton River was taken), and to continue to the south side of Manhattan Valley on a uniform grade of 0.021 foot per hundred, equal to about 13¼ inches per mile. For the pipe-lines across the Harlem and Manhattan valleys an

additional allowance of two and three feet respectively was to be added to the regular grade of 0.021 foot per hundred.

From the south side of Manhattan Valley to the receiving reservoir the grade of the conduit was to be only nine inches per mile.

In order to be able to draw a greater quantity of storage water from Croton Lake, it was subsequently decided to depress the inlet of the aqueduct below the elevation mentioned above and to increase the cross-section of the conduit, to compensate for the reduction of grade resulting from this depression to a point where the original grade-line would be reached. The top of the aqueduct was depressed only 0.583 foot and constructed level for 2276 feet to a point where it intersected its original grade-line. The bottom of the conduit was depressed 2.93 feet and built on a grade of 0.0113 foot per one hundred (about 0.6 foot per mile) for 4.949 miles to a point on its original grade-line.

For the first five miles the area of the water-channel of the conduit is gradually diminished from the inlet to a point where the original grades are reached. The upper arch and invert were made as required by the standard cross-section, the increased section being obtained by an additional height of the side walls.

The lengths and amount of "fall" of the different parts of the aqueduct are given by T. Schramke in his "Description of the Croton Aqueduct" as follows:

LENGTH AND GRADES OF AQUEDUCT.

Description.	Location.	Lengths.		"Fall" in feet.
		Feet.	Miles.	
1st plane of aqueduct...	From "inlet" to point where the original grade-line is reached..	26,130	4.9490	2.9507
2d plane of aqueduct...	From end of 1st plane to Harlem River..	147,479	27.9316	30.9700
Pipe-line.....	On bridge across Harlem River.....	1,450	0.2750	2.3450
3d plane of aqueduct....	Harlem Bridge to Manhattan Valley.....	10,635	2.0140	2.2334
Pipe-line.....	Across Manhattan Valley.....	4,180	0.7917	3.7783
4th plane of aqueduct..	Manhattan Valley to receiving reservoir..	11,471	2.1727	1.6295
Receiving reservoir.....	Influence-gate to effluence-gate..... ..	908	0.1720	
Pipe-line.....	Receiving to distributing reservoir.....	11,489	2.1760	4.000
Distributing reservoir..	.....	420	0.0800	
			40.5620	47.9069
The 47.9069 feet are the fall of the invert of the aqueduct. As this invert is, however, 11.4633 feet below the water-surface at Croton Lake and only 8.200 feet at the receiving reservoir, the difference between these two depths must be added to get the total head, viz.....			.....	3.2633
	Total.....		40.5620	51.1702

On the first plane of the aqueduct the arch and invert have different grades, as explained above.

The Inlet Gate-house (Plates 31 and 32).—The water is conveyed through a tunnel 180 feet long, constructed in solid rock and having a cross-section somewhat larger than that of the aqueduct, to the inlet gate-house, near the Croton Dam. This building contains

an inlet water-chamber connected with the tunnel just mentioned and an outlet chamber at which the aqueduct begins. In passing from one of these chambers to the other the water has to flow through screens (made originally of oak slabs 6″ × 1″, placed on edge, but replaced later by brass-wire netting) and through the openings of two sets of gates, the guard-gates and the regulating-gates. The former are made of cast iron, the latter of gun-metal. The details of these gates, which are operated by hand, are shown on Plate 37. The rods by means of which they are moved, having considerable length, are kept in line by wrought-iron guides, leaded into the stonework (*KK*, Fig. 3, Plate 32).

The Masonry Conduit was constructed as shown on Plates 33 and 34. The standard cross-section of the interior of the aqueduct is composed of the following three parts: A semicircle of 7′ 5″ diameter for the top, a trapezoid 4 feet high, the parallel sides being respectively 7′ 5″ and 6′ 9″ long, for the middle part, and a segment, having a chord of 6′ 9″ and a versed sine of 9 inches for the bottom or invert. The area of the whole cross-section contains 53.34 square feet.

The only departures from the standard cross-section of the interior of the aqueduct occurred in the first 4.949 miles of the conduit, where the size of the water-channel was somewhat increased as described on page 52, and in the cases of tunnels. If the latter were in good rock, the roofing arch was omitted (see Plate 33, Fig. 4); if in earth and clay, a section like that shown in Plate 33, Fig. 5, was adopted.

The conduit was founded on a course of concrete, 3–12 inches thick according to circumstances. The side-walls were built of rubble masonry. After these walls and the concrete foundation had been plastered with a coat of hydraulic mortar, about ⅜ of an inch thick, they were lined with four inches of brickwork in order to make the water-channel as smooth as possible.

The top arch was made of brickwork, eight inches thick, except in a few cases in which it was made of stone-masonry. The top of the arch and of the spandrel rubblework, which was built up solid from the side-walls as shown on Plate 33, was plastered with a coat of hydraulic mortar. Wherever the conduit was above the surface, it was covered with a bank of earth to a height of three to four feet above the crown of the arch. A similar covering of earth was placed over the aqueduct in open cuts.

Where the aqueduct crossed valleys, walls of dry rubble having a top-width of 11–15 feet were constructed as a foundation for the masonry conduit (see Plate 34). On both sides of this wall embankments of earth, formed in layers and carefully rolled, were brought up simultaneously with the dry rubble wall. The aqueduct was built with extra precautions on these foundation-walls, which were always allowed to stand for a few months before the masonry of the conduit was commenced. The bed of concrete was made twelve inches thick, the width of the side-walls was increased, more lime was used in the mortar, and the whole interior of the conduit was plastered with hydraulic mortar.*

The earth embankments were carried up to a height of three to four feet above the

* A settling of the aqueduct causing cracks in the masonry has occurred on most of these embankments.

crown of the arch, the slopes being generally covered by dry stone-walls. Along side-hills, where the aqueduct had to be constructed partly in cuts and partly in embankments, the lower side of the latter were protected by strong retaining walls.

The hydraulic lime used for the mortar was all obtained from Ulster County, N. Y. Each lot was carefully tested before being accepted. For the concrete and rubble masonry the mortar was composed of three parts of sand to one of lime, but for the brickwork and the plastering the proportion was two to one. On embankments the mortar for the rubble and concrete was mixed 2½ to 1.

Ventilators (see Plate 36).—To allow the air to escape when the aqueduct is being filled, and to maintain a free circulation of air over the water, 33 ventilators were constructed at regular intervals of a mile. Where the waste-weirs occurred the ventilators were omitted, as the former served for the same purpose. Eleven of the ventilators were provided with doors to give easy access to the interior of the aqueduct. They were constructed to one side of the centre line of the aqueduct, while the others were built on the crown of the arch of the conduit.

The ventilators were all constructed of good hydraulic masonry and made cylindrical in form, tapering slightly toward the top. The entrance ventilators have an inner diameter of 4 feet, while that of the others is only 2 feet. They are all 14 feet high above the surface of the ground and have the opening at the top, 15 inches in diameter, closed with an iron grating.

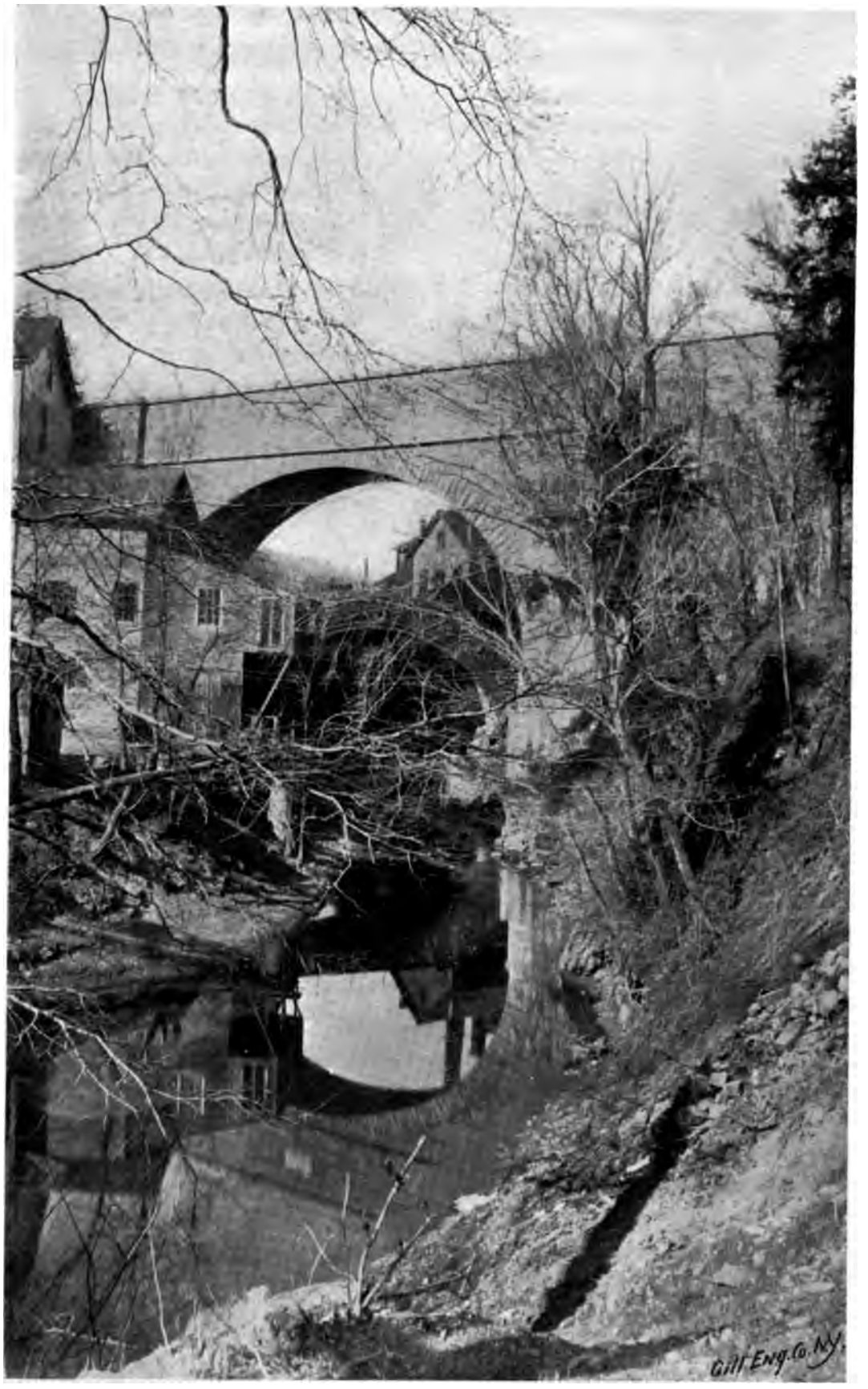
In addition to the ventilators, openings two feet square were left in the crown of the arch one quarter of a mile apart and covered with flagstone. These openings can be used in case of necessity either for ventilation or for entering the conduit. Their location is indicated by small stone monuments.

Culverts.—In order to pass streams and drainage-water under the aqueduct, 114 culverts of 18 inches to 25 feet span, aggregating 7959 feet in length had to be constructed. The culverts were generally built on a grade of one in twenty. When the upper end of a culvert was below the surface of the ground the water to be carried off reached it through a vertical well. On Plate 34 the details of some of the culverts are shown. In addition to the culverts required for passing water, five others, having spans of 14–20 feet, were built for crossings of roads.

Waste-weirs (see Plate 36).—At six suitable places on the line of the aqueduct waste-weirs were constructed, each having an overflow-dam, parallel with the centre line of the conduit, for regulating the height of the water in the aqueduct, and blow-off gates of cast iron, constructed similar to those shown on Plate 37, for emptying the conduit. The gates, etc., were protected by a masonry gate-house constructed over the aqueduct at each waste-weir.

The Aqueduct Bridge across Sing Sing Kill (see Plate 35).—In the village of Sing Sing the aqueduct was constructed across a deep valley, 536 feet wide at the grade of the top of the conduit, requiring three openings in the structure, viz., one for the Sing

PLATE 7.



AQUEDUCT-BRIDGE ACROSS SING SING KILL.

Sing Kill, a stream which had worn a deep channel for itself; another for a highway parallel with this stream, and the third for a farm-crossing.

The bridge across the stream consists of a masonry arch of 88 feet span and 33 feet rise, the form of the arch being a compound curve, drawn from five different centres. The arch was built of granite voussoirs, 3 feet thick at the crown and 4 feet at the spring-line, dressed to joints of $\frac{3}{16}$ of an inch. The faces of the bridge were carried up on a batter of one-half inch per foot, so that the length of the arch, measured at right angles with the line of the aqueduct, is less at the crown than at the spring-line. The distance from the top of the structure to the rock bottom is about eighty-two feet.

The abutments of the arch, which are twenty feet thick, were founded on rock. The spandrel backing of the arch was made solid to a certain height, sloping upwards, and then continued by open "hance-walls," connected to each other by bond stones and at the top by four-inch brick arches, as shown on Plate 35.

The form of the conduit is slightly altered at the bridge from the standard section, and the masonry is made stronger. To prevent leakage a lining of cast-iron plates, $\frac{5}{8}$ inch thick, bolted together, the joints being filled with iron cement, was built in the brickwork. If in spite of this precaution any leakage should occur, the openings between the "hance-walls" would drain off the escaping water. A six-inch space was left also between the parapet walls and the side-walls of the conduit, as a protection against frost and to drain off rain-water filtering through the earth covering of the aqueduct or water leaking from the conduit. The inside of the aqueduct was plastered with three coats of hydraulic mortar. That this arch was very well built was shown by the fact that a settling of only three quarters of an inch occurred when the centres were struck.

The opening for the highway mentioned above was made by a skew-arch of 20 feet span, the conduit being constructed here also with an iron lining. For the farm-crossing an opening of 7 feet span was provided. The aqueduct across the other parts of the valley was built on dry foundation-walls, having their faces laid in hydraulic mortar.

The "High Bridge" across the Harlem River (see Plates 38 and 39).—The bridge has a length of 1450 feet between the gate-houses at its ends. It consists of a succession of fifteen semi-circular arches, eight having spans of 80 feet and seven of 50 feet. The bridge is continued to the gate-houses on both sides, by foundation-walls of dry rubble, having their faces laid in cement to a depth of two feet. The soffit of the arches at the crown is 100 feet above high water.

There are two abutments and fourteen piers (seven on land and seven in the river). The abutments and four of the piers are founded on rock, but for the others pile foundations had to be prepared. The piles were of oak, and 16 to 38 feet long. They were spaced $2\frac{1}{2}$–3 feet, centre to centre, and driven until they did not penetrate the soil more than one inch under a blow of a twelve-hundred-pound hammer falling thirty feet. For the river piers, the piles were capped with 12″ × 12″ timbers, which were covered by two courses of 6-inch planking. Before the planking was placed, a course of concrete three feet deep was put

around the piles and between the caps. For the land piers the piles were left without caps and planking, and merely surrounded by three feet of concrete.

Before the piles were driven the foundations had to be excavated to more or less depth on account of a layer of earth containing large boulders, which interfered with the pile-driving. For all the river piers coffer-dams had, therefore, to be placed. The framework was put together on shore to the required height, floated to the position of the pier and sunk. The sheet piling was then driven, and a bank of earth placed on the outside. As the foundation was sunk additional sets of timber were placed to maintain the excavation. The deepest foundations had to be excavated near the south bank, the depth below high tide being for piers 10, 11, 12, and 13 respectively 35, 31, 35, and 54 feet. The details of the masonry and the centring for the arches are shown on Plate 38. The bridge was designed for supporting two lines of 48-inch pipe, but as these would have delivered much more water than was required at the time, only two 36-inch mains were laid across the bridge and connected by reducers with the influent and effluent gate-houses, at the termination of the aqueduct. The pipes were to be covered with four feet of earth as a protection against frost. Instead of this, screened gravel, through which the rain-water percolated freely, was used for this purpose. This was certainly no improvement.

The inlet to the pipes is formed by the gate-house shown on Plate 39. It is provided with a waste-weir and with blow-off gates, by means of which the aqueduct can be emptied into the Harlem River through a sewer having for the first thirty feet the cross-section of Fig. 5, which is then reduced to that of Fig. 4. The inlet to each of the 36-inch pipes is controlled by two cast-iron gates. The outlet gate-house for the pipes is similar to the inlet with the exception that it has no waste-weir and blow-off gates.

The consumption of water in New York increased so rapidly after the Croton water was introduced into the city that the two 36-inch pipes laid across High Bridge soon became insufficient for supplying the demand. Twelve years after the bridge had been completed its upper part had to be reconstructed in the manner described on page 71, in order to increase its capacity for conveying water into the city.

The cost of the bridge as originally constructed amounted to $963,427$\frac{80}{100}$.

The Crossing of Manhattan Valley.—About two miles south of the Harlem River, the aqueduct had to be built across another depression—Manhattan Valley, which has a length of 4180 feet at the grade-line of the aqueduct and a maximum depth of 105 feet below this level. A plan was made for carrying the aqueduct across this valley on an arcade of brick arches, but the estimated cost was so great that the Water Commissioners decided to effect the crossing by a siphon of four lines of 36-inch pipes, although three feet extra "head" had to be allowed for the latter plan.

The connection between the masonry conduit and the pipe-lines, at both sides of the valley, was made by a gate-house where suitable gates were provided for each line of mains. At the lowest point of the siphons, a blow-off vault (see Plate 40) was built and blow-off pipes, having stop-cocks, were connected to each line of mains, for emptying the pipes and for discharging any deposit that might accumulate in them. Originally only two lines of

36-inch mains were laid across Manhattan Valley, but the gate-houses and blow-off vault were arranged for two additional lines of pipes.

The Aqueduct across Clendining Valley (see Plate 41).—About half way between Manhattan Valley and the receiving reservoir at Eighty-sixth street, the aqueduct had to be constructed across Clendining Valley, a depression having a length of about 1900 feet and a maximum depth of about 50 feet below the grade of the aqueduct. The centre-line of the structure was located at this place, parallel with and 150 feet west of the centre-line of Ninth Avenue. As stated on page 43, openings were provided for three of the streets which the aqueduct crossed in this valley, viz., Ninety-eighth, Ninety-ninth and One Hundredth streets. For each of these streets a masonry arch of 30 feet span was constructed across the roadway, and two arches of 10½ feet span for the sidewalks, one on each side of the roadway. The structure at these crossings was built in a similar manner as the bridge across the Sing Sing Kill (see page 55), the aqueduct being provided with an iron lining* and the walls on top of the arches being built hollow to save masonry and to provide drains. Between the bridges, the aqueduct was constructed on foundation-walls of dry rubble, faced for the depth of one foot with masonry laid in hydraulic mortar. These walls were formed of very large stones, the interstices being filled with smaller ones. They were carried up with a batter of one inch per foot for each face to a width of 30 feet at the bottom of the conduit. On this foundation a course of concrete was laid upon which the conduit was built, its side-walls being made four feet thick. The parapet walls on either side of the conduit were laid in lime-mortar and the whole aqueduct was covered with earth which was sodded, giving the whole structure a finished appearance.

The Receiving Reservoir (see Plates 42, 43, and 44) was constructed on an elevated part of Manhattan Island, between Seventy-ninth and Eighty-sixth streets, and between Sixth and Seventh avenues. It is 1826 feet long and 836 feet wide, from outside to outside of the top of the exterior walls of the embankments, and covers about 35 acres of land. An earthen embankment divides it into a north and a south division, the water-areas of which contain respectively $18\frac{18}{100}$ and $12\frac{75}{100}$ acres, a total of about 31 acres. The maximum depth of the water is twenty feet in the north division and thirty feet in the south division, the capacity of the reservoir being 180,000,000 U. S. gallons.

The ground on which the reservoir was constructed was undulating and consisted of gneiss rock, covered in places by earth. It was graded to the required level by cutting and filling, with the exception of some points where the rock surface was left at a higher elevation in order to avoid expense. Some apprehensions were felt that leakage might occur along the surface of the rock or through fissures and seams, but, although the bottom of the reservoir was left as graded, no perceptible loss of water by leakage occurred.

The reservoir was formed by means of earthen embankments having "puddled core-walls." The puddle was made of clay, loam, and gravel, mixed in suitable proportions. It was laid in twelve-inch courses, each being wetted and cut through with spades vertically

* We are informed by Gen. George S. Greene that this iron lining was found to be in perfect condition, when the structure was removed, at this place, in 1870–1875.

every three quarters of an inch, in order to compact the whole mass. To avoid cracking or checking, the top course of puddle was covered soon with earth, the same precaution being adopted whenever the work was interrupted.

The embankments are of moderate height except on the western and eastern sides of the south division, where they are in places 38 feet high above the ground. They have a top width of 18 feet (which is, however, increased to 21 feet where the banks are high), outer slopes of one foot horizontal to three feet vertical, and inner slopes of 1½ to 1. The outside face of the embankments is protected by stone walls four feet thick, having the face-stones laid in mortar and the others dry. The inner slopes are covered by a dry stone paving 15 inches thick. The top of the embankments is four feet above the highest water-level in the reservoir.

A 30-inch cast-iron pipe was laid on the surface rock through the cross-embankment forming the two divisions, in order to equalize the height of the water. This pipe can be closed by a stop-cock that is operated by means of a long rod from a gate-house built on top of the bank.

Near the eastern end of the cross-embankment a waste-weir well was constructed in the bank, to prevent the water from rising above the desired level. The surplus water falls down the well to a sump at the bottom, 3½ feet deep, where a water-cushion is formed, and is carried off by a brick sewer. The height of the waste-weir can be varied three feet by means of stop-planks. The top of the cross-embankment is carried over the waste-weir well by means of a brick arch.

The aqueduct enters the reservoir at an inlet gate-house which was constructed in the west embankment at Eighty-fifth Street. Here the water can be discharged either directly into the north division or, through a conduit constructed in the west embankment, into the south division. The flow into either basin is regulated by means of cast-iron sluice-gates, constructed as shown on Plate 37. The superstructure of the gate-house was built of stone and brickwork and covered with flags of greywacke.

The outflow from the reservoir is arranged so that water can be taken from either division or from both at the same time. Each division has a masonry outlet-tower near the east embankment, with which it is connected by means of a foot-bridge. The side of each tower towards the reservoir is left open and contains two sets of frames, made of 10″ × 12″ white pine, for the gates and screens. The outer frames are for the screens, which were formed by nailing oak slats (one inch by six inches) placed edgewise one inch apart except near the top, where the frames are covered by planking. The inner or second set of frames are for the gates and are covered with plank except near the top and at the gate-openings. The original gates were made of two-inch pine planks to which cross-pieces were nailed and were operated by means of iron rods from the floor of the gate-house in a similar manner as the iron gates on Plate 37.

In the rear walls of the towers the reducers, forming the inlets to the pipes, were placed. Three lines of 36-inch mains leave each tower. Those from the north division were laid in a brick vault 540 feet long and 16 feet wide, which was constructed in the east embank-

PLATE 8.

DISTRIBUTING RESERVOIR AT FORTY-SECOND STREET.

DISTRIBUTING RESERVOIR, FIFTH AVENUE PILASTER.

ment. These pipes were joined as shown on Plate 44 to those from the south division. Pipes 1 and 3 convey the water to the distributing reservoir. Pipe 2 was also intended for this purpose, but was not laid at the time. Pipe 4 supplies the east side of the upper part of the city. Each line of pipes is provided with a stop-cock placed in the vault.

On the west side each division of the reservoir has an outlet-tower (similar in construction to those already described, but smaller). Each of these towers has only one outlet-pipe. The main from the north division was laid in a vault 400 feet long and 8 feet wide, which was constructed in the west embankment. The two west outlet-pipes are joined together as shown on Plate 42.

The Distributing Reservoir (see Plates 45, 46, 47 and 48) was constructed on what was known as Murray Hill, about three miles from the City Hall, the ground being higher at that point than any other in the vicinity or to the south. To reach the proper level for the water, the reservoir had to be formed almost entirely above ground by means of walls 36 to 49 feet high above the surface, and about five feet higher from their rock foundation. The reservoir is 420 feet square at the top and 436 feet at the base. It occupies about four acres of land between Fortieth and Forty-second streets just west of Fifth Avenue. Its capacity is 24,000,000 U. S. gallons, the maximum depth of the water being 36 feet.

In order to obtain a greater base with a given amount of masonry and also to afford ample facilities for detecting any leakage, the main walls of the reservoir were made hollow. They were formed of an exterior and interior wall of hydraulic stone masonry, connected every ten feet by cross-walls which were carried up to within 17 feet of the top, at which elevation brick arches 12 inches thick were built from one cross-wall to the other. The spandrels between the arches were filled with solid rubble masonry, the whole being covered with a six-inch course of concrete, which brought the walls to within ten feet of the top. From this level the exterior wall was carried up alone and finished with an Egyptian cornice, giving the whole structure a fine appearance. The inner wall and the arches were covered with earthen embankments (see Plate 45), as described hereafter.

The exterior wall is uniformly four feet thick and has a batter of two inches per foot. The inner wall is carried up vertical and has offsets, its thickness being six feet at the base, five at the middle section, and four feet at the top. The space between the inner and the outer walls is 14 feet wide at 41 feet below the top and 9′ 9″ at the spring-line of the brick arches.

The cross-walls are four feet thick at the bottom and three feet at the spring-line of the arches, the reduction of the thickness being made by a six-inch offset on each side, eight feet below the spring-line. Openings 6 ft. × 1½ ft. were left in all the cross-walls near the bottom to permit the inspectors to pass around the whole reservoir, and to form a drain for water leaking through the inner walls. Some modifications in the construction of the cross-walls were made at the corners of the reservoir and at the gate-chambers.

On each corner of the reservoir and at the centre of the walls in Fortieth and Forty-second streets and in Fifth Avenue pilasters were built. Those at the corners are 40 feet wide and project four feet from the main wall; the others are 60 feet wide and project six

feet. The pilasters were all built four feet higher than the main wall with the exception of the Fifth Avenue pilaster, which rises seven feet above the wall. By means of doors placed in the central pilasters access is obtained in Forty-second Street to the influent gate-chamber in Fortieth Street to the effluent gate-chamber, and in Fifth Avenue to a stone stairway leading to the top of the wall.

The exterior walls of the reservoir were built of coursed rubblework, roughly hammer-dressed, and the pilasters of ashlar masonry. An embankment of puddled earth was constructed on the water side of the interior wall and raised four feet above the high-water level, covering the interior wall and the brick arches connecting the cross-walls completely. It has a slope of four horizontal to one vertical for a width of 16 feet, and then a slope of 1 to 1 to the top of the bank, where it is 17 feet wide. Its faces are covered with rubble masonry laid in hydraulic mortar, and coped with dressed stones, upon which an iron railing is placed. The top of the embankment is covered with a course of concrete two feet thick, upon which flagstones are laid.

The bottom of the reservoir consists of very impervious hardpan, which was covered with puddled earth for a height of two feet, and then with 12 inches of concrete made with hydraulic mortar.

A central wall of concrete faced with rough masonry (see Plate 46) divides the reservoir into an east and a west basin, each of which has a separate inlet and outlet, and a blow-off gate for emptying the water into a sewer in Forty-second Street. The division wall is 19 feet thick at the bottom, 6′ 8″ at the high-water level, and 4 feet at the top. The lower parts of this wall are protected by banks of puddled earth paved with fifteen inches of hydraulic masonry.

A 36-inch pipe was laid in the central wall in order to maintain the water in both basins at the same level. It was provided with a stop-cock which is operated from the top of the wall.

Near the northerly end of the division wall a waste-weir is constructed for each basin, the overflowing water being discharged by a waste-well having two falls (together 52 feet), and a drain under the wall into a sewer in Forty-second Street.

The reservoir is arranged for three lines of 36-inch inlet-pipes and the same number of outlet-pipes, as shown on Plate 45. Originally only two inlet and two outlet pipe-lines were laid. Each line of pipes was provided with a stop-cock which is operated from a gate-chamber placed in the wall.

At the southerly end of the division-wall a gate-house was constructed, where the flow into the effluent pipes can be controlled by means of sliding gates. A screen of oak slabs six inches by one inch, put on edge, was placed in front of the gate-house.

CHAPTER IV.

THE MAINTENANCE AND EXTENSION OF THE WATER-WORKS BY THE CROTON AQUEDUCT DEPARTMENT.

AN Act passed by the Legislature on April 11, 1849, created "The Croton Aqueduct Department," which superseded the Water Commissioners appointed under the Act of May 1834 and the Croton Aqueduct Board organized by the Common Council in 1842. The new department was given full charge of all the water-works, and also of the construction, repairs, and cleaning of the sewers and drains. To these duties were added in 1857, under the amended city charter, the paving and repairs of the streets and the charge of the old wells, which were gradually filled up. All suits and claims arising from the construction of the water-works were to be settled by the new Board.

The management of the Croton Aqueduct Department was intrusted to three Commissioners, who were to be appointed by the Mayor, subject to the approval of the Common Council. One of the Commissioners was to be a civil engineer. The first Board of Management consisted of:

Nicholas Dean, President Commissioner;
Theodore R. De Forrest, Assistant Commissioner;
Alfred W. Craven, Commissioner and Chief Engineer.

The changes which took place in the membership of the Board are given in the following table:

CROTON AQUEDUCT DEPARTMENT.

Year	President Commissioner.	Assistant Commissioner.	Commissioner and Engineer.
1849	Nicholas Dean	Theodore R. DeForrest	Alfred W. Craven
1850	"	"	"
1851	"	"	"
1852	"	"	"
1853	Elias E. Smith	"	"
1854	"	"	"
1855	Myndert Van Schaick	"	"
1856	"	"	"
1857	"	"	"
1858	"	"	"
1859	"	Thomas B. Tappen	"
1860	Thomas Stephens	"	"
1861	"	"	"
1862	"	Robert L. Darragh	"
1863	"	"	"
1864	"	"	"
1865	"	"	"
1866	"	"	"
1867	"	"	"
1868	"	"	George S. Greene
1869	"	"	"

For a period of twenty-one years the Croton Aqueduct Department remained in charge of the city's water-works, sewers, etc., effecting important improvements. It was superseded in April 1870 by the Department of Public Works, created by chapter 137 of the Laws of 1870, which reorganized the entire city government. We shall only consider the work performed by the Croton Aqueduct Department in connection with the city's water-supply.

Maintenance of the Water-works.—The care of the existing works, especially of the masonry conduit, which for a great part of the distance from the Croton Lake to the receiving reservoir was above ground, exposed to the effect of the weather, required constant work and attention. An Assistant Engineer was given charge of this work.* For the purposes of inspection and maintenance the aqueduct was divided into eight divisions, each being put in charge of a competent superintendent, who was assisted by a number of workmen. In 1857 a stone dwelling-house was built at Croton Dam, and six plain cottages at suitable places on the line of the aqueduct for the superintendents, who were thus enabled to live near their work.

In connection with the care of the aqueduct regular stations were established in 1859 for keeping a record of the rainfall, and of the temperature inside and outside of the conduit.

For the first twenty years after its completion the aqueduct required only trifling repairs. The principal cause of occasional expenses was the settling of the embankments upon which the conduit had been constructed in places. These fills consisted of loose rock, held in place either by dry stone walls or by a facing of rubble masonry about two feet deep. The settling of the embankments caused longitudinal cracks in the invert of the aqueduct, through which water escaped. These fissures were always accompanied by corresponding cracks in the crown of the arch. The escaping water found its way occasionally below the foundations of the embankment and appeared again at the surface at a considerable distance from the aqueduct.

According to the law organizing the Department, the Commissioners were obliged to have the interior of the aqueduct examined semi-annually. During these inspections, which were generally made by the Chief Engineer in person, particular efforts were made to discover all longitudinal seams and to fill them with cement-mortar. It was found, in some cases, that leaks which had not been discovered on the surface had caused cavities in the embankments.

After a period of about twenty years, during which the embankments settled more or less, longitudinal cracks in the aqueduct were occasionally produced, at these places, by a sudden change of temperature.

In 1860 a large leak appeared about two miles from the Croton Dam. Upon emptying the conduit, the cause of the leakage was found to be a fissure (425 feet long by ¼ to 1 inch wide) in the invert of the aqueduct, on a high embankment. A similar fissure, about 350

* Mr. John C. Winder held this position for a number of years. He resigned in 1861, and was succeeded by Mr. B. S. Church, who remained in charge of the aqueduct until he was appointed Chief Engineer of the Aqueduct Commission in 1883.

feet long, was discovered in June 1901 about two miles north of High Bridge, and necessitated the emptying of the conduit for repairs.

During the six years of 1899–1904 inclusive, 2,[illegible] linear feet of cracks in the aqueduct of more or less extent were discovered and repaired. This trouble continued, but the records of the amount of such repairs have not been published since 1[illegible].

Owing to the great consumption of water which occurred after the introduction of the Croton supply into the city, the storage capacity of the two reservoirs on Manhattan Island was soon found to be insufficient. As these reservoirs were almost emptied during the time when the water was shut off in Croton Lake for the semi-annual inspections of the aqueduct, and as it required months to fill them again, owing to the limited amount of water which could be delivered through the two pipe-lines in High Bridge, the inspections of the interior of the conduit were made, after 1899, only once a year. In 1900 and 1901 they had to be omitted entirely.

A large new reservoir which was constructed in Central Park and put in service in 1[illegible] finally remedied this defect and enabled the Croton Aqueduct Department to make extensive repairs in the inside of the masonry conduit in 1903 and 1904, when the water was shut off in Croton Lake for two or seven days at a time, the city being supplied during this period by the reservoirs on Manhattan Island.

The maintenance of the interior of the aqueduct [illegible] valve chambers, etc., requires constant attention and involves at times very serious expense. In some cases the remaining value of embankments has to be entirely renewed after several years of service.

[illegible] were [illegible] to be made in the Croton Dam. The rapid action of the water was found to be undermining the timber [illegible] which had been [illegible] in front of the dam. During the summer of [illegible] when the water was [illegible] the waste-weir a large force of men and teams were employed in placing [illegible] bags, which were deposited in the river-bed in the place that had been scoured out by the water in front of the apron. New and stronger remaining walls were also built along the river below the dam, where required to sustain the steep hillside.

A serious breach occurred in [illegible] 1904 before the repairs in front of the timber apron had been completed, and [illegible] the [illegible] of the drawers. The [illegible] in March and April of the same year [illegible] the water trough which had to be repaired. Mill-dams and bridges were [illegible] a short [illegible] below the Croton Dam, which required the [illegible] considerably. Below the dam, however, much damage was done. The [illegible] of the drawers was [illegible] and the masonry [illegible] the masonry [illegible] were washed away, and a deep trench was [illegible] across the river, leaving the [illegible] exposed. The [illegible] of the river were undermined for a great height and finally destroyed. The [illegible] dam constructed for the [illegible] the main structure was [illegible] and carried away, as was also the highway bridge [illegible] the dam. [illegible] the Croton Dam had given way, [illegible] the city and [illegible] a panic.

Considerable damage was done along the line of the aqueduct by land-slides, etc. To meet the unusual repairs which had become necessary on account of this storm, the Common Council made a special appropriation of $30,000.

When the Croton Aqueduct was constructed, the land purchased by the city in this connection was not fenced in, and in many cases the shrubs and trees of the fine country seats and orchards through which the conduit passed were allowed to stand to the very edge of the excavation. This was done to conciliate the land-owners, who had suffered much annoyance during the construction of the work and considered the condemnation of their land for the construction of the aqueduct a great hardship. During the semi-annual inspection of the interior of the aqueduct in December 1851, it was found that at a point near Sing Sing a root of a willow tree had penetrated through the masonry in the crown of the arch and had grown in the conduit in six months to the length of twenty feet. To avoid any further injury to the masonry of the aqueduct from similar causes, the Croton Aqueduct Board ordered the land in its charge to be entirely cleared of trees and shrubs and also commenced to put up fences to enclose the city's property. Considerable opposition arose at once against the erection of fences from the owners of the abutting land, some of whom had been encroaching on the city's property. The fences were in some cases torn down and malicious attempts were even made to injure the retaining walls by removing stones. The proprietary rights of the city were not clearly defined in those days, and a test case had to be carried to the higher courts before the city's right to fence in the property it had acquired along the aqueduct was finally established. Under this decision the Croton Aqueduct Department continued to erect fences for a number of years until nearly all the property of which it had charge was enclosed.

Waste of Water.—When the old Croton Aqueduct was designed it was estimated that a daily water-supply of 30,000,000 imperial gallons would suffice for the city for many years. The masonry conduit was constructed large enough to deliver double that quantity, but the two lines of 36-inch mains laid across High Bridge and across Manhattan Valley were only capable of discharging about 30,000,000 gallons per day. The Croton water had scarcely been introduced in the city, before the citizens made an abuse of the unrestricted use of free water by wasting it lavishly without heeding the protests and warnings of the Croton Water Board. This wastage was caused by the access of a great many persons to the hydrants (every alderman having the right to issue permits for this purpose); by the sprinkling of the streets through hose by servants and children, who made the operation a pleasant pastime, and by the water being allowed to run through faucets all night in cold weather to keep it from freezing in the pipes. Defective plumbing was also an important factor in this loss. The wastage of water from these many causes became soon so great, in spite of the efforts of the Croton Aqueduct Department to check the evil, that the daily water-consumption in 1850—eight years after the water had been introduced—amounted, at times, to 40,000,000 gallons, equal to 78 gallons per day per capita for the whole population, and to 90 gallons per day for each water-consumer. The consumption was especially

large on Saturdays, when the distributing reservoir at Forty-second Street was often drawn down to half its capacity.

During the semi-annual inspection when the water was shut off from the city at Croton Lake for at least three days, the want of ample storage in the city was especially felt. What aggravated this evil was the fact that, owing to the limited capacity of the two 36-inch mains across High Bridge and across Manhattan Valley, the amount of water which could be delivered in the city was not much greater than the usual consumption. Under these circumstances it required months to fill the reservoirs when they had been emptied.

The New Central Park Reservoir.—[illegible] of the Water [illegible] drew the attention of the Common Council to the necessity of constructing an additional reservoir within the limits of the city. In [illegible] the Croton Aqueduct Department was authorized to acquire the land required for this purpose. The site finally selected for the new reservoir was a rectangular plot of land containing about 96 acres lying between Fifth and Seventh avenues from Eighty-sixth to Ninety-sixth street. About a quarter of the property belonged to the city. The plot chosen formed a natural basin, most of it being below the grade of that part of the city, upon which only a few small buildings had been erected at the time. It was [illegible] expensive embankments being required only on the west and south boundaries. [illegible] extending from the south side of the plot to the East River offered a good location for a sewer through which the reservoir might be emptied. The proximity of the old receiving reservoir, which was just south of Eighty-sixth Street, made a pipe connection between the two [illegible].

The site selected was [illegible], but owing to the [illegible] of the law it could not be acquired by the city until [illegible]. In spite of the efforts made to keep the location of the proposed reservoir a secret, the fact soon became known, and the property-owners [illegible] asked exorbitant prices for their land.

The engineers having presented their plans for the reservoir, the acquisition of the desired property was put in the hands of the [illegible] in [illegible]. The existing laws under which the property had to be [illegible] applied within the limits of the city, and [illegible]. They required as many [illegible] commissioners [illegible]. The expense and [illegible] may be appreciated when it is stated that the [illegible] of the new reservoir were held by about one hundred owners. These difficulties were finally obviated by the Legislature passing on June [illegible] an act [illegible] in the City of New York [illegible] appointment three Commissioners [illegible] the value of the site required for the reservoir.

In accordance with this law [illegible] were appointed in April [illegible]. After [illegible] their report [illegible] the Supreme Court on January 5, 1855, but owing to [illegible] was not acquired by the city until [illegible]. The [illegible] of the reservoir [illegible]

entirely within the limits which had been fixed for Central Park. By agreement with the Park Commissioners the area acquired for the reservoir was changed from a rectangle to conform to the contours of the ground. Some heavy rock cuts and embankments were thus avoided, a saving of about $200,000 being effected.

Proposals for the construction of the new receiving basin—designated the new reservoir at Yorkhill—were at last invited. The bids received, twenty-one in number, were opened on August 26, 1857. Fourteen were rejected as informal or as not meeting the requirements. Before the Croton Water Board could award the contract to the lowest regular bidders,—Fairchild, Coleman, Walker & Brown,—legal proceedings were commenced by one of the firms whose bid had been rejected, which, though unsuccessful, produced new delays. The Croton Aqueduct Department was finally enabled to award the contract for the reservoir to the firm mentioned above on January 11, 1858, the contract being confirmed by the Common Council on April 12th. Ground was broken in the presence of the city officials and a concourse of people on April 17th. The work was prosecuted energetically with a large force of men and teams, amounting during the good seasons, at times, to about twelve hundred laborers and one hundred horses.

The reservoir was practically finished early in the summer of 1862, but the water was not formally introduced into it until August 19, 1862. This was done with perfect success and with appropriate ceremonies.

The reservoir was formed by constructing an exterior bank of earth having a top-width of 15 feet and slopes of 1½ to 1. The top of the bank was carried up four feet above high water in the reservoir. The inner slope was paved with large blocks of stone laid in cement-mortar; the top of the bank and the outer slope were sodded. To insure water-tightness, a puddle-wall, made of clay, gravel, sand, and earth, was constructed in the middle of the bank and carried up to within two feet of its top. This wall was founded throughout on rock. It was given a top-width of 4 feet and battered on both slopes 2 inches per foot, its maximum width being 16 feet.

The reservoir was divided into an eastern and a western division by a central embankment, constructed in a similar manner as the outer bank, but having both slopes and also its top paved. Its puddle-bank was given a top-width of 6′ 2″. A brick wall, 20 inches wide and 4 feet high, was built from the top of the puddle-wall to the paving on top of the bank, which is 3 feet above the high-water mark.

The reservoir has a water-area of 96 acres and a capacity of about 1,000,000,000 U. S. gallons, the maximum depth of the water being 38 feet. It is connected with the aqueduct on Ninth Avenue by a branch masonry conduit, 2629 feet long. Owing to the grade of Ninety-second Street, through which it passes, this conduit had to be depressed about 7 feet below the general grade of the aqueduct. It has the same water-area as the main aqueduct, but was made stronger as it is "under pressure."

Three gates-houses were constructed in connection with the reservoir, viz.:

A junction gate-house on Ninth Avenue, where the branch conduit joins the aqueduct.

An inlet gate-house on the north side of the reservoir and an outlet gate-house on its south side.

The Junction Gate-house (see Fig. 12 and Plate 49) is situated on the line of the aqueduct at the N. W. corner of Ninth Avenue and Ninety-second Street. It serves to turn the water into the old or the new receiving reservoir in Central Park as may be desired. The aqueduct was opened for a space of 46 feet to make room for this gate-house.

The water from the aqueduct flows into a square chamber 22 ft. 6 in. × 22 ft. 10 in., in plan, and about 11½ feet deep. Five 5′ × 5′ openings for sluice-gates are provided in the

FIG. 12.—JUNCTION GATE-HOUSE.

south wall, and the same number in the east wall of the water-chamber. These openings can be closed by the sluice-gates or by stop-planks, placed in grooves in the masonry. By closing one set of gates and opening the other the water can be turned into the old or the new receiving reservoir. In the former case, the water passes from the main chamber of the gate-house to a smaller one connected with the aqueduct. In the latter case it passes into a similar small chamber, from which the branch aqueduct conveys it to the north gate-house of the new receiving reservoir.

The South Gate-house is situated at the south end of the centre bank of the reservoir (see Plate 54). The substructure, containing the water-chambers, pipe-vaults, etc., is shown on Plates 50 and 51. It is covered by a superstructure, built of granite masonry, similar to that shown in Fig. 13.

The substructure is 83 feet long, 40 feet wide, and 42 feet high above the paving of the water-chambers. It is divided into two parts, one for the east division and the other

for the west division of the reservoir. Each of the above divisions of the substructure is subdivided into fore-bays and back-bays by a wall 6 feet thick, which has openings for the sluice-gates which regulate the flow from the reservoir. The two divisions are separated by a centre wall which is 15 feet wide between the fore-bays and 9 feet wide between the back-bays.

Four partitions of granite, each 2 feet wide, extend across the fore-bays from 1 foot below the paving to the coping. They are braced by 12″ × 12″ granite beams, placed at right angles to the partition-walls and inserted 6 inches into them. Two sets of grooves are cut in the partitions and side-walls of the fore-bays. They are used for fish-screens and, when required, for stop-planks. Granite sills are placed in the paving of the fore-bays for each set of grooves.

The back-bays are subdivided by buttresses (4 feet wide at the bottom and 2 feet wide on top) which are supported on arches and rise 26 feet above the paving. An arched pas-

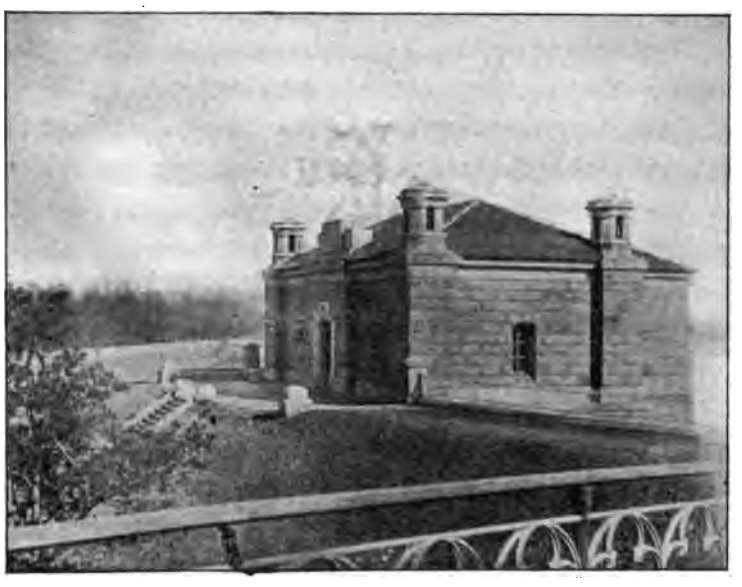


FIG. 13.—NORTH GATE-HOUSE.

sage, 9 feet wide and 5 feet high on the sides, connects the back-bays of the two divisions. It is lined with granite. A counter-arch is built under this passage. The bottom of the water-chambers is paved with two 4-inch courses of brickwork.

The outer wall of the substructure is lined towards the reservoir with granite, 1 foot thick, and on the inside with 1 foot of brickwork, laid in vertical arches. It has six arched inlet-openings, each 7 feet wide and about 18 feet high.

In each division the partition-wall between the fore-bays and back-bays has eight openings for sluice-gates, viz.: six bottom openings, 2½ feet wide by 5 feet high, and two openings, 2 feet by 5 feet, 13 feet above the paving. The gateways are all lined with granite. The sluice-gates are operated from the top of the wall by means of hand-wheels.

Six lines of 48-inch mains draw water from the gate-house. Each line of pipes has a well or chamber (2′ 6″ × 5′ 6″ in plan) which is connected by a 5′ 6″ × 5′ 6″ opening with the

back-bays, and by a granite mouthpiece having a curved, bell-shaped opening with the pipe-line, which begins with a reducer (4′ 6″ diameter at one end and 4′ at the other). The pipes are laid in brick vaults built through the outer slope of the reservoir dam to Eighty-sixth Street.

There are two 36-inch cast-iron waste-pipes, one for each division. Each waste-pipe begins with a reducer at a small chamber near the front wall, which is connected by a 4′ × 4′ opening with the reservoir. The chambers are provided with grooves for stop-planks.

Each line of mains and waste-pipe has a stop-cock which is placed in a pipe-vault, constructed adjoining the substructure.

Stone steps in the central wall, continued by a spiral stairway placed in a well 11 feet in diameter, lead from the floor of the gate-house to the vault. The mains are also provided with blow-offs, which discharge into the waste-culvert of the gate-house, presently to be described.

A waste-passage, 6 feet wide by 2 feet deep, is formed on top of the centre bank where it joins the gate-house. It is provided at both ends with grooves for stop-planks, for regulating the height of the water in the reservoir. The waste water, flowing through this passage, is conveyed by a waste-weir (6 feet wide, 8 feet high, and 11½ feet long) constructed in the centre wall of the substructure to a waste-well located in this wall. The waste-weir is provided with grooves for stop-planks. An opening (2½ feet by 6 feet) is left in the coping of the walls over these grooves.

The waste-well is 3 feet in diameter, except at the top, where it is bevelled to 4 feet diameter. It is 41 feet deep, its top being 9 feet below the coping of the substructure. A brick culvert 4 feet in diameter, constructed in the centre wall and through the pipe-vault, conveys the waste-water to a sewer in Eighty-sixth Street. The culvert serves also to drain the pipe-vault and as a waste-channel for the blow-offs.

A 6-inch drain-pipe is laid from the middle of the back-bay of each division to the culvert. It is kept closed except when the gate-house is emptied, when it serves to drain the water-chambers.

The openings in the coping of the substructure for pipe-wells, the entrances to the waste-weir and waste-well, are covered with iron gratings.

Four air-pipes, 15 inches in diameter, are placed for ventilation in the walls of the gate-house. They extend from the pipe-vault through holes in the coping to the top of the superstructure.

The North Gate-house is situated at the north end of the centre bank of the reservoir (see Plate 54 and Fig. 13). It forms the inlet of the aqueduct to the reservoir, and serves also as an outlet. The superstructure and substructure of the gate-house are shown on Plates 52 and 53. The substructure is 72 feet long, 40 feet wide, and 42 feet high. It has a projection (27 feet long by 22 feet wide) towards the reservoir, containing the inlet-gates.

The general arrangement for drawing water from the reservoir by the service or waste pipes, are similar to those of the south gate-house. The east and west divisions of the

substructure are divided by a central partition-wall, which is 22 feet wide between the fore-bays and 18 feet wide between the back-bays. The aqueduct enters the north side of the gate-house and is carried in the central partition-wall to the inlet-chamber, which is 22 feet long, 11 feet wide, and 13 feet deep. This chamber is provided with five 3′ × 5′ sluice-gates, on each side, and can discharge water thus into either or both divisions of the reservoir. The outer walls of this chamber are 5½ feet thick. A waste-weir, 5 feet wide, is placed at the south end of the chamber. It communicates with a semi-circular waste-well, which is connected near its bottom with a culvert, having a diameter of 4 feet and a length of 34 feet. This culvert discharges into a waste well (4′ × 4′ in section), constructed in the central wall of the substructure. A second culvert (4 feet in diameter) is built from the last-named well. It passes under the arched passage between the back-bays, and is connected with the main drain of the gate-house.

Openings are left in the coping over the aqueduct and at the waste-weir. The canals leading from the reservoir to the fore-bays are lined with support-walls which extend on the slopes of the reservoir banks to the same height as the paving. The thickness of these walls varies according to the height of the bank they support. They are battered 2 inches per foot on the face and have a coping 9 inches thick and 3 feet wide. Where they join the gate-house they were built up in connection with the walls of that structure.

The gate-house is provided with four lines of service-mains and two waste-pipes, all 36 inches in diameter. Only two lines of the service-mains have been put thus far into use. Each line of pipes is provided with a stop-cock which is placed in a vault (12 feet wide by 11 feet high and 72 feet long) adjoining the gate-house. Stone steps continued by an iron spiral stairway, placed in a brick well (12 feet in diameter, tapered at the top to 8 feet) lead to the vaults. Brick arches are built over the pipes for some distance from the vault to relieve them from the pressure of the outer slope of the reservoir dam.

The waste-pipes are connected by brick culverts with the waste-drain of the gate-house, which is 4 feet in diameter and discharges into one of the ponds in Central Park near One Hundredth Street and Eighth Avenue.

Each line of service-mains is provided, in the stop-cock vault, with a blow-off, discharging into the waste-culvert.

Making the Brickwork Impervious to Water.—When the water was admitted into the south gate-house, it was found to filter to a considerable amount through the brick face-walls of the back-bays. These walls, which are 12 inches thick, were built of the best quality of hard-burned bricks, laid in cement-mortar (1 part of cement mixed with 2 parts of sand). The space between the inner and outer face-walls, which was 4 feet wide, was filled with concrete. The gate-house was emptied and the brickwork was made impervious to water by the method known in England as "Sylvester's process for repelling moisture from external walls."

The process consists in applying alternately two washes or solutions to the surface of the brickwork. The first solution used is composed of Castile soap dissolved in water (¾ lbs. soap to 1 gallon of water). It is applied at a boiling heat, with a flat brush, care

being taken not to form a froth on the brickwork. This wash must remain 24 hours, so as to become dry and hard, before the second solution, which consists of alum and water (½ lb. alum to 4 gallons of water), is applied. The second wash should be at a temperature of 60°–70° Fahrenheit when used, and must be allowed to dry for 24 hours before the first solution is used again. The alum and soap used in the solutions combine to form an insoluble compound. The temperature of the air should not be below 50° Fahrenheit while the washes are being applied.

Experiments made at the gate-house showed that four coatings of both solutions made brickwork impervious to water under a head of 40 feet. After the brick facing of the back-bays had been treated in the above manner it was found to be perfectly water-tight.

The surfaces coated were as follows:

North gate-house	7,622 sq. ft.
South gate-house	11,268 "
Total	18,890 sq. ft.

The total cost for work and material amounted to 10.06 cents per square foot.*

The plans and specifications for the new receiving reservoir and the gate-houses were prepared by Captain, since General, George S. Greene, who had charge of all the works of the "Water Works Extension." The drawings were made by Mr. E. H. Barnes, who retired on account of ill health in 1860. He was succeeded by Mr. J. J. R. Croes, who had had special charge of the stone-cutting for the gate-houses. Mr. Robert M. Van der Heuvel was in immediate charge of the reservoir as Resident Engineer. Mr. George S. Greene, Jr., had charge of the gate-houses.

The Improvement of High Bridge.—We have stated in page 62 that the two 36-inch mains laid originally across High Bridge had only half the discharging capacity of the masonry conduit, viz., about 30,000,000 gallons per day. The necessity of laying additional mains across High Bridge was soon felt. In their annual report for 1851 the Commissioners of the Croton Aqueduct Department recommended strongly that the work be commenced at once, but the Common Council, generally slow in acting in such matters, did not grant the necessary authority until 1860.

The required means having been at last procured, the improvement of High Bridge was made in the following manner: The gravel covering of the two 36-inch mains was removed, the side-walls of the bridge were carried up about six feet and connected by a brick arch. In the vault which was thus formed on top of the bridge a large wrought-iron pipe, having an interior diameter of 30½ inches, was placed between the two 36-inch pipes as shown in Fig. 14. It was made of wrought-iron plates ⅜ inch thick, which were riveted together and supported on cast-iron stanchions and saddles. Proper provision was made for contraction and expansion by rollers and by movable joints, as shown in the cut.

The contract for furnishing the iron for the large pipe was 624,000 pounds of plate

* See paper by William L. Dearborn in the Transactions of the American Society of Civ. Engineers for 1870.

and 100,144 pounds of flange iron, was awarded on August 8, 1860, to Horace Abbott, of Baltimore, the work of putting the iron together being let on August 9, 1860, to Samuel Sneden and Thomas F. Rowland of Greenpoint, N. Y. The pipe was completed in December, 1861, and has been in successful operation ever since. Its capacity was estimated to be 60,000,000 U. S. gallons per 24 hours. As the two old 36-inch mains were left in the

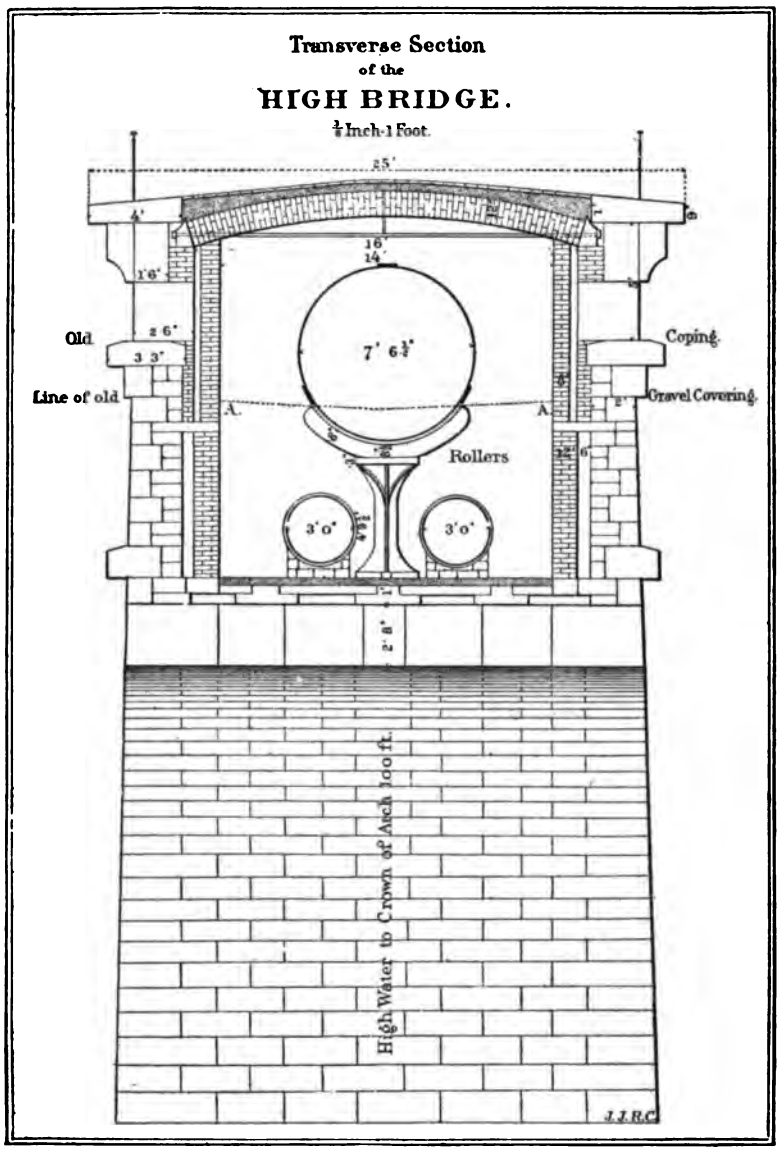


FIG. 14.

vault to be used or kept in reserve, the improvement described above changed High Bridge from the point of minimum to that of maximum capacity on the line of the aqueduct.

The work of raising the side-walls of the bridge and building the brick arch was let to J. B. Cumming, contractor, and was completed in 1863. The brick arch, which is 17 feet wide, 1381 feet long, and 12 inches thick, was built in the following manner:*

* See paper of William L. Dearborn in the Transactions of American Society of Civil Engineers, for 1870.

The first two courses of brick were laid edgewise, in cement-mortar (1 part cement to 2 parts sand). They were supported by cast-iron skewbacks, held together by wrought-iron tie-rods. A coating of asphalt, half an inch thick, was put on top of the brickwork and on the sides of the granite coping, where it terminated. The asphalt was heated to a temperature of 360°–518° Fahrenheit before being applied. On top of this coating a course of bricks was laid flatwise, each brick being dipped in hot asphalt before being laid and the joints being run full of hot asphalt. A top course of pressed bricks, laid flatwise in cement-mortar, was placed next, to form the paving and floor of the bridge. The asphalt used was the best kind from Trinidad. It was mixed with 10% (by measure) of coal-tar and 25% of sand.

To prevent any bad effect from the arch contracting in winter, three grooves, 2 inches wide by 4 inches deep, were made entirely across the brick arch immediately under the first coat of asphalt, and filled with elastic paint-cement. The grooves divide the arch into four parts, which can expand and contract slightly without causing leakage, owing to the elastic cement.

A large continuous layer of asphalt, covering a masonry arch, is apt to crack, owing to the fact that the asphalt expands or contracts more than the masonry when the temperature changes. This trouble was avoided by the arrangement described above. The work was performed very successfully and the arch has proved to be perfectly water-tight. In 1864 an iron railing was put on the bridge, and the grounds on the Westchester slope were terraced and put in order.

Mr. W. L. Dearborn was the Resident Engineer in immediate charge of the High Bridge improvements until 1862, when he succeeded Captain (since General) George S. Greene, who had resigned to enter the army, in charge of the whole Water Works. Mr. J. J. R. Croes succeeded Mr. Dearborn as Resident Engineer.

Pipe-laying.—The work of laying the distributing mains, which had been commenced by the Water Commissioners and by the Croton Aqueduct Board, was continued by the Croton Aqueduct Department. By the end of 1850 about 198 miles of water-pipe had been laid on Manhattan Island.

The stop-cocks provided for the 20 to 36-inch mains were originally made, with two or three exceptions, to open vertically, and were placed in the ground without proper protection. This arrangement was found to be objectionable, as it permitted the gates to shut suddenly, producing a water-ram whenever the screw-rods by which they were suspended broke. The Croton Aqueduct Department soon replaced these stop-cocks by new ones, opening horizontally and protected by suitable brick vaults.

The connection between the receiving and distributing reservoirs was made originally by two 36-inch mains laid side by side. This arrangement involved considerable danger of an interruption of the water-supply, as a break in one of these pipe-lines was apt to cause a similar accident on the other. The new mains which were laid subsequently soon eliminated this danger.

In 1849 and 1850 a 30-inch main was laid from the receiving reservoir through Seventy-

ninth Street to Third Avenue and thence down this avenue to Fourteenth Street. It was connected with the distributing reservoir by a branch in Forty-second Street and supplied Harlem through a 12-inch pipe branching off at Seventy-ninth Street.

In 1855 and 1856 a 30-inch main was laid from the receiving reservoir at Eighty-first Street down Eighth Avenue to Forty-second Street and thence through this street to the distributing reservoir.

In 1859, 1860, and 1861 a 48-inch main was laid from the receiving reservoir at Eightieth Street, passing through this street to Fourth Avenue and then down the avenue to Thirty-eighth Street, connecting by a branch in Forty-second Street with the distributing reservoir. It may be noted here that the pipes on this line were the first received in the city which were protected by a coat of coal-tar, a process first tried in Manchester, England. They were also the first cast for the city in lengths of 12 ft. 4-inch instead of 9 feet.

The advantage of having different independent pipe-connections between the two city reservoirs was soon realized, as several breaks occurred in the Fifth Avenue lines, which will be described below.

To bring the mains in the different avenues into direct connection with the Forty-second Street reservoir, a 30-inch main was laid, in 1853, in Forty-second Street from the reservoir at Fifth Avenue to Eleventh Avenue and connected with all the important pipe-lines it crossed.

We have spoken on page 64 of the city's water-supply having been limited to about 30,000,000 gallons a day by the fact that only two lines of 36-inch pipe had been laid across High Bridge and across Manhattan Valley. This defect was remedied at the latter point by the Croton Aqueduct Department laying in 1853 and 1854 an additional main 48 inches in diameter, 4087 feet long. The effect of this increase of water-area was an immediate gain of head in the reservoirs and, consequently, a greater pressure in the city mains. Another main, 5 feet diameter and 4116 feet long, was laid across Manhattan Valley in 1861 and 1862.

When the first two lines of 36-inch mains were laid from the receiving to the distributing reservoir the grades of the streets and avenues through which they passed had not been finally established. Changes of grade were made subsequently, which necessitated the lowering of the water-mains at several points.

The first case of this kind occurred in 1850 on Fifth Avenue at Murray Hill, where the pipes had to be lowered a maximum depth of 16 feet. The Commissioners intended at first to remove the 36-inch mains, at the point where the change was to be made, until the avenue had been excavated to the new grade. In this case the only remaining connection between the reservoirs would have been, for the time, the 30-inch main of Third Avenue. A plan proposed by Mr. Edward H. Tracy, one of the engineers of the Department, involving the lowering of the pipes in place, was, however, finally adopted and successfully carried out, the water being shut off only from one line of pipes at a time. The manner in which this work was performed, without the breaking of a joint or a pipe, was as follows; Both lines of mains having been uncovered, small drifts, were excavated, 8 feet apart, under both lines. In these drifts, separate timber cribs were placed under each line of pipe. By

means of wedges the weight of the pipes was brought to bear on the cribs; the earth between the cribs was then removed for several hundred feet at a time. Jack-screws were placed under the pipes and the cribs were gradually removed, the water being shut off from the line that was being lowered. The operation was much facilitated by the ground being hardpan.

In 1856 the Fifth Avenue mains had to be lowered from Forty-ninth to Fifty-fourth Street, the length being 1300 feet and the maximum depth 11 feet. The material to be excavated was solid rock. In this case the water was not shut off at all during the whole operation. The work, which attacted much attention at the time, was performed under the direction of Mr. J. P. Kirkwood, until he was appointed Chief Engineer of the Brooklyn Water Works, and was completed by Gen. Geo. S. Greene.

The solid rock on the east side was excavated to the new grade, the pipes being well protected by timbers against the blasts. Each line of pipes was then gradually moved by jack-screws and wedges to temporary bed-blocks placed in the vacant space on the east side. This was made possible by each pipe being drawn a trifle out of the socket of the adjoining pipe. The maximum distance to which the pipes were moved horizontally was 10 feet. The remaining rock on the avenue was then excavated to grade and a pipe-trench 8 to 9 feet wide was then excavated on the former location of the mains. Timber cribs having been placed at suitable intervals, the two lines of pipe were moved back to their original location and lowered simultaneously by means of jacks-screws and wedges, the cribs being gradually removed. But very little calking had to be done to the joints of the pipes while this change was being made.

Where the grades of the streets were raised the water-mains were usually left undisturbed. This led, in some cases, to the pipes being broken by the great weight of the material they were made to bear. The first case of this kind occurred in 1859 at Fifty-ninth Street, where one of the Fifth Avenue mains was ruptured. A similar but much more serious accident occurred on December 5, 1860, at Sixty-fourth Street and Fifth Avenue at 12 P. M. In this instance pipes on both of the Fifth Avenue mains were broken. Half an hour after the accident occurred Chief Engineer Craven was on the ground with a force of men and took energetic measures to stop the damage caused by the escaping water. By that time the Forty-second Street distributing reservoir had already been drained within a foot of the bottom and the water in the receiving reservoir had also been much lowered. The fact that the broken pipes were twenty feet below the surface of the street increased considerably the time required for making the repairs. Extraordinary measures became necessary. The manufactories were all ordered to stop using water, and the supply was cut off from the shipping and ferries. After fifty hours of incessant work the broken pipes were replaced by new ones and the Fifth Avenue mains were put again into service. If the annual inspection of the interior of the aqueduct, which had been fortunately postponed, had been under way, the city would soon have been entirely without water.

On December 21, 1861, another break occurred in the east line of the Fifth Avenue mains near Sixty-fourth Street, within a short distance of the spot where the accident just de-

scribed took place. In this case the pipes had been carried across a marsh in an embankment which was subsequently raised considerably on account of a change of grade. As might have been expected, a settling occurred which caused some of the pipes to be ruptured.

Warned by the above accidents, the Croton Water Board applied to the Common Council for the necessary funds for raising the mains wherever the street grades had been considerably elevated since the pipes had been laid. There was, however, some delay in obtaining the desired appropriation. As a consequence three more breaks similar to the ones described above occurred during 1862 on Fifth Avenue at points where the pipes were buried over twenty feet below the street surface. Fortunately no houses had been built at the time at the points where the breaks occurred. It was not until 1863 that the appropriation was obtained for relaying the two lines of 36-inch mains on Fifth Avenue from Fifty-fourth to Sixty-fifth Street, the place where the street grade had been raised considerably. While the change was being made both lines of mains were ruptured again. The old pipes were abandoned and new ones were laid above them, to conform to the elevated street grades.

The High-service Tower and Reservoir at High Bridge.—As early as 1851 the Croton Water Board reported that a high-service reservoir for supplying the more elevated parts of Manhattan Island would soon be required, and recommended that one or more suitable sites for the same be secured while the land was still comparatively cheap. Nothing was done in this matter, however, until the Legislature of 1863 passed an Act authorizing this work. Owing to legal delays in acquiring the necessary property the construction could not be commenced until 1866. The high-service works were to consist of a reservoir, covering about seven acres of land and having a capacity of 10,794,000 U. S. gallons, and of a water-tower, about 170 feet high, containing in its upper part a tank of 47,000 U. S. gallons capacity. The reservoir and the tank of the water-tower were to be filled by pumping water from the Croton Aqueduct.

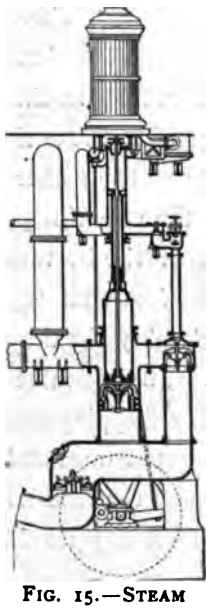


FIG. 15.—STEAM CYLINDER 32" × 72".

The depth of the water in the reservoir was to be 16 feet. The bottom of the reservoir was to be located 200.6 feet above mean high tide, which was 75.2 feet above the invert of the aqueduct at the western end of High Bridge, where the pumps were located. The highest level of the water in the tower was to be 324 feet above high tide, 57 feet above the highest point on Manhattan Island. The cost of the high-service works was estimated at $500,000.

The contract for the reservoir, and also for a wharf and coal-house, was given to Messrs. Roach & Jenkins in June 1866. The contract for the pump and boiler-houses was awarded to Messrs. Brown & Wetherell in 1867. Mr. W. E. Worthen furnished the pumping-engine (see Fig. 15), which was made according to his designs. By the end of 1869 the reservoir was completed, with the exception of some minor details, and most of the pipes were laid for distributing the water. The buildings for the pumps and boilers were also nearly finished and the high tower carried up ten

HIGH-SERVICE TOWER AND RESERVOIR AT HIGH BRIDGE.

feet. Before the works could be entirely completed the Croton Aqueduct Department was superseded, in April 1870, by the Department of Public Works. The location of the high-service works is shown in the frontispiece. A photograph of the tower and reservoir is given on Plate 9.

Change of the Aqueduct from Eighty-Fifth to Ninety-second Street.—An Act passed by the Legislature in 1865 obliged the Croton Aqueduct Department to remove the masonry conduit from Eighty-fifth to Ninety-second Street (where it was considerably above the level of the adjoining lots and interfered with the grading of the streets), and to substitute for the same iron pipes laid below the ground, or a depressed masonry aqueduct. This measure, which had been contemplated for some years, had been steadily opposed by the Croton Water Board, which claimed that all damages caused to the lots through which this high part of the aqueduct passed had been paid for when the work was constructed. At that time, however, no person anticipated the wonderful growth of the city. The change, although expensive, was a great improvement. The masonry conduit was torn down, within the limits mentioned above, and replaced by two lines of cast-iron mains, 6 feet in diameter, which were located as shown on Plate 10. The connections of the masonry conduit with the pipes were made by suitable masonry chambers.

The contracts for the materials and work were made in the latter part of 1864, and the work was commenced in 1865. The pipes were furnished by S. Fulton & Co., of Philadelphia, and R. P. Parrott, of the West Point Foundry. The contract for grading the line and for laying the pipes was awarded to F. L. Brown and John Wetherell, of New York.

The cost of making the change was estimated at $310,000, but exceeded this amount on account of the breaking of some of the pipes when subjected in the summer of 1867 to water-pressure for the first time. Out of 480 pipes, 18 were cracked at the hub and 1 at the spigot end. The cracks varied in length from 2 to 33½ inches, with the exception of two, which were respectively 3 feet 8¾ inches and 8 feet 9 inches long. They varied in width from a merely perceptible line to ⅛ inch. The cracks occurred invariably for their whole length in or near the centre of the bottom of the pipe. The broken mains were repaired by cutting off the hubs and pipes, as far as the cracks extended, replacing them by strong cast-iron sleeves (see Fig. 16 and Plate 10), and, where required, by short lengths of pipe.

Various theories were advanced to account for this failure. The facts in the case were fully discussed by Mr. A. W. Craven, at the time Chief Engineer of the Croton Aqueduct Department, in a paper read before the American Society of Civil Engineers, on January 29, 1868. Mr. Craven inclined to the opinion that the failure was due to water-ram caused by shutting the inlet-gate, while the outlet of the pipes was closed. It does not seem, however, that any great water-ram could have occurred. The maximum "head" was only 14.54 feet; the inlet-opening had an area of 2¼ square feet, while the area of the two 6-foot pipes was 56.5 square feet. Great care was taken in filling the mains. In the paper mentioned above Mr. Craven states:

"Whatever be the real cause of this failure, I am convinced that if large pipes must in

any case be used, an alteration should be made in their shape. If again obliged to use pipes of this calibre under similar circumstances, I would increase the thickness to 2 inches. This would diminish the chance of injury during the cooling of the metal. I think, also, that in pipes of very large size additional security would be ensured by dispensing with the hub or bell ends, and using sleeves as the means of making the joints."

The 6-foot pipes which were laid at the place in question had a thickness of only $1\frac{3}{8}$ inches. The foundations upon which they were placed consisted principally of street-embankments, into which large stone and earth had been dumped without any special care. Mr. Craven states, however, that no settling of any account had occurred when the failure took place, and that some of the pipes ruptured had been laid on rock. Breaks in the 6-

FIG. 16.—REPAIRING 6-FT. MAINS.

foot mains continued to occur, until finally the Department of Public Works replaced these pipes by three lines of 4-foot mains.

Survey of the Croton Watershed.—The rapidly-increasing consumption of water soon obliged the Croton Aqueduct Department to take steps towards constructing additional storage reservoirs in the Croton Valley. In order to discover the most favorable sites for such basins, the Water Board had a hydrographic survey made of the whole Croton watershed. This work was commenced in July 1857 and completed in November 1858, the map and calculations being finished the following year. Mr. J. H. Morely had charge of the survey in 1857 and Mr. C. A. Cushing in 1858. The watershed above the dam was found to have a ridge line 101 miles long, and to contain 352 square miles. Within this area are enclosed thirty-one natural lakes and ponds. The length of the Croton River above the dam was found to be 39 miles. Its minimum flow above the dam during 1858 was 33,804,000 New York gallons. According to the records kept by Mr. J. F. Jenkins, teacher at the Academy of North Salem, Westchester County, from 1840 to 1853, the average annual rainfall in this region was 42.68 inches for this period. Fifteen suitable sites for storage reservoirs were located and carefully examined. The map on Plate 54 shows these sites. The following table gives the area, storage capacity, etc., of the proposed reservoirs:

PLATE 10.

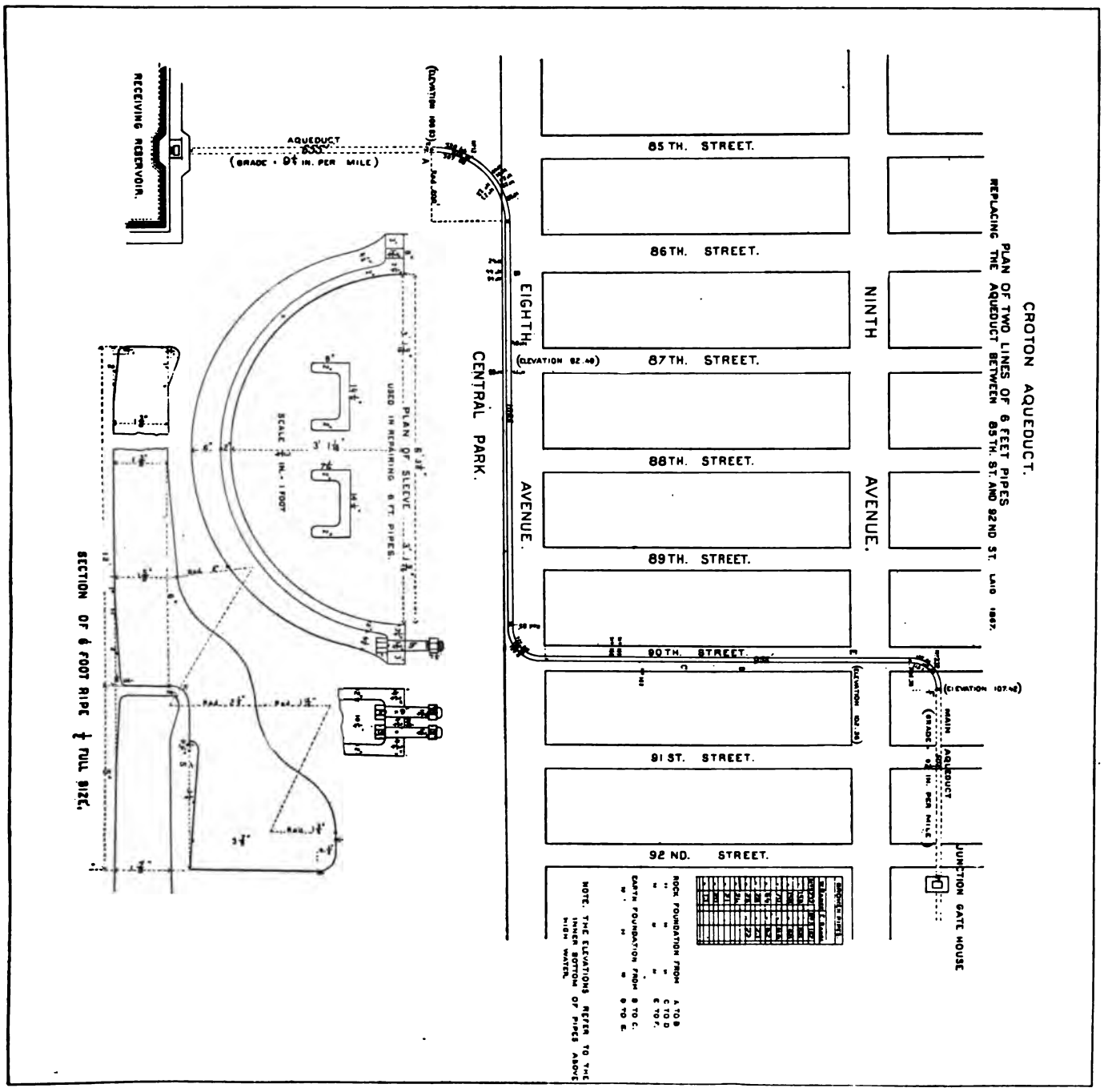

CROTON AQUEDUCT.
PLAN OF TWO LINES OF 6 FEET PIPES REPLACING THE AQUEDUCT BETWEEN 85TH. ST. AND 92ND ST. LAID 1887.
85TH. STREET.
86TH. STREET.
87TH. STREET.
88TH. STREET.
89TH. STREET.
90TH. STREET.
91 ST. STREET.
92 ND. STREET.
EIGHTH AVENUE.
NINTH AVENUE.
CENTRAL PARK.
(ELEVATION 92.40)
(ELEVATION 102.36)
(ELEVATION 107.42)
MAIN AQUEDUCT
(GRADE 9 IN. PER MILE)
JUNCTION GATE HOUSE
AQUEDUCT
(GRADE 9 IN. PER MILE)
RECEIVING RESERVOIR.
PLAN OF SLEEVE USED IN REPAIRING 6 FT. PIPES.
SCALE 1/2 IN. = 1 FOOT
SECTION OF 6 FOOT PIPE 1/4 FULL SIZE.
NOTE. THE ELEVATIONS REFER TO THE INNER BOTTOM OF PIPES ABOVE HIGH WATER.

PLATE 11.

BOYD'S CORNERS RESERVOIR.

BOYD'S CORNERS RESERVOIR, IN CONSTRUCTION.

RESERVOIR SITES.

TABLE FROM WATERSHED MAP OF 1857–58 OF CROTON BASIN ABOVE THE PRESENT CROTON AQUEDUCT DAM.

Proposed Reservoir.	Area.	Capacity.	Drainage Area.	Extreme Depth of Dam.	Extreme Length of Dam.	Length of Reservoir.	Distance from Croton Dam.	Elevation above Mean Tide.
	Acres.	Gallons	Sq. Miles	Feet.	Feet.	Feet.	Miles.	Feet.
A	455.00	5,211,015,625	20.45	64	1,500	12,300	9.500	390
B	192.00	1,721,535,337	15.2000	55	1,700	6,000	12.750	500
C	730.00	6,559,101,562	15.7100	45	1,700	16,600	14.300	550
D	1,005.00	4,055,632,812	41.9500	45	771	21,000	20.250	500
E	303.00	3,364,206,657	20.3700	64	700	7,500	23.750	600
F	600.75	6,120,335,937	12.5100	20.95	1,560	10,600	15.500	560
G	452.19	4,561,055,156	20.9045	75	541	12,200	15.700	575
H	384.67	2,491,062,500	75.4574	30	545	14,745	19.390	575
I	449.00	4,205,820,654	70.5230	62	551	12,745	20.447	415
J	191.58	2,514,074,703	11.0171	65	1,511	11,616	25.710	500
K	51.274	5,671,449,210	75.9000	72	904	14,605	15.215	275
L	262.75	2,325,217,735	21.6600	74	757	15,120	16.539	295
M	432.25	4,392,151,445	23.5449	72	925	12,300	15.651	315
N	197.00	1,671,049,171	50.9620	60	665	8,650	7.705	250
O	239.47	2,152,557,100	17.5170	90	1,170	7,629	9.970	305

Entire drainage area of Croton Basin above Croton Dam, 731.12 square miles.

Boyd's Corners Reservoir.—In the annual reports of the Croton Aqueduct Department from 1861 to 1865 stress is laid on the necessity of constructing at once an additional storage reservoir on one of the sites determined by the survey of 1857 and 1858. During the drought of 1864 and 1865 no water passed over the Croton Dam respectively for 52 and 42 days.

The necessary authority for constructing storage reservoirs in Westchester, Putnam, and Dutchess counties was at last obtained by an Act of the Legislature, passed April 3, 1865. After considerable preliminary investigations it was decided to build a new storage reservoir on the west branch of the Croton River at Boyd's Corners, a small settlement in Putnam County (see Plate 54).

The plans for the work were prepared by Gen. George S. Greene, who had charge of the construction of the reservoir until May 1868, when he was appointed Commissioner and Chief Engineer of the Croton Aqueduct Department. He was succeeded in the charge of the storage reservoir by Mr. J. J. R. Croes, who had been connected with the work from the beginning as Resident Engineer. As the expenditure authorized by the Legislature was insufficient, a contract for the lower part of the dam was made on August 28, 1866, with Roach and Jenkins. Additional expenditure was authorized subsequently, and the dam was completed as originally designed by November 1, 1870.

The reservoir was formed by building a masonry dam, having a length of 670 feet and a maximum height above the surface of 57 feet, across the west branch of the Croton River. An earthen embankment was constructed subsequently on the up-stream side of the dam by the Department of Public Works. The reservoir was finished by the spring of 1873 (see page 87).

CHAPTER V.

THE MAINTENANCE AND EXTENSION OF THE WATER-SUPPLY BY THE DEPARTMENT OF PUBLIC WORKS.

AN Act to reorganize the Local Government of the City of New York (chapter 137 of the Laws of 1870), passed by the Legislature in April 1870, created the Department of Public Works which superseded the Croton Aqueduct Department and the Street Department. The new Department was organized into the following bureaus, viz.:

The Bureau of the Water Purveyor.
The Bureau of the Water Register.
The Bureau of the Chief Engineer of the Croton Aqueduct.
The Bureau of Street Improvements.
The Bureau of Lamps and Gas.
The Bureau of Repairs and Supplies.
The Bureau of Streets and Roads.
The Bureau of the Collector of Assessments.
The Bureau of Sewers.

Chapter 574 of the Laws of 1871 added to the above:

The Bureau of Incumbrances.

The extensive and important responsibilities entrusted to the Department of Public Works were as follows:

1st. The maintenance and extension of the water-works.
2d. The maintenance and extension of sewers and drains.
3d. The collection of the water revenues.
4th. The opening of new streets and roads.
5th. The care of the old streets and roads.
6th. The care of the public buildings.
7th. The control of the street vaults.
8th. The lighting of the city.
9th. The filling up of sunken lots.
10th. The removal of incumbrances.
11th. The construction and care of the wells.

All this important work was put in the charge of one Commissioner of Public Works, who was to have complete control over all the employés of the Department. The Commissioner was to be appointed by the Mayor.

The first person who filled this responsible position was William M. Tweed. The

names of his successors, as also those of the principal engineers in charge of the water works are given in the following table:

COMMISSIONERS OF PUBLIC WORKS AND ENGINEERS IN CHARGE OF THE WATER-WORKS

Year.	Commissioner.	Chief Engineer.	First Assistant Engineer.
1870	William M. Tweed	Edward H. Tracy	John C. Campbell
1871	"	"	"
1872	George M. Van Nort	"	"
1873	"	"	"
1874	"	"	"
1875	Gen. Fitz-John Porter	"	"
1875	"	John C. Campbell	Geo. W. Birdsall
1876	Allan Campbell	"	"
1877	"	"	"
1878	"	"	"
1879	"	"	"
1880	"	Geo. W. Birdsall	.....
1881	H. O. Thompson	Isaac Newton	Geo. W. Birdsall
1882	"	"	"
1883	"	"	"
1884	"	"	"
1885	Rollin M. Squire	Geo. W. Birdsall	John E. McKay
1886	"	"	"
1887	Gen. John Newton	"	"
1888	"	"	"
1888	D. Lowber Smith	"	"
1889	"	"	"
1889	Thomas F. Gilroy	"	"
1890	"	"	"
1891	"	"	"
1892	"	"	"
1893	Michael T. Daly	"	"
1894	"	"	"

The only part of the work controlled by the Department of Public Works which we shall describe is the Maintenance and Extension of the Water-works.

The Croton Aqueduct.—When the construction of the Croton Aqueduct was commenced in 1837, an allowance of 22 imperial gallons per capita per day, based upon the consumption in European cities, was considered ample. The population of the city of New York was, at that time, about 300,000. In giving the Croton Aqueduct a capacity of 60,000,000 imperial gallons (equal to about 72,000,000 U. S. gallons) the constructors of this work thought that they had provided for the wants of the city for many years to come.

As has been stated on page 64, the waste of water became so great, soon after its introduction in the city, that it amounted in 1850, at times, to 90 U. S. gallons per capita per day. Aside from this waste, the natural growth of New York was so much greater than what had been anticipated, that twenty-five years after the Croton water had been introduced the aqueduct was delivering what had been calculated to be its maximum discharge (about 72,000,000 U. S. gallons per twenty-four hours). The rapid increase of the consumption of water is shown by the table on page 107.

As the demands for water grew larger the aqueduct was made to deliver more than the quantity given above as its maximum discharge. Two circumstances made this possible: 1st. The maximum flow of 72,000,000 U. S. gallons per twenty-four hours was calculated

on the supposition that the water was to be kept below the spring-line of the arch, which had not been designed to withstand any pressure from within. 2d. The maximum discharge stated had been calculated by the hydraulic formulæ based upon experiments on small pipes, which have since been found to underestimate the discharge of a large conduit. The necessity of delivering more water into the city obliged the Department of Public Works to increase the depth of the water flowing in the aqueduct, until it reached within a foot of the crown of the arch. Parts of the conduit which had settled on embankments 3 to 13 inches were thus placed entirely under pressure.

The maximum capacity of the aqueduct, when filled nearly to the crown, has been variously estimated in different reports of the Department of Public Works at 90,000,000 to 120,000,000 U. S. gallons in twenty-four hours. As the consequences had been disastrous when the aqueduct was forced to discharge 103,000,000 gallons daily, Chief Engineer Newton gave in 1881 the maximum safe discharge of the aqueduct at 95,000,000 gallons in twenty-four hours, which was based upon a depth of water of 7′ 5″ in the conduit, the surface of the water being 12½ inches below the crown of the arch, where the aqueduct had not settled below grade.

In order to enable the masonry conduit to resist the additional strain to which it was subjected, by carrying a greater depth of water than what had been originally intended, it was strengthened in the following manner:

The arch was uncovered and reinforced by one additional ring of brick (making the total thickness of the arch twelve inches). In some places the thickness of the arch was increased to 16–20 inches. The spandrel walls were carried up nearly to the level of the top of the arch, and retaining walls were raised correspondingly. The conduit had been originally covered with four to five feet of earth as a protection against frost. Experience having proved that two feet of earth covering was sufficient for this purpose, the earth refilling was only replaced to that depth at the crown of the arch, the surplus material being distributed on the outer slopes of the earth covering.

The work of reinforcing the aqueduct as described above was commenced in 1875, and continued from year to year, to the extent the annual appropriations permitted, until all the weak parts had been strengthened. As a result of this work five inches more depth of water was permitted to flow through the aqueduct in 1889 than in 1875. While the arch was uncovered, during this reinforcement, a great many small fissures in the masonry were discovered and repaired from the outside.

We have stated in Chapter IV that the Croton Aqueduct Department had frequently to stop leaks in the conduit, caused by settling of embankments. After the Department of Public Works took charge of the aqueduct this trouble increased, owing to the severe strain to which the conduit was subjected in obtaining a greater daily discharge. When the leaks were not very large, they were generally stopped by dumping sawdust, fine sand and loam, mixed with water into a paste, into the aqueduct above the leak. In ordinary cases, three barrels of sawdust mixed with 1½ barrels of sand and a little cement was all the material required. About an hour's time was consumed in dropping the paste slowly into the aque-

duct about a mile above the leak, and three to four hours later the leakage was generally stopped by the sawdust, etc., being drawn into the cracks of the masonry by the escaping water.

When the fissures to be closed were of any great extent the repairs had to be made from the inside of the aqueduct. This operation necessitated the emptying of the whole conduit whenever the repairs were near its lower end, as no provision had been made for discharging the water from only a portion of the conduit. To make repairs of two hours' duration in this manner, the aqueduct had to be shut off from the city for forty-nine hours, as it required thirty hours to empty the conduit and about seventeen to fill it again. The inconvenience caused by thus depriving the city of a two days' supply began to be seriously felt as the consumption increased.

In 1881 an improvement, suggested by Mr. B. S. Church, the Resident Engineer in charge of the aqueduct, was introduced in the construction of the work, and obviated the difficulties previously experienced in making repairs from the inside. At each of the four waste-weir gate-houses (viz., at Sing Sing, Tarrytown, Yonkers, and Kingsbridge) large shut-off cross-gates were constructed. By means of these gates and the blow-off gates the part of the aqueduct between two consecutive cross-gates could be emptied independently of the other parts. This arrangement reduced the total time required for making repairs of two hours' duration from the inside to about six to ten hours.

Instead of altering the existing waste-weir gate-house at Sing Sing for the cross-gates, a new building was constructed one quarter of a mile nearer Croton Lake, in order to avoid the necessity of laying a waste-weir pipe two thousand feet long. The work required in connection with the cross-gates was completed by 1886.

Notwithstanding the great improvement made by the introduction of these gates, the aqueduct had occasionally to be shut off from the city for several days at a time on account of extensive repairs rendered necessary by serious breaks. On September 11, 1885, such an accident occurred near Van Courtland Station. The aqueduct had to be shut off from the city for four days for repairs, during which time the water in Central Park reservoir was lowered ten feet. The whole conduit was emptied on this occasion and several other leaks were stopped, including a large one at Dobbs Ferry, which had been running for over twenty years. On July 11, 1886, a serious break occurred on the sixth division of the aqueduct, necessitating the shutting off of the conduit from the city for three days.

Whenever the aqueduct was shut off from the city the only available supply was the water stored in the three city reservoirs, the maximum capacity of which amounted only to 1,204,000,000 U. S. gallons. While the bad breaks occurred on the embankments, small fissures and cracks were discovered occasionally even where the conduit was constructed in cuts. From 1884 to 1889 the demand for water was so great that the Department of Public Works did not venture to make a thorough examination of the interior of the aqueduct. All leaks that occurred were consequently stopped from the outside.

The completion of the New Croton Aqueduct in the summer of 1890 afforded at last an opportunity for a thorough inspection of the old conduit which had been in service, without

a serious interruption, for nearly half a century, delivering, for the greater part of that time, much more water than had ever been intended by its constructors. Since the new aqueduct has been in use the old conduit has been thoroughly repaired from the inside, the work being done as rapidly as the annual appropriations permitted.

The Storage Reservoirs.—When the Department of Public Works took charge of the city's water-works in 1870, the available amount of water stored in the reservoirs was as follows:

Croton Lake *	600,000,000	U. S. gallons.
New reservoir in Central Park	1,000,000,000	" "
Old reservoir in Central Park	180,000,000	" "
Distributing reservoir at Forty-second Street	24,000,000	" "
Total	1,804,000,000	U. S. gallons.

The Boyd's Corners reservoir was in course of construction and not yet available.

During the year 1869 an extreme drought brought the city to the verge of a water-famine. On October 2d all the storage water mentioned above was practically exhausted and the only supply obtainable was the minimum flow of the Croton River, which had been estimated by various competent engineers between 1836 and 1842 as 32,400,000 U. S. gallons a day, above Croton Lake. The danger of part of the city being deprived of water was fortunately averted by a heavy rain-storm on October 3d. For some time previous to this event the consumption of the city had been materially reduced by the outlet-gates from the reservoirs in Central park being partially closed.

The year 1870 proved to be much drier than the preceding one. In this instance a water-famine was prevented by the energetic steps taken by the Department of Public Works to increase the water-supply by purchasing the rights to draw down some of the lakes and ponds in the Croton watershed by cutting down their outlets. The additional amount of water obtained during the drought of 1870 in this manner was as follows:

Name.	Area of Surface. Acres.	Lowered. Feet.	Water Obtained. U. S. Gals.
Lake Gleneida	182	3	168,000,000
Lake Gilead	122	12	398,000,000
Lake Mahopac	603	3	584,000,000
Lake Kirk	101	20	528,000,000
Barrett's Pond	70	10	198,000,000
China Pond	50	10	132,000,000
		Total	2,008,000,000

When the city stopped drawing water in this manner, dams provided with outlet-pipes and stop-planks were constructed across the outlets of some of these lakes and ponds, which,

* Above the level required to discharge 36,000,000 U. S. gallons per day through the aqueduct.

in some cases, rose higher than they had been originally. In 1872 the Legislature enacted a law by which the State ceded its title to three or more of these lakes to the city.

The Boyd's Corners reservoir (described on page 79) was completed by April 1873 and added 2,700,000,000 gallons to the city's storage supply, but even this increase proved to be insufficient for the growing wants of the city. In 1876 an unprecedented drought occurred, and continued from early in June until November 7th. Croton Lake was lowered 39 inches below the crest of the overflow, so that only 70,000,000 gallons per day could be obtained through the aqueduct. All the water was drawn from the Boyd's Corners reservoir, and, in addition, large draughts had to be made on the lakes and ponds in the Croton watershed. Several new lakes were acquired and their outlets cut down.

The severe drought of 1876, which will long be remembered from the inconvenience it caused, was unfortunately followed by another drought in 1877. When the latter terminated on October 5th, the water in the Central Park reservoirs had been reduced 10½ feet in depth from its normal elevation.

In 1872, Mr. E. H. Tracy,* the Chief Engineer of the Department of Public Works, foreseeing the need of additional storage, commenced the surveys for another storage reservoir which was to be located on the middle branch of the Croton River near Brewster. It was not, however, until December 1874 that the contract for this work was awarded. Owing to delays in procuring the required land and want of vigor in the prosecution of the work, this storage basin, known as the "Middle Branch Reservoir" (see page 88), was not completed until October 1878. It added about 4,000,000,000 gallons to the city's storage supply.

The engineers of the Department of Public Works commenced in 1877 the surveys for a third storage reservoir for which they selected a site on the east branch of the Croton River. The plans for this reservoir, which was to consist of two basins (viz., the Sodom reservoir and the Bog Brook reservoir), connected by a tunnel, were not perfected until 1881. The work was constructed by the Aqueduct Commission, appointed in 1883. It was commenced in 1888 and finished in 1892 (see page 191).

Chapter 445 of the Laws of 1877 authorized the city to acquire the permanent right to draw water from the available lakes and ponds in the Croton watershed. Commissioners of Appraisal were appointed under this law on October 20, 1877, and the legal proceedings were commenced. Much opposition arose against these steps on the part of the owners, who demanded extravagant damages. This was especially the case at Lake Mahopac, where the claimants proceeded to fill up the outlets, which the Department of Public Works could only reopen by means of a large force of men.

The lakes and ponds from which the city drew water from 1870 to 1892, either by acquiring permanent rights or by payments for a season in special emergencies, are given in the table on page 189.

The year 1880 was the driest recorded in the Croton watershed since water was introduced in New York in 1842. While the annual rainfall for the two years of exceptional droughts

* For biographical sketch see page 239.

1876 and 1877 was respectively 40.68 and 46.03 inches (see table of rainfall on page 309), it amounted in 1880 to only 38.52 inches. Besides the small amount of rain the following causes contributed to reduce the quantity of water which reached the lakes and reservoirs:

During the winter of 1879 and 1880 very little snow fell and there was not enough moisture in the ground to replenish the springs which feed the lakes and ponds. After the extreme drought of the summer of 1880 an early frost about the middle of October prevented the subsequent rainfall from reaching the springs. The severe winter of 1880 and 1881 diminished the flow in the Croton River and at the same time produced a great increase in the consumption by the waste of water caused by leaving the faucets in the houses open to prevent the water from freezing in the pipes.

From May 19 to December 31, 1880, there were only nineteen days in which water flowed over the Croton Dam. The insufficiency of the volume of the Croton River had to be supplied by large draughts from the reservoirs and lakes, by means of which a flow of 95,000,000 gallons per day was maintained in the aqueduct.

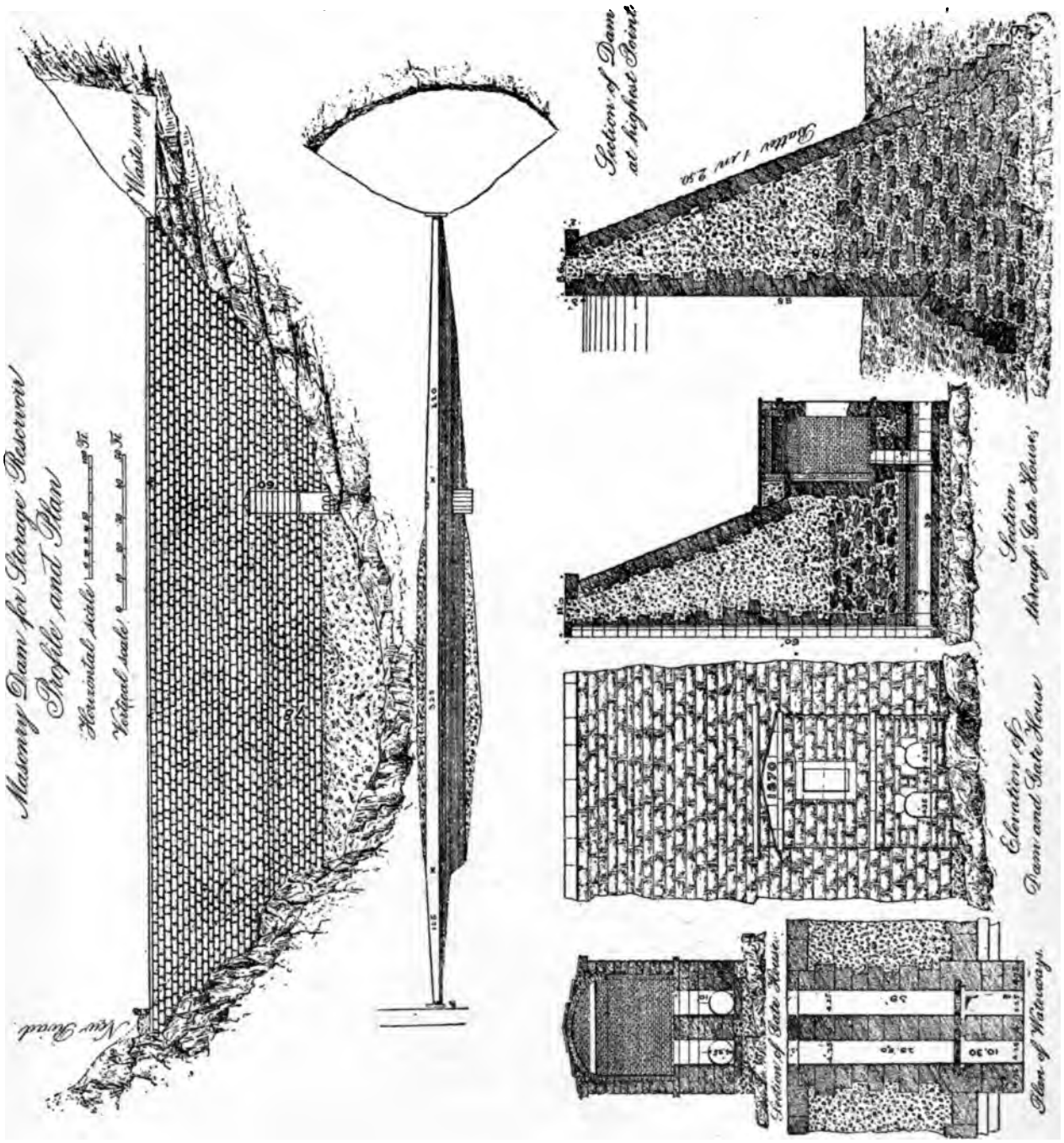
The amount of storage water drawn during this drought was as follows:

From Boyd's Corners reservoir	2,675,000,000	U. S. gallons
From middle branch reservoir	3,430,000,000	" "
From twelve lakes and ponds	2,116,000,000	" "
Total	8,221,000,000	U. S. gallons.

Severe as was the drought of 1880, it was surpassed by that of the following year. Although the total amount of rainfall for 1881 amounted to 46.33 inches, less than five inches fell during July, August, and September. For the sake of comparison we give below the rainfall for the corresponding months from 1866 to 1881.

Year.	July.	August.	September.	Total.
1866	4.01	6.56	4.92	15.49
1867	5.25	10.04	3.62	18.91
1868	2.13	6.98	9.33	18.44
1869	2.26	1.92	3.20	7.38
1870	3.43	5.10	2.85	11.38
1871	5.07	5.24	1.44	11.75
1872	4.34	5.99	3.69	14.02
1873	2.21	5.73	3.73	11.67
1874	5.98	2.75	3.56	12.29
1875	3.10	10.33	2.11	15.54
1876	3.42	1.20	5.21	9.83
1877	4.65	2.54	1.49	8.68
1878	4.28	2.66	6.61	13.55
1879	5.95	5.83	3.43	15.21
1880	5.65	3.60	2.69	11.94
1881	2.45	1.71	0.75	4.91

PLATE 12.


Masonry Dam for Storage Reservoir
Profile and Plan
Horizontal scale
Vertical scale
Waste weir
Section of Dam at highest Point
Section through Gate House
Elevation of Dam and Gate House
Section of Gate House
Plan of Waterways

Of the [illegible] for the period [illegible] were used for the city's supply by pumping during the first twelve days of July when water was running over the Croton Dam. From July [illegible] when the Croton [illegible] ceased to furnish the [illegible] gallons required by the city [illegible] gallons daily.

Up to this time the storage system of the city's water-works had been based on the assumption that the minimum flow of the Croton River would be [illegible] gallons per day. This estimate had been made by experienced engineers during the construction of the old aqueduct. The changes in the Croton watershed which had been made since then by the construction of dams and reservoirs and by the diversion of streams had practically changed the conditions upon which the estimate had been based.

During the struggle of [illegible] gallons [illegible] the reservoirs, lakes, and available ponds from July [illegible] which amounted to a daily average of [illegible] gallons for this period [illegible] day.

During the latter part of September and [illegible] steps were taken to reduce the daily consumption. [illegible] Parts were partially [illegible] the water was [illegible] by strict rationing [illegible] made to the public by the Mayor and by the Department of Public [illegible] Early in October [illegible] the supply of the reservoirs of the Croton Watershed and Croton and [illegible] By the middle [illegible] from the city.

The Boyd's Corners Reservoir [illegible] the City of New York [illegible] the west branch of the Croton River. [illegible] Aqueduct Commission [illegible] Public Works. The principal [illegible]

Length of dam [illegible]	[illegible]
Length of dam at crest	[illegible]
Maximum height above [illegible]	[illegible]
Maximum height above the [illegible]	[illegible]
Width at top	[illegible]
Width at base	[illegible]

The reservoir has a [illegible] maximum depth of the water [illegible]

The dam was [illegible] be [illegible] concrete [illegible]

When the Department [illegible]

Engineer Tracy, thinking it imprudent to trust to the strength of the masonry wall alone to retain the large amount of water stored in the reservoir, ordered an earthen bank 20 feet wide on top, having a slope of 2½ to 1, to be constructed against the up-stream face of the masonry dam.*

Water is drawn from the reservoir by means of two 36-inch pipes which pass through the wall, their inlets being controlled by suitable gates placed in a tower. The overflow, formed by excavating the rock on the northeast end of the dam, is 100 feet long. For the construction of the masonry dam 21,000 cubic yards of concrete and 6000 cubic yards of stone were required.

The earth embankment was so far completed by January 1, 1873, that the outlet-gates of the reservoir were closed. By April 1st the reservoir was full and the water commenced to overflow.

The Middle Branch Reservoir (Reservoir G, see Plate 54).—This reservoir is situated in the town of Southeast, Putnam County, N. Y., on the middle branch of the Croton River, near Brewster. The surveys for this storage basin were made in 1872 and 1873. Part of the required land was purchased at that time. Owing to various delays the contract for constructing the work (which was given to Belden & Denison) was not awarded until December 1874. The work was retarded by lack of vigor on the part of the contractors and by delays in requiring the necessary land, so that the reservoir could not be filled with water until October 1878.

The reservoir was formed by constructing an earthen dam having a masonry core-wall across the middle branch of the Croton River. The dam is 515 feet long and has a maximum height of 94 feet above the bottom of the foundation. It has a top-width of 50 feet, and a bottom width of 660 feet, at the highest part of the dam. The basin formed has an area of about 430 acres, and a storage capacity of about 4,000,000,000 gallons.

In constructing the reservoir the following principal items of work were performed, viz.:

Earth and riprap embankment	377,000	cu. yds.
Rock excavation	54,000	"
Earth excavation	62,500	"
Rubble masonry	17,000	"

The total cost of the work, including land and legal expenses, was about $690,000 amounting to $172.50 per million gallons stored.

The Amawalk Reservoir (Reservoir A, see Plate 54) is being constructed (1895) by the Department of Public Works on the Muscoot River near the village of Amawalk, Westchester County, N. Y. The reservoir will cover about 600 acres of land and will store about 7,000,000,000 U. S. gallons. Its drainage area contains 20.5 square miles.

The reservoir is formed by constructing a main dam across the valley of the Muscoot

* See "Memoir on the Construction of a Masonry Dam," by J. J. R. Croes, C.E., in the Transactions of Am. Soc. C. E. for 1874.

River, and an auxiliary dam across a depression on the west side of the reservoir. Both dams are of earth and have masonry core-walls. The principal dimensions of the main dam are as follows:

Length on top	1270 feet
Maximum height above surface	82 "
Width on top	50 "
Inner slope	5 to 1
Outer slope	3 to 1
Maximum height of core-wall above foundation	80 feet
Width of core-wall on top	8 "
Width of core-wall 28 feet below top	10 "
Width of core-wall 58 feet below top	12 "

The core-wall has vertical faces, the increase in width being made at the depths mentioned above by equal offsets on both sides. In addition to this wall, another—the guard-wall—is constructed in the inner slope of the dam, 289 feet upstream from the centre-line of the main core-wall. The guard-wall is 4 feet wide, and extends from its foundation to the paving of the inner slope, which consists of riprap 3 feet deep. The top and outer slope of the dam are sodded.

The auxiliary dam has a length of 400 feet, a top-width of 25 feet, and a maximum height above the surface of 20 feet.

The spillway, which is fifty feet wide, is located near the middle of the main dam. The outer face of its profile forms an ogee curve.

The water is drawn from a tower in the reservoir, 32 feet by 34 feet in plan, located near the foot of the inner slope of the main dam. A central wall divides the tower into two water chambers, each six feet wide. Towards the reservoir the chambers are left open. They can be closed, however, by means of stop-planks placed in grooves provided in the walls of the water-chamber. Each chamber has two sets of grooves, one being used ordinarily for timber screens. Toward the dam the tower is closed by a cross-wall with the exception of the opening left for a brick tunnel, having an area of about 81.337 square feet, which conveys the water through the inner slope of the dam to the core-wall. Two lines of 30-inch cast-iron mains, laid in the masonry of the core-wall and then in a brick tunnel through the outer slope of the dam, conduct the water from the tunnel of the inner slope to a gate-house built about 160 feet south from the centre of the main dam. Each of the pipe-lines begins with a reducer 6 feet long, having a diameter of 40 inches at the large end. At the gate-house the two lines of 30-inch pipe are connected with four lines of 20-inch pipe, each line being controlled by a stopcock. The four lines of pipe lead to a fountain-basin 50 feet in diameter, where they discharge the water in vertical jets in order to aerate it. The water flows from the basin to the waste-channel of the spillway and then into the old bed of the Muscoot River.

The contract for the Amawalk reservoir was awarded on July 25, 1889, to John McQuade Ground was broken for the main dam in December 1889. The work will prob-

ably be completed by December 1896. Col. John Mechan, Topographical Engineer of the Department of Public Works, has had charge of the construction since the beginning.

Deepening the Old Receiving Reservoir in Central Park.—We have stated on page 57 that the Water Commissioners, who had charge of the Old Croton Aqueduct, tried to save money by omitting to excavate some rock in the north division of the old receiving reservoir. In order to obtain more storage, the Department of Public Works had this material removed and the depth of the reservoir increased in 1890–1895.

Investigations for a New Aqueduct.—By the year 1875 the consumption of water in New York was rapidly approaching the maximum quantity which the Croton Aqueduct could deliver. In very cold weather and during extreme droughts more water was consumed daily in the city than was received through the aqueduct, the extra quantity being obtained by drawing down the reservoirs in the city. Upon the removal of the cause of the excessive consumption it required always a long period of time to raise the water in the reservoirs to its former level, owing to the limited capacity of the aqueduct, even though at the time hundreds of millions of gallons were running daily to waste over the Croton Dam.

The same inconvenience was experienced whenever the aqueduct had to be shut off from the city for inspection and repairs. The necessity of constructing a second conduit, either to the Croton watershed or to some other source of supply, was therefore seriously felt. As the minimum yield of the Croton watershed was estimated at about 250,000,000 gallons per day, of which quantity less than 100,000,000 were delivered into the city, the most natural manner of increasing the city's supply seemed to be by constructing a second aqueduct from the Croton Valley to New York.

The Legislature having granted the proper authority, surveys were made in 1875 by order of Gen. Fitz John Porter, Commissioner of Public Works, for such an aqueduct, the capacity of which was to be 150,000,000 gallons per day. Two routes, respectively 36.5 and 36.8 miles long, were surveyed, commencing a quarter of a mile below the head of Croton Lake and terminating near Jerome Park, where it was proposed to construct a large receiving reservoir. Nothing more was done towards constructing this work.

The unprecedented and continued droughts of 1876 and 1877 placed the city's water-supply in such a critical condition that the Department of Public Works, under the administration of Commissioner Allan Campbell, made extensive investigations of all means by which the water-supply might be augmented and the wastage curtailed. In his report for the quarter terminating September 30, 1877, Commissioner Campbell discussed these subjects very fully, reviewing all the sources of supply which had been suggested, such as the Hudson, Croton, Passaic, Housatonic, Bronx, and Byram rivers, as also water from Long Island.

Commissioner Campbell considered the best plan of gaining an additional supply to be the construction of a new aqueduct to the Croton watershed, where he estimated that by means of additional storage reservoirs a minimum supply of 250,000,000 gallons per day might be secured. The city's treasury was, at that time, in such a depleted condition, owing to former maladministration, that Mr. Campbell thought it unadvisable to undertake the construction of a new aqueduct to the Croton Valley, the cost of which he esti-

mated at $12,000,000. He stated that at least five years would be consumed in executing that work, during which time no addition would be made to the city's supply. Under these circumstances he concluded that the best project for the city to execute, at that time, was to obtain an additional supply of ten to twenty million gallons per day from the Bronx and Byram rivers. The Commissioner estimated that this additional supply could be secured within three years at a cost of $3,000,000. While he considered this plan only a temporary expedient to postpone the large outlay for a new aqueduct to the Croton Valley, he thought the supply from the Bronx River, which would be principally consumed in the "Annexed District" of New York, would always remain a valuable addition to the city's supply. The manner in which the Bronx project was actually carried out is described on page 92.

In investigating the sources from which an additional supply might be obtained, Commissioner Campbell had also a careful study made of the possibility of diverting a portion of the water of the Housatonic River into the Croton basin.

The Housatonic Project.—The surveys and investigations for a supply from the Housatonic River were made by Assistant Engineer Horace Loomis* in 1878. Three different lines were surveyed for a canal for diverting 100,000,000 gallons per day from the Housatonic to the head-waters of the Croton (see Plate 148).

The first line commenced a little north of Falls Village, Conn., just below the dam of the Housatonic Railroad Co., and terminated at Pawling, N. Y. Its length was 41.13 miles, including 30.19 miles of open canal, 8.44 miles of natural watercourses, and 2.50 miles of tunnel through the dividing ridge between the watersheds of the Housatonic and Ten-mile rivers. The water was to be taken from the Housatonic at an elevation of 622 feet above tide and to be conveyed to the Croton head-waters entirely by gravity.

The second line was surveyed between West Cornwall, Conn., (where the Housatonic was to be raised ten feet by a dam,) and Pawling in the Croton watershed. This route was for a gravity supply which was to flow for the whole distance, 28.8 miles, through open canals.

The third line commenced at Bull's Bridge on the Housatonic and followed from this point to Pawling the location of the second line. It was only 14.77 miles long, being the shortest of the three locations, but required the water of the Housatonic to be pumped to an elevation of 106 feet to the head of the canal. At first it was thought that the pumps could be operated entirely by water-power, but it was found that what might be obtained in this manner would be insufficient at low water. This location would, therefore, have necessitated the use of steam-power either to perform all the pumping or as an auxiliary to the water-power.

The areas drained by the Housatonic River were given as follows:

Above Falls Village	631 square miles
Above West Cornwall	709 " "
Above Bull's Bridge	790 " "

* Now Engineer in charge of Sewers, Department of Public Works of New York City.

Only a small part of these drainage areas are in the State of New York.

From May 22 to November 1, 1878, 17.96 inches of rain fell in this region. During this season the average daily flow of the Housatonic River was about 300,000,000 gallons, the maximum and minimum being respectively about 470,000,000 and 170,000,000 gallons.

The cost of obtaining a daily supply of 100,000,000 U. S. gallons from the Housatonic was estimated as $2,500,000. Nothing was done in connection with the Housatonic River project beyond making the surveys mentioned above.

The Water-supply from the Bronx and Byram Rivers.—We have stated in Chapter I that Dr. Joseph Browne recommended the Bronx River as the source of the city's water-supply as early as 1798. This project was carefully investigated in 1821 by Mr. Canvass White, a well-known civil engineer. According to the plans he proposed, the Bronx was to be dammed at Tuckahoe, the water diverted being conveyed to the Harlem River through an arched channel and thence to the city through iron pipes. Mr. White estimated that in this manner a daily supply of 6,600,000 gallons could be obtained at a cost of $1,949,543. Another estimate, made in 1830 by Mr. Francis B. Phelps, placed the cost of the necessary works at $2,600,000.

As stated on page 90, the scarcity of water during the droughts of 1876 and 1877 induced Mr. Allan Campbell, Commissioner of Public Works, to examine again the project of a supply from the Bronx River, and also the feasibility of diverting some of the water of the Byram River into the proposed conduit from the Bronx.

The surveys for this purpose were commenced in 1877. The definite plans and estimates for a supply from these rivers were first presented in Mr. Campbell's report for the quarter ending June 30, 1879. The plans proposed were as follows (see Plate 54):

1st. The construction of a dam, 15 feet high, at the outlet of the Little Rye Pond, which would convert the two Rye Ponds into one lake having an area of 280 acres and a storage capacity of 1,050,000,000 gallons.

2d. The erection of a dam, 45 feet high, across the Bronx River near the Kensico Station of the Harlem Railroad, whereby a reservoir of 250 acres of surface and 1,620,000,000 gallons storage capacity was to be formed.

3d. The construction of a dam, 15 feet high, across the Byram River, 1100 feet north of the State line, making a lake of 75 acres area and of 180,000,000 gallons storage capacity. From this dam a channel 3800 feet in length was to be cut, to unite the waters of the Bronx and Byram rivers.

4th. The construction of a conduit line, consisting of 48-inch cast-iron pipes, which was to take the water from the Kensico reservoir, at an elevation of 245 feet above tide, and to deliver it into a receiving reservoir at Williamsbridge, in the upper part of the Twenty-fourth Ward of the city, at an elevation of 195 feet above tide (about 76 feet higher than the normal surface of the Central Park reservoir). The Williamsbridge reservoir was to have a storage capacity of 120,000,000 gallons, and to serve as a settling-basin.

The total amount of available storage, according to the above plans, was estimated as follows:

Byram Pond	550,000,000	gallons
Byram Reservoir	180,000,000	"
The Rye Ponds	1,050,000,000	"
Kensico Reservoir	1,620,000,000	"
Williamsbridge Reservoir	120,000,000	"
Total	3,520,000,000	gallons.

The total cost of the works was placed at $4,849,443. The watershed from which the supply was to be obtained was as follows:

Bronx River	13.33	square miles
Byram River	8.66	" "
Total	21.99	square miles.

FIG. 17.—DAM OF KENSICO RESERVOIR.

It was estimated that with the above watershed and storage a daily supply of 1,000,000 gallons per square mile of watershed could be obtained.

The works were commenced in October 1880, and were substantially constructed as described above. Mr. George W. Birdsall, First Assistant Engineer, was in immediate charge of the whole construction until he was appointed Chief Engineer of the Croton Aqueduct.

Owing to the existing laws, which limited the appropriation for extending the waterworks to $1,000,000 per annum, and to the inevitable delays in acquiring the necessary property, considerable time was consumed in completing the works. The first contract

awarded was for the Kensico reservoir. The contracts for the other storage basins and for the different sections of the conduit-line were let as rapidly as the legal proceedings and the available appropriations permitted.

By September 4, 1884, the conduit-line, consisting of 15.2 miles of 48-inch pipe, was completed from the Kensico reservoir to the receiving reservoir at Williamsbridge. Although the work on the latter had only just commenced, a line of 36-inch mains had been

FIG. 18.—INLET GATE-HOUSE OF WILLIAMSBRIDGE RESERVOIR.

laid around it and to Jerome Avenue, where it connected with the distributing mains of the Twenty-third and Twenty-fourth Wards, and also with a pipe which was laid to convey the surplus water to the Croton Aqueduct at Croton Avenue. By this arrangement the supply from the Bronx became at once available. After the conduit had been tested, 5,000,000 gallons per day were delivered through it on September 9, 1884. Two days later the flow was increased to twice this quantity. The beneficial effects of this new supply can be judged from the following facts:

In the beginning of September 1884 the daily consumption of water had been so much in excess of the supply that the city reservoirs were being lowered at the rate of 2 to 2½

inches per day. By September 3d, when the Bronx supply had been received for about three weeks, the water-level in the city reservoirs had been raised as follows:

Large receiving reservoir in Central Park	3 feet
Small receiving reservoir in Central Park	11 "
Forty-second Street distributing reservoir	8 "

The gain of head in the city's mains averaged about eight feet for the above period. A daily supply of ten to nineteen million gallons per day was obtained from that time from the Bronx, although the Williamsbridge reservoir, commenced in June 1884, was not completed until the end of 1889.

Much delay was experienced in securing an additional supply from the Byram River. The two principal tributaries of this stream, flowing respectively from Wampus Pond and Byram Pond, unite near the Connecticut State line and empty into Long Island Sound at Portchester in Connecticut. Although the diversion of the waters was to be made in the State of New York, the riparian owners in Connecticut had to be compensated for this loss of water. As the damages had to be settled entirely by negotiation, instead of the condemnation proceedings resorted to in the State of New York, a great deal of time was consumed before the contemplated works could be commenced. The contracts for a storage basin on the Byram River and for the channel to the Bronx were awarded early in 1889, but it was not until the latter part of 1891 that all the necessary land was acquired. The works are now (1895) being constructed.

The High-service Works.—When the Department of Public Works superseded the Croton Aqueduct Department in April 1870, the high-service works at High Bridge, described on page 76, were in the following condition:

The reservoir was nearly completed, the foundation of the tower was finished, and the shaft commenced; the walls of the engine-house were erected, and the engine and boiler had been placed. The works were finished by the new Department, the reservoir being brought into use in November 1870 and the tank in the tower in the summer of 1872.

In order to supply the pumping-engine (Fig. 15) with water two 30-inch mains, about 200 feet long, were laid from the aqueduct directly to the pump. This arrangement caused a water-hammer when the pumps were put in motion, which was entirely stopped by leading the water from the mains into a tank in the engine-house, from which the pump was then supplied. The tank was 6 feet in diameter and 32 feet high. It was made of boiler-plate, and left open on top.

A second auxiliary pumping-engine of sufficient capacity to permanently supply the tank in the tower, and large enough, at the time, to pump all the water for the high service, was ordered late in 1870 and was put in service in the following spring. During 1873 a dock and incline were built at High Bridge and a hoisting-engine erected for delivering coal at the boiler-house.

In the latter part of 1875 it was decided to erect another large pumping-engine for the high service. Bids were advertised for and the contract awarded to the lowest bidder, Mr.

W. E. Worthen, for $27,000. The engine was constructed by the Delamater Iron Works according to the designs of Mr. John E. McKay, Assistant Engineer (now First Assistant Engineer) of the Department of Public Works, and was put into service in the summer of 1876.

The pumping station at High Bridge was intended originally for supplying only the neighboring region with a high service. In order, however, to furnish water to houses built on high ground in the other parts of the city a 20-inch main was laid in 1873 and 1874 from the High Bridge reservoir as far south as Murray Hill at Forty-second Street.

As the pumping-engines at High Bridge were unable to meet the increased demand for high-service water, the Commissioner of Public Works recommended in 1877 that additional high-service works be constructed further south, suggesting for their location the ground owned by the city between Ninety-seventh and Ninety-eighth streets, one hundred feet west of Ninth Avenue, which had been occupied by the aqueduct until it had been replaced between Ninety-second and One Hundred and Thirteenth streets by iron pipes (see page 99). A bill authorizing the construction of these works was introduced in the Legislature in 1877, but failed to become a law. The following year, however, a bill was passed which gave the Mayor and Common Council the power to authorize the Department of Public Works to construct the new high-service works.

In December 1878 the Common Council enabled the Department of Public Works to proceed with the construction of these works, the cost of which, including the buildings, stand-pipe and tank, and two pumping-engines with the necessary fixtures, was limited to $220,000.

The work was commenced in February 1879. The contract for the two pumping-engines was awarded to Mr. H. R. Worthington. The specifications required that each engine should be capable of raising 15,000,000 gallons 100 feet high in forty-eight hours with a coal consumption not exceeding 1784 pounds per million gallons raised 100 feet. In ninety days' continuous run the water-level in the stand-pipe was not to vary over ten feet. Only one engine was to be in operation, the other being held in reserve.

The tower constructed for these works is shown on Plate 13. The superstructure was built of brick and trimmed with Wyoming Valley blue sandstone. The tower is about 170 feet high and contains a stand-pipe of 6 feet diameter, made of plates of boiler-iron, $\frac{1}{2}$ to $\frac{3}{4}$ inch thick. The works were constructed within the original estimate, and were put into service in May, 1880, although the buildings and tower were not completed until the beginning of 1881.

In the latter part of 1880 the small engine which supplied the tank in the High Bridge tower was disabled and was replaced by a Worthington engine. The two boilers which had been placed in 1870 at this station also became unsafe, and new ones of a larger size were erected in 1881. As the old pumps at High Bridge were found to consume about twice as much coal as the improved Worthington pumps of the Ninety-eighth Street station, they were replaced in 1883 by a Worthington engine capable of pumping 6,000,000 gallons 100 feet high in twenty-four hours.

HIGH SERVICE TOWER AT NINETY-EIGHTH STREET.

By the year 1890 about 12,000,000 gallons per day had to be pumped at the Ninety-eighth Street station for high service. It became advisable to erect another pumping-engine, as in case of accident to one of the pumps in operation the other would have been unable to supply the demand for water. The necessary authority for purchasing a new pumping engine having been obtained by a resolution, passed by the Common Council on November 29, 1889, and approved by the Mayor, a new Worthington engine, capable of pumping 10,000,000 per day, 100 feet high, was ordered by the Department of Public Works for the Ninety-eighth Street station. It was put in service on May 1, 1891.

The performance of the high-service pumping-engines for the year 1891 is given in the annual report of the Department of Public Works as follows:

HIGH BRIDGE.

Number of Days Pumped.	Number of Strokes.	Height Pumped. Feet.	Number of Gallons Pumped.	Pounds of Coal Consumed.	Gallons of Oil Expended.	Pounds of Waste Expended.
365	27,316,667	1,200	1,943,891,863	3,388,650	822	365
Average per month	2,276,389	100	161,990,988	282,387	68.3	30.4

Average duty, 47,844,400 pounds raised 1 foot high with 100 pounds of coal.

574 gallons raised 100 feet with 1 pound of coal.

Average amount pumped daily, 5,325,732 gallons.

Average pounds of coal consumed per day, 9,284.

Average cost of pumping 1,000,000 gallons 100 feet high, $8.45.

20,000,000 gallons pumped 214 feet high into a tank in tower during year.

NINETY-EIGHTH STREET.

Number of Days Pumped.	Number of Strokes.	Height Pumped. Feet.	Number of Gallons Pumped.	Pounds of Coal Consumed.	Gallons of Oil Expended.	Pounds of Waste Expended.
365	58,942,332	1,056	5,870,637,262	7,567,124	1,400	853
Average per month	4,911,861	88	489,219,771	630,593	116.6	71

Average duty, 57,327,870 pounds raised 1 foot with 100 pounds of coal.

776 gallons raised 88 feet high with 1 pound of coal.

Average amount pumped daily, 16,088,938 gallons.

Average pounds of coal consumed per day, 20,731.

Average cost of pumping 1,000,000 gallons 88 feet high, $5.30.

The growth of the city northward soon made it necessary to increase the capacity of the high-service pumping station at High Bridge. A law passed by the Legislature (chapter 38, Laws of 1892) authorized an expenditure of $500,000 for this purpose. It was decided to build a new engine-house and tower on the property of the city, between Tenth Avenue and the Harlem River, at shaft 25 of the New Croton Aqueduct. The plans for this work have all been prepared and the construction has been begun. The pumps will be

supplied by one 36-inch cast-iron pipe which has been connected with the 36-inch main laid from shaft 25 to the old pumping station at High Bridge (see page 165). These pipes are placed in a masonry tunnel and terminate at a receiving tank which is to be erected in the new engine-house. This tank is to have an outer diameter of 8 feet and to be 47 feet high. Its base is to be made of cast iron, and its superstructure of steel plates, the two bottom sheets being $\frac{3}{4}$ inch thick, and the others having a thickness of $\frac{5}{8}$ inch. The receiving tank is to be provided with three 36-inch cast-iron flange connections (one for the inlet-pipe and the other two for the pipes supplying the pumps) and with a manhole.

The stand-pipe is to be placed in a tower constructed of stone and brick. It will be 6 feet in diameter and 138 feet high. It is to have a base of cast iron and a superstructure of steel plates. For the first 50 feet the steel sheets are to be $\frac{3}{4}$ inch thick, for the next 50 feet their thickness is to be $\frac{5}{8}$ inch, and for the remaining distance it will be $\frac{1}{2}$ inch. The bottom sheet is to fit into a grove in the cast-iron base, and to be leaded into it, on the inside and outside.

The plates for the receiving tank and for the stand-pipe are to be made of the best quality of soft, homogeneous steel, having a tensile strength of at least 50,000 pounds per square inch.

Provision has been made for:

3 pumps, each having a capacity of 10,000,000 U. S. gallons in twenty-four hours;

3 pumps, each having a capacity of 4,000,000 U. S. gallons in twenty-four hours.

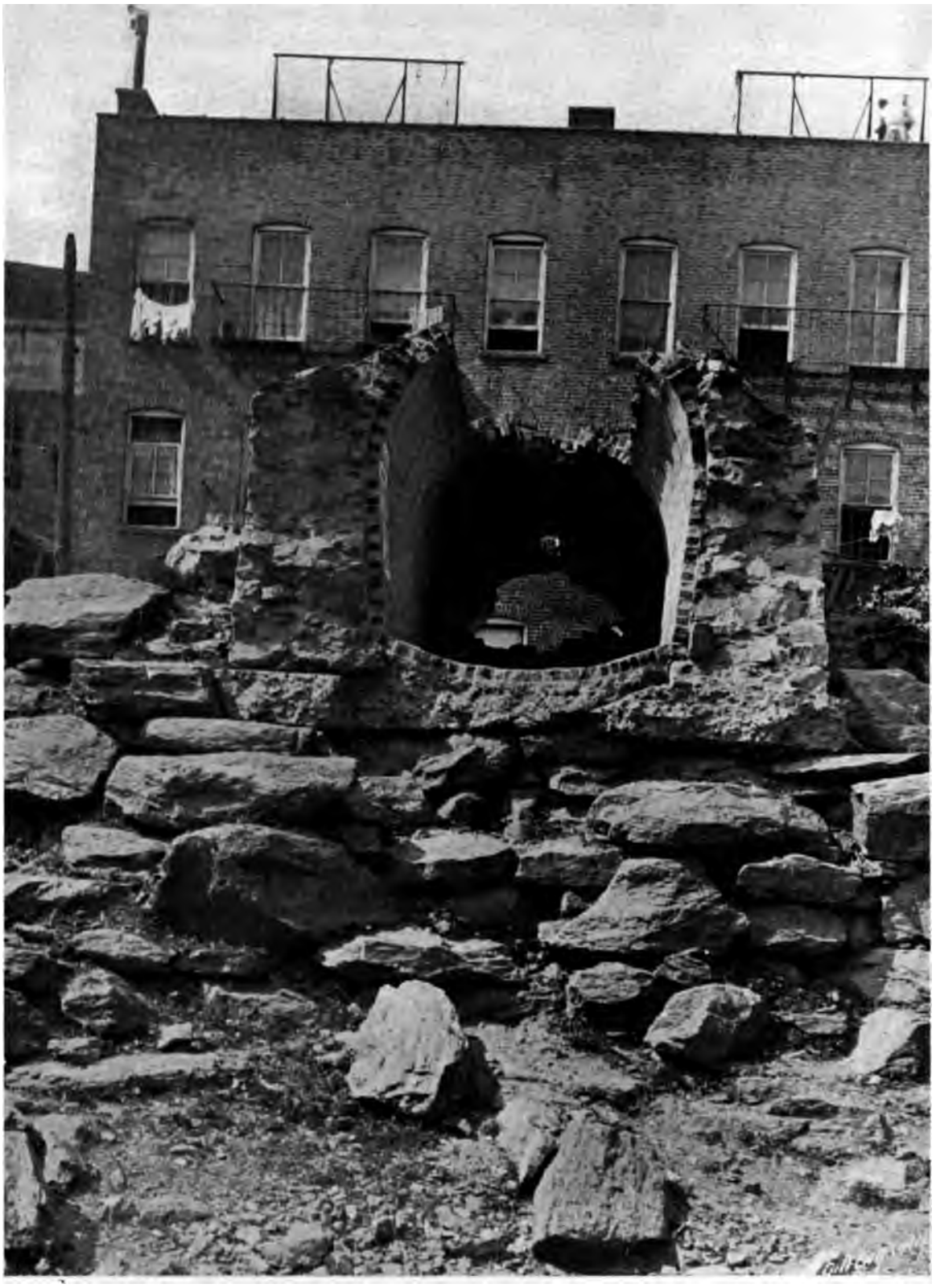
The larger pumps are to supply the old high-service reservoir at High Bridge; the smaller ones are to pump into the new stand-pipe. A contract for two of the large and two of the small pumping-engines, for the boilers and all appurtenances, was let on December 7, 1893, to the G. F. Blake Manufacturing Co. for $110,000. The pumping-engines are all to be vertical and have triple expansion. The specifications for the engines, boilers, etc., will be found on page 273.

The work of constructing the foundations for the buildings was let to Thomas Dwyer for $130,110 on March 1, 1893. The contract for the engine and boiler-house and tower was awarded to James R. F. Kelly on August 27, 1894, for $81,210. The work of building the receiving-tank and stand-pipe was let on August 20, 1894, to M. J. Drummond for $11,900.

In 1881 the quantity of water pumped for high service amounted to 4,445,526,368 U. S. gallons for the whole year, the average daily quantity being 12,200,000 gallons. During 1894 9,256,640,900 gallons were pumped, amounting to an average of 25,360,660 gallons per day.

Change of Aqueduct from Ninety-second to One Hundred and Thirteenth Street.—An Act of the Legislature of 1870 directed the Department of Public Works to remove the aqueduct between Ninety-second and One Hundred and Thirteenth streets, and to substitute therefor either a depressed masonry conduit or iron pipes, laid below the grades of the streets. When the aqueduct was constructed, Manhattan Island was used above Eighty-sixth Street only for agricultural purposes. The grades of the future streets

PLATE 14.



OLD AQUEDUCT NEAR ONE HUNDRED AND FOURTH STREET.

and avenues in this region had not yet been fixed and very little attention was paid to them in locating the aqueduct.

We have described in Chapter IV how the wonderful growth of the city made it soon necessary to replace the masonry conduit between Eighty-sixth and Ninety-second streets by iron pipes laid below the surface of the streets. The opening of Central Park necessitated soon afterwards a similar change from Ninety-second to One Hundred and Thirteenth streets, as the aqueduct was in this locality considerably above the established street grades.

In carrying out the Act mentioned above, the Department of Public Works concluded to replace the aqueduct, within the limits in question, by iron pipes laid in Tenth Avenue. The constant trouble experienced with the 6-foot mains laid from Eighty-sixth to Ninety-second Street (see page 78) decided the Department, in this instance, to lay six lines of mains only 48 inches in diameter.

In order to control the inlet and outlet of each of the six lines of pipes two gate-houses had to be constructed, one at One Hundred and Thirteenth Street and the other at Ninety-second Street near the junction gate-house (see Fig. 12, page 67).

To maintain the city's water-supply while the change from the masonry conduit to pipes was being made the mains on Tenth Avenue were laid at their northerly end, first to one side of the avenue, and connected with a temporary gate-house located north of the permanent one at One Hundred and Thirteenth Street. After the latter was built and the old masonry aqueduct had been removed the pipes were moved to the centre of the avenue and connected with the permanent gate-house.

FIG. 19.—LAYING MAINS ON TENTH AVENUE.

While the pipes were being laid brick sewers were constructed on both sides of the avenue in order to avoid subsequent blasting. The illustration above shows the work in progress. The change described was commenced in 1870 and completed by the end of 1875, with the exception of the superstructures of the gate-houses, which were finished in the fall of the following year. As only the required materials were obtained by contract and the labor was performed by day's work, at two dollars a day, this piece of work proved to be very expensive.

Change of Pipes between Eighty-sixth and Ninety-second Streets.—The two lines of 6-foot mains laid by the Croton Aqueduct Department in 1866 and 1867 from Eighty-sixth to Ninety-second streets were a source of constant expense. We described on page 77 how nineteen of these pipes cracked when first subjected to water-pressure. Similar accidents continued to occur almost every year. Thus in

1872	20 pipes were cracked.
1873	30 " " "
1875	32 " " "
1877	25 " " "

The expense of repairing broken pipes, and the resulting interruption of the water-supply through one or both lines of mains, induced the Department of Public Works finally to replace the 6-foot pipes by others of 48-inch diameter, one line being laid in 1881 and two more in 1890.

Extending the Pipe-system.—When the Croton water was first introduced an abundant supply with high head was furnished by all the mains which had been laid. As the consumption increased there was a corresponding diminution of pressure. By new mains from the reservoirs in the city being laid the collective area of the outlets from the city reservoirs became greater than the area of the Croton Aqueduct. The only way in which the water was retained in the reservoirs was by partially closing the outlet-gates. The table given on page 107 shows the increase in consumption of water and the population of the city according to the U. S. census.

The inconvenience of diminished pressure was especially felt in the lower part of the city. In 1870 the Department of Public Works determined to improve this condition by laying a 36-inch pipe from the 48-inch main in Forty-second Street down Madison Avenue in as direct a line as possible to Chambers Street to connect there with the down-town mains. The work was commenced in the fall of 1871, but was much delayed by the legal objection raised by the Comptroller to having pipes laid by day's work. The Common Council finally passed a resolution authorizing the work to be performed in this manner. On December 25, 1872, the main was connected with the pipes at Chambers and Chatham streets. The following spring it was continued in Chambers Street to Church Street and connected with other important down-town mains.

Some other large mains were laid by the Department of Public Works, as follows:

1873. The 20-inch high-pressure main was extended from High Bridge reservoir to Kingsbridge.

1874. A 20-inch high-pressure main was laid from the High Bridge reservoir south through the Boulevard to Fortieth Street and through Fortieth Street to Madison Avenue.

A wrought-iron pipe, ten inches in diameter and 750 feet long, was laid across the Harlem River at Second Avenue to supply the "Annexed" District.

A 48-inch main was laid from the new reservoir in Central Park through Eighth Avenue and Tenth Avenue south to Thirty-eighth Street. It was connected with the 48-inch main in Forty-second Street.

1875.—The 36-inch mains which lead from the north gate-house of the large Central Park Reservoir were connected with the 20-inch mains on Fifth and Eighth avenues.

1878.—A 48-inch main was laid from the new reservoir in Central Park through First Avenue to Fourteenth Street.

A 20-inch main was connected with the aqueduct at Fordham.

The table on page 310 shows the amount of pipe laid annually from 1849 to 1895.

In extending the pipe-system in the upper part of the city the Croton Aqueduct Department frequently omitted to lay pipes in streets in which the trenches would have been in rock excavation, in order to avoid expense. The consequence was that there were a great many pipes up-town having dead ends, and that complaints about bad water were frequently made.

The Department of Public Works in the early years of its work remedied this evil by drawing off the stagnant water and by laying additional pipes to establish a perfect circulation.

Much trouble was experienced with the mains laid near the river front, which were rapidly corroded by the salt water penetrating the soil.

For the purposes of repairs, the city was divided in 1883 into four districts, terminated on the north respectively by Houston Street, Fifty-seventh Street, One Hundred and Twenty-fifth Street, and the north boundary of the city. Each district was placed in the charge of a foreman, who had a repair gang under his orders.

During the construction of the water-works all the iron pipes were tested in the pipe-yard of the city before being laid. This custom was gradually abandoned. The result was that breaks in the mains became more numerous. In 1870 the Department of Public Works resumed the old method of testing all the iron pipes at the city's pipe-yard, where new presses capable of testing pipes from four to forty-eight inches in diameter were erected. As the pipe-laying in the city increased it became impossible to continue this system, and the testing had to be performed by inspectors at foundries.

The Croton Aqueduct Department had deemed it best to have the mains laid by day's work, thinking that this was the only way to insure good work. The Department of Public Works followed the same method until it resumed, in 1876, the contract system, as being much more economical. The difference between the city's having the pipes laid by day's work and by contract will be seen from the following table:

COST OF PURCHASING AND LAYING PIPES.

Year.	Average Cost of Iron per ton.	Cost of Laying Pipes per ton.	Total Cost per ton.
1872	$65 50	$70 86	$136 38
1873	65 50	74 16	139 60
1874	65 50	73 15	138 65
1875	65 50	115 78	181 28
1876	46 00	50 55	96 55
1877	23 00	17 35	40 35

Owing to the changes of the street grades, the Fifth Avenue mains had to be lowered, in 1870, about four feet in rock excavation, from Sixty-eighth to Seventy-second Street. This alteration was effected, without shutting off the water from the pipes, with perfect success. The pipes were placed on saddles which rested on greased skids. When the avenue had been excavated on one side to the grade of the pipes, they were removed to one side, one line at a time, by means of jackscrews. After the new pipe-trench had been excavated the pipes were moved back, in a similar manner, to their former position, being supported by blocking. They were then lowered to the new grade by jackscrews, the blocking being gradually removed.

The city institutions on the islands in the Harlem and East rivers were supplied with water by pipes laid on the bottom of the rivers in 30–100 feet of water. The length of these pipe-lines varied from 1000–1300 feet. Randall's, Ward's, and Blackwell's Island were supplied with water in this manner in 1850. For the first two islands lead pipes of three inches interior diameter, laid in wooden trunks below the bottom of the river, were used with perfect success, but at Blackwell's Island other means had to be employed owing to the very irregular and rocky nature of the river-bottom at this place. The Croton Aqueduct Department laid gutta-percha pipes to this island. Much difficulty was experienced in maintaining a constant supply through these pipes, as the swift and constantly changing current of the tides abraded them on the rocks. Occasionally they were also torn by vessels dragging their anchors. The frequent repairs which these gutta-percha pipes required caused much expense and inconvenience.

In 1871 and 1872 the Department of Public Works substituted several wrought-iron pipes, of three inches diameter, for those of gutta percha, but even these pipes were not found sufficiently strong to resist the dragging of the anchors of heavy vessels. Another difficulty experienced was the freezing of the water in the 3-inch wrought-iron pipes, which were laid in salt water that remains fluid at a lower temperature than fresh water. The Department finally laid, in 1873, a heavy 6-inch wrought iron lap-welded pipe (similar to those used for steam) from Manhattan Island at Sixty-second Street to Blackwell's Island, selecting for this purpose the deepest and widest part of the river, as the bottom was found to be comparatively regular at that place. The pipes were fastened together with heavy screw couplings which were strengthened and protected by strong cast-iron sleeves secured by lead joints. In this manner the joints were made as rigid as the other parts of the pipes. The pipe was placed in a heavy oak case, which was securely bolted and riveted together, the space between the pipe and the case being filled with hydraulic cement.

After the pipe had been properly placed in the box, which was thoroughly saturated with coal-tar, it was pulled across the river by a powerful dredge, having a steam-capstan of over 100 horse-power, which hauled on a heavy chain-cable fastened to the rocks on Blackwell's Island. Three powerful tug-boats assisted the dredge and would have been able to hold up the end of the pipe if the chain had broken. The pipe, as fitted in the box, was 1350 feet long and weighed over 200 tons. The river has a maximum depth of 100 feet where the pipe was laid.

In 1874 a 6-inch wrought-iron pipe, 1300 feet long, was laid in a similar manner to Ward's Island.

In 1876 a 6-inch wrought-iron pipe was laid across the Harlem River to Randall's Island.

In 1883 a 4-inch wrought-iron pipe was laid to North Brothers' Island.

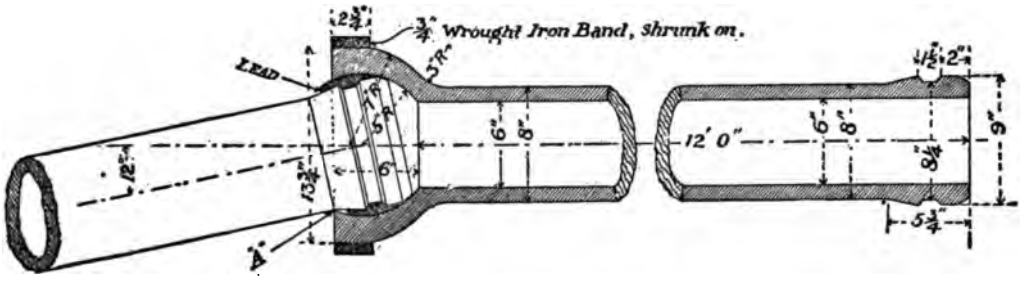


FIG. 20.—FLEXIBLE JOINT.

The wrought-iron pipes laid in the manner described above were found to be very expensive in first cost and difficult to maintain and repair. The last-mentioned pipe cost about $30,000, and lasted only three years, as the oak planking surrounding it was entirely eaten away by the teredo navalis. After many expensive and ineffectual attempts had been

FIG. 21.—LAYING PIPES TO BLACKWELL'S ISLAND.

made to have a diver repair this pipe, it was abandoned and replaced in 1888 by a line of 6-inch cast-iron pipes provided with improved flexible joints (see Fig. 20) made according to a design of Mr. James Duane, Assistant Engineer of the Department of Public Works, in charge of laying water-mains. The ordinary ball-and-socket joint for water-pipes breaks

frequently at the point *A* in Fig. 20. The improvement invented by Mr. Duane consists in shrinking a wrought-iron band around the hub, which is thus prevented from breaking.

The 6-inch cast-iron pipe, having more than double the capacity of a 4-inch pipe, was laid to North Brothers' Island for $16,000. At the point where it was placed the river is about 1700 feet wide and 90 feet deep, its bottom being very irregular. The tidal currents are very rapid and many boats are passing. The work of laying the pipe was completed in three days.

When tested under a pressure of 45 pounds per square inch, the leakage from the pipe was found to amount to only 0.3 cubic foot per minute. A year later, when the pipe was accepted, the leakage had diminished to 0.06 cubic foot per minute.

The pipes were laid from a scow (see Fig. 21), each joint being poured and calked before being lowered into the water. No diver was required in laying these pipes.

In 1888 a 6-inch cast-iron pipe was laid from Seventy-ninth Street to Blackwell's Island. In this instance flexible joints were used, but they were not reinforced by wrought-iron bands. The pipe-line proved a failure. It was replaced in 1890 by a line of 12-inch pipes, the hubs being strengthened according to Mr. Duane's design. This line has proved satisfactory in every respect.

One of the advantages of using flexible joints for pipes laid in water is the facility with which broken pipes can be replaced by hoisting the whole line above water at the place where the repairs are to be made. Trouble has been caused occasionally by the water freezing in the pipes near the surface of the river, but this can be avoided by maintaining a small flow through the pipe in very cold weather.

Waste of Water.—The reports of the Croton Aqueduct Department from 1849 to 1871 contain frequent complaints about the great waste of water, which the city authorities had unfortunately no legal power of checking. As long as the flow in the Croton Aqueduct could be increased, the demand for more water was satisfied by a greater delivery; but this simple process could not be continued when in 1875 the maximum safe discharge of the aqueduct (95,000,000 U. S. gallons per day) was reached.

The severe droughts of 1876 and 1877 (see page 90) induced the Commissioner of Public Works, the Hon. Allan Campbell, to investigate all possible means of increasing the city's water-supply and to take energetic measures to curtail the waste. The first practical step in the latter direction was the organization, in the fall of 1876, of a system of house inspection by competent experts, which led to the discovery and suppression of many leaks caused by defective plumbing. As private houses could not be entered at night, at which time during cold weather the greatest waste occurred from open faucets, the Department of Public Works tried in 1880 an apparatus for detecting this waste from the street, invented by Mr. B. S. Church, Resident Engineer in charge of the Croton Aqueduct.

The device consists of a specially constructed stop-cock which is placed in the service-pipe of a house, near the curb-line. The plug of the cock is turned by a small pipe which extends nearly to the sidewalk. During the inspection an ordinary pressure-gauge is attached to this pipe. When the plug of the stop-cock is turned so as to shut off the water from the house, the pressure in the street main is transmitted through suitable ports and ducts in the

shell and plug of the stop-cock, and through the small pipe to the gauge attached at its upper end. When the plug is turned so as to admit water to the house, the pressure in the service-pipe is transmitted to the gauge. It is evident that the pressure will be the same in both of the above cases when no water flows through the service-pipe, and that a difference in the pressures will occur the moment water is drawn in the house. By careful tests the difference in the pressure in the street-main and in the service-pipe may be made to indicate the quantity of water flowing into the house. A bill authorizing the use of this simple and effective contrivance was introduced in the Legislature of 1881, but failed to become a law.

Another instrument that was used by the Department of Public Works for determining whether water is flowing into a house is the waterphone, manufactured by the Bell Waterphone Company of Cincinnati, Ohio. It consists of a sound-receiver, somewhat similar to that of a telephone, which is held to the ear. An iron wire, which is attached to the sound-receiver at one end, is brought, at the other, in contact with the service-pipe. By this means the flowing of the water in the pipe can be heard, but no idea of the quantity is obtained.

To secure some proofs of the wilful waste that was occurring at night the Department of Public Works commenced in 1881 a system of inspecting the house connections in the sewers between midnight and six A.M. 426 examinations made in this manner in the fall of 1881 showed:

311 houses having a flow of water less than one gallon per minute;
102 houses having a flow of water of 1 to 5 gallons per minute;
11 houses having a flow of water of 6 to 15 gallons per minute;
2 houses having a flow of water of 30 gallons per minute.

The principal means of stopping the waste of water was the introduction of water-meters. The Croton Aqueduct Department commenced to supply meters as early as 1852. Full authority was given to the Department of Public Works by the laws of 1870 and 1873 to place meters in all stores, workshops, hotels, manufactories, public edifices, at wharves, ferry-houses, stables, and in all places in which water is furnished for business consumption, except private dwellings. A general application of meters, where permitted by law, was not commenced, however, until 1878. From that time on, the use of meters in the city increased rapidly, as will be seen from the following table:

WATER-METERS IN USE IN THE CITY OF NEW YORK.

Date.	Number of Meters.	Date.	Number of Meters.
Dec. 31, 1878	529	Dec. 31, 1887	16,452
Dec. 31, 1879	1,398	Dec. 31, 1888	17,811
Dec. 31, 1880	4,002	Dec. 31, 1889	19,170
Dec. 31, 1881	5,293	Dec. 31, 1890	21,072
Dec. 31, 1882	6,817	Dec. 31, 1891	23,064
Dec. 31, 1883	9,012	Dec. 31, 1892	25,441
Dec. 31, 1884	11,625	Dec. 31, 1893	28,286
Dec. 31, 1885	13,680	Dec. 31, 1894	30,328
Dec. 31, 1886	14,582		

The manner in which the meters were distributed by December 31, 1894, was as follows:

WATER-METERS IN USE DECEMBER 31, 1894.

Where Placed.	5/8"	3/4"	1"	1½"	2"	3"	4"	6"	Total.
Hotels	32	80	123	92	73	35	11	....	446
Breweries, bottlers, etc.	77	87	104	73	102	33	10	....	486
Charitable institutions	4	6	27	46	62	17	2	...	164
Offices	481	896	986	273	164	64	30	....	2,894
Manufacturing establishments	418	459	562	302	202	48	26	5	2,022
Gas-works	1	1	12	7	6	16	20	....	63
Railroads	11	121	98	30	20	23	41	8	352
Stables	667	894	581	169	64	7	1	....	2,383
Apartment-houses	44	68	167	146	135	15	4	....	579
Docks	31	30	17	7	37	56	44	1	223
Riverdale	60	38	13	2	1	1	....	2	117
Miscellaneous	6,914	6,287	5,251	1,301	688	128	24	6	20,599
Total	8,740	8,967	7,941	2,448	1,554	443	213	22	30,328

STYLES OF METERS IN USE DECEMBER 31, 1894.

Style of Meter.	5/8"	3/4"	1"	1½"	2"	3"	4"	6"	Total.
Gem	2	1	....	....	1	1	1	....	6
Crown	3,367	3,016	2,163	313	175	43	45	17	9,139
Worthington	619	2,380	2,571	1,445	955	302	109	1	8,382
Thomson	3,034	2,534	2,285	569	379	84	51	3	8,939
Nash	1,718	1,036	922	121	44	13	7	1	3,862
Total	8,740	8,967	7,941	2,448	1,554	443	213	22	30,328

As an example of the great saving in the use of water resulting from the application of water-meters, Commissioner Campbell gives in the report of the Department of Public Works for 1880 the following two cases:

One large hotel which on the first application of a meter was found to be consuming, or rather wasting, 115,000 gallons of water daily was reduced to 45,000 gallons, and another from 80,000 to 24,000 gallons per day. In the first case resort was had to the aid of a well, but in the second the saving was from stoppage of waste.

Prior to 1877 a great waste of water occurred along the river-fronts in supplying water to shipping, etc., as this service was given out for a fixed sum to contractors who were totally indifferent to how much water was wasted. When this license, which had existed for many years, expired in 1877, the Department of Public Works took this matter in its own hands and effected a great saving in the use of water.

Another source of loss of water along the river-fronts resulted from the cast-iron mains becoming corroded from the sea-water which penetrated the soil. The only method of stopping this loss consisted in renewing these pipes as rapidly as the annual appropriation permitted.

In spite of all the efforts of the Department of Public Works to stop waste, and notwithstanding the additional supply of about 15,000,000 gallons per day obtained in 1884 from the Bronx River, the rapid growth of New York made the task of supplying the city with water more difficult with every year. From 1885–1890 the increase of population was about 50,000 per annum, and each year water had to be furnished to about 30,000 new buildings.

The city's water-supply remained in a critical condition until the New Croton Aqueduct was brought into service in 1890 and increased the head of water twenty to twenty-five feet.

The following table shows the increase in the consumption of water from 1842, when it was first introduced, to 1895:

CONSUMPTION OF WATER IN NEW YORK CITY

FROM 1842, WHEN THE CROTON WATER WAS INTRODUCED, TO 1895.

Date.	Population. U. S. Census.	Average Daily Consumption. U. S. Gallons.	Date.	Population. U. S. Census.	Average Daily Consumption. U. S. Gallons.
1840	312,710	.....	1870	942,292	77,000,000
1842	.....	12,000,000	1875	.....	95,000,000
1850	515,547	40,000,000	1880	1,206,299	92,000,000
1855	.....	.....	1885	.....	100,000,000
1860	805,658	.....	1890	1,515,301	145,000,000
1865	.....	.....	1894	.....	183,000,000

CHAPTER VI.

THE CONSTRUCTION OF THE NEW CROTON AQUEDUCT.

Need of a New Aqueduct.—The necessity of constructing a new aqueduct from the Croton River to the city of New York was realized by the Department of Public Works as early as 1875, when preliminary surveys were made for that purpose. Owing to the condition of the city's finances, it was deemed unadvisable to construct the works at that time, and no further steps were taken in this matter until the severe droughts of 1880 and 1881 drew new attention to the inadequacy of the water-supply of the city.

On April 11, 1881, Mr. Isaac Newton, the Chief Engineer of the Croton Aqueduct, presented a special report on the subject of the water-supply to the Commissioner of Public Works, the Hon. Hubert O. Thompson. Mr. Newton stated that the Croton Aqueduct had been delivering for some years its maximum safe discharge of 95,000,000 U. S. gallons per day (corresponding to a depth of water in the conduit of 7 feet 5 inches). Since the supply had become stationary the population had increased twenty-five per cent, and the water consumption had augmented even in a greater proportion, as New York had become the largest manufacturing centre of the United States. To force a greater discharge through the aqueduct than the quantity mentioned might lead to disastrous results, as had been experienced when the flow had on one occasion been raised to 103,000,000 gallons per day. New works had been commenced on the Bronx River, but would only add about 15,000,000 gallons per day to the city's supply.

While New York was suffering from a scarcity of water millions of gallons were running to waste over the Croton Dam. Mr. Newton presented a table showing this wastage, from which he concluded that, with adequate storage and a conduit of sufficient capacity, at least 200,000,000 gallons could be delivered into the city even in the driest years. He urged that the construction of a new aqueduct from the Croton Valley, the only practical means of securing an ample supply of water for the city, be commenced at once.

The conclusions of Mr. Newton were indorsed by Mr. E. S. Chesbrough, the Consulting Engineer of the Department, who laid stress on "the great importance of beginning as soon as practicable the construction of a new aqueduct." What added greater urgency to this need was the fact that the old Croton Aqueduct, the only conduit supplying the city, was in many places in a dangerous condition owing to the strain to which it had been subjected.

Commissioner Thompson brought the recommendation of his engineers to the attention of the Mayor in the report of the Department of Public Works for the first quarter of 1881, promising soon to present detailed plans and estimates for a new aqueduct and the necessary storage reservoirs.

Plans Proposed by the Department of Public Works.—On February 23, 1882, Mr. Thompson submitted to the Mayor, the Hon. William R. Grace, a detailed report on the subject of the proposed new water-works, prepared by Chief Engineer Newton.

The plans recommended were as follows:

1st. To construct a high masonry dam across the Croton River near the "Quaker Bridge," about four and one-half miles below the old Croton Dam and five miles above the mouth of the river. The reservoir that would thus be formed was to have a surface of about 3635 acres, a storage capacity of 32,000,000,000 U. S. gallons, and to be supplied from a drainage area of 361 square miles (twenty-three square miles more than that of Croton Lake). This storage was estimated to insure a daily supply of 250,000,000 gallons, even in the driest weather on record.

2d. To build a circular aqueduct, 12 feet in diameter, having a maximum discharging capacity of 250,000,000 U. S. gallons per day, from the proposed reservoir to the city. The aqueduct was to be constructed almost entirely in tunnel, the Harlem River and Manhattan Valley being crossed by inverted siphons. Its length from a point near the proposed Quaker Bridge Dam to the receiving reservoir in Central Park was to be 31.89 miles. In order to excavate the aqueduct tunnel, thirty-five shafts, having an average depth of 100 feet, were to be sunk. The total cost of the new reservoir, aqueduct, four waste-weirs, and everything required for delivering the water in New York was estimated at $14,460,640, not including land or land damages, $4,000,000 of this amount being allowed for the cost of constructing the Quaker Bridge Dam and reservoir.

The Committee of Citizens.—The reports on the subject of a new aqueduct were sent by the Mayor to the Legislature, and caused the Senate to pass the following resolution on January 9, 1883:

"*Whereas*, With the return of business prosperity the rapidly increasing growth of the city of New York causes a constant increase in the complaints which have prevailed for years past, that by the insufficiency of the city's water-supply the people are deprived of the ordinary conveniences of domestic life, the public health is endangered, the security of property from fire is diminished, and the pursuit of commerce and manufactures is retarded; and

"*Whereas*, In a report dated February 22, 1882, the Commissioner of Public Works submitted to the Mayor of said city a plan for a new aqueduct, prepared by the Chief Engineer of the Croton Aqueduct and other eminent engineers; and

"*Whereas*, This body may be called upon to consider legislation to secure to said city an additional water-supply: Therefore

"*Resolved*, That the Mayor of the city of New York is hereby requested to select and appoint, within five days from the passage of this resolution, five citizens of said city, who, in conjunction with himself, shall, without delay, examine into the said plans, and report to this body within twenty days as to the practicability of the proposed plan, the probable cost, the time required for its execution, and such other views and recommendations as they may deem proper."

In compliance with this resolution the then Mayor of New York, Hon. Franklin Edson, appointed the following five gentlemen to assist him in investigating the proposed plans: Hon. Orlando B. Potter, John T. Agnew, William Dowd, Amos F. Eno, and Hugh N. Camp. After holding thirty-three public meetings, at which eminent engineers and citizens expressed their views with reference to the proposed works, the gentlemen mentioned above presented a report to the Senate on March 7, 1883, recommending unanimously:

1. That a circular aqueduct, 15 feet in diameter, be built at once, and also the storage-reservoirs required for insuring a daily supply of 250,000,000 gallons (the minimum yield of the Croton watershed above the proposed Quaker Bridge Dam).

2d. That the execution of the works be entrusted to an unprejudiced commission selected from the best citizens of the city.

In connection with this report the committee submitted a draft of a bill embodying the above recommendations, which formed the basis of "An Act to provide new reservoirs, dams, and a new aqueduct, with the appurtenances thereto, for the purpose of supplying the city of New York with an increased supply of pure and wholesome water" (chapter 490 of the Laws of 1883), which was passed by the Legislature on June 1, 1883.

The Aqueduct Commission.—The Act provided that the construction of the new works was to be entrusted to a Board of Aqueduct Commissioners consisting of the Mayor, the Comptroller, the Commissioner of Public Works, *ex officio*, and of the following three citizens: James C. Spencer, George W. Lane, and William Dowd. The salary of each of the citizen Commissioners was fixed by the Board of Estimate and Apportionment at $8000 per annum.

The first officials who became members of the Aqueduct Commission were: Hon. Franklin Edson, Mayor; Hon. Allan Campbell, Comptroller; Hon. Hubert O. Thompson, Commissioner of Public Works. Before the Commission commenced its work Mr. Campbell resigned (on July 27, 1883) from the position of Comptroller and was succeeded by S. Hastings Grant. Owing to the absence of Mr. Lane, who was in Europe when he was appointed Aqueduct Commissioner, the Board was not fully organized until August 8, 1883, when the first regular meeting was held at the Mayor's office. On this occasion the Mayor was elected President of the Aqueduct Commission, and Mr. Dowd Vice-President. Mr. James W. McCulloh, who had had large experience in business and in the construction of public works, was appointed Secretary of the Board.

The Aqueduct Commissioners entered at once upon their duties of constructing the new aqueduct and storage reservoirs. On December 30, 1883, Commissioner Lane died. The vacancy thus caused in the Aqueduct Board was filled by Governor Cleveland appointing Mr. Christopher C. Baldwin as Mr. Lane's successor.

During the fall of 1883 and the whole of the year of 1884 the Aqueduct Commissioners were occupied in locating the line of the new conduit, preparing the plans for the construction, obtaining the necessary land, and holding public meetings for the consideration of the plans, in accordance with the law.

The three *ex-officio* Commissioners mentioned above were succeeded on January 1,

1885, by Hon. Wm. R. Grace, Mayor; Edward V. Loew, Comptroller; and Rollin M. Squire, Commissioner of Public Works. The composition of the Aqueduct Commission was changed by an Act of the Legislature (chapter 337 of the Laws of 1886, amending chapter 490 of the Laws of 1883), passed May 13, 1886, which removed the Mayor and the Comptroller from the Commission and appointed in their stead Oliver W. Barnes, Edgar L. Ridgway, and Hamilton Fish, Jr. The Aqueduct Commission consisted, therefore, under the above law, of the Commissioner of Public Works *ex officio*, and of six citizen Commissioners, whose salaries were fixed at $5000 per annum.

The first meeting of the newly organized Commission was held on May 19, 1886. Hon. James C. Spencer was elected President and Mr. William Dowd Vice-President of the Board. Mr. James W. McCulloh was assigned to duty as Special Assistant to the Chief Engineer, and Mr. John C. Sheehan was appointed Secretary of the Commission.

The work of constructing the new aqueduct was continued by the new Commissioners until the Board was changed once more by an Act of the Legislature, passed on July 23, 1888 (chapter 584 of the Laws of 1888). According to this Law the Aqueduct Commission was to be composed of the Mayor, the Comptroller, the Commissioner of Public Works, and of four citizens appointed by the Mayor.

The first Aqueduct Commissioners under this new law were:

Abram S. Hewitt	Mayor.
Theodore W. Myers	Comptroller.
John Newton	Commissioner of Public Works.
James C. Duane.	Aqueduct Commissioner.
John J. Tucker	" "
Francis M. Scott	" "
Walter Howe	" "

The Commissioners elected Gen. Duane President and Mr. Tucker Vice-President of the Board. On August 22, 1890, Commissioner Howe died. He was succeeded by the Hon. H. W. Cannon, who was duly appointed by Mayor Grant. No other changes have occurred in the composition of the Aqueduct Commission up to the present time, except those due to the election of new city officials.

The *ex-officio* members of the Commission who succeeded those mentioned above to January 1, 1895, were:

Hugh J. Grant, Mayor	1889–1893.
Thomas F. Gilroy, Mayor	1893–1895.
Ashbel P. Fitch, Comptroller	1894–
D. Lowber Smith, * Commissioner of Public Works	1888–1889.
Thomas F. Gilroy, Commissioner of Public Works	1889–1893.
Michael T. Daly, Commissioner of Public Works	1893–1895.

* Mr. D. Lowber Smith succeeded Gen. John Newton, who resigned as Commissioner of Public Works in November 1888.

Mr. John C. Sheehan resigned as Secretary of the Aqueduct Commission on February 29, 1892, and was succeeded by Mr. J. C. Lully. Upon the death of the latter, which occurred on March 6, 1894, Mr. Edward L. Allen was appointed Secretary of the Board.

Plans for the New Aqueduct and Reservoirs.—According to the provisions of the Aqueduct Act (chapter 490 of the Laws of 1883), the surveys and plans for the new works were to be made by the Department of Public Works and to be submitted to the Aqueduct Commissioners, who were to approve, modify, or reject them, as they might deem proper. At their first regular meeting the Aqueduct Commissioners passed the following resolution:

"*Resolved*, That the Commissioner of Public Works be, and he is hereby, requested to submit to the Aqueduct Commissioners, as soon as practicable, a plan or plans, together with maps, specifications, estimates, and particulars, for the construction of a new aqueduct and dams and reservoirs and their appurtenances, as contemplated, set forth, and described in section 2 of chapter 490 of the Act of the Legislature of the State of New York entitled 'An Act to provide new reservoirs, dams, and a new aqueduct, with the appurtenances thereto, for the purpose of supplying the city of New York with an increased supply of pure and wholesome water;' and the said Commissioner of Public Works is hereby directed to include, set forth, and embody in said plan or plans:

"1st. Such a system or systems of water-supply as will, when perfected, secure all the water that can be obtained from the Croton Lake and River, and its tributaries, for the use of the city of New York, with a proper and suitable aqueduct and reservoirs for the same; to the end that an increased storage and supply of water can be provided for the present aqueduct, at the earliest time practicable; and for the new aqueduct to be constructed at an early day.

"2d. A plan for the immediate construction of the reservoir, or reservoirs, and dams, for the storage and retention of the water of the east branch of the Croton River and its tributaries, at a point near Brewster's Station, and known to said Commissioner and the Engineer of the Department of Public Works as the 'Sodom Reservoir.'

"3d. A plan and surveys and maps of the proposed line of the aqueduct that will provide for two routes or lines in the northerly portion thereof: one of which will reach or terminate at the Croton River, below the Croton Dam, and near the proposed site of a dam known as the 'Quaker Bridge Dam;' and the other route to reach or terminate at the Croton Dam, and near, yet above, the terminus of the present aqueduct."

In response to this request Hon. Hubert O. Thompson, Commissioner of Public Works, submitted at once a report, with maps, plans, and exhibits, which he had prepared. The plans recommended were those proposed by Chief Engineer Newton, mentioned on page 109. They involved the construction of a large storage reservoir as near the mouth of the Croton River as practicable, and of an aqueduct-tunnel for conveying the water to the city.

The reasons given by Commissioner Thompson for recommending the construction of one large reservoir instead of a number of smaller ones on the branches and tributaries of the Croton were:

1st. The proposed Quaker Bridge Dam, four and one half miles below Croton Lake, would add twenty-three square miles to the watershed supplying the city.

2d. The Quaker Bridge Reservoir would cost only $125 per million gallons stored, while the cost of the smaller reservoirs had been estimated at $200 per million gallons.

3d. It would be more expensive to maintain and guard a number of small reservoirs than one large one.

4th. The land to be flooded by the Quaker Bridge Reservoir was sterile, while that in the upper valleys of the Croton and its tributaries was largely arable and under cultivation.

5th. The deep settling basin which would be formed by the Quaker Bridge Dam was considered very advantageous.

6th. By constructing a reservoir near the mouth of the Croton River the difficulty which had frequently been experienced of conveying water in cold weather through miles of swamp and shallow streams would be avoided.

With reference to the plan of constructing the aqueduct almost entirely in tunnel, Mr. Thompson thought that the great expense involved in tunnelling would be largely offset by the shortness of the line which might thus be obtained, and by the low land damages resulting from this method of construction.

Mr. Thompson stated that the plans presented for the new reservoir and aqueduct were "the result of the steady work for over two years of Mr. Isaac Newton, Chief Engineer of the Croton Aqueduct, aided by the regular Consulting Engineer of the Department of Public Works, Mr. E. S. Chesbrough, who built the first aqueduct for the city of Boston, and the Chicago tunnel; by Mr. B. S. Church, for twenty-six years Resident Engineer in charge of the Croton Aqueduct, and also at the time, Consulting Engineer; by Mr. Julius W. Adams, the accomplished engineer of forty years' experience on water-works, and other large engineering enterprises; and by the staff of able assistants connected with the Croton Bureau."

In addition to the gentlemen mentioned, the following prominent engineers were consulted after the plans had been matured, and approved fully of the same, viz.: Mr. John B. Jervis, the designer and builder of the old Croton Aqueduct; General George S. Greene, who had constructed the large reservoir in Central Park and the Boyd's Corners Reservoir, and had been Chief Engineer of the Croton Aqueduct for several years; Mr. James B. Francis, the eminent hydraulic engineer; and Mr. Robert K. Martin, the constructor of the Baltimore Aqueduct tunnel and water-works.

All the distinguished engineers mentioned above recommended the construction of the Quaker Bridge Reservoir as the best means of making the whole yield of the Croton watershed available. The plans proposed by Commissioner Thompson were, therefore, indorsed by engineers of the highest standing in the profession. The report of Commissioner Thompson was accepted by the Aqueduct Commissioners, subject to future modifications.

As the work advanced the Department of Public Works made further surveys and general plans for the Aqueduct Commission as required by law. To avoid delays, however, most of the details of the new work were designed by the engineers of the Aqueduct Commis-

sion, in consultation with those of the Department of Public Works. These plans were then accepted by the Department of Public Works and submitted to the Aqueduct Commissioners for their final approval.

The most important modifications made by the Aqueduct Commissioners in the plans originally submitted by the Department of Public Works were as follows:

1st. The location of the aqueduct from its inlet to Yonkers was changed from a line commencing at the proposed Quaker Bridge Dam and following the Hudson River, to an inner line beginning at Croton Lake and following the valley of the Sawmill River. This was done to make it possible to draw water from the present Croton Lake through the new aqueduct, and to avoid the great expenses for land damages which would have resulted from constructing a tunnel through the valuable property along the Hudson River.

2d. It was decided to construct a large receiving reservoir at Jerome Park, in the Annexed District of the city of New York.

3d. The capacity of the aqueduct from Croton Lake to a point near the proposed Jerome Park reservoir (Station 1268 + 20—see Plate 54) was increased to that of a circular conduit of fourteen feet interior diameter (viz., 300,000,000 U. S. gallons per day.) From the point just mentioned to the terminus on Manhattan Island the capacity of the aqueduct was reduced to 250,000,000 U. S. gallons per day, as part of the water conveyed to Jerome Park was to be consumed in the Annexed District.

4th. The cross-section of the conduit from Croton Lake to Station 1268 + 20, near Jerome Park, was changed from a circular form to the "horse-shoe section" shown on Plate 60, with a view of facilitating and expediting the construction (see page 126).

5th. The grade-line for the above portion of the aqueduct was raised ten feet higher than established in the original plans. While this change involved a loss of storage capacity in the proposed Quaker Bridge reservoir of about 2,800,000,000 U. S. gallons, it effected a saving in construction of about a million dollars (see page 187).

Public Meetings.—Before the plans could be carried out the Commissioners were required by the Aqueduct Law to hold public meetings, after giving due notice of the same by advertisements in prominent newspapers, at which meetings all persons interested were to be given a full opportunity to be heard with reference to such plans. In accordance with this requirement the Aqueduct Commissioners held many public meetings (especially during 1883 and 1884, when the plans for the new aqueduct were being matured), at which prominent engineers and other citizens appeared and expressed their views with reference to the adoption of the proposed plans. While the public were thus given ample opportunity of criticising the plans, and much valuable information was brought out by this free discussion, the final responsibility of adopting the plans remained with the Aqueduct Commission.

The Construction of the New Aqueduct was commenced in January 1885. All the work was done by contract. The aqueduct was divided from Croton Lake to the Central Park receiving reservoir into seventeen sections, the work on each being let in a separate contract. Details of all the principal contracts awarded by the Aqueduct Commissioners, both for the aqueduct and for the new reservoirs, are given in the table on page 286.

By July 15, 1890, the work was sufficiently advanced to let the water flow through the new aqueduct from Croton Lake to the Central Park reservoir. The work was practically completed by June 24, 1891, on which day the aqueduct and its appurtenances (excepting some unfinished work on the surface) were turned over to the Department of Public Works and were put into service.

Having completed the new aqueduct and removed the danger of an interruption of the water-supply, which threatened New York on account of the dangerous condition of the old aqueduct at certain points, the Aqueduct Commissioners pushed the work of obtaining additional storage. The construction of a reservoir on the east branch of the Croton River was commenced in 1888. Contracts for two additional storage basins, one to be formed on the Titicus River, near Purdy's, and the other on the west branch of the Croton, near Carmel, were let respectively on February 18 and September 19, 1890.

The east-branch reservoir consists of two storage basins: **The Sodom and Bog Brook Reservoirs.** The former was practically completed and put into use by July 25, 1891, and the latter by March 25, 1892. The Titicus reservoir was practically finished by January 1, 1895. During the winter of 1895–1896 the Carmel reservoir will be ready for service.

The construction of a large reservoir on the lower Croton, which had been delayed by the opposition this project encountered at the public meetings, was finally determined upon by the Commission on January 22, 1891. The contract for the new Croton Dam, which is to form this reservoir and which is located about 1¼ miles above the site at the Quaker Bridge proposed originally, was awarded on August 26, 1892, to James S. Coleman. The progress that has been made up to January 1, 1895, in constructing this work is described on page 208.

When the new reservoirs commenced by the Aqueduct Commissioners and the reservoir on the Muscoot River, which is being constructed by the Department of Public Works near Amawalk, are completed, the capacity of the storage reservoirs in the Croton watershed, which amounted to 7,000,000,000 U. S. gallons in 1883, when the Aqueduct Commission commenced its work, will be increased to about 71,000,000,000 U. S. gallons.

In addition to the storage reservoirs in the Croton watershed, the Aqueduct Commission had plans prepared for an additional receiving reservoir within the limits of the city, viz., at Jerome Park (see page 209). The contract for this work was let on August 23, 1895, to John B. McDonald.

Works of the magnitude of those described above are never carried on without many casualties. During the construction of the new aqueduct ninety-two lives were lost and one hundred and fifty-five men were injured. In building the dams nine lives were lost and three men injured, up to January 1, 1895.

The New Aqueduct consists of three parts:

1st. A masonry conduit, "not under pressure," from the Inlet Gate-house at Croton Lake to a point near Mosholu Avenue, in the Annexed District of New York,* where a receiving reservoir of 1,900,000,000 U. S. gallons is to be constructed at Jerome Park.

* The part of the city north of the Harlem River.

This portion of the aqueduct, with the exception of a siphon under Gould's Swamp, 14 feet 3 inches diameter and 1135 feet long (see Plate 54), has the "horse-shoe" cross-section shown on Plate 60, and a uniform grade of 0.7 foot per mile. It is not subjected to pressure, except in the siphon just mentioned.

2d. A masonry conduit, "under pressure," from Mosholu Avenue to the gate-house on Manhattan Island at One Hundred and Thirty-fifth Street and Convent Avenue. This portion of the aqueduct forms a long inverted siphon. Its cross-section is circular, the inner diameter being 12 feet 3 inches, except in the tunnel under the Harlem River, where it was reduced to 10½ feet, for the reason stated on page 184.

3d. A pipe-line from the One Hundred and Thirty-fifth Street gate-house to a terminal gate-house at the Central Park receiving reservoir. Eight lines of 48-inch cast-iron mains are laid from One Hundred and Thirty-fifth Street to One Hundred and Twenty-fifth Street. Four lines are continued to the Central Park reservoir at Ninety-seventh Street, and the other four were connected at different points with the distributing pipe-system of the city.

The lengths of the above portions of the aqueduct are:

Masonry conduit not under pressure, except in the siphon under Gould's Swamp	23.92 miles
Masonry conduit under pressure	6.83 "
Pipe-line, One Hundred and Thirty-fifth Street to Central Park receiving reservoir	2.35 "
Total length	33.10 miles

The aqueduct was constructed from the inlet gate-house at Croton Lake to the One Hundred and Thirty-fifth Street gate-house below the surface of the ground, $29\frac{63}{100}$ miles in tunnel and $1\frac{12}{100}$ miles in open cut.

The capacity of the aqueduct from Croton Lake to Mosholu Avenue, in the Annexed District, was made equal to that of a circular masonry conduit having an internal diameter of 14 feet; viz., on the given grade, about 300,000,000 U. S. gallons in twenty-four hours. As part of the water is to be left in the proposed reservoir at Jerome Park to supply the Annexed District, the capacity of the aqueduct from Mosholu Avenue to the Central Park reservoir was reduced to 250,000,000 U. S. gallons per twenty-four hours.

Location and Grades (see Plate 54).—The new aqueduct begins at an inlet gate-house built near the old Croton Dam. From here a masonry conduit, constructed in tunnel or open cut, conveys the water to a gate-house built on Manhattan Island at One Hundred and Thirty-fifth Street and Convent Avenue (near Tenth Avenue). The location of the conduit from the inlet follows a southerly direction along Pocantico River, Sawmill River, and Tibbitt's Brook to a point on the Harlem River near High Bridge, where the line deflects to the west for the crossing of the Harlem River, which is effected by a tunnel located about 300 feet below high water. The tunnel turns into Tenth Avenue* near One Hundred and Seventy-ninth Street and continues under said avenue to a point near One Hundred and Fifty-

* Now called "Amsterdam Avenue" above Fifty-ninth Street.

second Street, where it was brought by means of a reverse curve of 350 feet radius into Convent Avenue (350 feet east of Tenth Avenue) in order to avoid blasting under the old aqueduct built in Tenth Avenue from One Hundred and Fifty-second Street to One Hundred and Thirty-fifth Street.

The tunnel follows the line of Convent Avenue to the gate-house at One Hundred and Thirty-fifth Street, where it terminates. From here the water is conveyed by eight lines of 48-inch mains, as already stated.

The Grades (see Plate 54).—The aqueduct commences at the new Croton gate-house, with its invert at elevation 140,* 26 feet below the crest of the overflow of the old Croton Dam and 60 feet below the high-water mark of the new Croton reservoir now being constructed. For the first 23.93 miles, from the beginning to a point near Shaft 20, the grade of the aqueduct descends uniformly 0.7 foot per mile, except for the length of 1135 feet near Tarrytown, where an inverted siphon was constructed under Gould's Swamp.

If the aqueduct had been continued south of shaft 20 on the former grade it would have been near or above the surface on very valuable property in the Annexed District of New York. To avoid heavy land damages, the aqueduct was depressed, near shaft 20, 115.64 feet by an incline having a 10-per-cent grade, and continued on a grade of 0.7 foot per mile to a point within 1100 feet of the Harlem River. Here the aqueduct was lowered 127.5 feet by a second incline, having a 15-per-cent grade, in order to reach the level at which the tunnel was to be driven under the Harlem River. The attempt of tunnelling under the river at this level had to be abandoned (see page 160), and the aqueduct was therefore lowered 172 feet by means of a short tunnel and a vertical shaft, sunk in the tunnel as a continuation of shaft 24, but located about 35 feet from its axis.

The tunnel under the Harlem River was constructed about 300 feet below high water, on a one-per-cent grade, descending towards Manhattan Island to shaft 25, where the invert grade of the conduit is — 307.50. A vertical well 12 feet 3 inches in diameter continues the aqueduct up shaft 25 to the conduit on Manhattan Island, which begins with an invert grade of 13.50 and ascends towards the One Hundred and Thirty-fifth Street gate-house at the uniform rate of .065 foot in 100.

At a point near this gate-house the aqueduct rises 26.30 feet on a 15-per-cent grade and then vertically to the main water-chamber of the gate-house.

From the One Hundred and Thirty-fifth Street gate-house the water is conveyed by mains which follow generally the grades of the streets and avenues in which they are laid, the pipes being placed at a depth which insures a covering of earth of at least four feet. Some exceptions to this rule for special reasons will be explained later on.

Available Head.—The invert of the aqueduct at the inlet gate-house at Croton Lake is at elevation 140.00. The maximum discharge will occur when the water in the conduit has a depth of 12.86 feet (see page 178). The high-water mark in the Central Park receiving

* The elevations for the old and the new aqueducts refer to Croton datum, which is mean tide at Sing Sing.

reservoir being at elevation 119.16, the total amount of available head, when the aqueduct has its maximum discharge and the receiving reservoir is full, amounts to 33.70 feet. The manner in which this "head" is distributed on the different parts of the aqueduct is explained on page 184.

The Geological Formations through which the aqueduct tunnel and cuts had to be excavated consisted principally of gneiss. This rock varied very much in quality, being in some places like granite and in others like mica-schist. It contained frequently soft seams of talc, clay, etc., and was occasionally decomposed, forming sand. The general strike of the rock was about N. 20° E., and its dip 20°–85° E.

At two places limestone was found, viz.: 1st. From a point near the crossing of the Sawmill River for about eight thousand feet south. Where the limestone terminated and the gneiss began, the two formations were found to be mixed, without any definite line of separation. 2d. In the tunnel under the Harlem River. Here the dividing line between the limestone and the gneiss was clearly marked. The strike of the limestone was about N. 46° E., and its dip 60°–70° S.E.

Some pockets of soft material (clay, sand, gravel, and decomposed rock) were encountered in the limestone formation. The greatest difficulties in the construction of the new aqueduct were met in driving the tunnel through these pockets.

No interesting specimens of minerals were found in excavating the aqueduct, except some fine fibrous asbestos in the tunnel under the Harlem River.

The material passed through from the Croton gate-house to the terminus of the aqueduct on Manhattan Island, at One Hundred and Thirty-fifth Street and Convent Avenue, is given in the table on page 119.

Open Cuts.—The aqueduct was constructed from Croton Lake to the terminal gate-house at One Hundred and Thirty-fifth Street, on Manhattan Island (a distance of 29.75 miles) in tunnel, with the exception of 1.12 miles of open trenches at the following four places (see Plate 54):

Cut.	Average Depth of Cutting. Feet.	Length. Feet.
Crossing of the Pocantico River	41	812
Pocantico blow-off Gate-house	24	1314
Crossing of the sawmill river	33	123
Ardsley	42	459
South Yonkers	20	3216
Total		5924

No part of the new aqueduct was constructed on embankments.

Shafts.—To excavate the aqueduct tunnel thirty shafts, giving sixty working "headings," were sunk originally. During the progress of the work ten additional shafts were excavated to expedite the construction. Two inclines, known respectively as shaft 0 and shaft 19¾, were also driven to reach the aqueduct tunnel. The working points of the

PLATE 15.

PEN [illegible] AT SAWKILL RIVER.

[illegible]

PLATE 16.

HEAD-HOUSE FOR SHAFT 29.

SINKING SHAFT 25.

GEOLOGICAL FORMATIONS THROUGH WHICH THE AQUEDUCT TUNNEL AND CUTS WERE EXCAVATED (COMMENCING AT CROTON GATE-HOUSE).

Character of Material.	Terminating at Station	Lineal Feet.	Miles.
Gneiss having occasionally soft seams of talc, clay, decomposed rock, etc.	727 + 00	72179	13.67
Sand, clay, gravel, and boulders	734 + 60	760	.14
Limestone more or less integrated	744 + 40	980	.19
Hard limestone	777 + 44	3304	.63
Disintegrated limestone	778 + 08	64	.01
Clay and quicksand	779 + 18	110	.02
Disintegrated and fissured limestone	779 + 81	63	.01
Hard limestone with occasional fissures containing clay and sand	800 + 06	2025	.38
Soft, disintegrated limestone	801 + 70	164	.03
Soft gneiss with seams of clay and talc	806 + 96	526	.10
Decomposed gneiss and compact clay	807 + 86	90	.02
Decomposed limestone with seams of clay and sand	808 + 46	60	.01
Compact clay and sand	809 + 10	64	.01
Limestone and gneiss mixed	814 + 37	527	.10
Compact gneiss, occasionally soft and blocky	1066 + 30	25193	4.77
Soft gneiss and sand	1067 + 63	133	.03
Sand	1068 + 99	136	03
Sand and soft gneiss	1070 + 05	106	.02
Hard gneiss	1109 + 15	3910	.74
Hard gneiss and earth (Yonkers cut)	1144 + 50	3535	.67
Gneiss, disintegrated and blocky, having soft seams	1200 + 97	5647	1 07
Hard gneiss	1238 + 64	3767	.71
Gneiss, blocky and seamy	1242 + 16	352	.07
Decomposed gneiss and sand	1250 + 62	846	.16
Soft gneiss, sand, and gravel	1256 + 03	541	.10
Decomposed gneiss	1269 + 44	1341	.25
Seamy and loose gneiss	1284 + 16	1472	.28
Hard gneiss, occasionally seamy and blocky	1490 + 70	20654	3.91
Hard limestone	1499 + 50	880	.17
Hard gneiss, occasionally with soft seams	1629 + 00	12950	2.45
		162379	30.75

aqueduct, shafts, inclines, and open cuts, were numbered consecutively from north to south. In a few cases, where the shafts were near each other, they were designated by a number and a letter, as shaft 11A, shaft 11B, etc. The additional shafts were designated either by a number and a letter, as shaft 11C, etc., or by a number and a fraction, as shaft 19½, 19⅔, etc.

Shaft 0, at the Croton Lake, was really an incline, driven on a grade of about 12 feet in 100. It was 6 feet high and 12 feet wide. The most southerly shaft was No. 32, near the terminus of the aqueduct tunnel, at One Hundred and Thirty-fifth Street and Convent Avenue.

From Croton Lake to the Harlem River the shafts were generally located about 4000–7500 feet apart. At difficult points, as Gould's Swamp, the crossing of the Sawmill River, etc., the distance between shafts was reduced to 400–1200 feet. On Manhattan Island, where the shafts were sunk in the middle of the avenues, no property having to be acquired for the purpose, the shafts were about 1400–2700 feet apart. The average distance between all the working points of the tunnel (shafts, inclines, and portals at the cuts) was 3382 feet.

The depth of the shafts from the surface to the top of the tunnel varied from 21 to 391 feet, the average depth being 127 feet. The standard cross-section adopted for the shafts was

a rectangle 8 × 17½ feet in the clear of all timbers. This allowed ample room for two hoisting-cages (elevators), and also a space for a ladder-way and for the air-pipes, etc. The ladders were generally omitted by the contractors. Shaft 24, located on the east side of the Harlem River, was excavated 8 × 10 feet in the clear of all timbers, as it was practically only used for one heading. It was provided with one cage and with a ladder. Shaft 25, located on the west bank of the Harlem River, was excavated 16½ × 33 feet in the clear of all timbers, as it was to contain two wells, 12 feet 3 inches in diameter, one forming part of the aqueduct and the other serving as a pump-well for the bailing-buckets used in emptying the siphon under the Harlem River. A detailed description of this important shaft will be found on page 164. Shaft 26 (see page 121), which forms the overflow for the aqueduct on Manhattan Island, was excavated 16½ × 16½ feet in the clear of all timbers.

To facilitate the work of the engineers in giving line, the shafts, with the exceptions of Nos. 25 and 26, were located with the greater dimension of their cross-section parallel with the centre-line of the tunnel, and were placed to one side of the centre-line of the aqueduct, so that the wires suspended by the engineers for giving the alignment in the tunnel would just clear the timbers of the shaft. A space 15 inches wide was reserved for the wires, to avoid the necessity of stopping the cages while line was being given. The manner in which the shafts were located on the centre-line is shown in Fig. 50, page 175.

With very few exceptions the shafts had to be timbered from top to bottom, in order to sustain the sides of the excavation and to prevent stones from falling down. Frames of 12″ × 12″ hemlock were placed 3 to 6 feet apart, and supported either by "hitches" (steps) cut in the rock or by being suspended by iron bolts from the frames above. The "lagging" on the outside of the frames consisted of 3″ × 12″ planks. The space between the "lagging" and the rock was filled by cord-wood or loose stones carefully packed.

In some cases, especially in Shaft No. 2, the timbering consisted entirely of heavy frames, one placed above the other.

In good rock the shafts were sunk 50–100 feet before being timbered. In these cases the timbering was done from the bottom upwards, the lowest frame being well supported by "hitches." Plate 55 illustrates how the shafts were timbered. The weekly progress in sinking the shafts is given in the table on page 298.

With few exceptions, the shafts used during the construction of the work were lined with masonry after the aqueduct had been constructed, and made permanent places for entering the tunnel for inspection or repairs. They serve also as ventilators and as openings where the air can escape when the conduit is being filled, except on the lower part of the work, where they are subjected to water-pressure and had consequently to be closed by manhole-covers.

The manner in which the shafts not subjected to water-pressure were built up is shown in Plate 57. At the bottom of the shaft, a working-chamber having an elliptical cross-section (6 × 12 feet) was built just above the conduit, in the roof of which an opening 6 feet in diameter was left. At a height of 10–20 feet above the conduit the cross-section of the working-chamber was gradually reduced until at a height of 20–35

feet it was circular, the inner diameter being 6 feet. This cross-section was continued to the top.

The elliptical working-chamber was lined with 24 inches of brickwork, backed with rubble masonry to the sides of the shaft excavation. The circular part of the shaft was lined with 16 inches of brickwork, the space between the brickwork and the sides of the shaft excavation being packed with dry filling. About every 50 feet a brick arch, 24 inches thick, was built across the shaft excavation (an opening being left for the manhole-shaft) to carry the weight of the dry filling. A cast-iron ladder fastened to the brickwork was placed in each shaft, landings being provided at intervals of about 35 feet to enable the workmen to pass each other. Over eleven of the shafts masonry head-houses were constructed (see Plate 57), each being provided with a large sheave placed directly over the shaft for a hoisting-rope. The shafts "under pressure" were finished as shown on Plate 58.

Shaft 11C, at the south end of the siphon under Gould's Swamp, was built up so as to have a circular section 14 feet 3 inches in diameter, in order to provide sufficient room for lowering a pumping-apparatus into the tunnel for emptying the siphon should it become necessary. The shaft is closed with a special iron cover.

Two portable hoisting-plants were purchased and stored in brick engine-houses near the aqueduct, one at the Yonkers blowoff gate-house and the other at the Pocantico gate-house. Each plant consists of:

1st. A twenty-horse-power portable boiler.

2d. A hoisting-engine with the necessary rope and two iron buckets.

3d. A water-wagon.

4th. A truck large enough to carry 1½ tons of coal. It is provided with a chest containing necessary working tools, etc. The hoisting-plants are to be used whenever repairs may be required, and also to furnish the power for lowering and raising buckets for inspection, etc.

Shaft 26 (see Plate 59) near Tenth Avenue is the overflow-shaft for Manhattan Island. It is built up from the top of the tunnel to elevation 118.0 as a well, 12 feet 3 inches in diameter, lined with 16 inches of brickwork which is "backed" to the solid rock with rubble masonry. A cast-iron ladder, fastened to the brickwork, extends from the top to the bottom of the shaft. At elevation 118.0 the well is finished by a granite coping and covered by a strong brick vault, to which access is obtained from the street by means of two 5-foot manholes. Two sets of granite stones are built opposite each other in the walls of the vault, on the side of the well towards the Harlem River. In each set of stones is cut a groove (9 inches deep and 20 inches wide), into which a casting is fastened. A third casting is placed half-way between the two just mentioned. The castings have grooves for two sets of 6″ × 12″ stop-planks, between which a puddling of clay, 6 inches thick, is rammed. An overflow-dam, the height of which can be varied by means of the stop-planks, is thus formed. In front of this dam a small basin is constructed from which two 48-inch cast-iron pipes lead the overflowing water to the Harlem River. The aqueduct on Manhattan Island is thus protected from being exposed to any undue pressure.

At elevation 136 the vault has an iron flooring, made of "I" beams and cast-iron plates.

Tunnel.—The alignment and profile of the aqueduct tunnel are given on Plate 54. The depth of the tunnel below the surface of the ground varies from 50–500 feet. The tunnel under the Harlem River is about 300 feet below high tide. Where the aqueduct is less than fifty feet below the surface, the excavation was generally made in open cut.

The tunnels between the different shafts were excavated by driving first a "top heading" (upper half of tunnel) and removing then the "bench" (lower half of tunnel). The only exception to this method was a stretch of 2215 lineal feet on section 2, which was excavated by means of a bottom heading.

The heading and bench were usually excavated simultaneously, the latter being kept to within 50–75 feet of the former. The drilling was performed by means of percussion-drills operated by compressed air, supplied from compressors located on the surface, near the shafts. Dynamite, forcite powder, and other similar explosives were used for blasting, the firing being done by electricity. Some details of the manner and cost of excavating the tunnels are given in Chapter VII.

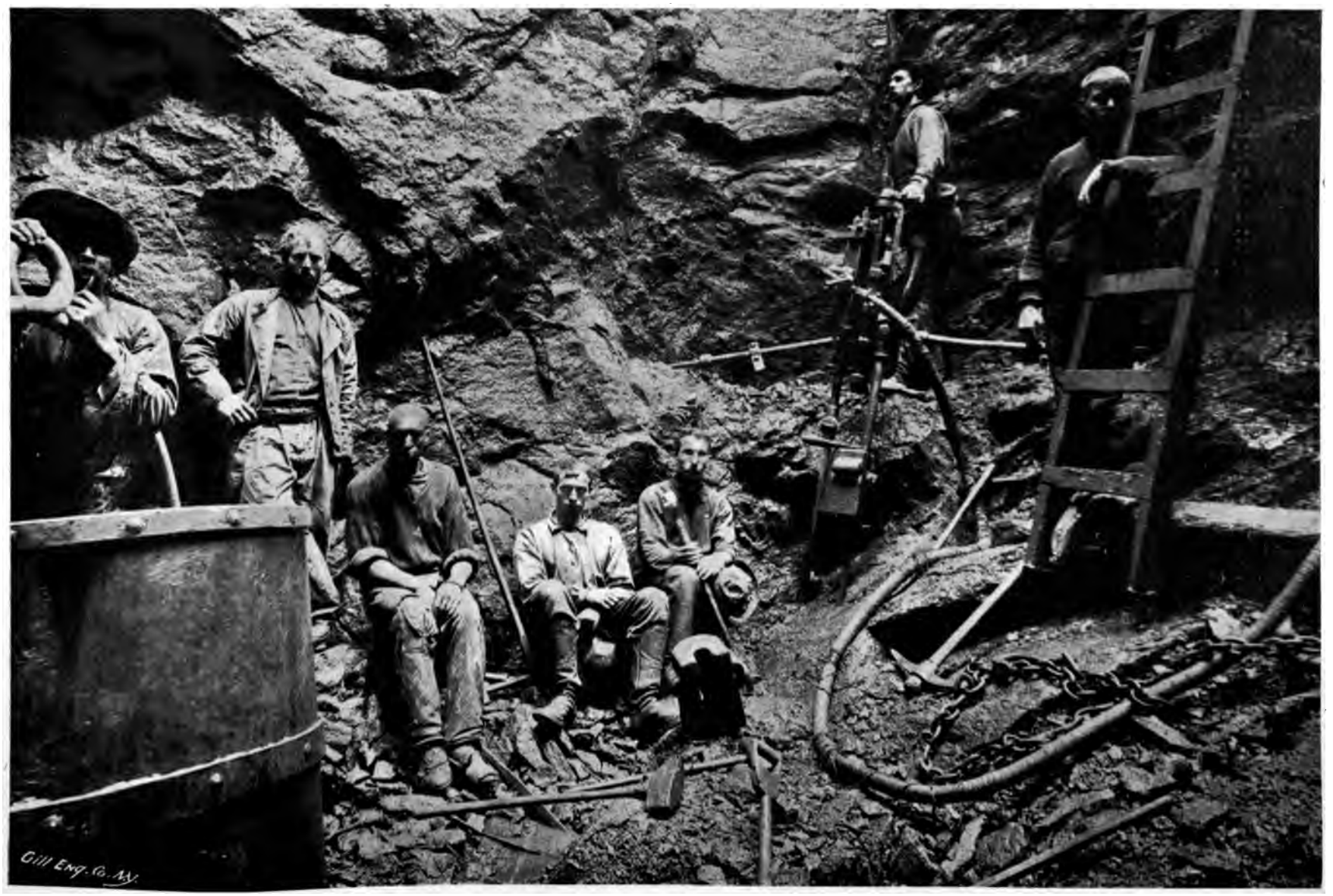
The material excavated ("muck") was removed in cars, which were hauled on tracks by mules, or, for short distances, shoved by hand to the shaft, where they were hoisted on "cages" (elevators) to the surface. Each car held about a cubic yard of broken stone. The muck was dumped near the shaft, the good stone being used subsequently for the rubble masonry in the tunnel and shafts. Plate 56 shows a shaft head-house, cage and cars.

In the heading the muck was generally removed in wheelbarrows and dumped from planks, supported by beams ("runners") placed across the tunnel, into the cars at the foot of the bench.

In some cases, after the tunnel had advanced a considerable distance from the shafts, the headings were driven alone to a meeting, the work on the bench being temporarily stopped. This was done with the twofold object of improving the ventilation in the tunnel (which was generally abominable) and of avoiding excavating the bench until the stones could be used for the rubble masonry. In these cases, an incline, about 400 feet long, was excavated from the heading to the bench, the tracks being laid in the heading as the excavation advanced. Stones to be used for rubble masonry were occasionally piled up on both sides of the tunnel. The tunnels were illuminated by electric lights, gasoline torches, miners, lamps, and, in laying the masonry in the top of the arches, by candles. In the early part of the work, gasoline torches, attached to the side of the tunnel, were used extensively. Each torch had a flat tin reservoir, which held about 3½ gallons of gasoline or naphtha, and had to be refilled every five hours. From the bottom of the reservoir a small gas-pipe extended downwards for about 2 feet and then horizontally for 10 inches, terminating in a burner. Three or four of these torches were used in the heading and six to eight for the masons.

The air in the tunnel became so vitiated by these lights that the Aqueduct Commissioners, after an investigation by experts, forbade their use in the tunnel. At times the smoke from these lamps made it impossible to see a light at a distance of 25 feet. In 1886 electric lights were introduced in all the tunnels, but as the lights were generally placed 500

PLATE 17.



SINKING SHAFT 26.

to 600 feet apart, except at points where work was in progress, the miners had to continue the use of their hat-lamps, in which miner's oil mixed with kerosene was burned.

Besides the nuisance from the smoke, the air in the heading was rendered foul by the gases from the dynamite, which remained in the tunnel for some time after a blast, and by the stone-dust from drilling the upper holes for the explosives dry. In some of the tunnels an attempt was made by the contractors to improve the ventilation by means of wooden flues into which jets of compressed air were admitted at intervals of 400–500 feet. The flues were laid on the floor of the tunnel. Their section, which varied from 10″ × 24″ to 18″ × 36″, was much too small for the desired object. As these flues were frequently injured by falling stones, etc., they were by no means air-tight and had, therefore, scarcely an appreciable effect in improving the ventilation.

On sections 6 to 11, inclusive, fans were used for exhausting the foul gases or for pumping good air into the tunnel, the latter method being generally adopted. Most of the fans were Baker blowers No. 4, 5, or 5½ (see page 222), one being placed at each shaft. A Sturtevant blower No. 6 (see page 223), arranged for "forcing" air, was used at shaft 18. An independent 10-H.P. steam-engine making about eighty revolutions per minute was required for driving a No. 4½ Baker blower. The air was conveyed to the tunnel through a spiral riveted, twelve-inch iron pipe, placed on one side of the tunnel, at about the spring-line of the arch. It was carried to within 100–200 feet of the point where the rock was being blasted.

According to the circular of the manufacturers a No. 4½ Baker blower is capable of delivering 16½ cubic feet of air per revolution. The capacity of the blowers was sufficient, but the contractors used them as sparingly as possible to avoid expense. At some of the shafts the only means adopted to improve the ventilation consisted in letting compressed air escape in the heading for a short time after each blast from the pipes supplying the drills. While this improved the air in the heading, it drove the foul gases to the bench, where they remained a considerable time.

Timbering in stretches of 10–500 feet was frequently required in excavating the tunnel to support the roof, where the rock was "blocky," or where soft seams of talc, clay, decomposed rock, etc., occurred. The amount of timbering on the different tunnel sections is given in the table on the following page.

The ordinary style of timbering adopted is shown on Plate 64. Frames consisting of a cap and two slanting legs, made generally of 12″ × 12″ hemlock, were placed from 2 to 5 feet apart in the heading. The legs rested on sills laid on the floor of the heading. As the bench was excavated, vertical posts bearing on the floor of the tunnel were put under the sills. On the outside of the frames a sheeting ("lagging") of planks (2–3 inches thick) was driven. The void spaces between the lagging and the sides of the tunnel were filled with cord-wood, stones, etc.

Instead of the frames described above, timber block-arches (see Fig. 39, page 157) consisting of five or seven segmental pieces were used in a few cases. This style of timbering was generally used in connection with the bar-timbering described below.

TIMBERING.

Section.	Length of Section in feet.	Timbering, Lineal Feet.	Percentage of Ground Timbered.
2	20,329	5400	26.5
3	19,550	3032	15.5
4	19,400	1196	6.2
5	8,900	420	4.7
6	7,000	2007	28.7
7	17,150	4139	24.1
8	14,650	3487	23.8
9	17,430	7519	43.1
10	12,300	6452	52.5
11	11,833	10	0.1
12	1,937	...	....
13	4,700	379	8.1
14	7,200	1008	14.0
Total	162,379	35,049	21.6

Long stretches of timbering were required at the following places.

LONG STRETCHES OF TIMBERING.

Station to Station.	Lineal Feet of Timbering.	Character of Ground.
1144 + 50 — 1200 + 97	5647	Disintegrated gneiss with earthy seams.
1238 + 64 — 1272 + 60	3396	352 feet in seamy gneiss. 3044 feet in decomposed gneiss and sand.
1338 + 56 — 1349 + 50	1094	Seamy and loose gneiss.

At the following four places where the ground was unusually heavy the tunnel was driven by the English system of crown-bars.

TUNNELS EXCAVATED BY THE CROWN-BAR SYSTEM.

Locality.	Station to Station.	Lineal Feet.	Character of Ground.
Crossing of Sawmill River	729 + 20 — 732 + 72	352	Sand, gravel, clay, and boulders.
South heading of shaft 13	778 + 05 — 779 + 19	114	Clay and quicksand.
South heading of shaft 17	1067 + 63 —1068 + 06	43	Sand.
South heading of shaft 30	1595 + 10 —1595 + 65	55	Seamy rock which had caved in.

In driving a tunnel by the bar-timber system (a method generally used only in soft ground) the masonry is completed as the excavation proceeds. A strong timber bulkhead is maintained in front of the masonry to keep the soft material from entering the tunnel. The system consists in forming an arch of crown-bars (logs 12–20 inches thick and 15–20 feet long) above the space required for the masonry. A small heading drift is carried at the top of the arch beyond the bulkhead mentioned above, and two strong crown-bars are placed, resting usually with one end on the completed masonry arch and the other on props in the small heading. The excavation is then widened by side-drifting, additional crown-bars being

placed until an arch of logs has been formed. A lagging of boards and small timber keeps the soft material in place. The crown-bars are supported by wooden block-arches or simply by timber frames, erected as the excavation proceeds. They are also braced by cross-timbers from one bar to the other (see Fig. 39, page 157).

After a section of the tunnel, about 15 feet long, has been excavated in this manner the masonry is built, the timbering being gradually removed wherever possible. In the usual system of bar-timbering the two top crown-bars are moved forward after a section of the masonry arch has been completed, and are used again. In constructing the aqueduct, however, these crown-bars were generally left in the masonry. The manner in which the bar system was applied in driving the tunnel through clay and quicksand in the south heading of shaft 13 is described on page 155.

In spite of the precautions taken in driving the aqueduct tunnel in treacherous ground, some heavy falls of rock occurred. On section 2 (near stations 106, 125, and 126) cases of this kind took place owing to diagonal seams of soft material. The timbering was knocked out for some distance and big cavities, extending 15 to 40 feet above the grade of the crown of the aqueduct, were formed in the roof. The cavities were filled to a certain height above the arch with solid rubble masonry and then with a packing of wood and stones.

Unusual difficulties were encountered in excavating the tunnel only at a few points, viz.:

In the south heading of shaft 13.....See page 152
In the north heading of shaft 14..... " " 158
In the south heading of shaft 17..... " " 158
In the south heading of shaft 30..... " " 161
In the tunnel under the Harlem River..... " " 159

The nature of the difficulties and the manner in which they were overcome are described in Chapter VII.

The Masonry Conduit.—The aqueduct tunnel and open trenches were lined throughout with masonry. According to the original plans, this lining was to be wholly or partially omitted wherever the nature of the rock permitted. It such cases the roughness of the wetted perimeter of the rock tunnel was considered to be offset by the increased area of water-channel. Although a considerable saving in the first cost of the aqueduct might have been effected by omitting the masonry lining in good rock, the Aqueduct Commissioners finally decided to line the whole aqueduct with masonry, in order to avoid possible falls of rock in the tunnel, which might lead to expensive repairs and a temporary interruption of the water-supply.

As stated on page 116, the first 23.92 miles of the conduit are not "subjected to pressure" except in an inverted siphon, 1135 feet long, under Gould's Swamp. The remaining 6.83 miles of the conduit form an inverted siphon, which is "under pressure."

The standard cross-section adopted for the masonry conduit "not under pressure" was the "horseshoe section" shown on Plate 60. It gives the aqueduct a capacity equal to

that of a circular conduit of fourteen feet inner diameter. This form was decided upon (although it cost about $3 per lineal foot more than an equivalent circular section) in order to facilitate and expedite the work. It provided more room for the tracks used during the construction of the acqueduct than a circular section, and made it possible to lay the invert (bottom) masonry last.

As the specifications required the contractors to keep the masonry within 200–500 feet of the heading of the tunnel, the last consideration was important. If the débris from the tunnel had been transported over the invert masonry, the latter might have been more or less injured.

The conduit "subjected to pressure" was made circular (see Plates 63 and 64). The inner diameter of the siphon under Gould's Swamp is 14 feet 3 inches. From Jerome Park to the One Hundred and Thirty-fifth Street gate-house the diameter is 12 feet 3 inches, except in the conduit under the Harlem River, where it was reduced to ten and one half feet.

In constructing the conduit according to the "horseshoe section" the water-channel was lined with brickwork varying in thickness from twelve to twenty-four inches for the sides and arch, and from eight to twenty-four inches for the invert, according to the inward pressure to be resisted. The junction of the invert and the side-walls was made by special bricks (see Plate 62).

A foundation of concrete or rubble was prepared for the brick invert. In a few places, however, where the bottom of the tunnel was in soft material, the conduit was built upon a timber foundation consisting of two courses of 12″ × 12″ oak or yellow-pine timbers.

The space between the sides and roof of the tunnel excavation and the brick lining was filled to the haunch of the arch with rubble masonry, and above this level with a "dry packing" of stones. The plans were modified during the construction of the aqueduct by carrying the rubble backing to a level of four feet above the crown of the intrados of the arch.

The ground-water draining into the tunnel was not excluded from the conduit, as it was of good quality. Small "weepers" (openings) placed about twenty feet apart, when required, permitted this water to flow into the aqueduct. About 4,000,000 U. S. gallons per day enter the conduit between Croton Lake and the Harlem River in this manner. No weepers were constructed in the conduit under pressure. Here the space between the sides and roof of the tunnel and the brick lining was filled with solid rubble masonry. The brickwork was made twelve to twenty inches thick, according to circumstances. The arch was plastered with mortar. Plate 64 shows some cross-sections adopted for the conduit in tunnels made in soft ground. The manner in which the aqueduct was built in open cuts is shown on Plate 61.

A special method of construction was used for 234 lineal feet in the south tunnel from shaft 30. Owing to a soft seam in the rock there was danger at this place of the water, which is under great pressure, finding its way to the surface of the ground. To make this impossible the conduit was provided with an inner lining of cast-iron plates (see Plate 104). A detailed description of this lining is given on page 164.

At the top of the inclines at shafts 11A and 19⅝ an iron grating is placed in the aqueduct

PLATE 18.

NEW CROTON GATE-HOUSE.

POCANTICO BLOW-OFF.

on the down-stream side of the shaft to prevent large floating bodies from entering the depressed portions of the aqueduct. The bars of the gratings can be removed by hand so as to provide a passage for inspection or repairs.

Gate-houses.—The following gate-houses were constructed in connection with the new aqueduct, viz.:

The Croton gate-house, the inlet to the aqueduct at Croton Lake.

The gate-house at One Hundred and Thirty-fifth Street and Convent Avenue (on Manhattan Island), the terminus of the conduit and the beginning of the pipe-line.

The Central Park gate-house, the terminus of the pipe-line at the large receiving reservoir in Central Park.

Three "overflow and blow-off gate-houses," located respectively at the Pocantico River, at Ardsley, and at South Yonkers.

The Croton Gate-house was constructed for controlling the inlet into the new and old aqueducts. It consists of a substructure of masonry (see Plates 65 to 72), containing the water-chambers, sluice-gates, etc., and of a substantial masonry building forming the superstructure (see Plate 18).

The gate-house was located on a rocky side-hill, south of the Croton River, about 250 feet below the old dam (see Plates 19 and 65). To provide the space required for the structure an area of about 90 by 100 feet had to be excavated to a depth of 90 to 160 feet. A large amount of rock had also to be removed from the slopes toward the hill. For the first one hundred feet from the surface this side of the excavation was sloped about 1/2 to 1, and for the remaining seventy feet about 1/8—1/4 to 1. The highest slope-stakes were about 210 feet above the bottom of the excavation. In preparing the site for the structure about 118,000 cubic yards of rock and 9000 cubic yards of earth were excavated.

The gate-house is provided (see Plates 65 and 66) with five different inlets, with a view of producing a circulation in the reservoir by drawing water from different points and depths. The by-pass inlet is situated in the southeast corner of the substructure, near the bottom. A circular masonry conduit (the by-pass), having an inner diameter of 14 feet and a length of 624 feet, connects it with the present Croton Lake. It is the only inlet that can be used until the new Croton reservoir now being constructed (see page 203) has been formed. The surface, middle, and bottom inlets are short circular conduits, serving to draw water at different elevations at the gate-house. The first enters the substructure above the by-pass inlet; the second and the third enter on the east side, the former being above the latter. Each of the four inlets described above has an inner diameter of 14 feet.

The by-pass can be closed at Croton Lake by means of a timber gate, 15 feet 8 inches square. It bears against a ring of aluminum bronze, about nine inches wide, which is made in segments and is bolted to the cut-stone facing of the inlet.

The surface, middle, and bottom inlets can each be closed by 12″ × 12″ stop-planks or a suitable drop-gate, placed in grooves, provided in a small chamber at the mouth of the inlet.

The fifth inlet (which has a diameter of only 8.5 feet) is situated on the north side of

the substructure. It is to be connected by a short circular conduit, of 8.5 feet interior diameter, with the old Croton Aqueduct, which is also to be connected with a small gate-house at the New Croton Dam. By this arrangement the fifth inlet will draw water from the lower end of the reservoir.

The new aqueduct begins at the southwest corner of the Croton gate-house, with the grade of its invert (bottom) at elevation 140 (sixty feet below the highest flow-line of the new reservoir and about twenty-six feet below the crest of the old Croton Dam). As the aqueduct is not to be subjected to pressure for the first twenty-three miles (see page 116), the "head" of the water flowing from the reservoir to the aqueduct is gradually reduced to the proper level by making the water pass through three or four sets of sluice-gates placed in the cross-walls of the building; the gates of each set being opened a little more than those of the preceding one.

The main walls and principal cross-walls divide the substructure into ten water-chambers and a pump-chamber. Brick cross-walls, having arched openings, are built in some of the water-chambers to strengthen the principal walls and to support the floor-beams. Most of the chambers are provided with a wrought-iron ladder, attached to the side-walls, and reaching from the bottom of the chamber to the floor of the building.

The water flowing through any one of the inlets passes first into a small chamber, which is gradually widened to make room for the first set of sluice-gates. At its entrance 12″ × 12″ vertical grooves are cut in the side-walls for stop-planks or drop-gates, made of wood and iron, by means of which the inlet can be closed.

The water flows through the first set of sluice-gates into a second chamber, and then through another set of sluices into the main water-chamber, which occupies a space of 30 × 28 feet at the bottom. From here the water passes through a third set of gates into a large chamber in the northwest corner of the building, where a curved side-wall turns the current at right angles to its former direction.

The water flows next through a fourth set of sluices into the screen-chamber, from which it passes through the screens into the aqueduct. The screens are made of No. 10 brass-wire netting (1/4-inch mesh or opening), fastened by brass screws to 4′ × 8′ oak frames. They were placed originally in an inclined position, but this arrangement was found to be disadvantageous, and the screens are therefore to be changed to a vertical position.

The screen-chamber has also a second set of gates, at right angles to the first (see Plate 66). By this arrangement water drawn from the by-pass or surface inlet can flow into the screen-chamber without passing through the main water-chamber. In this case, however, the head of the water has to be reduced by means of only three sets of sluice-gates.

The screen-chamber can be separated from the adjoining water-chambers by stop-planks, when required. For this purpose grooves (6 × 18 inches) are cut in the sides of the chamber, in front of the gates, to receive cast-iron beams which provide a double set of grooves for 6″ × 12″ stop-planks.

Grooves (12 × 12 inches) are also cut in the sides of the chamber having the curved side

and in its central pier, supporting the brick cross-walls. Stop-planks placed in these grooves serve to break the force of the current.

The bottom of all the water-chambers is paved with rectangular blocks of Connecticut red sandstone, eighteen inches deep. Below the paving inverted brick arches (24 to 44 inches thick, according to the span) are constructed on a concrete foundation, to resist any upward pressure which may exist when a chamber is emptied. The space between the arches and the paving was filled with concrete.

The main walls of the substructure are faced with cut stone (Sandy Hill dolomite) to elevation 200.83, and above this with brickwork to a 12-inch coping of granite.

According to the original plans the face-stones were to be "backed" with rectangular stones laid in regular courses corresponding to those of the facing. The horizontal joints of this backing were not to exceed 3/8″ in thickness, and the vertical joints to be less than two inches thick. Instead of this cut-stone backing, concrete was used up to elevation 200.83, and rubble above this level. The concrete was composed of one part Portland cement, two parts sand, and three parts stone. Between elevations 170 and 190, however, concrete mixed in the above proportion was used only to a certain thickness, in the outer walls, and was backed to the sides of the excavation by a cheaper kind of concrete composed of one part American cement, two parts sand, and five parts stone.

The mortar used for the cut stone and rubble was made with Portland cement, one part cement being mixed with two parts of sand.

The outer walls of the substructure are backed with concrete to the sides of the rock excavation to elevation 190. Above this level only a few anchor-walls (at right angles to the main walls) are built to the sides of the excavation, the space between these sides and the main walls being filled with earth and stone.

The brick cross-walls, which were built in some of the water-chambers, are 3 feet thick at the bottom and 2 feet at the top, the reduction in thickness being made by offsets.

The sluice-gates are made according to the design shown on Plates 96, 97, and 98. They all control openings of 3 × 6 feet in the cross-walls. Thirty-eight gates will be required when the new Croton reservoir has been completed. Only sixteen gates (all that are needed under the present circumstances) have thus far been placed.

The gate-openings are constructed a foot above the paving, except where six openings are provided in the walls of the main water-chamber. In these cases four gates are placed at the bottom and two 25 feet higher (see Plate 68).

At the south wall of the main water-chamber sluice-gates are to be placed on each side for the four lower sluice-openings.

In order to relieve the pressure on the first set of sluice gates, when the gate-house is empty (which will be due to 60 feet head when the new reservoir is completed), 12-inch iron pipes, controlled by stop-cocks, are placed in the first cross-wall of each inlet at elevation 167.5. By opening these pipes and letting water flow into the next chamber the pressure on the sluice-gates can be reduced to a maximum of about 33 feet.

The gates and their frames are made of cast iron, the wearing surface being lined with

strips of bronze. By means of adjustable wedges or inclines the gates can be made to close perfectly water-tight.

The stems for raising and lowering the sluices are made of bars of cold rolled steel, 3¼ inches in diameter, coupled together in lengths of 20 feet. At the upper end of each stem a screw 9 feet long is cut. The screw fits into a bronze nut, which is held between two collars and can be revolved by hand by a suitable arrangement of cranks and bevel-gear (see Plate 98). Plans and provisions have been made for operating the first banks of the sluice-gate by a turbine, by means of shafting, etc.

By a system of drain-pipes laid below the paving (see Plate 71) any one of the water-chambers, except those at the inlets and the screen-chamber, can be emptied independently of the others. The system can also be used for turning water from any one of these chambers into any other.

The drains are formed of 12-inch cast-iron pipes which commence at the water-chambers with elbows that can be closed by suitable covers, moved by means of long screw-rods from the floor of the superstructure. All the drains lead to a central drainage-well, which is connected by a 12-inch cast-iron pipe with the "sump" (well) of the pump-chamber. At the central well four of the drain-pipes are controlled by stop-cocks operated by stems (rods) from the floor of the superstructure. The stems are 2 inches in diameter at the top and 1⅝ inches at the bottom. They are made of bars, coupled together in lengths of 7 to 20 feet, and guided by brackets about 10 feet apart, fastened to the brickwork. The bars are made of steel, except those at the top, which are made of bronze and provided with a screw-thread. A bronze nut is fitted to the screw-end of each stem. The nut is held betwen two collars fastened to the floor, which prevent it from moving vertically. By revolving the nut, the stem and the gate attached at its lower end can be moved up and down.

The 12-inch drain-pipe leading to the sump in the pump-chamber has a stop-cock at the sump which is operated in a similar manner.

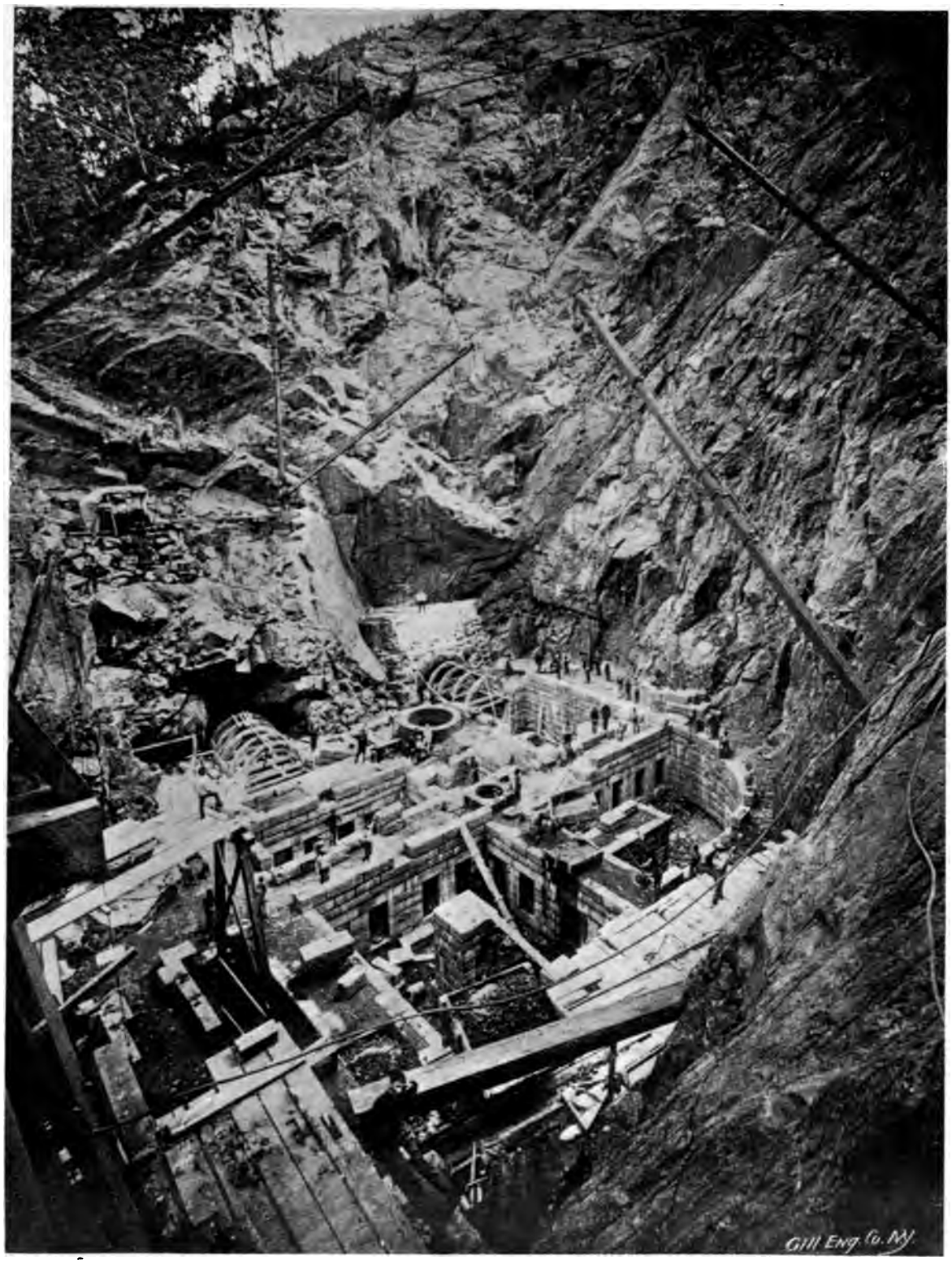
The drain-pipes not provided with stop-cocks are controlled by means of the covers in the water-chambers mentioned above.

The drainage-well is lined with 2 feet of brickwork. Its inner diameter is 5 feet, except at the bottom, where it is enlarged to 6 feet. It contains, besides four stop-cock stems, a cast-iron ladder attached to the brickwork.

From the drainage-well the water is conducted by a 12-inch drain-pipe to a sump (10 feet in diameter and 8½ feet deep below the paving of the water-chambers) located in the pump-chamber. A circular iron stairway leads from the floor of the superstructure to the floor of the pump and turbine chamber.

The drainage-water is pumped out of the sump into the aqueduct by a 9-inch anti-friction centrifugal pump operated by a 30½-inch Leffel improved turbine wheel. The pump has a capacity of 3000 to 3500 gallons per minute. The turbine is supplied with water by means of a circular connection, 48 inches in diameter, from the by-pass. Its waste water is discharged into a small chamber connected with the aqueduct by a passage

PLATE 19.



NEW CROTON GATE-HOUSE, IN CONSTRUCTION.

walled and arched with brickwork. The floor-grade of this passage is a little above the invert of the aqueduct. The pump discharges the drainage-water through a 9-inch cast-iron pipe which enters the aqueduct at its haunch.

By means of a sluice-gate the sump of the pump-chamber can be connected directly with the screen-chamber, and thus with the aqueduct.

From the description we have given the reader will be able to form some idea of the magnitude of the work involved in constructing the new Croton gate-house. The principal items were:

Earth excavation	9,046	cubic	yards
Rock excavation	118,018	"	"
Tunnel excavation	5,809	"	"
Brickwork	5,357	"	"
Concrete	18,092	"	"
Rubble	10,158	"	"
Dimension-stone	1,364	"	"
Cut facing-stone	2,949	"	"

The total cost of the building, including the sixteen sluice-gates and all appliances which have thus far been placed, has been $746,656.

The Gate-House at One Hundred and Thirty-fifth Street and Convent Avenue (see Plates 20, 72, and 73) forms the terminus of the masonry conduit and the beginning of the pipe-line. The old Croton aqueduct and the old mains on Tenth Avenue have been connected with this building, which receives all the water conveyed to Manhattan Island, and distributes it through twelve lines of 48-inch mains.

The gate-house consists of a masonry substructure containing the water-chambers, sluice-gates, stop-cocks, etc., and of a fine masonry building, forming the superstructure. (See Plate 20.) The main building (about 53 × 79 feet in plan) is designed for the new aqueduct, which is connected with it by a vertical well. An addition on the west side of the building receives the water from the old aqueduct on Tenth Avenue, with which it is connected by a short masonry conduit. In the following description the two parts of the gate-house mentioned above will be designated respectively as Division I and Division II.

The elevation of the natural surface of the ground, at the site of the building, is about 115 feet above Croton datum (mean tide in the Hudson River at Sing Sing). As the water is calculated to reach elevation 127 under the maximum discharge, the substructure was built up to elevation 132. The excavation for Division I was made to a depth of about 29 feet below the surface, as the eight lines of mains, leaving this division, were to be laid at a depth which would make them drain completely the proposed distributing reservoir at Jerome Park. For Division II the excavation was only 8 feet deep. The total amount of excavation for the gate-house consisted of about 1600 cubic yards of earth and 7600 cubic yards of rock. About 4000 cubic yards of this material was used in grading the grounds around the building.

Division I of the substructure is connected by a well, located in the northeast corner of the building, with the aqueduct tunnel, and by eight lines of 48-inch pipes with the adjoining new mains on Convent Avenue. The well has a depth of 84 feet from the floor of the gate-house (elevation 132) to the invert of the tunnel. Its diameter is 12 feet 3 inches from the bottom to the foundations of Division I, where it is enlarged to 13 feet to compensate for the loss of head caused by the water-passages. The junction of the tunnel and the well is rounded off by a "goose-neck turn." The well is lined with brickwork and coped at the floor of the building with granite stones, 12 inches thick. A cast-iron ladder, fastened to the brick lining, reaches from the tunnel to the paving of Division I. The connection between the well and the main water-chamber of Division I is made by two passages, 5 feet wide and 28 feet 3 inches high. These openings are formed by means of a central granite pier from which two brick arches, 12 inches thick and 2 feet wide, are sprung at elevation 104.25 to the side walls of the building. On top of the arches a brick wall, 24 inches thick, is built to the floor of the building, where it is coped with granite. The pier mentioned above is 11 feet 10 inches long at its base, 3 feet wide, and 43 feet 6 inches high, its top forming part of the floor of the building. Towards the well its end is rounded; the opposite side forms an angle of 90°. Two sets of grooves, $4\frac{1}{2} \times 4\frac{1}{2}$ inches, spaced 12 inches apart, are cut in each face of the pier and in the opposite walls for stop-planks, by means of which the water in the well can be shut off from Division I of the gate-house.

The main water-chamber has a length of 69.5 feet, a width of 14 feet, and a depth below the floor of the building of 43.5 feet. Its bottom is paved with granite blocks (18 inches deep, placed on a concrete foundation), except at the well and in the two channels between the central pier and the side-walls, where the paving is replaced by large granite stones 2 feet 6 inches thick. The north, east, and west walls of the water-chamber have a facing of granite stones 2 feet thick, laid in regular courses and backed by rubble masonry. At elevation 109.75 three openings in the west wall, controlled by $2' \times 5'$ sluice-gates (see Plates 94 and 95, and page 263), connect Divisions I and II.

The walls of the water-chamber of Division I were designed to be from 4 to 6 feet thick at the foundations, the rubble backing being carried to the solid rock up to its surface. On the south side of the main water-chamber eight small pipe-chambers are constructed by means of seven piers built of granite dimension-stone. The piers are 2 feet 6 inches wide, 9 feet long, and spaced 6 feet 6 inches apart in the clear. They are carried up from the paving of the main chamber to the floor of the building, a height of 43.5 feet. The north ends of the piers are joined together by semicircular brick arches, 16 inches thick and 16 inches wide, which are sprung at elevation 104.25. From the east pier a similar arch is sprung to the side-wall of the building. On top of these arches a 16-inch brick wall is built up to the floor of the building, where it is coped with granite stones 12 inches thick. Each pier has two sets of grooves on each face (respectively $4\frac{1}{2} \times 4\frac{1}{2}$ inches and $4\frac{1}{2} \times 6\frac{1}{2}$ inches, placed 18 inches apart) for stop-planks. Corresponding grooves are cut in the walls of the building opposite the end piers. The smaller set of grooves is ordinarily used for the wire screens described on page 134. The pipe-chambers are closed on the south by a wall, built

PLATE 20.

GATE-HOUSE AT ONE HUNDRED AND THIRTY-FIFTH STREET

GATE-HOUSE AT ONE HUNDRED AND THIRTY-FIFTH STREET, IN CONSTRUCTION

from the east to the west wall of Division I, to separate the water-chamber from the stop-cock vault. The wall is 6 feet thick at the base and 4 feet at the floor of the building, where it is coped with granite stones. It is constructed of rubble masonry faced on the water side with granite stones 2 feet thick, laid in regular courses, and on the opposite side with 12 to 16 inches of brickwork, bonded with the rubble. Eight cast-iron reducers, for the pipe-lines, pass through this wall. A 2′ × 5′ sluice-gate (see Plate 73), operated by means of a hand-wheel or by capstan-bars from the floor of the building, is placed in front of each reducer.

The stop-cock vault or chamber is 74.5 feet long by 15 feet wide at its bottom, the width being reduced by means of arches to 10–12 feet at the floor of the building. This chamber is closed on the south by the outer wall of the building. Seven brick cross-walls divide the chamber into eight compartments, one for each line of pipes. Two sets of circular openings in these walls, 8 feet in diameter, one set above the other, permit access to the different compartments of the vault. The compartments are 7 feet wide between the cross-walls, with the exception of the first one, which has a width of 14 feet 6 inches, to provide room for an iron stairway to the floor of the building, and also for the manholes of the sewer and drains of the building.

Eight 48-inch stop-cocks, of the pattern shown on Plate 90, are placed in the stop-cock chamber. They are connected at each end to a pipe having a manhole casting, and then to the reducers on the north side and to the 48-inch pipes which pass through the wall of the gate-house on the south. From the description given it will be seen that each of the eight lines of pipes which leave Division I of the gate-house can be closed by a stop-cock or by a sluice-gate, and if both should fail, by stop-planks.

Division II of the gate-house contains the connections with the old aqueduct and mains on Tenth Avenue. It has a water-chamber 31 feet long and 6 feet 6 inches wide, except at its north end, where it has a width of 14 feet 6 inches for 4 feet, in order to provide room for three 2′ × 5′ sluice-gates, by means of which the connection with the old aqueduct can be shut off. This same purpose may be accomplished by stop-planks, for which two sets of grooves (6 × 6 inches, placed 12 inches apart) are cut in the walls of the outer chamber where its width is only 6 feet 6 inches. The chamber is paved at elevation 108.75 with granite blocks resting on a foundation of concrete. All its walls are faced with granite. Four reducers pass through its west wall. In front of each reducer is placed a 2′ × 5′ sluice-gate, operated by a hand-wheel or capstan-bars from the floor of the building. The reducers are connected with the four lines of mains leading to Tenth Avenue, each of which is controlled by a stop-cock placed in a chamber in Division II. The conduit connecting with the old aqueduct has at the gate-house a circular section of 10 feet inner diameter. It enters a vault 8 ft. × 12 feet 6 inches in plan, which is placed outside of Division II, as shown on Plate 72. Access is obtained to the vault by two manhole-openings. An iron ladder is fastened to the west wall of the vault, to which is also attached a vertical, rectangular, cast-iron overflow-pipe, 12 × 36 inches in section, which is connected with the drains of the building and has its top placed at elevation 125.5.

The gate-house is drained in the following manner: A circular brick receiving basin, 4 feet in diameter and 6 feet deep, constructed below the floor of the east compartment of the stop-cock chamber of Division I, receives all the leakage from the water-chambers, pipes, etc., the discharge of the blow-offs, and the drains from the roof. This drainage is discharged, by means of an egg-shaped brick sewer constructed in Convent and Ninth avenues, into the main sewer of Manhattan Street.

A drain 12 inches wide and 4 to 5 feet high, built under the stop-cock chamber of Division I and connected with a similar drain in Division II by a vertical weeper 2 × 2 feet in section, leads all the leakage from the stop-cocks and pipes to the circular receiving basin. It also serves for emptying Division II, as will be explained hereafter. A 12-inch cast-iron blow-off pipe is laid under the paving of the water-chamber of Division I from a point near the well from the aqueduct to the receiving basin. It has a circular inlet, covered by an iron grating, in the paving and a stop-cock placed in a 2½′ × 2½′ manhole in the stop-cock chamber. The pipe serves for emptying Division I. A weeper is constructed at elevation 106, in the north and east walls of the water-chamber of Division I, and also in the walls of the well. It has a section of 12 by 24 inches. At the dividing wall between the water-chamber and the stop-cock chamber the weeper passes down vertically to a 12″ × 18″ drain below the floor of the latter chamber, which connects it with the receiving basin. At elevation 106 an opening 18 inches wide (except around the well, where its width is 3 feet) and about 5 feet high is left in the walls over the weeper, to which it permits access.

Division II has a 12″ × 4′–5′ drain under its stop-cock chamber. This drain is continued under the paving of the wide part of the water-chamber and of that part of the entrance-chamber of the connection with the old aqueduct. By raising a conical valve placed in each of the two last-mentioned chambers Division II can be emptied.

The rain-water from the roof is discharged into the drains through 4-inch cast-iron pipes, which are built into the masonry.

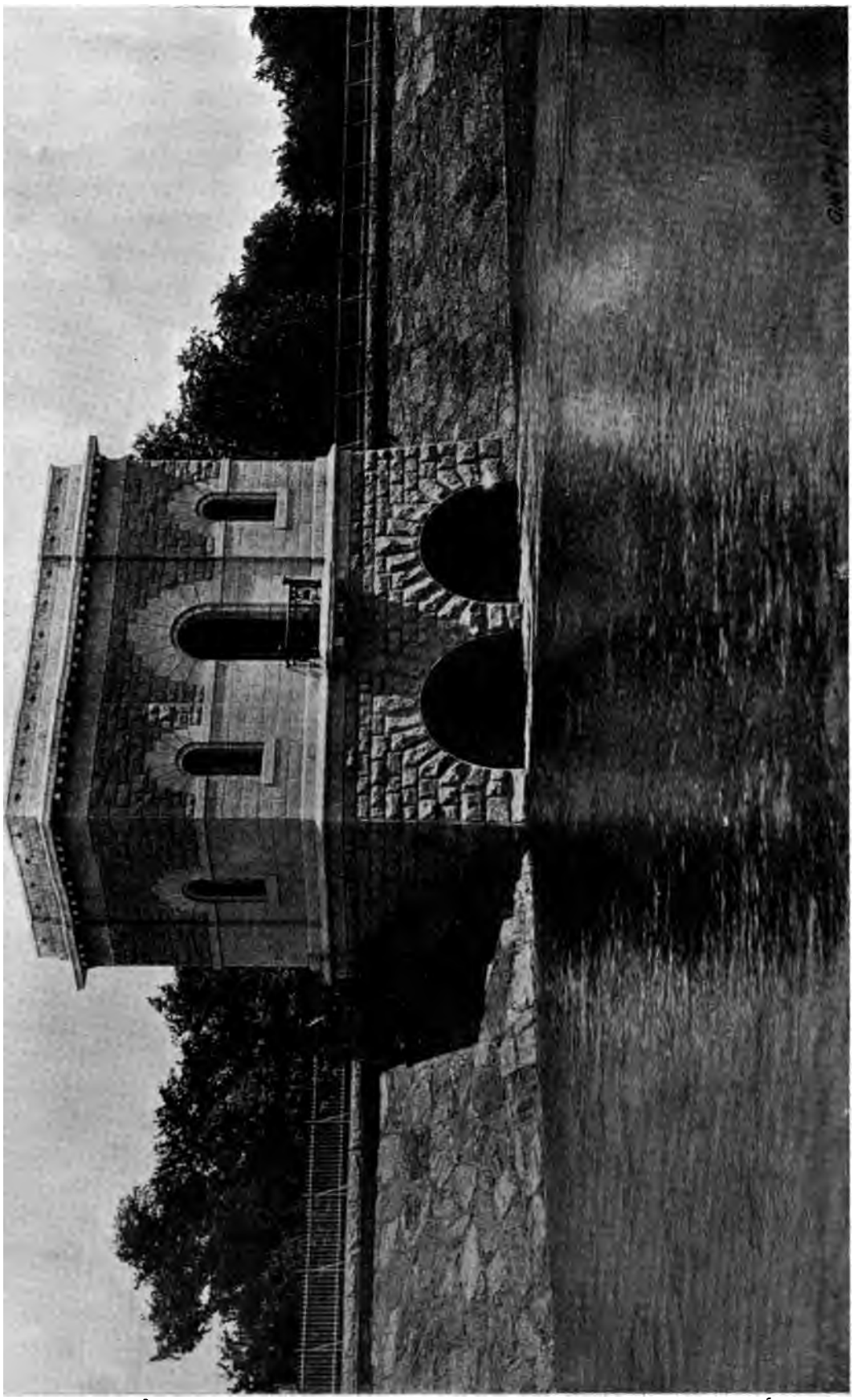
The substructure is covered at elevation 132 with a floor formed of 12-inch "I" beams and cast-iron plates (see Plate 74), with the exception of two openings 9 ft. × 8 ft. 10 in. over the water-chamber of Division I and of the well. These open spaces are enclosed with strong iron railings having a brass top-rod. The walls of the substructure which reach the floor of the building are all coped with granite stones 12 inches thick, having the exposed surfaces fine-hammered (six-cut).

As already stated, one set of grooves in the pipe-chamber of Division I is used for screens. The grooves in the water-chamber of Division II (see Plate 72) serve ordinarily for the same purpose. The screens have frames, made of 3″ × 4″ oak, fastened together by brass screws, to which wire cloth made of No. 10 brass wire, spaced ¼ inch apart, is attached by brass screws.

The stop-planks for the gate-house are all made of 6″ × 12″ yellow-pine pieces, the ends being trimmed to fit the grooves.

The general appearance of the superstructure of the gate-house is shown on Plate 20. The outer walls are constructed of granite except the exposed portions of the substructure

PLATE 21.



CENTRAL PARK GATE-HOUSE.

and broken ashlar of the upper portions of the superstructure, which are built of rock-faced brown stone. The voussoirs, window-sills, cornices, water-table, and other trimmings are all made of the best quality granite, the exposed faces being fine-hammered (six-cut). On the inside the building is lined with red, black, and buff-colored bricks, equal in shape and quality to Philadelphia front brick.

The doors are made of iron. The window-frames and sashes are of oak. The lower portion of the windows is glazed with the best quality of double-thick German or French glass. For the transom sashes heavy cathedral stained glass was used.

The roof of the gate-house (with the exception of that of the tower) is constructed of iron beams and rods, as shown on Plate 73. It has a covering of slate on the outside, and is ceiled on the inside with 3″ × ¾″ yellow-pine boards, which are tongued, grooved, and beaded. The roof of the tower is formed of brick arches sprung from iron "I" beams, the bricks being laid in asphalt.

The total cost of the gate-house, including gates, stop-cocks, etc., was about $160,000.

The Central Park Gate-house (see Plates 21, 75, and 76) forms the terminus of the pipe-line at the large receiving reservoir in Central Park. Four lines of 48-inch mains enter the building on the north side. A small water-chamber (3 × 5 feet in plan) is provided for each pipe-line. From these chambers the water flows through four openings, controlled by 2′ × 5′ sluice-gates (see Plates 94 and 95 and page 263), into two large chambers (one for each pair of mains), whence it passes through two arched openings of 13 feet span into the reservoir.

In front of each inlet-pipe and of each sluice-gate a double set of grooves (4 in. × 5 in., placed 9 inches apart) for stop-planks is cut in the granite facing of the chambers. A 12-inch cast-iron drain-pipe, placed under the four small water-chambers, draws off the water when the gate-house is emptied.

The superstructure of the gate-house is about 20½ × 36½ feet in plan. The walls are of granite masonry, and are lined on the inside with pressed red brick. The roof is formed of 10½-inch "I" beams placed three feet apart, from which brick arches 8 inches thick are sprung. The top of the roof was levelled with brickwork and covered with asphalt and gravel. Four leaders 3 inches in diameter, made of 16-ounce copper, discharge the rain from the roof. The leaders pass down inside the building, and have goose-necks at the top, with strainers in the gutter. Where they pass through the floor-plates they have a movable section 2 to 3 feet long.

The roof is provided with "Excelsior" ventilators and with a trap-door. The building is floored at elevation 124 with 10½-inch "I" beams covered with cast-iron plates similar to those shown on Plate 74.

The doors, window-frames, and sashes are of first-class oak, the fastenings, etc., being of bronze. The sashes are glazed with the best quality of double-thick German or French glass. The transom frame and sash above the windows has latticed openings, which are glazed with heavy cathedral stained glass.

The masonry of the substructure was laid in mortar made of Rosendale cement mixed

with an equal part of sand. For the superstructure the mortar was composed of one part of cement mixed with two parts of sand. The total cost of the gate-house was about $38,000.

Blow-offs and Overflow-weirs.—At three places between Croton Lake and the Harlem River (viz., at the Pocantico River, at Ardsley, and at South Yonkers) gate-houses were constructed, each having an overflow-weir for regulating the height of the water in the aqueduct, and blow-off gates for emptying the conduit. These gate-houses were all constructed on the same general plan (see Plate 77). Each has a substructure consisting of a masonry chamber, 37 × 55 feet in the clear and about 20 feet high, which is divided by an overflow-weir, built parallel with the axis of the aqueduct, into two parts: a water-chamber, 17 feet feet wide, forming part of the aqueduct, and a waste-chamber, about 9 feet wide, which receives the water flowing over the weir or discharged by the blow-off gates and delivers it through a culvert to a brook or stream near by.

The walls of the substructure consist of rubble masonry faced with 8 to 12 inches of brickwork. The overflow-weirs are constructed of granite cut-stone masonry. Three piers divide the overflow-weir into four parts, each 6 feet wide. In each of these parts an opening for a 3′ × 4′ blow-off sluice-gate is provided.*

Three sets of 4½″ × 4½″ grooves for stop-planks are cut in the piers and opposite to them in the north and south walls of the substructure. The first set of grooves is used for stop-planks, which are placed on top of the overflow-weir, for regulating the height of the water in the aqueduct. The other two are used for forming a dam of stop-planks in front of the blow-off gates, when required for repairs.

The stop-planks are made of 6″ × 12″ yellow pine, dressed at the ends to fit the grooves. When they are placed in the grooves a piece of tarred cord (marline) is generally tacked to the bottom side of each stop-plank, in order to make the joints between the planks as water-tight as possible.

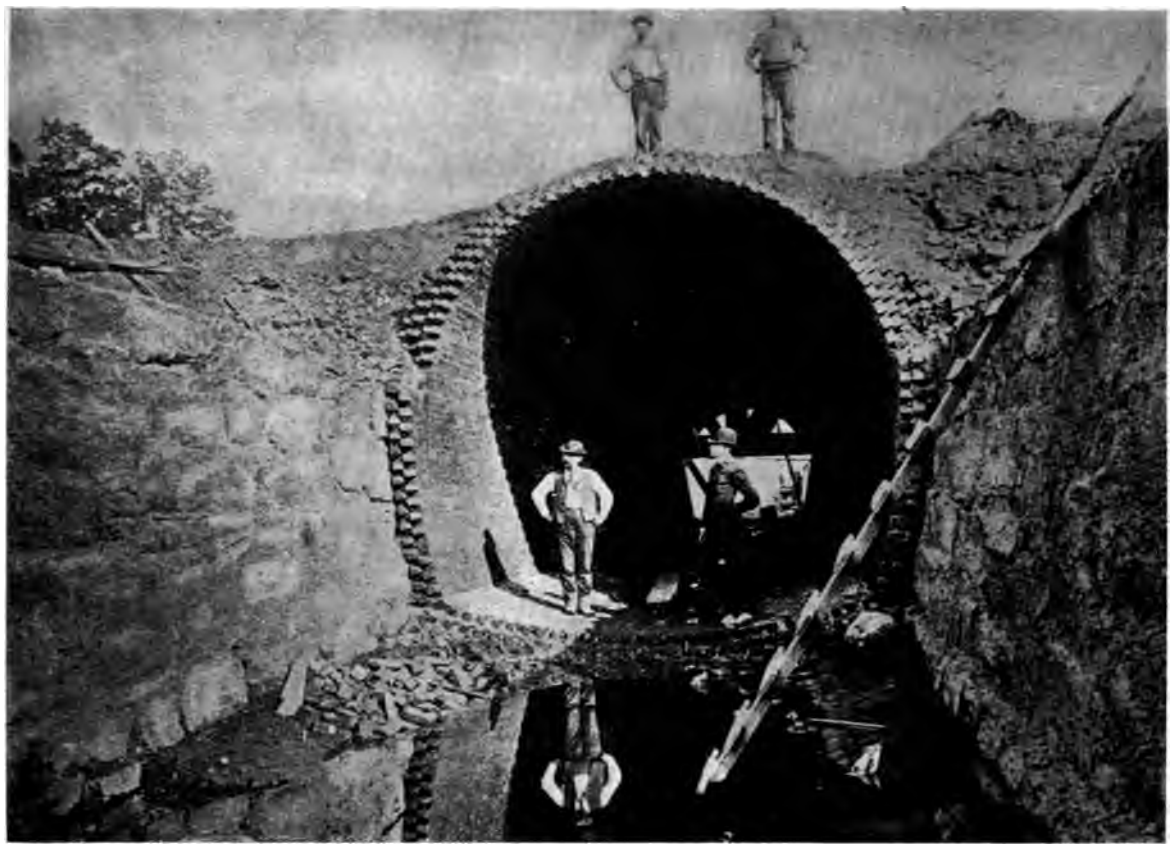
Near the southerly end of the water-chamber, a central pier, three feet wide by eleven feet long, having both ends rounded, is placed in the middle of the water-channel, dividing the stream into two currents, each seven feet wide; 4½″ × 4½″ grooves are cut in the sides of this pier, in the east wall of the substructure, and in one of the overflow-piers, for stop-planks or timber drop-gates, by means of which a dam can be quickly formed across the water-channel. In this manner the section of the aqueduct between two of the blow-off gate-houses can be separated from the other parts of the conduit and emptied by the blow-off gates when necessary for repairs or inspection.

The cast-iron sluice-gates for the blow-off are shown on Plates 99 and 100. Each has two stems, as they are 4 feet wide.

The three blow-off gate-houses mentioned above differ from each other only in unimportant details which are due to local circumstances. At the first gate-house, Welkers Brook, which carries much driftwood in freshets, is conveyed over the conduit as shown on

* The most southerly gate-opening in each of the blow-off gate-houses was closed temporarily by a wooden bulkhead, as these openings and the corresponding gates will not be required until the large drop-gates for closing the aqueduct at each blow-off are needed.

PLATE 22.



NEW AQUEDUCT NEAR YONKERS.

YONKERS BLOW-OFF, IN CONSTRUCTION.

Plate 18. The waste water from the gate-house passes through a 15-foot culvert to the Pocantico River, west of the aqueduct. At South Yonkers, Tibbit's Brook, into which the waste water is discharged, passes under the gate-house through two circular culverts, 6 feet in diameter, directly into the waste-chamber, and is carried off through a paved channel (see Plates 77 and 78).

The Ardsley gate-house required some special construction, as the aqueduct was considerably below the surface of the ground at this place. The waste water is carried from the gate-house through a culvert a distance of 800 feet to the Sawmill River.

In addition to the blow-offs mentioned above, two more are provided at the Harlem River, viz., at shafts 24 and 25. They serve for emptying the conduit from the Yonkers gate-house to the terminal gate-house at One Hundred and Thirty-fifth Street and Convent Avenue, with the exception of the part under the Harlem River, which is emptied by pumping, in the manner described on page 166.

The blow-off at shaft 24 (see Plate 79) serves a double purpose:

1st. For emptying the aqueduct.

2d. For discharging the water leaking into the conduit, when empty, between the Yonkers gate-house and the top of the incline at shaft 24 directly into the Harlem River, to avoid the expense of pumping it from the tunnel under the river.

The blow-off is formed by a line of 20-inch cast-iron pipe laid from the top of the incline at station 1479 to shaft 24 and carried up the shaft, in the backing masonry, to the proper elevation. It is continued by 30-inch pipes laid in a horizontal drift, and then by 36-inch cast-iron pipes laid in a trench, to the Harlem River, the end of the pipe-line being protected by a small masonry wall. The diameter of the blow-off pipe was enlarged from twenty to thirty-six inches to check the velocity of the water and to enable it also to carry off the drainage-water from the head-house of shaft 24, which is led into the blow-off. The pipe is opened or closed by two 36-inch stop-cocks placed, one behind the other, in a brick vault, where the horizontal drift joins the pipe-trench. A 20-inch pipe, controlled by a stop-cock, branches from the blow-off in this vault. It is to be continued in the future, and to serve as a feeder for the distributing system of the "Annexed District."

At the inlet of the blow-off, at the top of the incline, a small basin was formed in the invert of the conduit, and grooves for stop-planks were provided in the sides. A hand-hole for cleaning out the pipe was provided at its lowest point, viz., at the foot of shaft 24.

The blow-off at shaft 25 consists of two 48-inch cast-iron pipes, laid in a drift and surrounded by masonry as shown on Plates 81 and 83. Each of the blow-off pipes is controlled by two stop-cocks, which are placed in a masonry vault. The object of having two sets of stop-cocks is to provide against accidents in cases of leakage or breakage of one of the stop-cocks.

The Pipe-line.—The new aqueduct is continued from the One Hundred and Thirty-fifth Street Gate-house by eight lines of 48-inch mains, four of which terminate at the large receiving reservoir in Central Park; the other four being connected at various points with the old pipe system.

The latter were laid by the Aqueduct Commissioners only for a short distance after branching off from the main pipe-line, and were closed by stop-cocks placed in vaults below the paving of the street (see Plate 93). They were continued by the Department of Public Works and connected with the distributing system.

Plate 85 shows the location of the different pipe-lines laid by the Aqueduct Commissioners. The grades of the pipe-lines follow generally those of the streets in which they are located, being sufficiently low to allow a covering of three or four feet of earth on top of the mains. At the One Hundred and Thirty-fifth Street gate-house, however, the pipe-trench had to be excavated to a depth of 26 feet below the surface of the ground, in order to enable the pipes to drain completely the proposed distributing reservoir at Jerome Park (see page 209). At One Hundred and Twenty-fifth Street and Ninth Avenue the pipe-trench was 11 feet deep, as the mains had to pass under the Cable Railway. The width of the trenches was fixed so as to allow a clearance of two feet between the pipes of adjoining lines, and the same clearance between the outer lines and the sides of the excavation.

At two low points in the pipe-lines, viz., in Ninth Avenue just south of One Hundred and Twenty-fifth Street, and in the Ninety-seventh Street Transverse Road in Central Park, blow-offs for emptying the mains and discharging any material that may be deposited in the pipes are provided. A special casting (see Plate 86) having in the bottom a connection for a 12-inch blow-off pipe was placed, at these places, in each pipe-line. The 12-inch blow-off pipes are provided with stop-cocks.

At the One Hundred and Twenty-fifth Street blow-off the stop-cocks are placed in the same vault (see Plate 87). A 20-inch pipe conveys the water from the blow-off pipes to the sewer of Manhattan Street, to which it is connected by the manhole shown in Plate 88, into which the 20-inch pipe discharges the water vertically. The bottom of the manhole is provided with an iron lining (formed of a piece of 48-inch pipe, closed by a cap) to withstand the shock.

A manhole casting (see Plate 86), permitting entrance to the pipes in case of necessity, was placed in each line of mains at the One Hundred and Twenty-fifth Street blow-off. The manhole-covers were leaded and completely covered by the refilling.

At the Ninety-seventh Street blow-off each stop-cock is placed in a separate manhole casting. The water discharged is conveyed by a 12-inch pipe to a sewer crossing Ninety-seventh Street, to which it is connected by a manhole in a similar manner as at One Hundred and Twenty-fifth Street.

In order to discharge the air which collects in the mains at the summit of the grades, special castings (see Plate 86) were placed in each line of pipes at high points.

The casting has a 6-inch branch on top, which is connected by a 6-inch pipe, provided with a stop-cock, to a hydrant.

When the main is being filled the hydrant is left open until all the air has been discharged. An occasional opening of the hydrant is sufficient to keep the pipe free of accumulated air.

An arrangement for discharging air as described above was made at the summit of the

PLATE 38.

PIPE-LINE IN GENERAL MASS

PIPE-LINE IN CONVENT AVENUE.

grades at Ninety-seventh Street and Eighth Avenue, and at the stop-cock vaults in One Hundred and Tenth and One Hundredth Street (see Plate 85).

The sections of the iron pipes laid by the Aqueduct Commissioners (which are the stand-

FIG. 22.—POURING A JOINT.

ard sections adopted by the Department of Public Works) are shown on Plate 89. The special castings, stop-cocks, and hydrants will be found respectively on Plates 86, 90–94, 103. The specifications are given on page 257.

The total cost of the pipe-line of the new aqueduct, including some incidental work, such as the grading of Convent Avenue from One Hundred and Thirty-fifth Street to One Hundred and Twenty-seventh Street, a brick sewer from One Hundred and Thirty-fifth Street to Manhattan Street, etc., was $1,013,220.54. The principal items of work were:

Earth excavation	126,900 cubic yards
Rock excavation	49,700 " "
Refilling and embankment	157,000 " "
Telford-Macadam pavement	21,900 square yards
Cast-iron hub and spigot pipe	24,200 tons
Special castings	890 "
Laying 48-inch iron pipe	71,100 lineal feet

A number of sewer-basins had to be rebuilt in order to carry their outlet-pipes under or over the water-mains. In Morningside Avenue (see Plate 85) the Telford-Macadam paving (16 inches deep) had to be taken up and relaid.

An interesting piece of work had to be done on Convent Avenue, where the pipes had to be laid on embankments. In accordance with the custom of the Department of Public Works, the slopes of the embankments had been allowed to cover part of the adjoining lots. After all the pipes had been laid at this place, the west slopes had to be removed and replaced by a retaining wall, built on the city's land, owing to legal complications with owners of the adjoining property. This work involved considerable difficulties, as at one place the slope of an embankment 25 feet high had to be removed right up to the westerly ine of pipe. Fortunately the pipes had been laid on longitudinal 12″ × 12″ hemlock timbers, which prevented settling at joints. The slope was excavated in short sections of 13 to 20 feet, the construction of the wall following the excavation closely. When the water was let into the pipes only two small leaks were found at these walls.

The Engineers of the Aqueduct Commission.—On August 15, 1883, the Aqueduct Commissioners appointed Mr. B. S. Church as their Chief Engineer. Mr. Church had been in charge of the old Croton aqueduct for about twenty-six years, as Resident Engineer, and had been consulted by the Department of Public Works in connection with the plans for the new works. He remained at the head of the Engineering Department of the Aqueduct Commission until he resigned from this position on November 21, 1888. Mr. Church still remained connected with the work as Consulting Engineer until August 1, 1889.

The Engineering Department of the Aqueduct Commission was not fully organized until January 23, 1884, when the following appointments were made:

Alphonse Fteley, Principal Assistant and Executive Engineer.
H. S. Craven, Engineer of Construction.
Edward Wegmann, Assistant Engineer of Construction.
F. W. Watkins, Assistant Engineer of Construction.
F. S. Cook, Assistant Engineer in charge of Draughting Bureau.

Mr. Fteley had been Resident Engineer in charge of the construction of the Sudbury conduit and new reservoirs for the city of Boston. His title was changed by the Aqueduct Commissioners in May 1885 to that of Deputy Chief Engineer. Owing to ill health he resigned from this position on July 31, 1886, and was appoined Consulting Engineer to the Aqueduct Commission. He succeeded Mr. Church as Chief Engineer in November 1888, upon the latter's resignation, and still occupies this position.

Mr. Craven was a civil engineer in the service of the United States Navy, who had obtained a leave of absence to take an active part in the construction of the New Croton Aqueduct. He remained connected with this work in the above capacity until March 4, 1886.

On April 9, 1884, the Aqueduct Commissioners appointed Mr. J. P. Davis, who as City Engineer of Boston (November 25th, 1872, to March 20th, 1880) had constructed the new water-works and the improved drainage system of that city, as their Consulting Engineer. Mr. Davis served in this capacity until July 21, 1886, with the exception of a short period of time (February 1 to May 1, 1886), when he was replaced during a temporary absence by Mr. Wm. R. Hutton, a well-known civil engineer.

During the first months of 1884 the engineers of the Aqueduct Commission were en-

gaged in preparing plans for the work and in making test borings for the new conduit, with the diamond drills described on page 219. By May 1884 the plans had been sufficiently matured to enable the engineers to stake out the final location of the aqueduct, and field-parties were organized for this purpose. By the end of the year the Commissioners were ready to commence the construction of the new aqueduct. Prior to letting the contracts, the work was divided into seven divisions and the engineers mentioned below placed in charge.

DIVISIONS OF THE NEW CROTON AQUEDUCT.

Division.	Length, Miles.	Engineer in Charge.
No. 1	5.11	Charles S. Gowen.
2	4.92	J. B. McIntyre.
3	3.54	J. M. Wolbrecht.
4	5.36	Alfred Craven.
5	4.62	E. S. Gould.
6	4.57	F. W. Watkins.
7	5.00	Edward Wegmann.

After the Aqueduct Commission was changed by chapter 337 of the Laws of 1886, the Engineering Department was reorganized as follows: The work was divided into a northern and a southern district, which were subdivided into five divisions. The Aqueduct Commissioners appointed on July 27, 1886, J. Imbrie Miller, Principal Assistant Engineer in charge of the Northern District, and Charles Pugsley, Principal Assistant Engineer in charge of the Southern District.

The former served in this capacity until November 24, 1888, and the latter until May 31, 1887.

The engineers placed in charge of the different divisions are mentioned in the following table.

DIVISIONS OF THE NEW CROTON AQUEDUCT.

District.	Division.	Length, Miles.	Engineer in Charge.
Northern	No. 1	7.55	Charles S. Gowen.
	2	6.68	J. M. Wolbrecht.
Southern	3	6.02	Alfred Craven.
	4	7.53	J. B. McIntyre.
	5	5.34	Edward Wegmann.

Division Engineer McIntyre resigned on April 27, 1887, and was succeeded by S. F. Morris.

The work in connection with the construction of the east-branch reservoir (known as Double Reservoir I) was organized as a sixth division in 1887. Mr. George B. Burbank being placed in charge. He resigned June 17, 1891, and was succeeded by Mr. Walter McCulloh, who had been connected with the work from the beginning as Assistant Engineer.

As the work on the new aqueduct drew near its end, some of the division engineers

resigned and others were transferred to the new reservoirs. When the construction of the new aqueduct was practically finished, the Aqueduct Commissioners divided the work on October 13, 1892, into four divisions as follows:

DIVISIONS OF THE RESERVOIRS CONSTRUCTED BY THE AQUEDUCT COMMISSION.

Division.	Engineer in Charge.
New Croton Dam division.....	Charles S. Gowen.
Carmel and Purdy's Dams division.....	Alfred Craven.
Brewster's Dams division.....	Walter McCulloh.
Croton River division *.....	Edward Wegmann.

During the whole period of the construction (from January 1884 to date) Mr. F. S. Cook, Assistant Engineer, has remained in charge of the important Draughting Bureau.

After Mr. Fteley's resignation as Deputy Chief Engineer on July 31, 1886, this position was left vacant until July 6, 1887, when Mr. George S. Rice, who had been engaged on the construction of the new water-works and the improved sewerage system of Boston, was appointed Deputy Chief Engineer. Mr. Rice occupied this position until he resigned on July 15, 1891.

* Embracing the changes of roads and bridges for the new Croton reservoir and the Muscoot Dam.

CHAPTER VII.

PRACTICAL DETAILS OF THE CONSTRUCTION OF THE NEW CROTON AQUEDUCT.*

Contractor's Plant.—A detailed statement of the machinery and appliances used at the different shafts of the New Croton Aqueduct is given in the table on page 292. Descriptions of the principal machines and appliances used will be found on pages 213 to 232.

The cost of the plant and buildings required for one shaft and one mile of tunnel was about $30,000, as will be seen by the following approximate estimate:

ESTIMATE OF COST OF PLANT AND BUILDINGS FOR ONE SHAFT AND ONE MILE OF TUNNEL (TWO HEADINGS).

Three boilers, 50 H. P. each	$3,000 00
One duplex compressor, 16″ × 30″ cylinders	5,200 00
One air-receiver	200 00
Two blowers	1,200 00
One engine, 10″ × 11″ cylinders, for blowers	1,100 00
One engine, 6″ × 6½″ cylinders, for electric light	450 00
One hoisting-engine, 8″ × 12″ cylinders	1,250 00
Two safety-cages	500 00
One pump, at foot of shaft	300 00
One dynamo, 10-light	800 00
Four drills, in heading	1,000 00
Four drills, on bench	875 00
One spare drill	220 00
Air-pipes, 12,500 feet 4-in. pipe at 40 cents	5,000 00
Electric lights, 8 at $25 each	200 00
Wire, 26,000 lineal feet	3,300 00
Track, 60 tons at $25 (laid)	1,500 00
Twelve dump-cars	1,000 00
Compressor-house / Boiler-house	650 00
Cement and sand shed	190 00
Blacksmith and machine shop	600 00
Office	160 00
	$28,695 00

NOTE.—The above estimate was furnished by Messrs. Denton, Breuchaud & Co., the superintendents (sub-contractors) for section 8.

* Some of the facts given in this chapter have been taken from the series of articles on the construction of the Croton Aqueduct that appeared in the "Engineering Record" of 1889 and 1890.

The approximate cost of the compressed-air equipment for one shaft for running about twelve drills for tunnelling was about as follows:

COST OF COMPRESSED-AIR PLANT.

Twelve rock drills, 3⅛-in., with tripods, drill-columns, drill-steels, and hose, at $378	$4,536 00
One air-compressor, cylinder 20″ × 24″	3,060 00
One air-receiver, cylinder 48″ × 12″, complete	279 00
Two horizontal boilers, 60″ × 14′, complete, with iron fastenings, grates, gauges, valves, injector, and stack, each 70 H. P., at $1210 each	2,420 00
Pipe and fittings for connecting boilers and compressor and air-receiver	125 00
Main air-pipe and distributing pipes, and fittings (variable), say	250 00
Cost of material and labor for setting boilers, 22,000 bricks, etc. (estimated)	400 00
Cost of material and labor for foundation of compressor (estimated)	175 00
Cost of material and labor for connections and starting plant	100 00
Freight and incidental expenses dependent upon the distance from New York, variable, estimated, 75,000 lbs., at from 10 to 15 cents per cwt., say	112 00
Total cost	$11,457 00

NOTE.—This estimate was furnished by the Ingersoll Drill Company of New York.

Four kinds of drills were used: Ingersoll, Rand, Sergeant, and Rattler. They are described on pages 215 to 219.

Air-compressors were placed generally at each shaft. There were, however, two exceptions to this rule. The compressors for shafts 0 and 1 were placed together, near Croton Lake, to secure a supply of pure water for the boilers. The air was conducted to these shafts in a 4-inch wrought-iron pipe having screw-joints. This pipe was laid on the surface and carried to the foot of shaft No. 1, where it was continued by branch-pipes to the north and south heading. The maximum distance from the compressor to the drills was about 1½ miles. On Manhattan Island the compressor-plant for shafts 27 to 32, inclusive, was concentrated at shafts 28, 29, and 31, the air-pipes (wrought-iron pipes 3 to 4 inches diameter, laid generally in the gutter of Tenth Avenue) being connected so as to equalize the supply for the different shafts.

Three styles of compressors were used, viz.: the Ingersoll, the Rand, and the Norwalk. (For description see pages 213 to 215.)

From the compressor, the air, raised to a pressure of 80 to 100 pounds per square inch, was conducted first to a cylindrical wrought-iron receiver having a diameter of 3 to 5 feet and a length of 8 to 14 feet. The object of the receiver, which was placed generally out-of-doors, was to equalize variations in the pressure and delivery of the air, and to condense the moisture it contained. The latter object was especially important for the Ingersoll compressors, in which a spray of water was injected directly into the air-cylinder. In the receivers used for these machines the air was made to pass through a large number of tubes surrounded by water. These tubes were not required in the receivers for the other compressors. Cocks were placed at the bottom of the air-receivers for drawing off the condensed water.

From the receiver the air was conducted in wrought-iron pipes (usually 3 to 4 inches in diameter) to within 100–200 feet of the heading. The pipe was continued by a rubber hose of the same diameter (the "bench-hose"), which was covered with canvas or marline to

protect it from wear. The hose terminated at a "manifold" (see Fig. 23), which was usually placed at the foot of the bench. From the manifold the air was distributed to the different drills by means of small hose-pipes 1 to 2 inches in diameter. A stop-cock was provided at

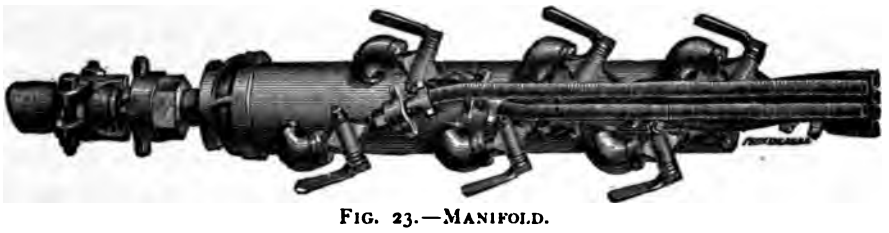


FIG. 23.—MANIFOLD.

the manifold for each hose. The bench-hose, manifold, and small hose-pipes could easily be moved to one side during the blasting.

Electric-light Plants.—The dynamos and open arc lamps were furnished by the Thomson-Houston Electric Co. of Boston, Mass., the Schuyler Electric Co. of Mid-

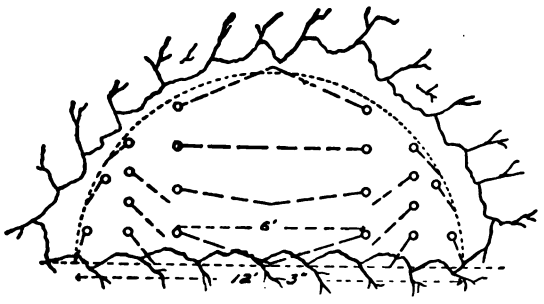


FIG. 24.—HEADING DRILL-HOLES.

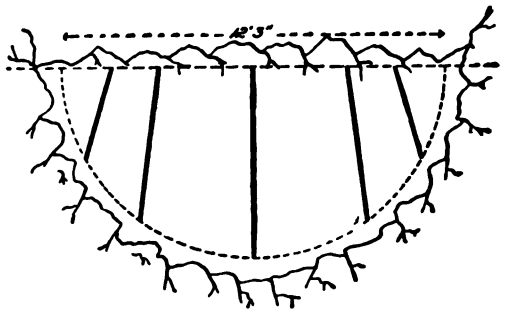


FIG. 25.—BENCH DRILL-HOLES.

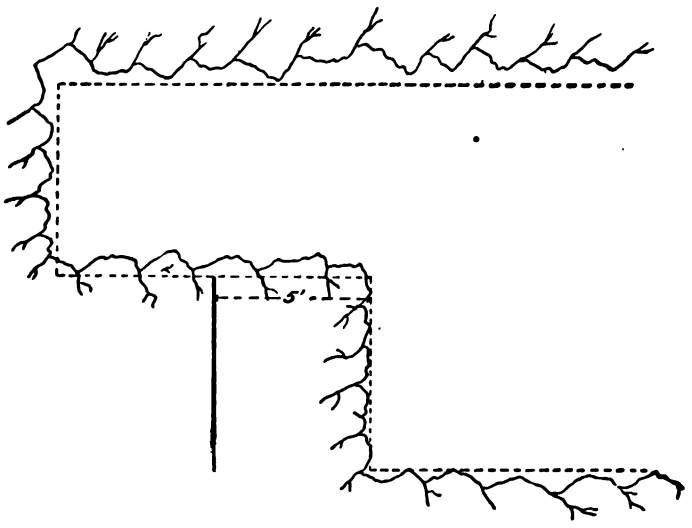


FIG. 26.—BENCH DRILL-HOLES.

dletown, Conn., the Bell Electric Co., the United States Electric Lighting Co., and the Brush Electric Co., the last three companies having their offices in New York.

An electric-light plant was placed at each shaft, except on sections 13 and 14, on Manhattan Island, where a thirty-lamp dynamo at shaft 30 gave light to shafts 27–32, both inclusive, the wires being brought from shaft to shaft by attaching them to the telegraph poles on Tenth Avenue.

The open arc lamps were similar to those used in the streets, but specially adapted for rough usage in the tunnel. They were generally attached to the rock in the roof of the tunnel. Each lamp had about 1200 candle-power and required 3/4 horse-power to operate it. An engine of 15–20 horse-power was placed at each shaft (except on Manhattan Island) to run the dynamo. It was supplied with steam from the boilers used for the air-compressors. To avoid accidents the dynamos were generally placed in special rooms and separated from the other machinery. They were protected by lightning-arresters on the main current wire, except in the Ball system, in which the wet poles answered this purpose.

Cages and Hoisting-engines.—In sinking the shafts and driving the headings for about 100 feet the material excavated was hoisted to the surface in iron buckets (see Plate 16). When the headings had reached the distance mentioned the buckets were replaced by "cages" (elevators) running on guides and provided with the usual safety appliances. About one month's time was required for making this change.

Three styles of cages were used: the Dickson, the Otis, and the Lidgerwood. (See pages 227 to 231.) The cages were hoisted by means of steam-engines (see pages 224 to 227) placed on the surface near the shafts. With few exceptions two cages were placed in each shaft, and operated by the same engine, one ascending while the other was being lowered.

Pumps.—In sinking the shafts, hanging pumps were generally used for getting rid of the water. When the headings were fairly started, powerful pumps were placed near the bottom of each shaft and kept in almost continual operation in raising to the surface the ground-water filtering into the tunnels. Cameron, Dean, Davidson, etc., pumps were used. For details see table on pages 292 to 298.

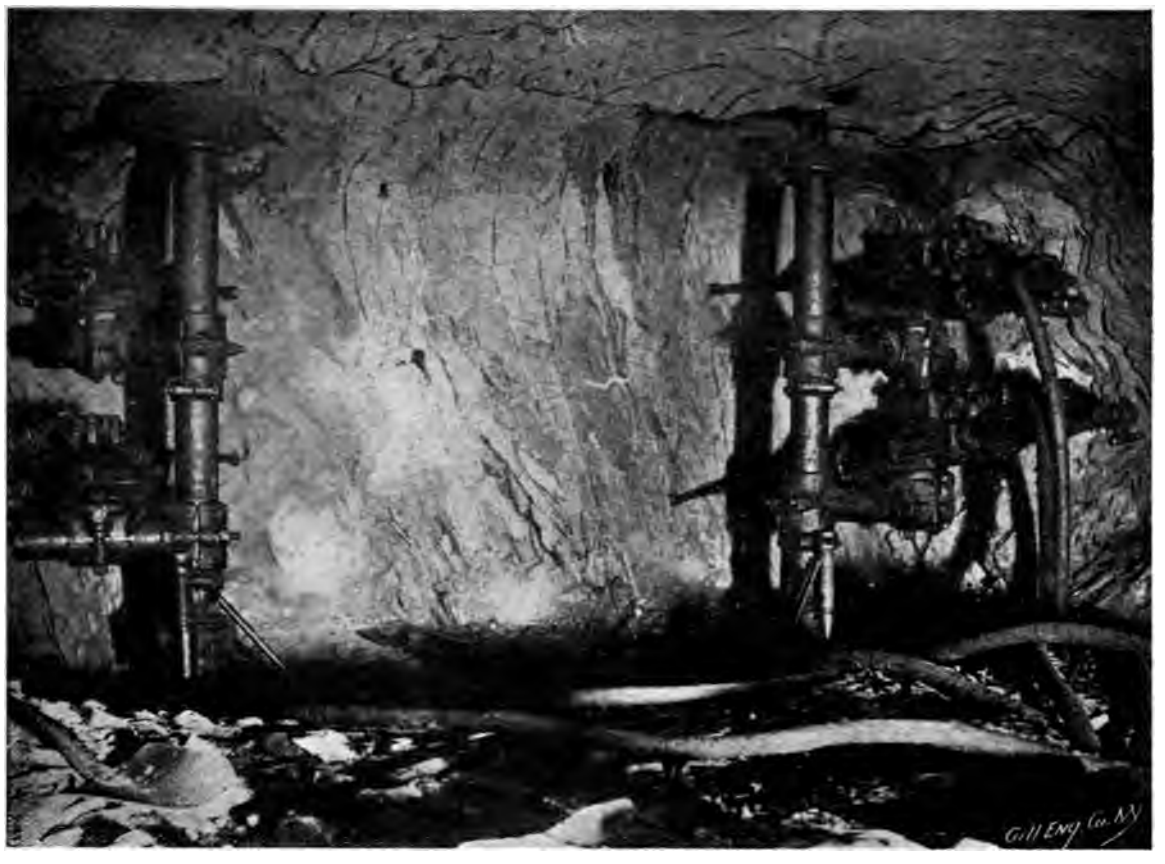
Tunnelling in Ordinary Rock.—The general method in which the aqueduct tunnel was excavated has been described on page 122. The details differed but slightly on the various sections of the work. With the one exception mentioned on page 122, the "heading" in rock excavation was always driven in the top, the American or "centre-cut" system being used. Eighteen to twenty holes were drilled for the "heading" and four to six for the "bench." Figs. 24, 25, and 26 show how the drill-holes for the circular aqueduct were generally located in ordinary rock. Figs. 28, 29, and 30 show how the drill-holes were placed for the "horseshoe" tunnel. Sometimes two or three "horizontal lifting" holes were drilled for the "bench" near the bottom of the tunnel.


Fig. 27.

The drilling was done with the percussion-drills described on pages 215 to 219. On some sections four drills were used for the "heading" holes, two mounted on the same column. (See Plate 24.) On others this work was done by two powerful drills. The latter method was found to be the more economical of the two. Six to nine hours were usually required for drilling the "heading" holes. The "bench" holes were drilled by one or two machines.

The steel bits used in drilling were of the usual + form. (See Fig. 27.) For each hole a set of bits differing by 1/8–1/4 inch in diameter were required, the holes being tapered from about 3 inches to 2 inches in diameter. In ordinary rock a bit

PLATE 24.



DRIVING THE HEADING.

AT A PORTAL.

would have to be sharpened after drilling 2–4 feet. A blacksmith and his helper could sharpen the bits for about six drills.

The drilling required for the "heading" and "bench" for the circular aqueduct (see Figs. 24, 25, and 26) was about as follows:

For Heading.

Eight centre-cut holes, each 8 feet deep	64.0	linear feet
Six side-holes, each 7½ feet deep	45.0	" "
Eight crown-holes, 5½ feet deep	44.0	" "

For Bench.

One bench-hole	8.0	" "
Two bench-holes, each 6 feet deep	12.0	" "
Two bench-holes, each 3½ feet deep	7.0	" "
Total	180.0	linear feet

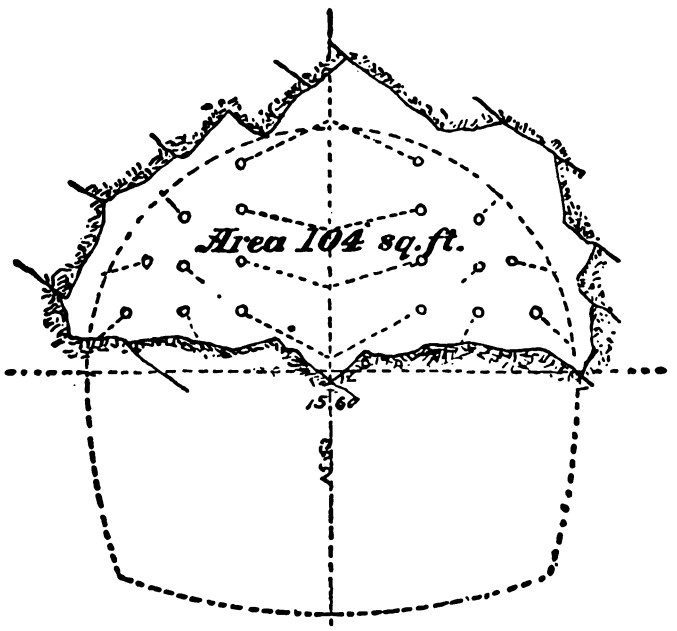


FIG. 28.—CROSS-SECTION OF HEADING.

The upper four heading-holes, which inclined upwards, were drilled dry, the others wet.

The explosives used were Atlas powder, forcite powder, rackarock, Atlantic giant powder, and dynamite. The different grades of these explosives all contain from 40 to 75 per cent of nitro-glycerine, with the exception of the rackarock, which is composed of 77.7 per cent of chlorate of potassium and 22.3 per cent of nitro-benzole. A powder containing 60 per cent of nitro-glycerine was generally used for the eight centre-cut holes and a 40-per-cent grade for the others. The cartridges were about 1½ inches in diameter and 8 inches long, each weighing about a pound.

The holes for the circular aqueduct were loaded in ordinary rock about as follows:

Heading-holes.

	Average Weight.
Eight centre-cut holes, each 5–5½ cartridges	42.0 lbs.
Six crown-holes, each 2–3½ cartridges	16.5 "
Six side-holes, each 2–2½ cartridges	13.5 "

Bench-holes.

One centre-hole, 5 cartridges	5.0 lbs.
Two side-holes, each 3–3½ cartridges	6.5 "
Two side-holes, each 1½–2 cartridges	3.5 "
Total	87.0 lbs.

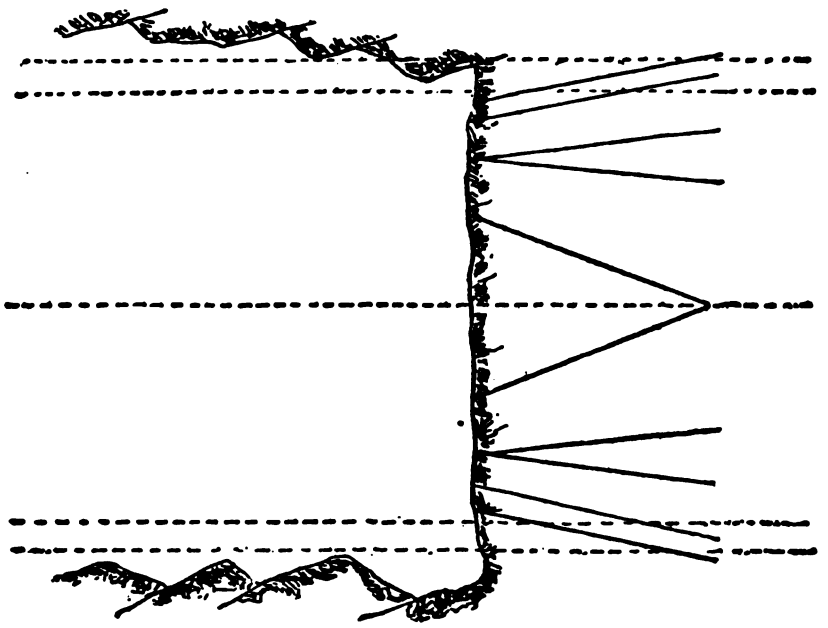


FIG. 29.—PLAN OF HEADING.

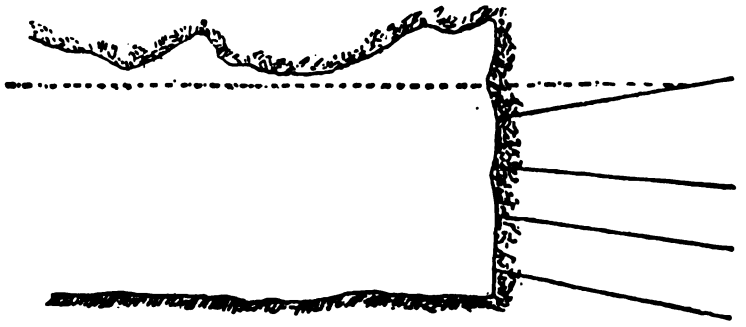


FIG. 30.—LONGITUDINAL SECTION OF HEADING.

Allowing for "block-holes" and wastage, about 100 lbs. of powder, half with 60 per cent and half with 40 per cent of nitro-glycerine, was required to fire the heading and bench holes for the circular tunnel, 14′ 10″ in diameter.

Except when dynamite was used, the holes in the heading were generally all charged

at the same time. An electric exploder was placed in the middle or last cartridge of each hole. As the men worked in two ten-hour shifts (7 A.M. to 6 P.M., 7 P.M. to 6 A.M.) the blasting was usually done at six o'clock, in the morning and afternoon. The explosives were fired by an electric machine, either from the surface or from a safe distance in the tunnel. First the eight centre-cut holes were fired, next the first set of side-holes, and finally the remaining side-holes. Sometimes all the side-holes were fired simultaneously. Between the rounds the blaster went into the tunnel to connect the wires for the next blast. The bench-holes were all fired together.

Some contractors preferred to charge each set of holes just before firing, a method which enabled them to use some judgment in charging the heading side-holes. The blasting of one set of heading and bench holes advanced the tunnel usually from 3 to 6 feet, according to the nature of the rock. The area of the excavation paid for where the "horseshoe" cross-section was used was 230–257 square feet, of which about 104 square feet was in the heading. For the circular conduit having an inner diameter of 12′ 3″ the total area of excavation paid for was 200–245 square feet, 90 square feet being in the heading. The total excavation made was from 0 to 100 per cent greater than the amount which was ordered and paid for, the difference being generally about 20–30 per cent.

On Manhattan Island, where the headings did not exceed 1000 feet in length, the average amount of labor required for excavating a circular tunnel 14′ 10″ in diameter, in both directions from a shaft (two headings), was about as follows:

COST OF LABOR FOR TWO TUNNELS DRIVEN FROM THE FOOT OF A SHAFT.

No.	Classification.	Time. Days.	Rate per Day.	Amount.	
	FOR BOTH TUNNELS.				
1	Superintendent	½	$6.00	$3.00	
1	Time-keeper	½	2.00	1.00	
1	Engineer	1	2.50	2.50	
1	Fireman	1	2.00	2.00	
1	Blacksmith	1	2.50	2.50	
1	Blacksmith's helper	1	1.50	1.50	
1	Blaster	½	2.00	1.00	
1	Fitter	½	2.00	1.00	
1	Electrician	½	2.00	1.00	
1	Hoister	1	2.00	2.00	
3	Topman	1	1.50	4.50	
1	Horse and driver for cars on top	1	2.50	2.50	
1	Sumpman	1	1.50	1.50	$26.00
	IN NORTH TUNNEL.				
1	Heading foreman	1	3.00	3.00	
3	Drill-runners	1	2.50	7.50	
3	Drill-runners' helpers	1	1.75	5.25	
1	Muck-boss	1	2.00	2.00	
10	Muckers	1	1.50	15.00	
6	Car-shovers (and trackmen)	1	1.50	9.00	
1	Nipper	1	1.50	1.50	
4	Hammersmen	1	1.75	7.00	50.25
	In south tunnel				50.25
	Total for one shift				$126.50
	Total for one day				$253.00

The Weekly Progress made in sinking the shafts and driving the tunnels will be found in the Tables on pages 300 to 307. In ordinary rock the tunnels advanced usually about 25 to 40 feet per week. The best average weekly progress *for the whole period of construction* was made in the following headings:

Heading.	No. of Weeks Worked.	Average Weekly Progress. Lin. Ft.	Tunnel Area. Square feet.	Drills Used.	Character of Rock.
25N.	23	43	150	Ingersoll	Limestone; some Gneiss
12A.N.	113	42	220	do.	Gneiss
15S.	95	40	220	Rand	do.
23S.	79	40	190	Ingersoll	do.
18N.	106	39	220	Rand and Ingersoll	do.
0S.	76	39	220	Ingersoll	do.
16S.	96	39	220	Rattler	do.
6N.	93	38	220	Ingersoll	do.
7N.	91	38	220	do.	do.
9N.	46	38	220	do.	do.
11A.N.	114	38	220	do.	do.
22N.	93	38	190	do.	do.
16N.	109	37	220	Rattler	do.
11B.S.	105	36	220	Ingersoll	do.

In some cases much greater progress than given in the above table was made for a short period of time. In the south heading from shaft 15, Paige, Cary & Co., the superintendents (sub-contractors) for section 7 drove the tunnel through hard, fine-grained gneiss 102 feet in 13 shifts during one week (February 19 to 26, 1887). Only the usual force of men were employed. Three Rand "Slugger" drills were used. The holes were charged with rackarock. A blast was fired in each shift.

When the tunnel, driven north from shaft 16, reached the rock in which the great run mentioned above had been made in the south heading from shaft 15, Denton, Breuchaud & Co., the superintendents for section 8, made an effort to surpass the record of their neighbors, to prove the merits of the system of tunnelling they had adopted. They succeeded in driving their heading 127 feet in a week (14 shifts), a progress which we believe has never been surpassed in similar rock. The trial was made during the week ending July 23, 1887. The contractors divided their working force into two 12-hour shifts, allowing to each two extra men to help in jacking up the drills and four extra muckers. During the whole week the work was never allowed to stop, only part of the men leaving the tunnel at a time for their meals. The crews of the drills worked enthusiastically to make the best record on the aqueduct, but the muckers, who were principally Hungarians, took very little interest in the matter and required constant supervision.

The measurements were kept carefully by Assistant Engineer Gaylord Thompson, of the Aqueduct Commission. On the invitation of the contractors, the technical journals sent representatives to watch the test, and published the results at the time.* The drills used

* See *The Engineering and Mining Journal*, July 30, 1887; *Engineering News*, August 6, 1887; *The Railroad Gazette*, July 30, 1887.

were No. 3 "Rattler" drills, 3⅝ inches in diameter by 8-inch stroke, which had been in constant service on the work since October 1885, all the repairs having been made in the contractors' machine-shop. The drill-holes were located as shown in Figs. 28, 29, and 30.

The compressed air was furnished by an 18" × 30" Rand Duplex compressor (class "B"), delivering 1325 cubic feet of free air per minute at 75 revolutions. The air-pressure, which at the reservoir was 80 lbs. per square inch, was reduced by passing through 1900 feet of 4-inch pipe, 1415 feet of 3-inch pipe, and 650 feet of 2-inch pipe, to 60 lbs. at the drills. The heading, the longest on the aqueduct, was ended at a distance of 3965 feet from the shaft.

The rapid progress made during the trial week was not found to be economical, nor is it likely that the speed attained could have been continued. According to the contractors' statements, it cost 10¢ more for powder, 25¢ more for coal, and 63 cents more for labor per cubic yard in this trial than was required for the ordinary method of working.

Messrs. Denton, Breuchaud & Co. have furnished us with the following details of this remarkable run:

TABLE I.

RECORD OF RUN MADE DURING THE WEEK ENDING JULY 23, 1887.

NORTH HEADING, SHAFT 16.

Date—July.	No. of Shot.	Commenced to Muck Out and Set Up.	Commenced to Drill.	Finished Drilling.	Commenced to Blast.	Finished Blasting	Remarks.
16	1	10.00 A.M.	11.30 A.M.	4.30 P.M.	5.00 P.M.	6.30 P.M.	Delayed in blasting by broken wire.
16	2	7.00 P.M.	9.30 P.M.	3.00 A.M.	3.30 A.M.	6.00 A.M.	After first blow air-pipe burst, which caused delay in blasting.
17	3	7.00 A.M.	9.00 A.M.	2.00 P.M.	2.30 P.M.	3.30 P.M.	Delayed 1 hour 20 minutes by air tank taking fire.
17	4	3.45 P.M.	7.00 P.M.	11.45 P.M.	12.00 P.M.	1.00 A.M.	
18	5	1.15 A.M.	3.15 A.M.	8.45 A.M.	9.00 A.M.	10.00 A.M.	Running smooth.
18	6	10.15 A.M.	12.30 P.M.	5.30 P.M.	6.00 P.M.	7.00 P.M.	Cut fired twice.
18	7	7.15 P.M.	9.30 P.M.	2.30 A.M.	3.00 A.M.	4.00 A.M.	Muckers struck, and 3 hours lost.
19	8	7.00 A.M.	9.30 A.M.	3.00 P.M.	4.00 P.M.	4.45 P.M.	
19	9	5.00 P.M.	7.30 P.M.	1.30 A.M.	2.00 A.M.	3.00 A.M.	
20	10	3.15 A.M.	5.30 A.M.	10.15 A.M.	10.45 A.M.	11.45 A.M.	Cut fired twice.
20*	11	12.00 M.	1.30 P.M.	6.00 P.M.	6.15 P.M.	7.00 P.M.	Everything running like clockwork at this time.
20*	12	7.15 P.M.	9.15 P.M.	2.00 A.M.	2.15 A.M.	3.30 A.M.	
21*	13	3.45 A.M.	5.00 A.M.	9.30 A.M.	9.45 A.M.	10.15 A.M.	
21	14	10.30 A.M.	12.00 M.	5.30 P.M.	6.00 P.M.	7.00 P.M.	Cut fired four times.
21	15	7.30 P.M.	10.00 P.M.	3.30 A.M.	4.00 A.M.	4.45 A.M.	Muckers quit and new crew organized.
22	16	7.00 A.M.	9.30 A.M.	2.30 P.M.	3.00 P.M.	4.00 P.M.	
22	17	4.30 P.M.	7.00 P.M.	1.30 A.M.	2.00 A.M.	2.45 A.M.	
23	18	3.00 A.M.	4.30 A.M.	9.00 A.M.	9.15 A.M.	9.45 A.M.	Record for week ends.

* These three shots were made inside of 24 hours.

Actual area of heading, 104 square feet. Progress, 12[illegible] feet. Two thousand and fifty pounds 60-per-cent aqueduct dynamite was used altogether for the 18 shots. Cubic yards excavated, 490. Dynamite per cubic yard, 4.2 pounds. Total number cars muck hoisted, 953. Working time, 14 shifts of 12 hours each. Average total feet of 2⅝-inch holes drilled per blast, 143. Average time to drill heading, 5¼ hours. Average feet drilled per hour for each machine, 13.6.

TABLE II.

SUMMARY OF RESULTS.

Length of heading driven, lineal feet	127
Actual area of heading in square feet	104
Cubic yards removed	490
Cars of muck removed	953
Number of blasts during 14 twelve-hour shifts	18
Average feet of 2¾-inch holes drilled per blast	143
Number of (3⅝-inch) machines in heading	2
Feet drilled per blast by each machine	71
Average time to drill heading, hours	5½
Amount of 60-per-cent aqueduct dynamite per cubic yard, pounds	4.2
Average air-pressure in heading, pounds per square inch	60
Average cubic feet of free air supplied to machine per minute	430

Force in charge of drilling per shift: 1 foreman, 1 nipper, 2 machine runners, 2 helpers, 2 jackmen.

Force employed in removing muck: 1 muck boss, 12 Hungarian laborers, 2 hammermen, 2 mule-drivers, 2 mules, 12 cars.

The mucking crew consisted of two hammermen or miners and twelve Hungarian laborers. The usual gang for ten hours' shifts had four Hungarians less. An extra mule and driver were used during the day shift, when the masonry was being laid in the tunnel.

Tunnelling through Soft Ground.—The most difficult piece of work involved in the construction of the new aqueduct was the excavation of the tunnel through the soft ground encountered 460 feet south of shaft 13.

The south heading was started from this shaft on June 1, 1885. It advanced, at the rate of about eighty feet per month, for 392 feet through good limestone rock (dolomite), which then became softer. On December 9, 1885, when the heading had reached a point 407 feet from the shaft, a fissure was encountered from which about 100 cubic yards of decomposed limestone, clay, sand, and dirty water poured into the tunnel, partially filling it for a distance of 125 feet. After three days' delay, when only clear water was flowing into the tunnel, the fissure was plugged with straw. The heading was advanced twenty feet further, until, on December 22, 1885, a second outpour, three times greater than the first, occurred, covering everything in the heading out of sight.

The work in the heading was temporarily abandoned, until the contractors had timbered the tunnel from the point where the soft rock commenced to the heading. The excavation of the tunnel was then resumed, the heading being driven and timbered to the beginning of the soft ground, 461 feet from the shaft. A strong timber bulkhead was built at the end of the heading and well braced by heavy hemlock "spreaders." While this work was being performed the bench was excavated to within 32 feet of the heading.

During the succeeding 59 weeks (February 13, 1886, to April 2, 1887) various efforts were made to close the fissure in the rock from the surface and to drive small drifts through the soft ground in front of the heading, but all without success.

After the bulkhead had been constructed, the soft material, which was liquid mud, con-

tinued, for several days, to force its way through the timbers. A small cave-in occurred on the surface, over the tunnel, and was followed in February 20, 1906, by a much larger one, about twenty-five feet east of the centre-line, directly in the line of a small stream which partly filled the hole with water. The second "cave-in" was supposed to be connected with the fissure in the limestone, from which the soft material had poured into the tunnel. After the stream had been diverted and the water pumped out of the hole, attempts were made to plug the fissure by throwing bales of hay, brushwood, logs and stumps of trees into the hole. This material, instead of closing the fissure, found its way eventually into the tunnel as the cave-in extended, and had to be brought to the surface again.

An effort was next made to reach the fissure from the surface and to line it with masonry. For this purpose a crib 12 by 12 feet in plan, made of square hemlock timbers, was sunk in the large cave-in east of the tunnel. At a depth of fifty feet the crib reached a layer of hardpan in the west side, which caused the crib to incline. A sheet piling was driven on the east side, and the crib finally rested on a plate of hardpan, and was prevented from sliding down.

After three weeks' work, costing about $[illegible], the work was abandoned. Two years later, when the tunnel had been completed, the crib and sheet piling were found to be full of earth.

Before making any further efforts to reach the heading, borings were made in the surface with a diamond drill to determine the character of the ground in front of the tunnel. It was found that at a point [illegible] feet east of the axis of the tunnel and extending [illegible] feet in front of the tunnel, there was a layer of soft material consisting of sand, gravel, clay and decayed rock, which had a depth of about [illegible] feet in the vicinity of the top of the tunnel. It started [illegible] against the timber [illegible] as it takes [illegible] hours and had to be [illegible].

After the [illegible] the next effort made was to [illegible] the soft ground in front of the [illegible] see Fig. [illegible] was commenced [illegible] the heading. After [illegible] advanced only twenty feet and had [illegible] as the soft material poured [illegible] removed. An attempt was made [illegible] with perforated [illegible]

The [illegible] 31, 32, and 33, which [illegible] large sums for collecting [illegible] square timbers being placed [illegible]

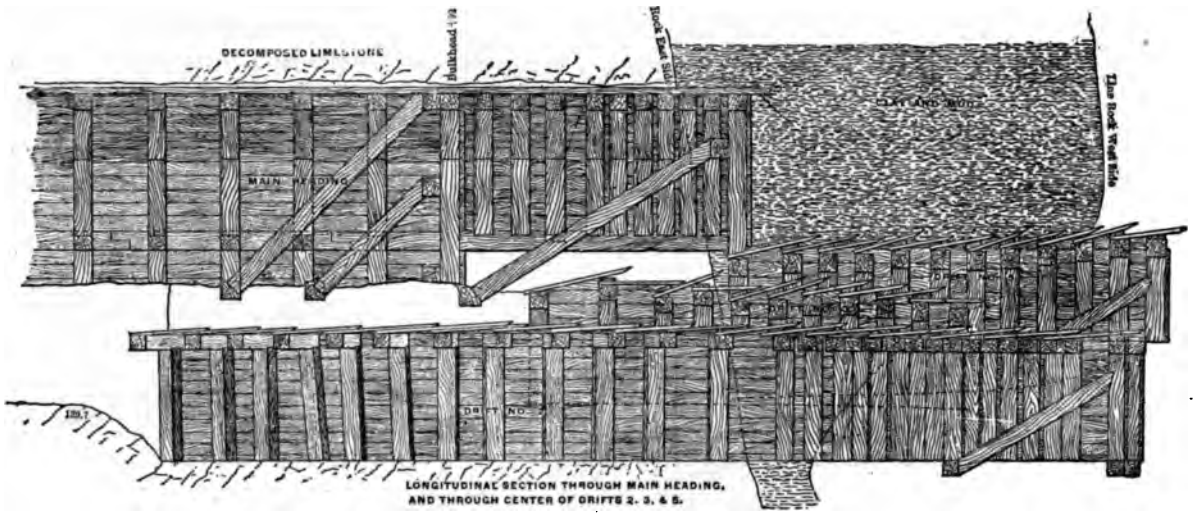


FIG. 32.

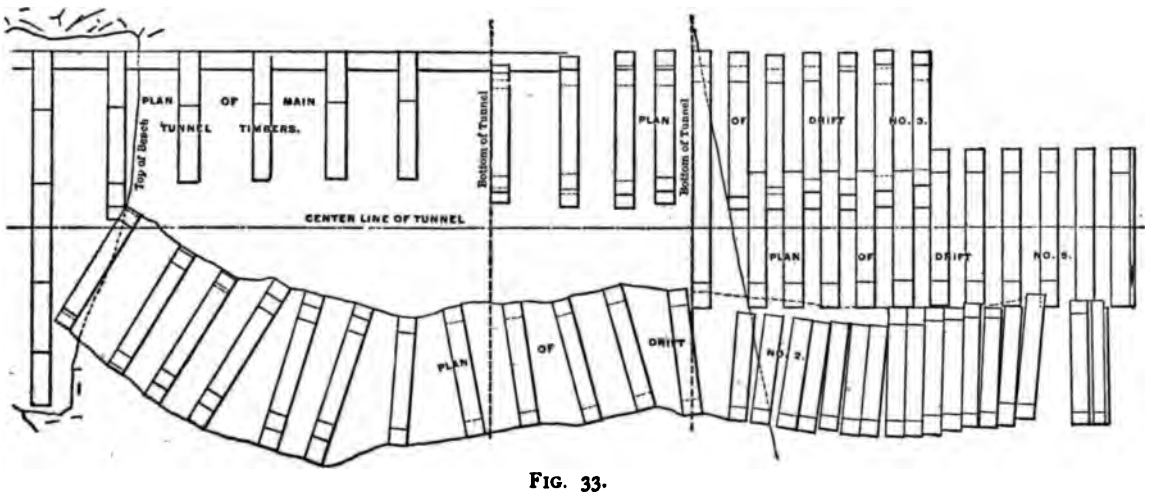


FIG. 33.

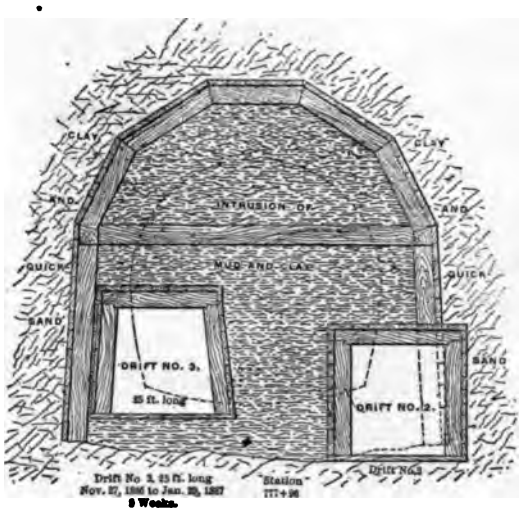


FIG. 34.

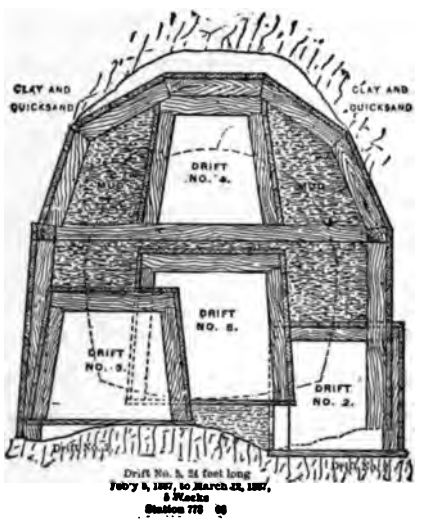


FIG. 35.

of five feet in the clear. After being driven in seven weeks [illegible] feet through decomposed limestone and [illegible] feet through hard ground which made the timber track [illegible] had to be abandoned for the same reason as No. [illegible]. The great difficulty experienced was caused by the quantity of water amounting to [illegible] gallons per minute which entered the tunnel from the soft ground. At the end of the month there was no indication of [illegible] diminishing.

After the failure of drift No. [illegible] the work was practically stopped for about ten weeks. It was then decided to complete the cross drift [illegible] before attempting to advance any further. By December [illegible] the drift had at about [illegible] feet from the shaft, which was [illegible] the total [illegible] had been driven a year previously.

During the term four months three drifts [illegible] were driven in front of the bulkhead but had to be abandoned.

Drift No. [illegible] was commenced [illegible] and was advanced [illegible] feet in nine weeks.

Drift No. [illegible] in the bottom of the [illegible] was [illegible] in eight weeks.

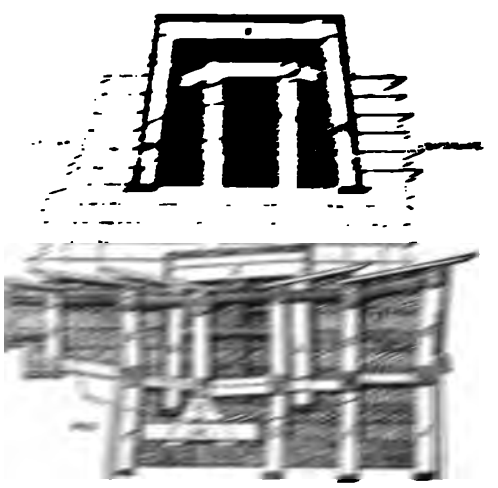
Drift No. [illegible] in the bottom of the bulkhead was [illegible] feet in six weeks.

The work of advancing the [illegible] ground [illegible] series of unsuccessful experiments [illegible] of the [illegible] the [illegible] amounting to [illegible] water [illegible] water [illegible] water [illegible].

The [illegible] section was [illegible] feet [illegible] thick. The [illegible] of the [illegible] which the [illegible] and [illegible]

[illegible] feet [illegible] the [illegible] water [illegible] the [illegible] water [illegible] the [illegible] water [illegible] the [illegible] water [illegible].

[illegible] feet [illegible]



[illegible]

feet were excavated, by means of a top drift, from the top downwards, and the remaining 60 feet, by means of a bottom drift, from the bottom upwards. The latter plan was found to be by far the better of the two. A timber bulkhead had to be maintained at the end of the excavation to keep the soft material from pouring into the tunnel. The general method adopted for excavating the tunnel by means of a bottom drift was as follows:

First operation. After a small drift had been driven a distance of about 25 feet, at the bottom of the tunnel and in the centre, it was enlarged to a size of six by eight feet (Fig. 36).

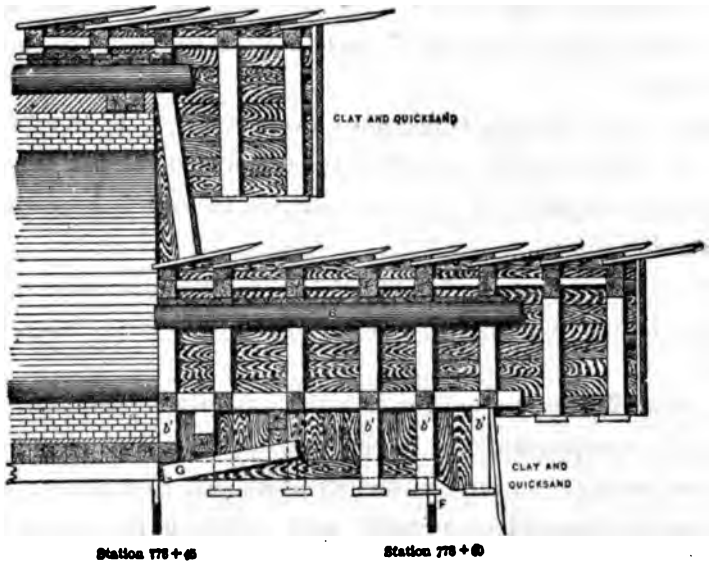


FIG. 37.

Second operation: Widening the drift (Figs. 36 and 37). Two bearing-bars (*B B*) about twenty inches in diameter and twenty feet long, were placed under the caps of the drift and supported by posts resting on longitudinal sills (*b b*). By means of blocks and wedges the bars (*B B*) were made to support the caps of the drift. The operation of widening the excavation wasthen commenced by side-drifting, additional bars (*c c c c*), supported by posts (*d d d d*), resting on longitudinal sills (*e e e e*) being placed.

Third operation: Constructing the timber platform (Figs. 36, 37, and 38). For this purpose a trench 10–15 feet wide by 15–18 feet long was excavated in the bottom of the tunnel. Before commencing the excavation, sheet-piles were driven on both sides of the trench and in front of it, to prevent the mud upon which the platform had to be placed from being disturbed. The water was pumped from a small sump in front of the trench.

As the excavation proceeded posts (*e′ b′*) resting on mud-sills were placed to support the sills (*b b e e*). The first course of 12″ × 12″ yellow-pine timbers, laid longitudinally, in lengths of about fifteen feet, was then placed. Where the posts interfered, the timbers were temporarily omitted. They were finally placed by substituting for each post a cross-sill (*H*), resting on the platform, and blocking between said sill and the longitudinal sill (*b*).

Fourth operation. After a section of the platform was completed the cross-beams

(*JJ*, Fig. 38) were placed, about three feet apart, and supported by posts resting on the timber platform. By means of blocking and wedges the beams (*JJ*) were made to sustain the bearing-bars (*BC*). The first set of posts and sills (*d d*, *b b*, *c c*) were then removed, and the masonry invert and two feet of the side-walls were built, the beams (*JJ*) being supported by

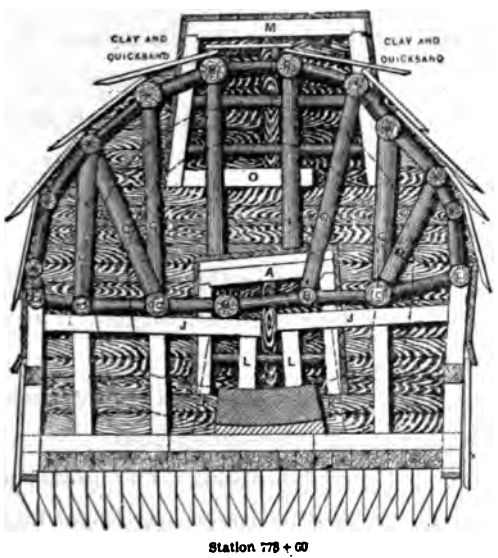


FIG. 38.

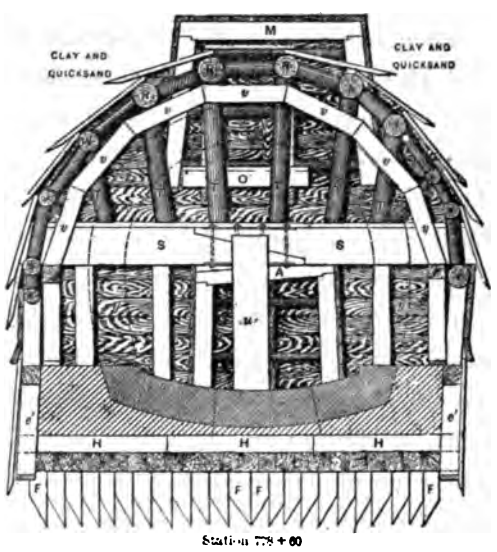


FIG. 39.

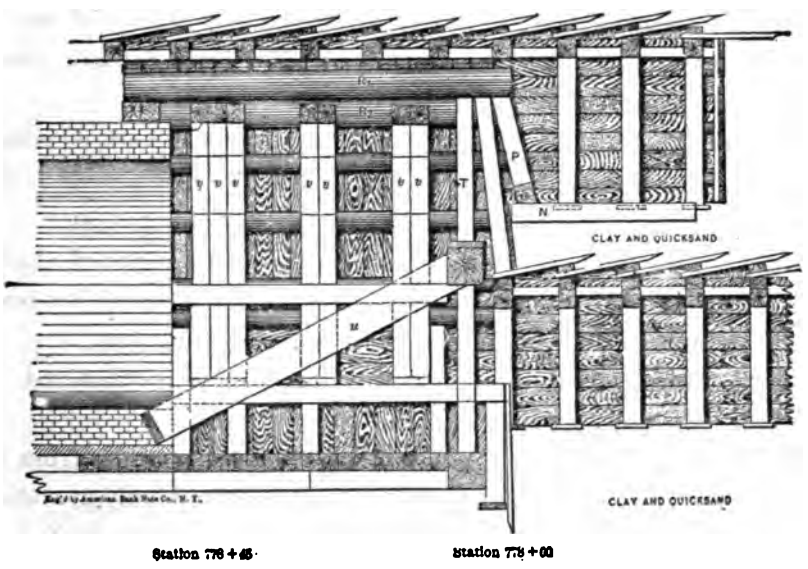


FIG. 40.

posts resting on the masonry, as the first set had gradually to be removed. While the invert was being constructed the top heading *M* (Fig. 39) was advanced 15 feet.

Fifth operation; Placing of the crown-bars R_1, R_2, etc. (Figs. 38, 39, and 40). They were supported at one end by the completed masonry arch * and at the other by posts. The two bars R_1 and R_2 were placed first, their heading ends being supported by posts *P* resting on a cross-sill *O*, which was laid on two longitudinal sills *N* in the heading drift. The excavation

* After the first set, both ends of the crown-bars were supported by timbers.

was then widened on both sides and the remaining crown-bars were placed and supported by struts (*Q*) resting on the bearing-bars (*Bt*). A large cross-beam (*S*) 24″ × 24″ by 26 feet long, was then placed against the bulkhead, in front of the invert, and supported by posts. By means of strong rakers, *u*, it was made to sustain the thrust of the soft material against the bulkhead. It was also made to support the crown-bars by means of the posts (*T*). When a section of the tunnel had been completed the beam (*S*) was sawed off and removed, the ends being left in the masonry.

The crown-bars were finally supported by the block-timbering *v*, placed two to three feet apart as required.

The masonry was now completed. No attempt was made to remove the crown-bars. The block-timbering was also generally left in position and surrounded by masonry.

It required sixty weeks' work to advance the tunnel 85 feet in the manner described above, the excavation and the laying of the masonry proceeding simultaneously. The average progress was, therefore, only 1.4 feet per week.

To expedite the work, through the soft ground, an additional shaft, 13A, was sunk 644 feet south of shaft 13 and a heading started northward towards the soft ground.

The work of sinking shaft 13A was commenced in December 1886. The north heading was started from the foot of the shaft in June 1887. It was driven 106 lineal feet, 28 feet being in soft ground (clay and quicksand).

The engineers who directed the work were Mr. Alfred Craven, Division Engineer, and Mr. C. P. Bonnett, Assistant Engineer, in immediate charge. The work was performed by Paige, Cary & Co., superintendents (sub-contractors) for O'Brien & Clark, who had the contract to construct sections 6 to 10 of the new aqueduct.

Mr. J. P. Carson, E.M., has published a full account of the work described above, and has given other interesting details about the construction of the new aqueduct, in the Transactions of the American Institute of Mining Engineers for September 1890.

Our description of the tunnelling through the soft ground south of shaft 13 (probably the most difficult piece of work of its kind performed in this country) has been taken from this source. Cuts 31 to 40 (incl.) are used by Mr. Carson's permission.

In the north heading from shaft 14 some soft ground was encountered, but it was not as wet and heavy as that described above.

Tunnelling through Sand and Gravel in the South Heading from Shaft 17.—In the tunnel driven south from shaft 17 the solid rock stopped suddenly at station 1067 + 63. Wet sand and gravel flowed into the heading, filling it completely for some distance back. This soft material was found to be contained in a pocket in the gneiss rock, having a length on the axis of the tunnel of about 135 feet. After allowing the sand and gravel some time to settle, the heading was cleaned out and the tunnel driven for 43 feet by the English or bar-timber system, which has been fully described on page 155.

While performing this work a serious accident occurred in the afternoon of September 9, 1887, resulting from the collapse of the timber bulkhead (see Plate 25 and Figs. 41 and 42), which retained the soft material in front of the tunnel. At the time a space 16

PLATE 25.

TIMBER BULKHEAD NEAR SHAFT 17.

feet long, 22 feet wide, and 25 feet high had been excavated in front of the completed arch and was nearly ready for the masons. The cave-in occurred without the slightest warning and caused a greater concussion of the air than an ordinary blast. All the lights were extinguished. Of the fourteen laborers engaged in the tunnel at the time, three were caught between the falling timbers and suffocated by the sand flowing into the tunnel.

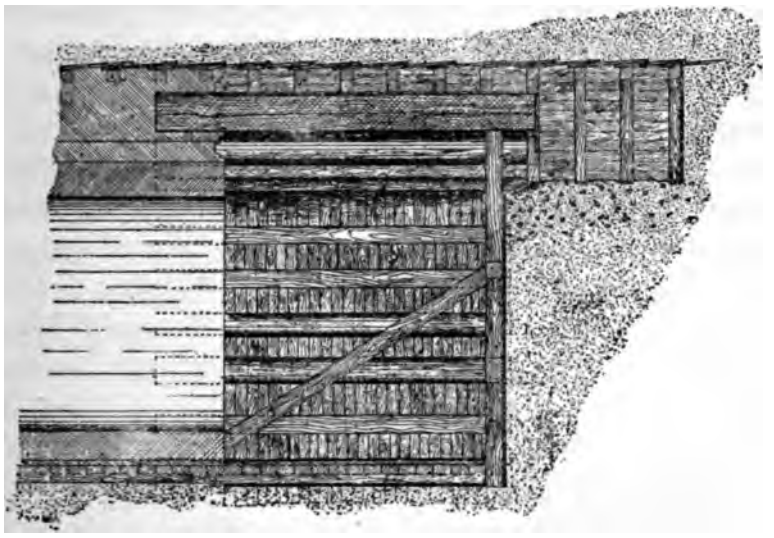


FIG. 41.*—LONGITUDINAL SECTION OF SOUTH HEADING, SHAFT 17.

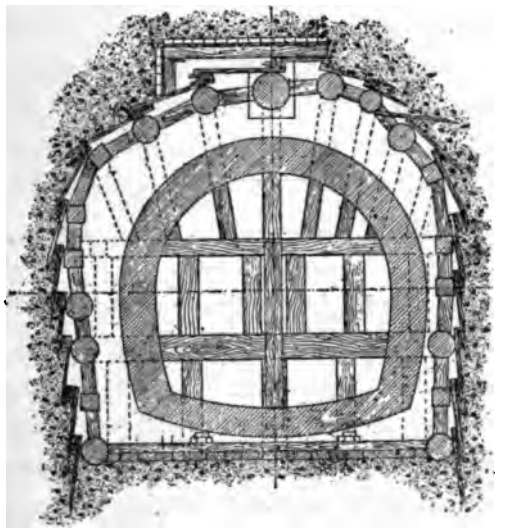


FIG. 42.*—SECTION AT END OF MASONRY.

The whole timber section seemed to fall together, the crown-bars breaking as their forward ends struck the bottom. Those on the east side fell to the bottom, while the west bars were partially held up. The photograph shown on Plate 25 was taken twenty-four hours before the bulkhead collapsed. The accident is supposed to have been caused by removing material in front of the sill of the bulkhead which started the sand running.

The Tunnel under the Harlem River (see Plate 80) was driven entirely from shaft 25. The preliminary borings made by the Department of Public Works indicated a pocket

* Figs. 41 and 42 by permission of the "Engineering News."

of soft rock in the bed of the Harlem River near the west bank. The tunnel was located at a depth which was supposed to insure a roof of at least 30 feet of solid rock. As the borings left considerable uncertainty concerning the compactness of some of the rock, the specifications required the contractors to drive a small test-drift, 7 feet wide and 6 feet high, as far as the pocket of soft rock. If the rock were found to be satisfactory, the test-drift was to be enlarged to the size of the aqueduct tunnel. If the contrary proved to be the case, the drift was to be abandoned and shaft 25 was to be sunk to such a depth as might be determined by the engineer.

In accordance with this provision a test-drift was started from shaft 25 on October 30, 1886. Instead of giving the drift a cross-section of 6 ft. × 7 ft., the contractors were permitted to make it a semi-circle, 14 feet in diameter—the size of the regular heading—in order to avoid the expense of subsequently enlarging the drift. For about 300 feet the drift passed through solid gneiss rock which was almost perfectly dry. Softer rock was then encountered. On December 15, 1886, when the drift had advanced 308 feet from shaft 25, test-holes drilled by the workmen in advance of the excavation admitted water, under great pressure, and sand, which soon closed the holes. The work of driving the test-drift was stopped until additional test-borings could be made with a diamond-drill. A wooden bulkhead was constructed at the breast of the drift, to keep the soft rock from being forced in by the great outside pressure.

The drilling of the test-holes was commenced on December 28, 1886. Two horizontal and four inclined holes were bored from the drift, and two vertical holes from platforms in the river. These test-holes, as also those made by the Department of Public Works, are shown on Plate 80. It was found that the soft pocket, instead of terminating about 30 feet above the drift, as had been supposed, continued for about 75 feet below it. In front of the bulkhead the rock was entirely disintegrated for about 26 feet. Beyond this point hard rock was found, but it contained seams full of water having the whole pressure due to the river.

The important question for the engineers to decide was whether to attempt to drive the drift across the short distance where the ground was really bad, or whether to abandon it and to commence another tunnel at a lower depth. The first decision was in favor of the former alternative. Orders were given to the contractors to enlarge the test-drift to the full size of the tunnel and to start a "heading" from shaft 24. Some unsuccessful negotiations were had with the owners of the patents of the "freezing process" with a view of adopting this method of passing through the decomposed rock. While these parties were ready to make the attempt, they were unwilling to guarantee success. The contractors were very much opposed to driving the drift any further, as they could not have attempted the work without providing a large pumping-plant. After the matter had been fully discussed, it was finally decided to abandon the drift and to sink shaft 25, 155 feet.

The work of deepening the shaft was commenced on April 4, 1887. The new tunnel under the river was begun with an invert grade of − 307.5, on September 6, 1887, and reached shaft 24, on the other side of the river, by April 3, 1888. For the whole distance

good. [illegible] rock was met [illegible] for the first [illegible] feet and then [illegible] limestone.

Very little water had to be pumped from shaft No. [illegible] and the tunnel. During the sinking of the shaft the water was [illegible] commenced a No. [illegible] Dearman pump [illegible] diameter, stroke [illegible] inches and capacity [illegible] raised the water from the sump of the shaft [illegible] Harlem River through the blow-off [illegible] inches, water-cylinder [illegible] inches diameter [illegible] and capacity [illegible] per stroke. The pumps were [illegible]

The laying of the masonry [illegible] and was completed in September of that year. [illegible] in equal proportions was used [illegible] the aqueduct under the Harlem River [illegible] of brickwork [illegible] the original plans a lining of [illegible] points where fissures in the rock [illegible] the depth at which the tunnel was finally [illegible]

To prevent water from the [illegible] through the masonry when the aqueduct is empty a small drain was constructed [illegible] the side of the aqueduct. [illegible] the conduit is empty [illegible] through the tunnel.

Tunneling through the Bad Ground South of Shaft 25. [illegible] of shaft 25 in December [illegible] about twelve inches wide was [illegible] feet south of the shaft [illegible] the tunnel [illegible] attempted to [illegible] of soft material [illegible] the [illegible]

The work was [illegible] heavy [illegible] was [illegible] the [illegible]

A small drift [illegible] about [illegible] inches in diameter [illegible]

vertical props from the floor of the drift. Four more bars—two on each side of the central log—were put through the débris in like manner.

The top lagging of the small drifts was blocked up from the bars. In this manner a roof of crown-bars, properly lagged, was formed above the space required for the masonry arch.

The work of excavating the bench was then commenced. As rock was removed by light blasts, heavy frames of 12″ × 12″ hemlock timbers were erected to support the bars. Smaller logs were placed on top of the caps between the principal bars, to prevent any stones from falling. The principal bars were not moved forwards as the heading progressed, but were left in place, new bars being used. On the west of the tunnel the posts of the timber frames rested on small blocks placed in the bottom of the tunnel, and were capped by long longitudinal timbers on which the lower ends of the braces bore. There was a great pressure against the timbers on this side, close lagging being required to keep the soft material in the seam from moving. On the east side of the tunnel the rock was much better at the start, and the caps in many cases rested on that side only in steps cut in the rock.

The principal soft seam crossed the axis of the tunnel at an angle of about 6°, so that in a distance of about 150 feet the bad ground changed from the west to the east side of the tunnel. Besides the principal soft seam, very thin layers of a soft, slippery material between the strata of solid rock tended to produce slips.

The original fall of rock extended for about 30 feet. The loose rock above the bars was removed as much as possible and replaced by small logs. After this bad spot had been passed, the rock was excavated by light blasting about 10 feet in front of the timbering, which was continued, but without crown-bars, as the heading advanced.

Caps and braces resting on sills, as shown on Plate 64, Fig. 2, were put in the heading. As the bench was removed, strong posts were put under the sills. The very heavy ground extended only for about 50 feet, but timbering with bents about 4 feet apart had to be continued for 500 feet further. About 540 feet south of the shaft a second fall of about 60 tons of rock occurred on May 29, 1886, right after a blast, and knocked down one of the timber posts. Four sets of timbers were crushed by the rock, the fall extending for about 20 feet.

According to the specifications, the engineer ordered timbering wherever he thought necessary, but the manner in which this work was done was determined by the contractor, who was paid for an additional area of excavation in such places. In the bad ground south of shaft 30 the contractors commenced by placing timber bents, made of 12″ × 12″ hemlock timber, about 4 feet apart, although they were notified by the engineer that this timbering was considered insufficient. Soon some of the caps broke under the heavy pressure of the material resting on them. Additional bents of timber had, therefore, to be placed, until in some places the bents formed almost a continuous timbering. Props were also put in many cases under the centre of the caps. Although the caps were placed originally 6 inches above the space required for a 20-inch ring of brickwork, many of them sagged into this space, and had to be removed before the masonry could be laid, an operation involving

commence operations until March 21, 1889. They completed their contract by September 6, 1889.

Breuchaud, Pennell & Co. commenced laying masonry near the south end of their work. The removal of the timber, which interfered with the laying of the masonry, involved considerable danger, and could only progress very slowly. A large number of the important timber pieces were left in the masonry, the lagging and small logs, etc., being removed, except in a few spots, where the side-pressure of the soft rock made this unadvisable. Most of the caps were removed, but the side-braces were generally left in the masonry. The manner in which the aqueduct was constructed in the iron-lined portion is shown on Plate 104.

Each iron ring was put together in ten segments, the upper ones being made shorter than the others, to facilitate putting them in place. Plate 26 shows one of the iron rings, erected on the ground.

The longitudinal joints of the ironwork were made with lead gaskets, and also with a filling of a rust-joint (iron shavings mixed with sal ammoniac and water). The circumferential joints were only filled with Portland cement. The rings were made with "hub and spigot joints." This allowed some play in fitting the rings together, which was an important consideration on account of the many obstructing timbers, etc. The iron segments were given two coats of P. & B. paint before being shipped from the foundry.

The iron lining was backed by 18 inches of brickwork, the space between the brickwork and the rock being filled as perfectly as possible with rubble masonry. A considerable amount of timber had to be left embedded in the masonry, as already stated. There were also some loose rocks which could not be removed without danger, and open seams which were inaccessible to the mason. To remedy these defects and insure a solid block of masonry all around the iron lining, grout-holes had been bored in the iron lining and closed by screw-plugs. From these holes pipes which had been left in the masonry led to open seams and loose rock. After the iron-lined section had been completed, grout composed of Rosendale cement mixed with an equal quantity of sand was pumped through the holes in the iron lining.

Shaft Twenty-five, from which the tunnel under the Harlem River was driven, involved so much special construction that a detailed description may be of interest. The shaft, which is the largest and deepest on the new Croton aqueduct, is located on a bluff on the west side of the Harlem River. Its cross-section was made 16.5 × 33.0 feet, in the clear of timbers and rock, in order to provide sufficient room for two wells 12 ft. 3 in. in diameter, one forming part of the aqueduct, and the other serving as a pump-well for the bailing-buckets used in emptying the siphon under the river.

The shaft was sunk originally only 252 feet, the tunnel under the Harlem being started with an invert grade of — 152.50 The attempt of tunnelling at this elevation had to be abandoned (see page 160). Shaft 25 was sunk 155 feet deeper (making the total depth from the surface of the ground to the bottom of the pump-well 426.5 feet), and the tunnel was commenced again with an invert grade of — 307.50.

Plate 82 shows the manner in which shaft 25 was built up. It contains in addition

to the two wells mentioned above a 3-foot manhole-pipe, in which a wrought-iron ladder, reaching from the bottom to the top of the shaft, is placed, and also the stem of a gate which closes the connection between the two wells at the bottom of the shaft.

The aqueduct-well begins about 6 feet below the invert of the tunnel, forming a sump into which any matter carried through the conduit to shaft 25 can settle. The well is lined with cast-iron plates $1\frac{1}{4}$ inches thick (securely bolted together and anchored by rods to the brickwork) from the bottom of the sump to the spring-line of the arch of the tunnel. Where the invert of the tunnel joins the well, granite stones are placed in order to secure strength and hardness. From the spring-line of the tunnel arch (elevation -302.25) to elevation -67 the aqueduct-well is lined with two feet of brickwork, which is backed with rubble masonry to the sides of the excavation.

As shaft 25 was located near the side of a bluff, some apprehension was felt that considerable leakage through the seams of the rock might occur when the water, which has sufficient head to rise to elevation 130, was admitted. In order to insure great water-tightness the aqueduct-well was lined with iron from elevation -67 to the top. This lining consists up to elevation 5 of cast-iron hub and spigot rings $1\frac{1}{4}$ inches thick and 3 feet deep. The joints of the rings were filled with Rosendale cement-mortar, the cement and sand being mixed in equal proportions.

At elevation 5, two 48-inch blow-off pipes (one from each well) were laid in a small drift from shaft 25 to the Harlem River. A 20-inch drain-pipe, serving to discharge the water percolating into the tunnel on Manhattan Island, when empty, into the Harlem River, was laid around the north side of the shaft and connected with one of the blow-off pipes. The arrangement of the blow-off pipes and the drain-pipe is shown on Plates 81 and 82.

The tunnel on Manhattan Island begins at shaft 25 with an invert grade of 13.50. Where this tunnel leaves the shaft a rectangular chamber ($16\frac{1}{2}$ ft. $\times$ $16\frac{1}{2}$ ft. $\times$ $16\frac{1}{2}$ ft.) lined with iron plates was constructed in the aqueduct-well. The plates, $1\frac{1}{4}$ inches thick, were bolted together, sheet lead $\frac{1}{16}$ inch thick being placed in the joints.

The tunnel itself is lined with iron rings ($1\frac{1}{4}$ inches thick, bolted together in segments) for a short distance.

The roof of the rectangular chamber mentioned above is at elevation 27.96. From here to elevation 32.67 the aqueduct-well has an iron lining. It is terminated at this elevation by a roof of iron plates to which a manhole casting is connected. Near the top of the well (elevation 28.5) a connection is made with a 36-inch supply-pipe, which leads the water from the new aqueduct to the High Bridge pumping station.

Two manhole castings (having elliptical openings 5ft. 3 in. $\times$ 4 ft. 5 in.), one placed above the other, and a small chamber constructed between the castings, form a continuation of the aqueduct-well to elevation 56.46. Above the upper manhole casting a well 12 ft. 3 in. in diameter, lined with brickwork two feet thick, is carried to elevation 77.63, from which point it is gradually contracted by corbelling to the size of a large top-casting, provided with a manhole, which terminates the well at the floor of the masonry head-house constructed over shaft 25. A 12-inch drain-pipe, placed at elevation 81, carries off any water which may leak into the well when the shaft is under pressure.

The pump-well is 15.62 feet deeper than the aqueduct-well. A passage (20 × 30 inches in cross-section), which can be closed by a phosphor-bronze gate, connects the two wells. The pump-well is lined with iron from the bottom to elevation 32.67, where the first of two sets of manhole castings (similar to those of the aqueduct-well) is placed. The bottom of the well is filled with about six feet of solid brickwork, part of which is laid as an inverted arch 36 inches deep. A granite paving is placed on top of this brickwork.

From the paving to elevation — 122 the iron lining of the well consists of cast-iron hub and spigot pipes, 12 feet 3 inches in diameter, 3 feet deep, and 1¾ inches thick. From elevation — 122 to + 4 the iron rings are only 1¼ inches thick. The joints of the iron rings are filled with Rosendale cement-mortar. The rings are backed with 2 feet of brickwork and then with rubble masonry to the sides of the shaft.

At elevation 4 one of the 48-inch blow-off pipes mentioned above is connected to the pump-well. In front of the blow-off pipe a cast-iron catch-basin, into which the bailing-buckets empty their contents when "tripped," is constructed in the well. From the top of this basin to the first set of manhole castings (elevation 32.67) the well is carried up in the same manner as below elevation 4.

Two sets of manhole castings are placed, one above the other, in the pump-well at the same elevations as in the aqueduct-well. As two bailing-buckets are used, four manholes, two for the hoistway of each bucket, are provided. A small working chamber is constructed between the two sets of manhole castings to give the workmen the necessary room for handling the lower manhole-covers.

Two small phosphor-bronze conical valves (see Plate 82), fastened to the same stem and operated from the floor of the head-house, serve (when the pump-well is being emptied) to discharge any water which may have collected above the manhole-covers. A similar arrangement was provided for the aqueduct-well. On the pump-side the stem consists of a brass pipe, 3 inches in diameter, which is screwed through both valves and is kept open to prevent a vacuum from being formed in the pump-well. The pipe extends above the hydraulic grade.

At each set of manhole castings an inverted brick arch, 4 feet deep, was built across shaft 25 (see Plate 81) from rock to rock, to resist the upward pressure of the water.

The pump-well is continued above the upper manhole casting, 12 feet 3 inches in diameter, without any iron lining, to elevation 85, where an open chamber, 14 × 16 feet in plan, is constructed. Here the hand-wheels and gearing for operating the large gate at the bottom of the shaft, and also a 36-inch stop-cock for the supply leading to the High Bridge pumping station, are placed. The walls of this chamber are coped with granite stones, 12 inches thick, at the level of the floor of the head-house of the shaft.

The bailing-buckets are shown on Plate 107. The buckets, which are made of boiler-iron, are 4 feet in diameter and 14 feet deep, each having a capacity of 1390 gallons. A flap-valve, opening upwards, placed in the bottom, permits the water to fill the bucket when it is being lowered, but closes when the bucket is raised. A sliding gate, serving to discharge the water, is placed in the side of the bucket near the bottom. It is connected by rods with a trip-bar, fastened to the top of the bucket. This bar is moved

when the bucket reaches the catch-basin at the blow-off pipe by a tripping-post placed in the well, and opens the discharge-gate.

The guides for the buckets are made of 6″ × 8″ yellow-pine timbers, which are fastened to iron brackets, bolted, about 9 feet apart, to the iron lining. The bailing-buckets are lowered and raised by means of a large high-pressure hoisting-engine, having two cylinders 25 inches in diameter and 60 inches stroke. (See Plate 84.)

An Otis hoisting-engine (see page 224), having two cylinders 10 inches in diameter by 12 inches stroke, and two drums, is placed on a masonry foundation near the aqueduct-well. It serves for lowering and raising an ordinary iron hoisting-bucket in this well (when empty) for inspection and repairs. This engine was used by the contractors during the construction of the work, and was subsequently bought by the Aqueduct Commissioners, and made part of the permanent plant at shaft 25. The two hoisting-engines described above are supplied with steam from four horizontal tubular boilers, 66 inches in diameter and 16 feet long, arranged in pairs, only one pair being required at a time. The boilers were placed near shaft 25 in a temporary frame building (about 53 × 53 feet) having a rubble and concrete foundation.

The bronze gate placed at the bottom of the shaft, to close or open the connection between the two wells, is shown on Plate 105. Its stem consists of wrought-iron bars ($3\frac{1}{2} \times 3\frac{1}{2}$ inches for the lower portion and $3\frac{3}{4} \times 3\frac{3}{4}$ inches for the upper part) in sections securely bolted together. This stem and also a wrought-iron ladder are placed in the 3-foot manhole-well, formed of cast-iron flange-pipes and extending from the top to the bottom of the shaft. The top of the manhole-well is closed by a suitable cover, which is provided with a stuffing-box, through which the gate-stem passes. By means of a hand-wheel and proper gearing (see Plate 106) four men can start the gate, only two men being required to keep it moving.

Laying the Masonry of the Conduit.—The specifications required the contractors to keep the laying of the masonry within 500 feet of the end of the completed tunnel. In many cases, however, the masonry was not commenced until the tunnel had been excavated between two adjacent shafts.

In building the conduit according to the "horseshoe cross-section" (see Plate 60), while the tunnel was still being driven, the method adopted was as follows:

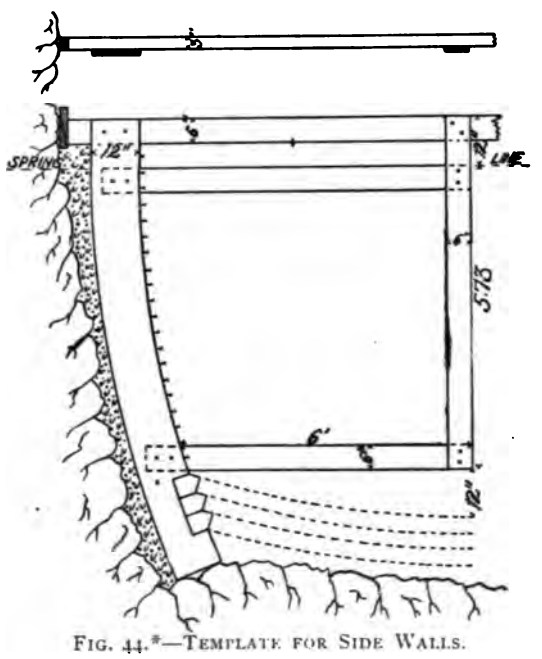


FIG. 44.*—TEMPLATE FOR SIDE WALLS.

The side-walls were built first and carried forward to within two hundred and fifty feet of the end of the completed tunnel. The arch was constructed next, but kept about five

* By permission of "The Engineering Record."

hundred feet from the point where blasting was still in progress. After the side-walls and arches, approaching each other from adjacent shafts, had met, the invert was laid from the meeting-point in both directions back to the shafts.

In building the side-walls the rubble backing was usually laid first, and then the brick lining. The bricks were laid to lines stretched between templates (see Fig. 44) placed 30–35 feet apart. The templates were nailed to cross-beams which were placed across the tunnel and wedged firmly. Line and grade were given by the engineers on

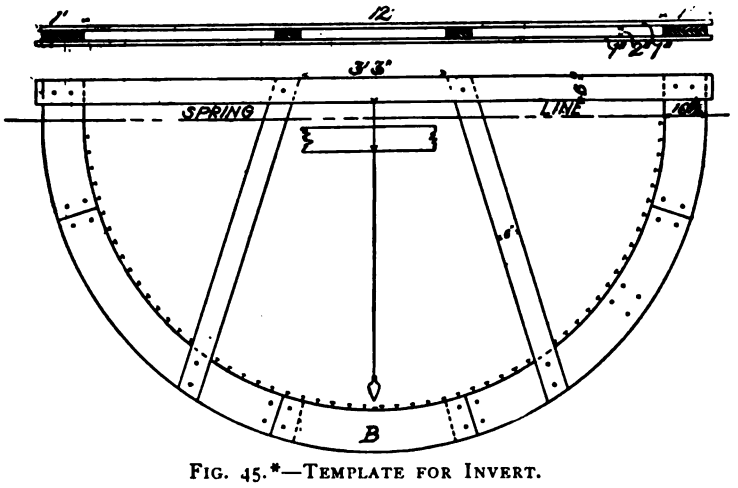


FIG. 45.*—TEMPLATE FOR INVERT.

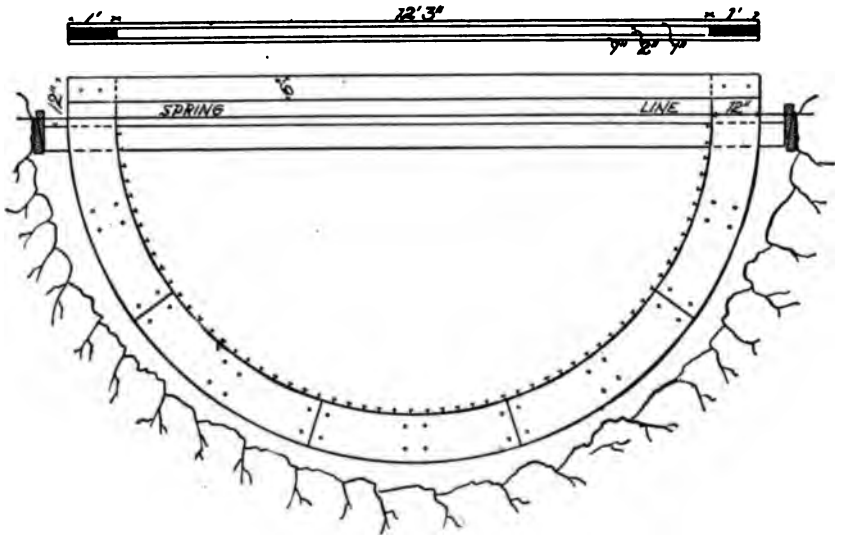


FIG. 46.*—TEMPLATE FOR INVERT.

the cross-beam before the templates were set. The position of the special bricks at the corners made by the invert and side-walls was determined by the shape given to the lower part of the template. Nails driven on the inner side indicated the position of the joints.

The side-walls were usually carried up about one foot above the spring-line of the arch.

For the circular conduit the invert templates were made for the whole lower half-circle.

Figs. 45 and 46 show the templates used respectively on sections 10 and 11.

* By permission of "The Engineering Record.

The cross-beams to which the templates were fastened by clamps consisted, in section 10, of two pieces of 3″ × 6″ scantling which were held together at the centre of the tunnel by iron clamps and wedged at their ends (see Fig. 47).

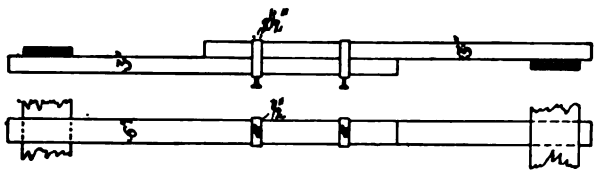


FIG. 47.—CROSS BEAM.

The invert-templates in section 11 were made only 10½ inches wide, although the standard thickness of the brick lining was 12 inches, in order to facilitate the moving of the templates by having 1½ inches clearance between the forms and rubble.

In building the arches the centring and scaffolding was supported by put-logs (cross-beams) placed about four feet apart, in holes left for that purpose in the side-walls. The put-logs were usually 6″ × 8″ wooden beams, laid flatwise; but in some sections iron rails were used for this purpose. Two longitudinal beams were laid upon the put-logs and served to support the centres which were placed about four feet apart and adjusted to the

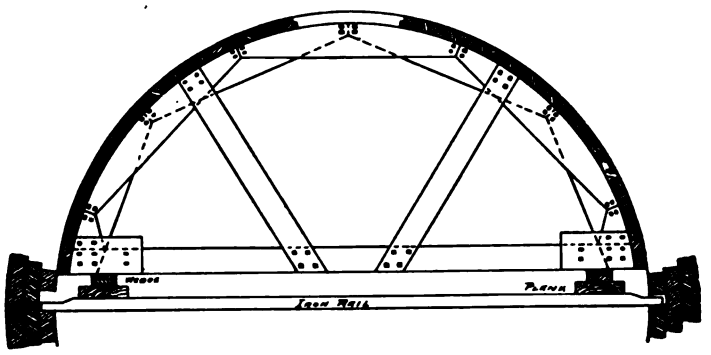


FIG. 48 —CENTRE FOR ARCH.

proper height by counter-wedges. Fig. 48 shows the style of centres used for the circular aqueduct. On section 6 the contractors used a centring of iron.

The lagging on top of the centres consisted usually of strips 2 inches by 2 inches by 16 feet long. In some cases, however, the lagging was made of the width of one course of brick and one joint, to assist the masons in keeping the courses of brick in line.

In constructing the arch the whole force of bricklayers would work on one side of the arch, until they had laid six to eight courses. They would then move to the other side, while the stone-masons would lay the backing. The work would be carried up in this manner, on each side to within twelve inches of the crown.

The arch would then be keyed, the masonry at the crown being supported by block-lagging (see Fig. 48) two feet by one foot. The keying of the brick and rubble work was usually completed over one board of the block-lagging before the next one was placed.

The scaffolding for the masons was supported first on the put-logs and later (when the higher courses of the arch were being laid) on the chords of the centres.

The mortar was mixed dry on the surface and lowered in cars on the cages. It consisted usually of American cement and sand, mixed in the proportion of one part of the former to

two parts of the latter. Where the tunnel was very wet or where great strength was required Portland cement was used.

The dry mortar was mixed in the tunnel with water in suitable boxes. When the arches were being built, the mortar-boxes were supported on timbers at the end of the centring. The mortar was shovelled into pails, which were placed on a small car (about one foot by four feet) that was shoved to the point where the masons were at work. The car ran on a track (consisting of ten-inch boards to which two half-inch round irons had been fastened as rails), which was placed on the chords of the centres.

The centres were usually allowed to stand for forty-eight hours after the arch had been keyed. After the centring had been removed the put-log holes in the side-walls were filled with brickwork.

The amount of bricks required was about 5,212,000 per mile for the horseshoe section and 4,338,000 for the circular conduit.

Making Brickwork Impervious to Water.—The masonry conduit "under pressure" (from Mosholu Avenue, in the Annexed District, to the One Hundred and Thirty-fifth Street gate-house, on Manhattan Island) forms a bold feature of the new aqueduct, which is without precedent. This inverted siphon, having a length of about 7 miles, is subjected for the greater part to a pressure due to a "head" of more than 100 feet of water. If the water were not confined to the tunnel, it would rise in many places (especially on Manhattan Island) through fissures in the rock to the surface and would cause much damage. It was considered important to treat the brickwork of this portion of the aqueduct with some preparation which would reduce the outward percolation to a minimum.

Elaborate experiments were made during many months to find the best manner of making brickwork impervious to water at a reasonable cost. The details of these investigations have been published by Mr. A. W. Hale, the Assistant Engineer in charge of the experiments, in the *Engineering News*, January 3 and 10, 1891. It was found that one or more coats of fine Portland cement (mixed with water and applied with an ordinary brush) increased the imperviousness of the brickwork largely, at a minimum cost.

Three coats of Portland cement were applied to the brickwork of the conduit "under pressure," except where the aqueduct was at a considerable depth below the surface. After this treatment the loss of water in the conduit "under pressure" was found by gaugings to amount to only about 225,000 U. S. gallons in twenty-four hours. This loss is insignificant compared with the daily gain of about 4,000,000 U. S. gallons (see page 126) from inward percolation in the 25 miles of aqueduct, which are not subject to pressure.

Repairing Defective Masonry.—After a considerable amount of the masonry lining of the tunnel had been laid, the engineers discovered, first by chance and then by systematic investigation, that a large amount of this masonry had been improperly laid. The examination was made by rapping the masonry with steel bars and cutting holes in the lining wherever the sound indicated large vacancies in the backing. The sounding-bars were made of 3/4-inch hexagonal steel, and were about 11 feet long. The end with which the brickwork was struck was "upset" and rounded. After a little practice in using these

bars a person could tell from the sound whether the masonry rapped was solid or not, and in the latter case could judge as to the nature of the defects.

As a rule the brickwork proved to be satisfactory, but in some places the outer rings were found without mortar. The chief defects were in the rubble backing, which was generally laid with little or no mortar, and in places was omitted entirely. Empty cement barrels were sometimes substituted for the backing masonry behind the side walls. On top of the arch the void spaces were concealed by building cross-walls at intervals.

The existence of the large amount of defective masonry which was found in the tunnel lining requires some explanation. It was due to several causes.

1st. The difficulty and hardship of the work, which, on top of the arch, had to be performed in vitiated, smoky air, inclined the masons to slight their work.

2d. They could do so easily, as the many timbers, arch-centres, etc., in the tunnel made it impossible to watch an individual mason unless the inspector or engineer was standing right beside him.

3d. Among the more than two hundred inspectors who were employed in the tunnel it is more than probable that some were inefficient or dishonest.

4th. While the principal contractors may have been ignorant of the bad work that was being done, the systematic building of cross-walls and the filling with cement-barrels cannot have been done without the knowledge and connivance of some of the sub-contractors or foremen.

5th. The engineers could give but little time to inspection, as they were kept busy with their technical duties and as the work was being carried on at a great many points at the same time.

6th. Most of the defective work was probably done at night, when the engineers were usually absent. Some of the inspectors may have taken advantage of this fact to neglect their duties.

The work of repairing the defective masonry was commenced in March 1888. Where the soundings indicated large vacancies, holes were cut into the work and the spaces were filled with rubble masonry. For the many cases where the backing masonry had been laid dry or without a sufficient amount of mortar, a cheaper but very efficient method of remedying this defect was employed, viz., by injecting grout, composed of one part of American cement and one part of sand, into the work. Portland cement was not found to answer as well for this purpose, as it would separate from the sand owing to its lightness.

The grout was forced through 2-inch holes, which were drilled through the lining masonry to the rock, at frequent intervals. At first the grout was poured by means of pails into large tin funnels which were inserted into the holes. After two weeks' trial this primitive method was replaced by pumping the grout by means of ordinary double-acting deck fire-pumps manufactured by W. & B. Douglas, of Middletown, Conn.

Each pump was bolted to a narrow truck, about 3 feet wide, and just long enough for the men to stand upon while pumping (see Plate 108). The wheels of the truck were made of wood and were about 20 inches in diameter. A grout-box was placed on each side of the

pump. The suction-hose was 2½ inches in diameter and 6–9 feet long. The discharge-hose (which was guaranteed to stand a pressure of 200 lbs. per square inch) was 2 inches in diameter and about 20 feet long. A piece of 1½-inch gas-pipe, 15 inches long, formed the nozzle and was inserted into the grout-holes in the masonry. The grout was forced into the work under a pressure of 50–100 lbs. per square inch. About 50 lineal feet of tunnel could be grouted without moving the pump.

The force of men required for each grout-pump was:

1 foreman.
4 pump-men.
1 stirrer.
1 hosemen.

We are indebted for some of the facts given above to a paper on "Pumps and Methods of Grouting," by Mr. P. F. Brendlinger, published in the Proceedings of the Engineers' Club of Philadelphia, Pa., for December, 1889. Mr. Brendlinger, who was the engineer for Brown, Howard & Co., the contractors for sections 2–5, inclusive, states in the above paper that this firm had twenty-three grout-pumps in operation at the same time on their work and four more in reserve. These pumps used about 1000 bbls. of cement per day, the maximum amount required for one pump being 120 bbls. in ten hours.

According to Mr. Brendlinger, Brown, Howard & Co. used in all 165,000 bbls. of cement and the same quantity of sand for this grouting. When mixed with the proper quantity of water this cement and sand formed about 317,000 bbls. of grout having the consistency of cream.

Wherever the masonry was cut into, after having been treated in the above manner, the grout was found to have filled every void space and to have become hard.

CHAPTER VIII.

ENGINEERING DETAILS OF THE NEW CROTON AQUEDUCT.

Surveys Above Ground.—The final location of the aqueduct was made with great care. The centre-line of the conduit was permanently established on the surface by means of monuments, placed on prominent points 900 to 1800 feet apart. Additional monuments were located at intermediate points for establishing the boundaries of the land acquired by the city. A monument was placed near each shaft and open cut.

The monuments (see Plate 109) consisted generally of stone posts (6 inches square on top, 12 inches square at the bottom, and 5 feet 6 inches long) set in concrete so as to project about 3 inches above the surface. In the top of each monument a one-inch copper bolt, 6 inches long, having a head $1\frac{3}{4}$ inches in diameter, was placed. The centre-line of the aqueduct was marked on these copper bolts. The projecting parts of the monuments were painted white to make them more conspicuous. When suitable rock was found at the surface the stone posts were omitted, the copper bolts being set in brimstone in holes drilled in the rock. A wooden post, painted red, was placed near each monument to indicate its location when it was covered by snow.

The centre-line of the aqueduct was established with great accuracy, long sights being taken from one prominent monument to another. A special transit (Fig. 49) was made for this work by Messrs. Heller & Brightly, of Philadelphia, Pa., according to a design of Mr. Alfred Craven, who was the Assistant Engineer in charge of these surveys. The telescope of the instrument was of ordinary power. It had a long bubble attached to its axis, at right angles with the line of collimation, which made it possible to adjust the instrument very accurately for taking sights in a vertical plane. The telescope could be reversed or taken out of the "Y's" and turned, like a theodolite. It was provided with two sets of cross-hairs, one having a vertical and a horizontal hair, while in the other both hairs were inclined thus, ⊗. When one set was brought into focus the other set disappeared. This arrangement was found very advantageous.

The centre-line was "run" a great many times, and was tested at night with lights. The first tangent, commencing at Croton Lake, was about 10.4 miles long. It was established from a central point, with a fore-sight of about five miles and a back-sight of about four miles. On Plate 109 some of the targets used for long sights are shown. They were generally made of boards, 4 to 8 inches wide by 6 feet long, fastened at the bottom by means of two bolts to a $4'' \times 4''$ post. The bolts passed through slots in the targets which could be moved a certain distance to the right or left. Centre stripes, 2 and 4 inches wide, were painted red and white or black and white on the targets. At night, trial sights were taken

to a bullseye lantern placed behind a 2-inch circular hole cut in the target, intermediate points being tested with plummet-lights.

To avoid clearing the line through valuable property, timber towers (see Plate 109) were built on prominent points. Each tower consisted of two parts, which were entirely disconnected, viz.: an inner trestle of four posts upon which the large Heller & Brightly transit, supported by the tripod shown in Fig. 49, was securely fastened, and an outer tower carrying a platform for the observer. The posts were set on a concrete foundation.

FIG. 49.—TRANSIT FOR TUNNEL ALIGNMENT.

An alignment monument was placed under the centre of each tower. Seven of these towers, 22 to 50 feet high, were built and proved to be very satisfactory.

After the centre-line had been properly monumented, its length was measured with great accuracy. As the steel tapes of different makers, and even those of the same manufacturer, were found to vary considerably in length, two 100-foot steel tapes were sent to Professor E. J. Hilgard, United States Superintendent of Weights and Measures, to be tested. The errors compared with the U. S. standard measure were determined in each tape for the whole length, and for each 10 feet at a temperature of 62° Fahrenheit, and under a pull of twelve pounds.

With these tapes a standard base-line was established at the engineer's office in Tarrytown. Three stone monuments were placed fifty feet apart. In the top of each monument a copper bolt was set, upon which the distance-mark was cut. A table of 2×4 inches white pine was placed between the monuments, and provided with copper bolts 10 feet apart, upon which the 10-foot distances were marked. The standard tapes were preserved for future trials of the base-line; all the tapes used in measuring the length of the aqueduct being tested by comparison with the latter.

The tapes used in the location of the line from Croton Lake to the Harlem River were marked as follows: The 0 mark was 10 feet from one end. From the 0 the tape was divided in opposite directions, the marks being made towards the far end only for every 10 feet, but towards the near end so as to divide the length of 10 feet into feet, tenths, hundredths, and half-hundredths. In chaining the line on uneven ground, inclined measurements were taken, and afterwards reduced to horizontal distances. On Manhattan Island the line was all measured with a Stackpole Bros.' spring-balance tape.

Great care was taken in running the levels from Croton Lake to Central Park, and in establishing the "bench-marks." The latter consisted generally of one-inch hexagonal steel bolts, 6 inches long, which were set in brimstone in solid rock. Each bolt had its top rounded and its bottom upset. A white square, having sides of 18 inches, was painted around the bolt, the centre being marked by a blue triangle (see Plate 109).

Probably more care was taken in locating the line of the aqueduct than was absolutely necessary. The great accuracy with which the surveys on the surface were made was proved by the almost perfect manner in which the headings of the tunnel met.

Surveys under Ground.—The alignment was transferred from the surface to the tunnels by means of wires suspended in the shafts and placed accurately "on line." A base-line about 15 feet long was thus obtained at the foot of the shaft and was produced into the

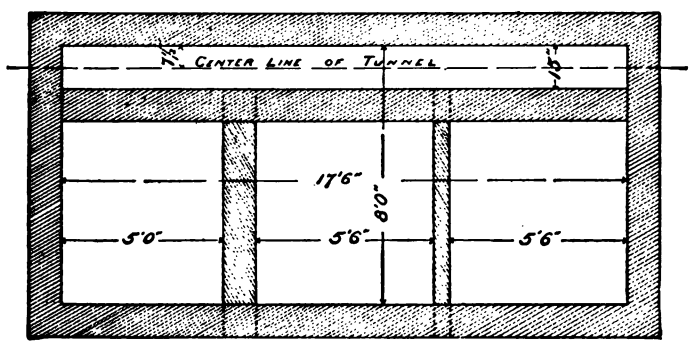


FIG. 50.—CROSS-SECTION OF SHAFT.

headings by means of an ordinary engineer's transit. The wires used were No. 8 piano steel wire. They were annealed and wound around reels, about 6 inches in diameter, provided with clamp-screws or brakes. A 25-lb. cast-iron weight (see Plate 109) was usually fastened to the end of each wire, and placed, in the bottom of the shaft, in a pail filled with oil or water to stop the oscillation of the wire. On account of the water dripping down the shaft the

pail was provided with a cover through which the wire passed. Instead of two independent weights, a bar to which both wires were attached was used by some of the engineers (see Plate 109).

As stated on page 120, a space of 15 inches was reserved at one side of each shaft to enable the engineer to "drop his wires" without interfering with the work (see Fig. 50). The wires were placed accurately on line at the top of the shaft by means of a transit instrument which was set up about 40–50 feet from the shaft and sighted to a distant monument or target. The reels on which the wires were wound were secured to the top timbers of the head-house. At the first frame of the shaft the wires were held by clamps which could be moved by tangent screws. This arrangement permitted the engineer to place each wire "on line" without changing the position of the reel from which it was suspended. Considerable trouble was experienced in making the contractors timber the shafts so as to leave sufficient space for the wires.

Until the headings had advanced about 100 feet from the foot of a shaft, the base-line given by the two suspended wires was generally produced by means of a fine fish-line. When the headings had been driven the distance mentioned, the engineer would set up his transit in the tunnel about 30–50 feet from the shaft, and would bring it exactly in line with the two wires. This was an operation requiring considerable patience, especially in the deep shafts in which the wires were apt to oscillate in spite of all precautions. There was always some difficulty in distinguishing the cross-hair of the transit and the two wires from each other. To obviate this difficulty, Mr. F. W. Watkins, the Division Engineer in charge of sections 10 and 11, devised an apparatus for substituting an illuminated slit for the wires. In a paper on Tunnel Surveying, read before the American Society of Civil Engineers in July 1890, Mr. Watkins describes his device as follows:

"This instrument consists of two vertical strips of brass about 3 inches high, attached to separate horizontal bars, moving in guides, and with a tangent-screw motion, by which one or both could be moved right or left, and the vertical opening between them made as small as desired.

"One of these instruments was screwed to a plank bracket, close behind each plummet-wire, and placed at such a height that on looking through the transit the farther one could be seen in line just above the other.

"These vertical slits were then adjusted by the tangent screws to be directly behind the plummet-wires, and with an opening slightly larger than the thickness of the wire, and so that a light held beyond it on line would illuminate an equal space on each side of the wire; this could be estimated very closely by the eye.

"The plummets and wires were then removed, lights placed behind these slits, and two fixed and illuminated lines substituted, which could be very closely bisected by the cross-hair of the transit, and transferred to the headings."

Having placed his transit in line by sighting to the illuminated slits described above, or directly to the wires, the engineer would reverse the telescope and centre a plug, driven into a hole drilled in the roof of the tunnel. The first plug in each heading was usually placed about

100 to 150 feet from the shaft. The true centre-line on the first plug in each heading was established by taking the average of a number of trials. To facilitate the recording of the different trials some of the engineers attached to the plug in the roof a horizontal metal scale, divided in both directions from a central 0. A movable vernier, to which a plummet lamp* was suspended, was hung under the metal scale. When the flame of the plummet-lamp had been put on line, the reading on the vernier east or west of the 0 mark was recorded. Having accurately established a centre-point in each heading, it was comparatively easy to produce the base-line, 200 to 300 feet long, which had thus been obtained. In doing this work the sights were usually taken to plummet-lamps.

The levels were carried down the shafts by means of long steel tapes. Bench-marks were established in the tunnel with the enginneer's level and rod, in the usual manner. An excellent bench-mark was made by drilling a hole in a projecting point of rock, driving a wooden plug into the hole and a railroad spike into the plug.

With very few exceptions, the numerous "headings" of the aqueduct tunnel "met" with great accuracy. The difference in line was generally less than 0.2 feet, and the differences in levels and in length were trifling.

The tunnel excavation was accurately cross-sectioned about once in 10 feet. This was done by radial measurements taken by means of long rods and special disk instruments, made by Messrs. Heller & Brightly, of Philadelphia, Pa., according to a design of Mr. Alfred Craven, Division Engineer. Each of these instruments (see Plate 109) consisted of a circular disk of wood, 18 inches in diameter, attached to a rod of brass, which was supported by a tripod, having extension legs, ball- and socket-joint, levelling-screws, etc. The rod could be slid up or down in the socket and clamped at the desired height. By means of the levelling-screws the disk could be made vertical.

The disk instrument was placed in the tunnel, with its centre in the centre plane of the tunnel. By means of a small sighting-tube, which was attached to the back of the disk, the latter could be kept at right angles to the centre-line of the tunnel. The face of the disk was divided from a 0 point on top, in both directions, into degrees, to 180 at the bottom. A wooden arm was pivoted in the centre of the disk. It served as a support or rest for the rod (about 14 feet long) with which the radial measurements were taken. The elevation of the centre of the disk had to be determined for each cross-section.

After the cross-sections of the tunnel had been taken in the above manner (15 to 20 measurements for each one being usually sufficient) they were carefully plotted in the office, on specially prepared sheets, by means of circular protractors, about 3 inches in diameter, each provided with a graduated revolving arm, and divided into degrees in the same manner as the disk instrument.

The areas of the cross-sections were determined by means of polar planimeters. With proper care very accurate results were obtained by this method, the errors resulting from using the planimeter being usually less than 0.5 per cent. As in a rough rock tunnel the

* A lamp in the form of a large plumb-bob, suspended by chains and provided with a small wick.

areas obtained for the same cross-section by two different engineers might easily vary 5 per cent, the planimeter was thought to be sufficiently accurate for determining the areas.

Hydraulic Formulæ.—In preparing the plans for the new aqueduct, the flow through a circular masonry conduit of 14 feet inner diameter, "not under pressure," was calculated in the following manner:

The maximum flow was found by trial calculations practically to occur when the water-surface subtends an angle of 52° at the top of the conduit* (see Fig. 51, page 182). Assuming a depth of water corresponding to the above condition, the maximum discharge of the conduit was calculated by the general formula

$$D = v \times a \times 7.4805 \times 86400, \quad (1)$$

in which D = discharge in U. S. gallons in twenty-four hours;

v = mean velocity in feet per second;

a = area of water-channel in square feet.

In the above equation v is the only quantity which has an uncertain value. It was determined by the following empirical formulæ:

THE CHEZY FORMULA.

$$v = c\sqrt{rs}, \quad (2)$$

in which c = a constant found by experiment;

r = mean hydraulic radius = $\frac{\text{area of water-channel}}{\text{wetted perimeter}}$;

s = sine of slope = $\frac{\text{total fall}}{\text{total length}}$.

c is found to vary with r. The experiments in the Sudbury Aqueduct of Boston, made by Messrs. Fteley and Stearns,† give values of c for values of r, varying from 0.5–2.33 feet (see Fig. 52, page 183). No experiments have been recorded for $r = 3.5$, the mean hydraulic radius of a conduit 14 feet in diameter when full.

An approximate value of c for $r = 3.5$ was determined by plotting the results obtained by Messrs. Fteley and Stearns, taking the c's as the ordinates and the r's as the abscissas. The curve obtained, which became almost a straight line for the higher values of r, was produced and gave

$$c = 141.6 \quad \text{for} \quad r = 3.5.$$

Substituting this value of c in the Chezy formula, and the value of v thus obtained in the general formula (1), the maximum discharge was found to be

$$D = 318{,}777{,}000 \text{ U. S. gallons in 24 hours.}$$

* As the versed-sine for 26° is .1012060, the maximum flow in the above case practically occurs when the water-surface is one tenth of the radius from the crown of the arch.

† See Transactions of American Society of Civil Engineers for 1883.

THE KUTTER FORMULA.

$$v = \frac{41.66 + \frac{1.811}{n} + \frac{0.00281}{s}}{1 + \left(41.66 + \frac{0.00281}{s}\right)\frac{n}{\sqrt{r}}} \sqrt{rs}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

In this formula v, r, and s have the same signification as in formula (2); n = coefficient of roughness of the wetted perimeter.

n is found by experiment. For good brickwork "Kutter" $n = 0.013$.

Substituting this value of n in formula (3) and the resulting v in formula (1), we find

$$D = 323{,}257{,}000 \text{ U. S. gallons.}$$

The Kutter formula, as used above, equals the Chezy formula with $c = 143.59$.

BAZIN'S FORMULA.

$$Av^2 = rs.$$

From which we obtain

$$v = \frac{1}{\sqrt{A}} \sqrt{rs}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

v, r, and s have the same signification as in the preceding formula.

The following values of A based upon experiments are given by M. Bazin:

$$\text{For very smooth walls,} \quad A = .000046\left(1 + \frac{0.10}{r}\right);$$

$$\text{For fairly smooth walls,} \quad A = .000058\left(1 + \frac{0.23}{r}\right).$$

Using the first value of A, we find

$$D = 327{,}873{,}000 \text{ U. S. gallons.}$$

For the second value of A,

$$D = 287{,}484{,}000 \text{ U. S. gallons.}$$

DR. LAMPE'S FORMULA.

$$v^{1.8} = \frac{sr^{1.25}}{K}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

in which (all values being taken in metres)

v = velocity in metres per second;

K = a value found by experiment;

s and r have the same signification as in the preceding formulæ.

Mr. Lindley's experiments in the sewers of Frankfort-on-the-Main gave

$$K = 0.00019$$

Using this value and English measures, Lampe's formula becomes

$$v = 167.89 r^{0.694} s^{0.555} \quad \text{(6)}$$

Substituting the value of v, found by this formula, in equation (1), we find

$$D = 302{,}872{,}000 \text{ U. S. gallons.}$$

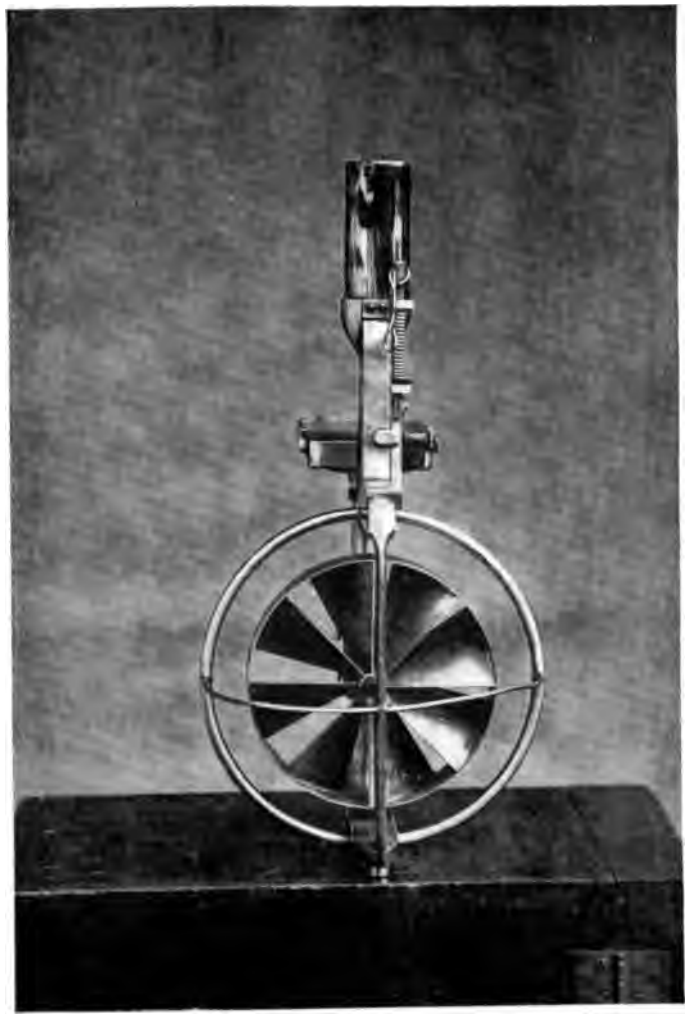
The results obtained by gaugings, as described below, proved that the maximum daily flow through the aqueduct amounts to about 302,500,000 U. S. gallons.

Gauging the Flow through the Aqueduct.—After the aqueduct had been completed, careful gaugings were made to determine the discharge of the masonry conduit for different depths of water. The first measurements were taken with a small current-meter (see Plate 27) made by Buff & Berger of Boston, Mass., according to the designs of Messrs. Fteley and Stearns. A manhole was constructed about 1000 feet south of the Yonkers gate-house to give access to the aqueduct, and was fitted up with a special apparatus (see Plate 143) for insuring accuracy in the use of the current-meter. It had flat faces on the north and south sides. A graduated limb of brass was placed in the manhole and fastened to three 4″ × 8″ yellow-pine posts. Grooves $\frac{7}{16}$ inch deep were cut in this limb $\frac{3}{4}$ inch from centre to centre. Two iron beams were placed across the aqueduct above the probable flow-line and covered with planks, to form a platform for the observers.

The current-meter was attached to a brass rod ($1\frac{1}{16}$ inches in diameter) which passed through a swivel, as shown on Plate 143. The rod was made in 5-foot sections, which were screwed together. It was provided with a number of projecting lugs which fitted accurately into the grooves of the limb. The lugs and the grooves of the limb were marked in such a manner that the position of the current-meter in the aqueduct was always known. Four men were required in making the observations: the first moved the current-meter by shifting the lug of the rod along the grooves of the limb; the second held the meter against the current by means of a stout rod fastened by wire to the brass tube just above the meter; the third was stationed at the top of the manhole and assisted in raising or lowering the rods; the fourth, watch in hand, timed the observations and gave the signals. The recording index could be put in operation or stopped by means of a wire. To read the index the meter had to be raised to the platform.

The area of the water-channel was subdivided into a great many small areas of equal size, each containing about a square foot. The average velocity in each of these areas was determined in two ways: first, by moving the meter slowly and uniformly through all the small areas, recording the time and the total number of revolutions; second, by leaving the instrument for a minute in each separate area, recording the time and the total number of revolutions. From these observations, which were plotted as shown on Plate 144, the average velocity for the whole area could be calculated. The results obtained by both of these methods agreed generally very closely, the usual difference being less than one per

PLATE 27.



CURRENT-METER USED IN THE NEW CROTON AQUEDUCT.

cent. Owing to its smallness and to the protecting wires with which it was provided, the current-meter could be brought very close to the sides and invert of the conduit. The meter was "rated" originally with great accuracy. During the observations it was rerated to make sure of its reliability.

While the gaugings were being made at Yonkers, the depth of the water in the conduit at the Croton Lake inlet gate-house and at the Pocantico gate-house, about nine miles south from the inlet, was carefully measured, in order to compare the theoretical flow given by formula (2), page 178, with the results obtained by the gaugings. The depth of the water was determined by means of a lead pipe, laid in the aqueduct for several hundred feet, in order to eliminate the irregularities of flow at the gate-house.

All the gaugings indicated that the flow through the aqueduct was less than the quantity given by formula (2), with $c = 141.6$. The ground-water percolating into the conduit "not under pressure" produced some irregularity in the flow. Observations made at various points during a year showed that this water amounted, on an average, to 4,000,000 U. S. gallons per day. The correctness of these observations was proved by graphical studies of the flow made by assuming the above amount of inward percolation.

The second set of gaugings was made by means of a double weir, having a total width of 16 feet, which was constructed in the gate-house at Croton Dam. The results obtained, except for small flows, were not satisfactory. This was due to the fact that the water rose from the bottom of a deep chamber in front of the weir, instead of approaching it in the usual manner. The inapplicability of the usual weir formulæ to the above case was proved by using the aqueduct from the inlet to the Pocantico gate-house (a length of nine miles) as a measuring-chamber.

The next observations were made with the current-meter at different points in the aqueduct, about a mile apart, between the inlet and the Yonkers gate-house, the meter being held by hand from the stern of a boat. Gaugings were also made from two platforms constructed in the aqueduct, one about 500 feet south of the Croton gate-house and the other about 500 feet north of the Pocantico blow-off. Although these observations could not be made with the same exactness as with the permanent apparatus at Yonkers, they all gave uniform results, and confirmed the first gaugings made with the current-meter.

The final conclusion reached by all the observations was that the flow through the aqueduct was only 95 per cent of the quantity found by formula (2), with $c = 141.6$.

Mr. A. Fteley, Chief Engineer of the Aqueduct Commission, gives in his report on the construction of the aqueduct, dated January 1, 1895, the diagram Fig. 52, page 183, for the flow through the aqueduct, to show the results obtained with the current-meter, and, also, a table of the flow through the new aqueduct for various depths of water, which we give in a condensed form on page 307.

For depths greater than 1.9 feet Mr. Fteley has found the following empirical formula for the flow in the New Croton Aqueduct which agrees very closely with the above-mentioned table, the maximum difference being only 0.6 per cent:

$$v = 124 r^{0.56} s^{0.5}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

in which

$$v = \text{velocity in feet per second};$$
$$r = \text{mean hydraulic radius};$$
$$s = \text{sine of the slope} = \frac{\text{total head}}{\text{total length}}.$$

The Cross-section of the Aqueduct.—The plans made by the Department of Public Works for the New Croton Aqueduct contemplated the construction of a circular conduit, having an inner diameter of 12 feet, and a grade of 1 foot per mile. The Aqueduct Commissioners subsequently modified these plans for that portion of the aqueduct which was not to be under pressure, by making the inner diameter of the conduit 14 feet and the grade 0.7 foot per mile.

To facilitate the excavation of the tunnel and the laying of the masonry, the cross-section for this portion of the aqueduct was finally changed to the "horse-shoe section," shown on Plate 60, which was designed to have the same discharging capacity as a circular conduit of 14 feet inner diameter.

The "horse-shoe" section was determined by trial calculations. The maximum discharge through a circular conduit was taken as occurring when the surface of the water was 0.101 of the radius of conduit below the crown of the arch (see Fig. 51). By means of the Differential Calculus it was found that for a cross-section consisting of a semi-circle and a rectangle (see Fig. 53) the maximum discharge for a given area was obtained when the height was equal to the width.

As the "horse-shoe" section differed but slightly from this simple cross-section, its height was made about equal to its width. The radius of the upper semi-circle and the radius of the invert were fixed after one or two trial calculations, and the radius of the side-arcs was then varied, until the cross-section obtained became practically equivalent to that of a 14-foot circle, as regards flowing capacity.

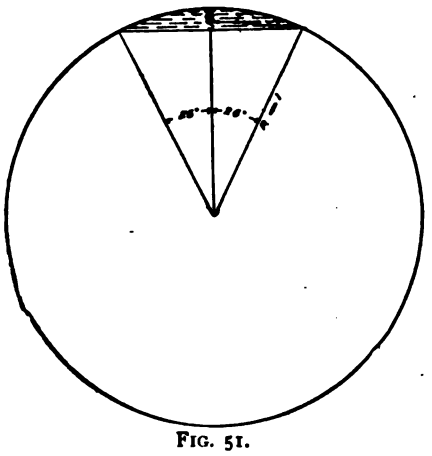


FIG. 51.

For the portions of the aqueduct which were to be "under pressure" a circular cross-section was adopted. The inner diameter of the circular conduit at the Gould Swamp siphon (station 637 + 31 to station 648 + 66) is 14′ 3″. The inner diameter of the long siphon from station 1268 + 20 to the One Hundred and Thirty-fifth Street gate-house is 12′ 3″, with the exception of the aqueduct under the Harlem River, which has an inner diameter of 10′ 6″. The capacity of the long siphon just mentioned is not equal to that of a circular conduit with a diameter of 14 feet, but just sufficient to deliver 250,000,000 U. S. gallons per day, as explained on page 114.

According to the original contract drawings, the tunnel was to be lined entirely with

masonry only where it passed through material requiring to be supported or where the aqueduct was under pressure. The roughness of the wetted perimeter where part or all the masonry lining was omitted was considered to be offset by the increased area of waterway.

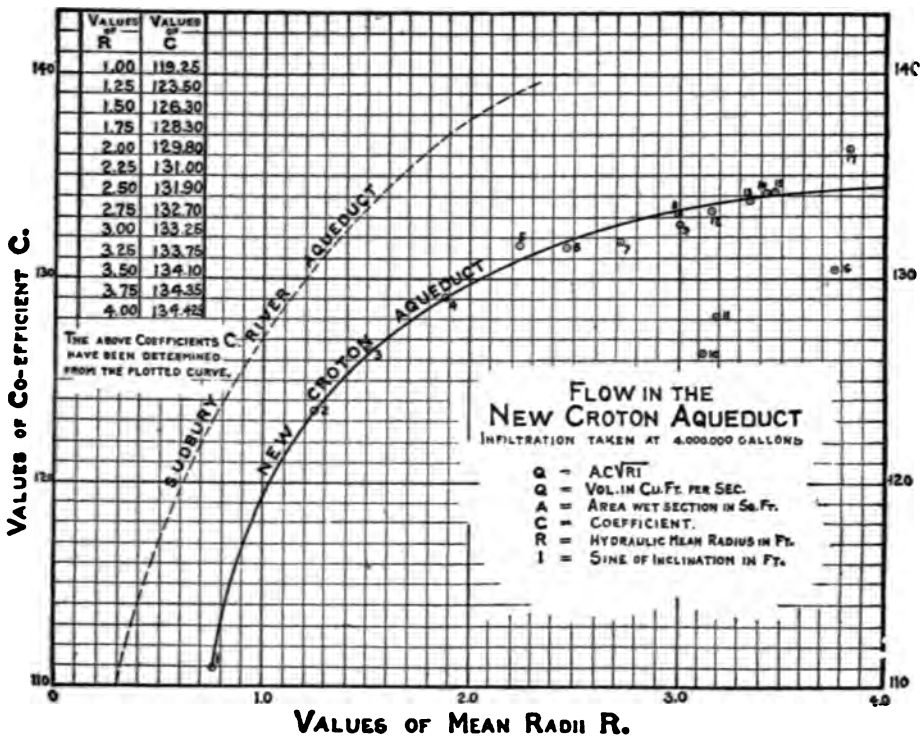


FIG. 52.

It was estimated that probably one-third of the tunnel would require only a partial masonry lining or none at all. On February 17, 1886, however, after the work of excavating the tunnel had been about a year in progress, the Aqueduct Commissioners decided, after considerable discussion, to line the aqueduct with masonry throughout its entire length.

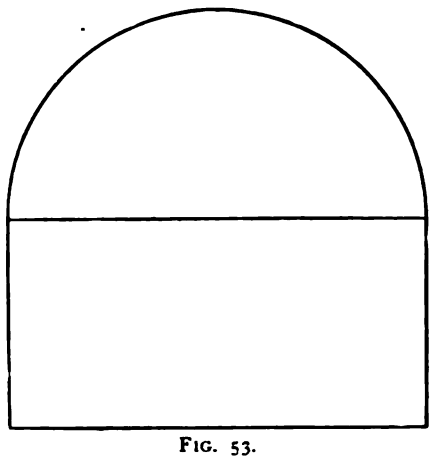


FIG. 53.

On Plates 60–65 we show the cross-sections given in the contract drawings for the various portions of the aqueduct. These drawings, taken in connection with the specifications (see page 245), explain themselves. It will be noticed that in the aqueduct "not under pressure," "weepers" were to be built to permit the ground-water, which in the region passed through was potable, to enter the conduit. As stated on page 181, about 4,000,000 gallons per day are added to the city's supply by the ground-water percolating into the aqueduct. The line *AAAA*, shown on the various cross-sections, is the limiting line of the area of excavation which was paid for. The reinforcement of the arch at the haunches, for the aqueduct in open trench, was found by graphic statics.

In the circular conduit under the Harlem River, the inner diameter was reduced to 10½ feet to increase the velocity of the current in order to prevent the deposit of silt.

Capacity of Aqueduct.—The Aqueduct Commissioners determined (see page 114) that the capacity of the aqueduct from Croton Lake to the incline at shaft 20 was to be equal to that of a circular conduit 14 feet in diameter, and that from the incline at shaft 20 to the Central Park reservoir the capacity of the aqueduct was to be reduced to 250,000,000 gallons per 24 hours.

The Distribution of the Available Head.—The cross-sections adopted for the different parts of the aqueduct were determined before the final location of the centre-line was made. The actual distribution of the available head differs, therefore, slightly from the original assumptions. The data upon which the hydraulic calculations for the cross-sections of the aqueduct, etc., were based were as follows:

LENGTH OF AQUEDUCT.

	Feet.	Miles.
Aqueduct not under pressure:		
Croton Lake to incline at shaft 20	128,500	24.337
Aqueduct under pressure:		
1st. Masonry conduit (incline at shaft 20 to One Hundred and Thirty-fifth Street gate-house)	36,656	6.942
2d. Pipe-line (One Hundred and Thirty-fifth Street gate-house to Central Park reservoir)	15,050	2.850
Total length	180,206	34.129

AVAILABLE HEAD.

Elevation of invert of aqueduct at Croton Lake above datum plane	140.00 feet
Depth of water for maximum discharge (see page 178)	12.86 "
Elevation of water in aqueduct at Croton Lake above datum plane	152.86 "
Elevation of high water in Central Park reservoir above datum plane	119.16 "
Total fall in aqueduct	33.70 "

The available head (33.70 feet) was considered as being required entirely in overcoming the friction in the masonry conduit and pipes, as the head required for producing the velocity of the current and in overcoming the resistance at the entrance of the aqueduct is lost in the gate-house. The grade of the aqueduct not under pressure was fixed at 0.7 foot per mile, which was calculated, according to the formula given on page 178, to produce a velocity of

3.27 feet per second. Experience proves that a velocity of 3 to 4 feet per second in a masonry conduit is sufficient to prevent the deposit of "silt" and yet not so great as to injure the masonry by the friction of the material carried along by the current. With the velocity just given, the maximum discharge of a circular aqueduct 14 feet in diameter was calculated to be 318,777,000 gallons.

Under the above assumptions the head required for the aqueduct not under pressure is $24.337 \times 0.7 = 17.036$ feet. It was estimated that 1.50 feet of head would be lost on account of the various curves of the aqueduct, and the change of velocity where the size of the cross-section was reduced, etc. Consequently the "available head" for the aqueduct under pressure was only 15.16 feet. If this amount of head had been uniformly distributed over the whole length of the aqueduct under pressure, viz., from shaft 20 to the Central Park reservoir, only 4.41 feet would have been available for the pipe-line. Under this assumption twelve lines of 48-inch pipe would have been required to convey 250,000,000 gallons per 24 hours from the One Hundred and Thirty-fifth Street gate-house to the Central Park reservoir. As the pipe-line under these circumstances would have cost considerably more per lineal foot than the masonry conduit under pressure, it was decided to reduce the number of pipe-lines and to increase the diameter of the conduit, making thus the cost per lineal foot of the whole aqueduct under pressure nearly uniform.

The amount of head reserved for the pipe-line was fixed after a few trial calculations at 8.50 feet. Seven lines of 54-inch pipe would have been sufficient with this head to have conveyed the required amount of water. The only calculation which remained to be made was to determine the diameter of the masonry conduit under pressure for which 6.66 feet of head was available. This head was, however, not distributed entirely uniformly. The inner diameter of the conduit under the Harlem River had been reduced to 10.5 feet, as stated on page 184. Assuming the length of this tunnel as 1250 feet, the head required for discharging 250,000,000 gallons per 24 hours was found to be 0.47 foot. There remained, consequently, 6.19 feet for the remaining 35,406 feet of the masonry conduit under pressure. The diameter of this part of the aqueduct under pressure was calculated by the formula given below and was fixed at 12.25 feet, which was slightly in excess of what was required.

We have already stated that the diameter of the different parts of the aqueduct were determined before the final location of the centre-line had been completed. In the table given below will be found the assumed distribution of the head which we have just explained, and also the actual distribution as recalculated by us, using the actual lengths of the different parts of the aqueduct. The same formulæ were applied in both cases. It will be noticed that, although the length of the pipe-line was reduced, more head is required than what was assumed. This is due to the fact that in the original calculations allowance was made for seven lines of 54-inch pipe, while it was finally decided to lay eight lines of 48-inch pipe.

DISTRIBUTION OF THE "AVAILABLE HEAD."

Distribution.	Lengths. Assumed.	Lengths. Actual.	Head. Assumed.	Head. Actual.
Aqueduct not under pressure (diameter 14 feet, grade 0.7 foot per mile)	128,500	126,809	17.04	16.81
Aqueduct under pressure:				
Conduit under Harlem River (diameter 10.5 ft.)	1,250	1,219	0.47	0.46
Conduit (diameter 12.25 feet)	35,406	35,028	6.27	6.11
Pipe-line	15,050	12,420	8.50	9.17
Curves, change of velocity, etc	.....	.....	1.42	1.15
Total	180,206	175,476	33.70	33.70

On Plate 110 will be found the hydraulic grade-line of the aqueduct, plotted in accordance with the actual distribution of its available head, given in the above table. It will be noticed that in the lower part of the aqueduct the hydraulic grade line is partly above the surface of the ground.

The formulæ used in making the calculations given above are as follows:

$$v = \sqrt{142rs}, \qquad (8)$$

in which v = the average velocity per second;

142 = a constant, based upon experiments;

r = mean hydraulic radius $= \dfrac{\text{wetted area}}{\text{wetted perimeter}}$;

s = sine of the slope $= \dfrac{\text{total head}}{\text{total length}}$.

The value of the constant 142 varies directly with the hydraulic radius. No allowance was, however, made for this fact in the preliminary calculations, 142 being taken as a fair average value for masonry conduits of 10.5 to 14 feet diameter.

The total discharge per 24 hours was calculated by the formula

$$Q = \pi R^2 142 \sqrt{rs}.\ GS, \qquad (9)$$

in which 142, r and s are as given above.

Q = gallons discharged in 24 hours.

$\pi = 3.14159$.

R = radius of conduit.

$G = 7.4805$ gallons in one cubic foot.

$S = 86400$ seconds in 24 hours.

From the above equation we obtain

$$\left(\frac{Q}{142\pi GS}\right)^2 = \frac{R^2 h}{l}. \qquad (10)$$

For $Q = 250{,}000{,}000$ we find

$$\log R^2 + \log h - \log l = 0.1771458, \qquad (11)$$

in which h = "head" in feet and l = length in feet.

From this formula we can find the radius of a conduit of a given length, having a capacity of 250,000,000 gallons per 24 hours, when we know the available head, or we can calculate the required head for a given radius.

The velocity in the 54- and 48-inch pipes was calculated by the formula

$$v = 141.6 \sqrt{rs},$$

in which v, r, and s have the same signification as in equation (8).

The experiments made by Mr. F. E. Stearns on a 48-inch pipe (see Transactions of the Am. Soc. C. E., XIV. 1.) show this formula to be reliable for a 48-inch pipe. For a 54-inch pipe a higher constant could have been safely assumed.

We have stated on page 114 that the Aqueduct Commissioners raised the grade-line of the new aqueduct ten feet higher than what was originally intended. The new grade-line was kept parallel with the original line to the first incline near Jerome Park. The ten feet additional head obtained by the above change were utilized entirely in the long siphon extending from the incline just mentioned to the Central Park reservoir and made it possible to reduce the diameter of the aqueduct under pressure and of the number of pipe-lines. The saving thus effected in the construction and the reduction in depth of the cuts and of most of the shafts was estimated at about $1,000,000.

CHAPTER IX.

THE CROTON WATERSHED.

THE Croton River (see Plate 54) lies entirely in the State of New York. It is formed by three branches (known respectively as the East, the Middle, and the West Branch), which rise in the southern part of Dutchess County, flow in a southerly direction through Putnam County, and unite near its south boundary. The river continues in a southwesterly course across Westchester County to the Hudson River, into which it empties at Croton Point, about 30 miles from the city of New York. The principal tributaries of the Croton are the Titicus, Cross, Kisco, and Muscoot rivers.

The watershed of the Croton, extending about 33 miles north and south and 11 miles east and west, lies almost entirely in the State of New York, only a small portion being in Connecticut. Its area amounts to about 339 square miles above the Old Croton Dam, and to 360 square miles above the New Croton Dam, now being constructed. The watershed is very hilly. Its surface soil is composed principally of sand and gravel. Clay, hardpan, and peat are found in a few localities, but only to a very limited extent. The rock formation consists generally of gneiss. Strata of limestone, some micaceous and talcose slates, veins of granite, serpentine, and iron ore occur in a few places.

The monthly and annual amount of rainfall in the Croton watershed from 1870–1895 are given in the table on page 309. The average annual amount for this period was 48.38 inches, the minimum and maximum being respectively 38.52 and 63.51 inches.

During the driest year of the above period an amount of water equivalent to 15 inches over the whole watershed (700,000 U. S. gallons per square mile) flowed off in the Croton River. If this amount of rainfall were collected for the whole drainage area above the New Croton Dam (360.44 square miles) and stored without any loss, it would furnish an average supply of 250,000,000 gallons per day.

Thirty-one lakes and ponds, fed by streams or springs, are contained in the Croton watershed. Many of them have been utilized as natural storage-basins by cutting down their outlets and building dams across the same. A cast iron outlet-pipe, controlled by a stop-cock, passes through each of these dams.

The amount of available storage in the artificial and natural basins in the Croton watershed, prior to the commencement of the new works, is given in the report of Isaac Newton, Chief Engineer Croton Aqueduct, dated January 30, 1882, as follows:

ARTIFICIAL AND NATURAL STORAGE IN THE CROTON BASIN, JANUARY 1, 1882.

	U. S. Gallons.
Boyd's Corners reservoir	2,727,000,000
Middle Branch reservoir	4,004,000,000
Lake Mahopac *	575,000,000
Lake Kirk *	565,000,000
Lake Gleneida *	165,000,000
Lake Gilead *	380,000,000
Lake Waccabuc	200,000,000
Lake Tonetta	50,000,000
Barrett's Pond *	170,000,000
China Pond	105,000,000
White Pond	100,000,000
Pine Pond	75,000,000
Long Pond	60,000,000
Peach Pond	230,000,000
Cross Pond	110,000,000
Haine's Pond	25,000,000
Total gallons	9,541,000,000

NOTE.—The lakes and ponds marked * are now (1895) owned by the city. Water is drawn from the others by special agreement.

The total amount of storage water obtained from the above sources during the dry years 1880 and 1881 was as follows:

Total storage drawn in 1880 ..... 8,520,000,000 U. S. gallons

Total storage drawn in 1881 ..... 8,605,000,000 " "

Since Mr. Newton wrote his report the storage in the Croton basin has been largely increased by the construction of the East Branch and Titicus reservoirs. Other storage basins are being constructed by the Aqueduct Commission and the Department of Public Works. The new reservoirs which have been completed since January 1, 1882, or are in course of construction are given in the following table:

NEW RESERVOIRS IN THE CROTON BASIN.

Name.	Site, see Plate 54	Constructed	Built by	Capacity. U. S. Gallons.
East Branch reservoir	I	1888–1893	Aqueduct Com'n	9,028,000,000
Titicus reservoir	M	1890–1895	" "	7,000,000,000
Carmel reservoir	D	In construction	" "	9,000,000,000
New Croton reservoir		" "	" "	32,000,000,000
Amawalk reservoir	A	" "	Dept. Pub. Works	7,000,000,000
Total new storage				64,028,000,000

NOTE.—The capacities of the reservoirs, with the exception of the first, are only approximately known as yet.

The location of all the new and old reservoirs, lakes, and ponds in the Croton basin are shown on Plate 54.

When the new reservoirs have all been completed the total amount of available storage in the Croton basin will amount to 72,633,000,000 U. S. gallons. Mr. A. Fteley, Chief Engineer of the Aqueduct Commission, states, in his report on the construction of the new works from 1887–1895, that a storage of 70,000,000,000 gallons will insure a daily supply of 280,000,000 gallons.

When the old Croton water-works were constructed (1837–1842) the watershed of the Croton River was but sparsely inhabited. Tests of the water made when it was first introduced and others of later date are given on page 285. The deterioration of the quality of the water, shown by these tests, is due to the increase of population in the watershed. In 1888 the population on the watershed draining into Croton Lake was estimated at about 20,000, distributed in 1879 houses in the town of Brewster, in small villages and on farms. The number of domestic animals (cows, horses, pigs, and sheep) on this part of the watershed was estimated at 12,243.

As the Croton water was being much polluted by manufacturing wastes, the drainage from manure-heaps, pigsties, etc., the Board of Health of the State of New York had a careful sanitary survey made of the watershed of the Croton in 1888, and framed the rules and regulations given on page 277 for protecting the purity of the water-supply of New York.

For some years these regulations were not enforced. In March 1893 the Legislature passed "An Act to provide for the sanitary protection of the sources of the water-supply of the City of New York" (chapter 189 of the Laws of 1893, known as the Webster Act), which enables the Department of Public Works of New York to condemn all property adjacent to any stream, pond, or reservoir, used for the city's water-supply. With the power given by this Act energetic measures were taken at once by the Department of Public Works and by the Aqueduct Commissioners to remove all sources of pollution from the Croton watershed. To protect the water-supply in the future the city is acquiring gradually a margin of about 300 feet around all reservoirs and along all streams emptying into the same.

CHAPTER X.

RESERVOIRS CONSTRUCTED BY THE AQUEDUCT COMMISSION.

THE original plans of the Department of Public Works for an increased supply of water from the Croton watershed involved the construction of a large storage reservoir, which was to be formed by building a high masonry dam across the Croton River near the Quaker Bridge (see page 109). The storage thus obtained was to be increased subsequently, if required, by the construction of smaller reservoirs on the branches and affluents of the Croton. Owing to the opposition to the building of the Quaker Bridge Dam which was made by some citizens at the public hearings, the construction of the proposed reservoir was not begun simultaneously with the building of the new aqueduct, as originally intended. The result was that some delay occurred before any additional storage was obtained.

While the question of constructing the Quaker Bridge Dam remained undecided, the pressing necessity of obtaining additional storage caused the Aqueduct Commissioners and the Department of Public Works to commence the construction of the four smaller reservoirs known as the East Branch, Titicus, Carmel, and Amawalk reservoirs.

The plans for these reservoirs, with the exception of the one at Amawalk which is being constructed by the Department of Public Works, were all prepared by the engineer of the Aqueduct Commission. The designs were based upon the same general principles. Where the water to be impounded was to have considerable depth, the central part of the dam was constructed of masonry, provided a rock foundation could be obtained at a reasonable expense. The overflow-weirs were in all cases built of masonry and were made sufficiently wide to pass safely in 24 hours a quantity of water equivalent to not less than 6 inches of water over the whole drainage-area of the respective reservoirs. The bulk of the masonry consists of rubble made of stone quarried in the vicinity of the dams. In some cases the facing-stone was brought from a distance.

As no clay or material suitable for puddle-walls could be found near the reservoir, earthen dams, when used, were always provided with a core-wall of rubble masonry, founded on rock, hardpan, or compact earth.

The East Branch Reservoir (known as the Double Reservoir I; see Plate 54), constructed near the town of Brewster, Putnam County, N. Y., consists of the following two basins:

	Watershed, Square Miles.	Flooded Area, Acres.	Storage Capacity, U. S. Gallons.
The Sodom reservoir.....	73.42	534	4,883,000,000
The Bog Brook reservoir.....	3.50	394	4,145,000,000
Total.....	76.92	928	9,028,000,000

The two reservoirs have about equal storage capacity, but their watersheds differ very much in area. In order to equalize the supply received by each, the two basins were connected by a tunnel 10 feet in diameter and 1778 feet long. The tunnel was excavated entirely in rock and was lined with brickwork, backed by rubble masonry. (see Plate 111).

The Sodom reservoir (see Plate 112) was formed by constructing:

1st. A masonry dam, 500 feet long, across the east branch of the Croton River.

2d. An earthen dam with rubble core-wall, 600 feet long, on a ridge parallel with the river and about 75 feet above it.

3d. A masonry overflow-weir, 500 feet long and about 8 feet high.

The earthen dam starts from the east abutment of the masonry dam and is in front of this structure and nearly perpendicular thereto. The overflow-weir forms a continuation of the earthen dam.

The masonry dam was constructed according to the profile shown in Plate 114. Its principal dimensions are:

Length at coping	500 feet
Maximum height above bed-rock	98 "
Maximum height above surface	78 "
Thickness at foundation	53 "
Thickness under coping	12 "

Before the construction of the dam was commenced, the river was diverted from its old bed in the following manner:

A crib dam was built across the stream, about 80 feet above the site of the dam. The water, thus turned from its ordinary course, was conducted by a canal, excavated into the west hill, to a point about 500 feet below the dam. The east branch of the Croton River is generally an insignificant stream, but during freshets its flow amounts, at times, to 250,000 cubic feet per minute. To give sufficient protection to the work the diversion canal was made 26 feet wide and 15 feet deep, dimensions which subsequent experience fully justified.

The river being turned from its course, the easterly half of the dam and the gate-house near the centre of the structure were first built to a height of 25–30 feet above the discharge-pipes. During the dry season of 1889 the water was turned into these pipes, and the remaining part of the dam was then constructed.

The dam was founded entirely on rock, with the exception of a small portion on the west side, which was above the water-line. The rock bottom was found to be partially disintegrated and fissured. All unsound portions were removed by barring or by light blasts. Before the masonry was laid, the foundation was swept with wire stable-brooms and washed clean with streams from hose-pipes. The pockets in the rock were then filled with concrete or rubble (the latter being generally used) and the foundation "levelled up."

A large quantity of water found its way through the loose rock above the foundation and, in some cases, through seams in the rock bottom. When the water came from the bottom, the small streams, in which it issued, were led to small wells, about two feet in

SODOM DAM.

SODOM DAM, IN CONSTRUCTION.

diameter and one to two feet deep, left at various points in the masonry until the mortar had hardened. The water was then bailed out and the wells filled with dry mortar. A large stone, laid in a good bed of stiff mortar, was placed over each well and closed it effectually.

The dam was constructed of rubble masonry with the exception of a facing of cut stone (beginning at the back at elevation 357 and at the front at elevation 364, see Plate 114) and the dimension stone used for the cornice and gate-house. The rubble masonry was composed of stones, varying from one cubic foot to one cubic yard in size, laid in cement-mortar consisting generally of one part cement to two parts sand. The stones were quarried about 1¼ miles from the work. Excellent sand was obtained on the reservoir lands about one mile from the dam. The rubble was laid without any regular courses, the stones being interlocked in all directions. The joints between the large stones were filled with mortar into which small stones were forced. No grouting was permitted.

The face-stones (blue-gray limestone) were quarried at Towners, N. Y., 7 miles from the work, and were delivered by rail. The stones, left with "rock-face," were laid in regular courses, diminishing in rise from the bottom to the top. The stretchers were 3–6 feet long and the headers about 4 feet. The stones were laid normal to the face of the dam. The dimension stones were obtained from granite quarries on the Brandywine River, Del., and delivered by rail.

All stones before being laid were thoroughly washed. Most of the masonry was laid in Portland cement-mortar. Of the total quantity of Portland cement used, 15 per cent was "Burham" English cement and the remainder "Giant" Portland cement, made by the American Cement Co. of Philadelphia, Pa. A considerable quantity of American natural cement made by this company was also used. A small quantity of masonry was laid during freezing weather, hot brine (5 lbs. of salt to 1 bbl. of water) and heated sand being used for the mortar, but the work was stopped when the temperature was lower than 20° Fahrenheit. The maximum amount of masonry laid per month was 3000 cubic yards, twelve masons being at work, with three derricks. The average monthly quantity was about 1700 cubic yards.

In order to control the flow from the reservoir, a gate-house, 37 by 42 feet in plan, was constructed near the centre of the dam, on its up-stream face (see Plate 113). The water can be drawn into the gate-house at three different elevations: from the surface, by flowing over a weir into the gate-chamber, from the middle depth through two sluice-gates, and in like manner at the bottom. The sluice-gates are of the standard pattern shown on Plate 95, and have openings of 2 × 5 feet.

From the gate-house the water flows through two 48-inch outlet-pipes to a circular fountain-basin, 80 feet in diameter (see Plate 112), where the water is projected vertically through two 48-inch and five 12-inch pipes in order to aerate it. From the circular basin the water is conveyed by a short masonry channel, having a weir for measuring the outflow from the reservoir. A small well is constructed on one side of the channel a short distance above the weir, and is connected with the channel. The height of the water above the weir is determined in this well. The waste water from the reservoir is conducted from the overflow-

weir by a channel, excavated to the bed-rock and confined by curved retaining walls, to the old course of the stream.

The Contractors' Plant.—In making the excavation and in laying most of the masonry the contractors used a steel cable, 2 inches in diameter, stretched (parallel with the dam and 10 feet from its back face) between two towers, 667 feet apart, and anchored back of the towers to posts, 2 feet in diameter and 10 feet long, placed in trenches cut 6 feet into the solid rock. On this cable ran a trolley, controlled by a double-drum reversible engine, placed near one of the anchorages. The engine regulated the motion of the load carried by the trolley both vertically and horizontally.

The cable was composed of seven strands, each of 19 wires, and weighed 7 lbs. per foot. Its total length between anchorages was 990 feet. A turnbuckle placed near one of the anchorages served to regulate the length of the cable when changed by variations in temperature. The sag of the cable was about 20 feet. It would be increased about 3–5 feet by the usual load. The original cost of the cable plant, ready for use, was $3750.

The cable was raised in July 1888 and was kept in constant service until October 1889, when it broke at a point 50 feet from the east tower, where the trolley had frequently been stopped for unloading. An Italian workman was struck by a piece of the trolley and killed. At the time of the accident the trolley, carrying a load of only 6 tons, was about 200 feet from the west tower.* The cable was replaced by a new one of the same size. In order to diminish the strain upon it, the towers were raised 10 feet to allow more sag. No further difficulty was experienced. When the cable was taken down in August 1892, it was found to be in excellent condition.

Besides the cable three stiff-leg boom-derricks, with double-drum horse-powers, were used and shifted from place to place as the work required. When the dam had been carried up to within 30 feet of the top, the derricks standing on the ground were replaced by a traveller carrying a 55-foot boom-derrick at its front end. The traveller was placed on a trestle 30 feet high and ran on a track of 36 feet gauge. The derrick was secured by two stiff

* With reference to the breaking of the cable Mr. Walter McCulloh, who was the Assistant Engineer in charge of the work, states in his Memoir on the Construction of the Sodom Dam (see Transactions of Amer. Soc. C. E. for March 1893): "No satisfactory conclusion was ever reached as to the cause of the failure. In the writer's opinion it was due to unequal wear at that point, for it parted directly over the place where stone and cement boxes were loaded and taken up by the cable."

Mr. Spencer Miller, Assoc. Amer. Soc. C. E., in a paper on "Cableways" (see Transactions of the Amer. Soc. C. E. for April 1894), states: "This Sodom Dam cableway was not designed by an engineer, and possibly to this fact is traceable the deplorable accident in October 1889, when the main cable broke, resulting in the death of a laborer. The reason it broke was because it was strained up too tight, allowing too small a sag or deflection. This cableway was an assemblage of parts picked up here and there, without regard to efficiency. The engine was built in New York, the carriage in Pennsylvania, the cables in New Jersey. The main cable broke with a sag of 15 feet and a load of 6 tons. With a span of 667 feet, sag 15 feet, and load of 6 tons, the strain on a 2-inch cable is about 80 tons. This cable, when new, was tested and broke at 132 tons. It is not surprising, therefore, that a cable used constantly for nearly two years should break at 80 tons, when its ultimate strength, new, was only 132 tons, showing a factor of safety less than two."

legs to the back corners of the platform of the traveller, and was operated by a double-drum hoisting-engine, placed on the traveller.

The location of the East Branch reservoir is one of those suggested by the Topographical Survey of the Croton Watershed, made in 1857 (see page 78). The construction of this storage basin was decided upon by the Aqueduct Commissioners in 1883. In August 1887 the Commissioners sent a small party of engineers into the field to sink test-pits and to make borings for the Sodom Dam. The site finally selected was practically the one proposed in 1857.

The contract for constructing the Sodom reservoir was awarded on December 30, 1887, to Sullivan, Rider & Dougherty. Ground was broken on February 22, 1888. The laying of the masonry was begun in August 1888. Owing to many delays from various causes, among which we may mention the "blizzard of 1888," a great flood in November 1889, and strikes at the quarries, the work was not completed until October 31, 1892, nearly three years later than required by contract. A serious loss to the work was the death of Mr. John Sullivan, the senior partner of the contracting firm, which occurred in January 1889. Mr. Sullivan was replaced by his executor, Mr. Clinton Stephens.

During the winter of 1890–91 the water was stored in the reservoir to elevation 390. It was raised the following winter to elevation 415 (the elevation of the top of the overflow-weir). The Sodom Dam was found to be perfectly tight when subjected to water-pressure. The slight amount of sweating which occurred at a few points at the joints was not sufficient to produce a trickle. In dry weather no moisture can be seen on the face of the dam, but when the air is humid dampness is visible on the face-stones and at the joints.

The principal items of work in constructing the Sodom reservoir were:

Earth excavation	5,986 cubic yards
Rock excavation	19,860 " "
Masonry of all kinds	35,887 " "

The total cost of the dam, including appurtenances, was $436,499.05.

The designs for the work were prepared by Mr. B. S. Church, Chief Engineer of the Aqueduct Commission. Mr George B. Burbank was the Division Engineer in charge of the East Branch reservoir from the beginning of the work until June 17, 1891, when he resigned. He was succeeded by Mr. Walter McCulloh, who had been the Assistant Engineer in immediate charge of the Sodom Dam.

The description we have given above has been taken principally from the detailed account of the construction of the Sodom dam given by Mr. Walter McCulloh in the Transactions of the Amer. Soc. C. E. for March 1893.

The Bog Brook Reservoir (see Plate 54) was formed by constructing two earthen dams, having masonry core-walls: one across Bog Brook, an affluent of the east branch of the Croton River, and the other across a depression on the dividing line between the watershed of Bog Brook and that of another small stream.

Dam No. 1 (Plate 115), across Bog Brook, has a top width of 25 feet, a maximum

height above the surface of 60 feet, and a length on top of 1340 feet. It has an inner (upstream) slope of 2:1, and an outer slope of 2½:1. The former is covered with a paving (12 inches deep, laid on 6 inches of broken stone) which extends 7 feet above the flow-line; the latter, the top of the dam, and the inner slope above the paving are sodded.

The core-wall, built of rubble masonry, is 4 feet wide on top, and is battered on both faces so as to be 10 feet wide at a depth of 48 feet below the top of the wall. It has a maximum height of 46 feet above the foundation. From the south end of the dam to the bed of the brook the core-wall was founded on rock, which had to be excavated at several places to a considerable depth to prevent the water in the reservoir from percolating through fissures. A slight leakage occurs through this part of the dam. The water escaping in this manner is collected by a system of drains, and is led finally through a small pipe, where its volume can be measured. On the north of the brook the rock sloped off very rapidly. The core-wall was founded on this side only for about 120 feet on rock, and for the remaining distance (about 500 feet) on hardpan. The trench for the core-wall had a maximum depth of about 50 feet.

Dam No. 2 (see Plate 115) is only 12 feet wide on top. Both of its slopes are 2:1, the inner one being paved and the outer one sodded, in the same manner as for Dam No. 1. Its maximum height above the surface is 24 feet, and its length is 1956 feet. On top, the core-wall has a width of 2 feet 6 inches and at 12½ feet below the top a width of 4 feet, both faces having the same batter. It has a maximum height of 46 feet above the foundation. The core-wall was founded for its whole length on hardpan.

The outflow from the reservoir is regulated by a gate-house (see Plate 115) which is located near the centre of Dam No. 1. It admits water at three elevations, viz.: at the top, over a weir whose height can be regulated by stop-planks; at mid-depth, through a 36-inch cast-iron pipe laid in the inner slope of the dam and supported by a pier of rubble masonry; and at the bottom, through a similar pipe laid in the inner slope on rock in the side-hill. Each of the inlet-openings can be closed by stop-planks placed in a double set of grooves provided in the central wall and in the side-walls of the gate-house. The double set of grooves is formed by cast-iron beams of proper shape placed in recesses in the masonry walls.

The substructure of the gate-house is divided by a central wall, reaching from the bottom to the top, into two water-chambers, each of which is subdivided by a cross-wall into an inlet and an outlet chamber. The cross-walls reach only to the level of the inlet-weir, but they can be raised by stop-planks, placed in a double set of grooves provided in the central wall and in the side-walls, to the floor of the building. A cast-iron ladder attached to a side-wall is placed in each inlet and outlet chamber. An opening controlled by a 2′ × 5′ sluice-gate, operated from the floor of the building, is provided in the cross-wall between each inlet and outlet chamber.

The superstructure of the gate-house, built of granite masonry, is 25 × 27 feet in plan. The roof is formed of arches of brick laid in asphalt, which are supported by iron beams resting on the side-walls.

From the outlet-chambers the water is conveyed by two 36-inch cast-iron pipes, laid in a

brick tunnel through the outer slope of the dam, to a fountain-basin 30 feet in diameter (see Plate 111), where the water is discharged in vertical jets. Each line of pipes is provided with a stop-cock placed in a brick vault near the toe of the outer slope. The water is conducted from the fountain-basin to the old channel of Bog Brook.

Neither of the dams of this reservoir has a spillway. A waste-weir is provided in the gate-house of Dam No. 1, and the waste from the reservoir can also be made from the Sodom reservoir, with which it is connected, as already stated, by a tunnel. The flow through this tunnel is controlled by a gate-house (see Plate 116) located on the centre-line of the tunnel near its north portal, close to Dam No. 1. The water-chamber of the gate-house is divided into two parts by a cross-wall, which is 6 feet thick at the bottom and 3 feet thick near the top. This wall does not reach to the top of the substructure of the gate-house, but can be raised to this height by means of stop-planks placed in a double set of grooves made in the side-walls. An opening, lined with cast-iron plates 1¼ inches thick, is provided in the cross-wall, and is controlled by two 2′ × 10′ sluice-gates. Besides the sluices, a gate of the butterfly pattern is placed in the water-chamber, and can be closed quickly in case of an emergency. The water-chamber can be separated from the tunnel, at each end, by means of stop-planks placed in grooves in the masonry.

The superstructure of the gate-house, which is 23 × 27 feet in plan, is constructed of granite masonry.

The contract for the Bog Brook reservoir was awarded on December 19, 1888, to David R. Paige & Co. Ground was broken in Februray 1889 for Dam No. 1, and in April 1891 for Dam No. 2. Both dams were completed by August 15, 1893. The cost of the reservoir was about $330,000.

The Titicus Reservoir (Reservoir M, see Plate 54), was formed near the village of Purdy's, Westchester County, N. Y., by constructing a dam across the Titicus River, a tributary of the Croton. The reservoir, when full, covers 725 acres of land, and stores 7,167,000,000 U. S. gallons. It is supplied by a water-shed of 22.8 square miles.

The location of the dam was determined by numerous borings. Rock was found near the surface in the river-bed and for a short distance on both sides, but was so much fissured that it had to be excavated to a considerable depth before a satisfactory foundation could be obtained. At a short distance from the river the rock was found on both banks at a great depth below the surface.

The central part of the dam and the spillway, joining it on the south, were constructed of masonry, founded on rock. This structure was continued on both sides by an earthen dam having a masonry core-wall, which was founded only for a short distance on rock, and then on compact earth.

The length of the dam is as follows:

Masonry dam, including spillway	534	feet
North earth dam	732	"
South earth dam	253	"
Total length	1519	feet

The dam is built in plan as shown on Plate 117. A small spur projects from the north side of the valley towards the stream. As the strength of this hill to resist the pressure in the reservoir was considered somewhat doubtful, the north earthen dam was continued back of the hill, which forms thus a reinforcement to the north end of the dam. The profiles of the masonry dam and the spillway will be found respectively on Plates 119 and 121. The latter has a length of 200 feet, measured on the crest.

The principal dimensions of the dam are:

Width under coping	20.7	feet
Width about 109 feet below coping	75.2	"
Maximum height above foundation	135.0	"
Maximum height above surface	109.0	"

The masonry consists of solid rubble, faced up-stream and down-stream with cut range stone. Large stones, 3 to 30 cubic feet in size, were used for the bulk of the rubble, the spaces between them being filled with mortar into which small stones were bedded. The mortar was composed of American or Portland cement mixed with good sharp sand, obtained near the dam, generally in the proportion of 1 part cement to 2 parts sand. All the cement used was furnished by the American Cement Co. of Philadelphia, Pa. The cement was brought to the dam over a spur track of the New York and Harlem Railway. The sand was delivered by teams into a bin of 200 cubic yards' capacity, placed at the end of the cement house. The sand ran through openings directly to the mortar beds. In the beginning of the work the sand and cement were delivered to a mechanical device which measured the amount to be used of each, mixed and tempered the mortar, and delivered it into iron buckets. The iron box in which the cement and sand were mixed was revolved by means of a turbine. While this device was mechanically a success, its use was abandoned, as three and even four different mixtures of cement and sand were being used at the same time.

Part of the masonry was laid during freezing weather. In this case, the mortar was mixed with brine, the sand being first heated. The stones were steamed before being laid. No masonry was allowed to be laid when the temperature was lower than 20° Fahrenheit. The average amount of masonry laid in the dam per month was about 3240 cubic yards, the force engaged being about thirty-six masons using six derricks. The maximum amount laid per month was 5700 cubic yards.

The cornice of the dam, the top of the spillway, and the superstructure of the gate-house were constructed of granite dimension stone. All the stone required for the dam and gate-house was obtained from a quarry, which the contractors opened about 1½ miles north of the work. The floor of the quarry was about 400 feet above the bed of the stream at the dam. The empty cars were delivered at the far end of the quarry. When the brakes were released the cars would move by gravity along the face of the quarry to the point where the stones were washed, to the stone yard, or to the crusher. After leaving the quarry the cars would run by gravity to the head of an incline, operated by a cable. A train of four 8-ton cars would be attached to the cable, which was controlled by a powerful brake. The loaded

TITICUS DAM, FRONT FACE.

TITICUS DAM, BACK FACE.

cars in descending pulled a train of empty cars to the top of the incline. At the foot of the incline a seven-ton locomotive took the loaded train to the dam, switching it into the proper place for unloading. As the dam was carried up, the track for the locomotive was raised on the hillside. When the dam had been built to a height of about 50 feet above the stream, a trestle was constructed in front of the wall for the track. The stones were placed in the wall by means of boom-derricks.

The earthen dam, constructed on both sides of the masonry structure, has a maximum height of 102 feet above the surface and rises 9 feet above the crest of the spillway. It has a top width of 30 feet, and slopes of 2½ to 1, which are slightly modified at some points. The up-stream face is covered with a paving of stones (18 inches deep, laid on 12 inches of broken stone), which extends 5 feet above the top of the spillway. The top of the dam, the down-stream slope, and the up-stream slope above the paving are covered with 6 inches of good soil and sodded.

The core-wall is constructed of rubble masonry. It is 5 feet wide on top and 17 feet wide at a depth of 98 feet, both faces being battered about .06 ft. per foot. The maximum height of the core-wall above the foundation is 124 feet. As already stated, the core-wall is founded partly on rock and partly on earth. Some settling being expected where the foundation changed from rock to earth, a 5′ × 8′ well was constructed in the north core-wall where this change occurred. If the settling produced a crack in the wall, it was sure to be at its weakest point, viz., at the well. Two objects were accomplished by the well: 1st. It enabled the engineers to observe settling which was expected to occur. 2d. It made it possible to repair the core-wall, at this point, should it be necessary. When the wall had reached a height of about 50 feet above the foundation, a very slight crack was produced in the core-wall at the well. No further settling occurred. The well was finally filled with gravel.

The earthen dam on both sides of the masonry structure was carried up in 6-inch layers and thoroughly rolled as provided in the specifications (see page 267). For the north embankment the contractors used a steam-shovel, which excavated earth on the north slope of the valley. The steam-shovel worked successively in three pits, which were situated at such elevations that the loaded cars—each containing about one cubic yard of earth—could generally run by gravity to the point where the material was to be placed. The track used was of 18-inch gauge.

The flow from the reservoir is regulated by a gate-house constructed on the up-stream face of the masonry dam, near the spillway (see Plates 117, 118, and 120). The substructure is divided by a central wall into two divisions, each of which is subdivided by a cross-wall into an inlet and an outlet water-chamber.

Each inlet-chamber has three inlet openings, viz., one at the bottom, one at mid-depth, and one at the surface of the reservoir. These openings are 6 feet wide and 8–9½ feet high. They are protected by iron screens made of ½″ × 2½″ iron, and can be closed by means of stop-planks or by a wooden drop-gate. Two sets of grooves, 2′ 5″ centre to centre, are provided in the side-walls for the stop-planks. This makes it possible

to shut off the gate-house from the reservoir by a coffer-dam constructed with the stop-planks. The cross-wall between each set of inlet and outlet chambers has a bottom and a mid-depth opening for a 2′ × 5′ sluice-gate, operated from the floor of the building. The top of the cross-wall is 14 feet below the floor. It forms a weir, between the inlet and outlet chambers, whose height can be regulated by means of stop-planks. Two sets of grooves are provided in the side-walls for these planks.

Two 48-inch outlet-pipes (one from each division of the substructure) convey the water from the outlet-chambers to the old channel of the stream, which was excavated for a short distance to rock and roughly graded to form a waste-channel for the spillway. The outlet-pipes are controlled by stop-cocks placed in a vault (see Plate 120) located about 80 feet below the gate-house. A 24-inch pipe used for drainage during the construction passes through the bottom of the dam. Its up-stream end is closed by a flap-valve.

The superstructure of the gate-house is 32′ 6″ × 35′ in plan. It is constructed of granite masonry and has a roof of brick arches sprung from "I" beams. The floor of the building consists of a cast-iron grating resting on "I" beams.

Before the work of constructing the masonry dam was commenced, the Titicus River was diverted by constructing a crib dam, 24 feet high, about 1000 feet above the site of the dam (see Plate 122). The river, turned thus from its channel, was led to a point below the dam, first by a canal 25 feet wide, 8 feet deep, and 1000 feet long, excavated in the south bank, and then by a timber flume (see Plate 123), about 600 feet long, having two compartments, each 9 feet wide by 7 feet 9 inches high. Where the flume crossed the site of the dam it was 25 feet high above the original bed of the stream. After the dam had been raised above the flume (except the part immediately under it) the flume was turned so as to connect with the lowest inlet of the gate-house, from which the water was discharged by the two 48-inch outlet pipes. This arrangement was found to suffice for taking care of the stream at its ordinary volume. Provision was made for freshets by keeping part of the overflow-weir 10–15 feet below the rest of the masonry. During floods the valley would fill up to this low point where the water could overflow. A number of freshets were taken care of in this manner both before and after the removal of the flume.

Although the flume described above seems large compared with the ordinary flow in the river, it was only designed for ordinary freshets. It proved to be insufficient for two great freshets which occurred in the winter of 1890–1891. The damage caused to the construction on this occasion (the contractors claims for which were approved by the Aqueduct Commissioners) was not as great as the cost would have been of constructing the flume large enough to carry all the water in the river during these freshets.

The contract for constructing the Titicus Dam was let to Washburn, Shaler & Washburn * on February 18, 1890. Ground was broken on March 12, 1890. The work was practically completed by January 1, 1895.

Minor contracts for making new highways, boundary walls, etc., were let as follows:

* The firm was composed of Elmer Washburn, Ira A. Shaler, and Frank S. Washburn.

New highways and boundary walls, May 31, 1893, to John Twiname, for $64,500;

Clearing basin of trees, brush, etc. (two contracts), $4598;

Four sluice-gates and two timber gates in gate-house, to Coldwell, Wilcox & Co., for $4479;

Iron (highway) bridge, 38 ft. 4 in. span, to Berlin Iron Bridge Co., for $673.

The plans for the Titicus reservoir were prepared by Mr. A. Fteley, Chief Engineer of the Aqueduct Commission. Mr. Charles S. Gowen had charge of the work as Division Engineer until November 1, 1892, when he was transferred to the new Croton Dam, and was succeeded by Mr. Alfred Craven. Mr. Robert Ridgway was the Assistant Engineer in immediate charge of the work during the whole construction.

The Carmel Reservoir (Reservoir "D," see Plate 54) is being constructed on the west branch of the Croton River, near the village of Carmel, Putnam County, N. Y. The work is well advanced and will probably be completed by the summer of 1896.

The reservoir will cover more than 1100 acres of land and will store 9,000,000,000 U. S. gallons. It is formed by the construction of two dams, which will back the water to within a quarter of a mile of the Boyd's Corners reservoir (described on page 87).

The main dam was constructed across the west branch of the Croton River. It is about 1800 feet long and has a maximum height of 65 feet above the river-bed. The dam consists of a central masonry overflow-weir (spillway), flanked on each side by an earthen dam (see Plate 124). A masonry gate-house for controlling the flow from the reservoir was built on the north side of the spillway.

The overflow-weir (see Plate 125) was constructed of rubble masonry, faced with heavy blocks of blue-gray limestone from the Sandy Hill quarries, near Saratoga, N. Y. The crest of the spillway has a length of 260 feet, and a height of 53 feet above the bed of the river. The up-stream face is vertical except near the bottom, where it is battered. The down-stream face is formed by a series of steps. The overflow-weir and the gate-house, joining it on the north, were founded on rock. An extensive apron was constructed in front of the spillway to withstand the action of the falling water. It consists of a paving of heavy blocks of stone (3 feet thick for 30 feet from the weir, 2 feet thick for the next 50 feet, and 18 inches for the remaining part) which were placed upon a foundation of rubble masonry. The width of the apron is equal to that of the lowest step of the spillway at the weir. It is contracted by strong, curved wash-walls to 100 feet, at a distance of 35 feet from the weir. The apron is extended with this width to the end, its total length being 144 feet. Two falls of 18 inches in the apron bring it to the level of the original river-bed.

In this gate-house the inlet water-chamber is made at right angles to the two outlet-chambers. The latter are 5 × 6 feet in plan. They are separated by a cross-wall forming two compartments, each 6 feet wide, which are connected with the main inlet-chamber and can be separated from it by means of stop-planks. Openings are constructed in the above-mentioned cross-wall for two 2′ × 5′ sluice-gates, which regulate the flow from the reservoir. Provision has been made for two additional sluice-gates at the outlet-pipes, in case they

should be required. Two 48-inch outlet-pipes take the water from the outlet-chambers and discharge it upon the paving of the apron.

The earthen dam constructed on both sides of the overflow-weir has a top width of 15 feet, a slope of $2\frac{1}{2}:1$ on the water side and of $2:1$ on the outer side. Its crest rises 12 feet above the top of the spillway. The up-stream slope is protected by a paving of stone (18 inches deep, laid on 12 inches of broken stone), which extends to a height of 6 feet above the high-water mark. The top of the dam, the down-stream slope, and the up-stream slope above the paving are covered with sods.

The dam has a core-wall of rubble masonry except for a portion, 400 feet in length, north of the overflow-weir, constructed on ground the natural surface of which was near the elevation of the flow-line.

The core-wall, which extends 3 feet above the high-water mark, has a maximum height of 77 feet above the foundation. The wall has a top width of 5 feet. It is battered about 1′ in 16′, up and down stream, to the foundation-course, which projects about a foot beyond each face.

For about 20 feet north, and the same distance south, of the spillway, the core-wall was founded on rock. Beyond this distance the rock was at so great a depth below the surface that it was found unadvisable to excavate to it. The core-wall was therefore founded on a compact stratum of hardpan, at an average depth of 25 feet below the surface.

During the construction of the dam the west branch of the Croton was carried by a flume 30 feet wide and 6 feet high, until the masonry had been built up to such a height that the water could be discharged through the gate-house.

The auxiliary dam was constructed about one mile southwest of the main dam, across the valley of a small tributary of the west branch of the Croton River. Its length is about 800 feet and its maximum height above the surface about 50 feet. It was constructed in the same manner as the earthen portions of the main dam, except that it was made 22 feet wide on top, to provide room for a highway which crosses the valley on the dam.

Rock was found near the surface on the whole site of the dam, but it had to be excavated to a considerable depth, as it was fissured and disintegrated. The whole core-wall and the gate-house, which was located near the centre of the dam, were founded on rock. A portion of the outer slope of the dam had to be constructed on ground containing many springs in wet weather. It was drained in the following manner:

A large trench was dug near the toe of the slope and filled with broken stone. A similar blind ditch was made from the first trench to a point in the valley below where it discharged the water drained from the ground. For a height of about 12 feet above the sub-drains the outer slope was constructed with selected sandy and gravelly materials. It was paved with stone to this height.

The gate-house is located in the centre of the dam, on the line of the core-wall. It has a single water-chamber, about 5 by 17 feet in plan, which is provided with one $2' \times 5'$ sluice-gate for regulating the flow from the reservoir. The gate-house has a top and a bottom inlet, the latter consisting of a 36-inch cast-iron pipe laid in the dam and covered on

the outside with 12 inches of brickwork. The outlet-pipe is a 36-inch cast-iron main, which is laid in a brick culvert, constructed in the outer slope of the dam. It discharges the water into a circular fountain-basin. The pipe is provided with a stop-cock which is placed in a vault near the dam.

The contracts for constructing the two dams of the Carmel reservoir were let on September 19, 1890, to M. S. Colemen for $480,355 (on the basis of the estimated quantities). Ground was broken for the main and auxiliary dams respectively on the 21st and 19th of November, 1890. By consent of the Aqueduct Commissioners, Frank S. and Elmer Washburn became interested in the above contracts on May 23, 1893.

The work of constructing new highways and boundary fences was let in two contracts as follows:

First contract let to Peter J. Moran on April 11, 1893, for $88,389.

Second contract let to John Flanagan & Son on September 25, 1894, for $102,765.

Peter J. Moran assigned his contract, with the consent of the Aqueduct Commissioners, to John Flanagan.

The principal piece of work in connection with the new highways consisted in the construction of a causeway embankment about 1800 feet long, for a roadway across the reservoir. Its maximum height above the bottom of the reservoir is 45 feet. The highway is 22 feet wide between the guard-walls. Both slopes are riprapped 4 feet deep up to the guard walls of the roadway. Three circular brick-lined culverts, built one above the other in a rubble pier in the centre of the embankment, allow the water in the reservoir to flow through the causeway. The diameters of the bottom, middle, and top culvert are, respectively, 8 feet, 9 feet, and 10 feet.

Besides the work mentioned above, a contract for constructing the iron superstructure of a highway bridge of 50 feet span has been awarded to the Berlin Iron Co. for $1122. The work of clearing the reservoir basin of timber and brush has not yet been let.

The plans for the Carmel Reservoir were designed by Mr. A. Fteley, Chief Engineer of the Aqueduct Commission. The construction of the work has been, since the commencement, in the charge of Mr. Alfred Craven, Division Engineer.

The New Croton Reservoir.—During the delay which occurred in deciding the question of constructing a large storage reservoir in the lower part of the Croton Valley, the Engineers of the Aqueduct Commission explored this valley from the head of tide-water to the Old Croton Dam by borings with diamond-drills and by test-pits (see Plates 126 and 127), in order to determine whether a better site than the original location near the Quaker Bridge could be found.

The results of the investigations were presented to the Aqueduct Commissioners by their Chief Engineer, Mr. A. Fteley, in a report, dated October 8, 1890, in which three possible locations for the dam were considered, viz.:

PROPOSED SITES FOR NEW CROTON DAM.

Location.	Extreme Height * above River-bed.	Extreme Depth below River-bed.	Extreme Total Height.*	Length of Dam between Flow-lines.	Capacity in Gallons.	Estimated Cost.			Probable Time of Construction.	Water-shed above Dam
						Dam Proper.	Railroads, Roads, Bridges, and Clearing.	Muscoot Dam as previously estimated.		
	Feet.	Feet.	Feet.	Feet.					Years.	Sq. Miles.
Quaker Bridge.....	180	91	271	1402	34,000,000,000	$4,087,000	$1,075,000	$300,000	6	377.8
Cornell's.....	159	70	229	1736	32,000,000,000	†3,650,000	1,075,000	300,000	5	376.3
No. 2: Masonry.....	105.5	100.5	206	995	16,000,000,000	2,450,000	910,000	300,000	4	355.4
Earth and masonry as recommended....	105.5	100.5	206	995	16,000,000,000	1,750,000	910,000	300,000	3 to 4	355.4

* Top of dam assumed at elevation 206. † Approximate.

NOTE.—The Cornell site (named after the owner of a farm near by) is 1¼ miles above Quaker Bridge. The location designated as No. 2 is less than a mile below the Old Croton Dam.

Mr. Fteley stated that the construction of the East Branch, Titicus, Carmel, and Amawalk reservoirs, which had been begun and would increase the amount of storage, within a few years, to about 40,000,000,000 U. S. gallons, had changed the conditions which had caused eminent engineers to recommend the construction of the Quaker Bridge reservoir. Under the existing circumstances he advised that the proposed dam be built on the last-mentioned location (No. 2), for the following reasons:

1st. The storage thus obtained, added to that of the reservoirs under construction, would be sufficient for the wants of the city for many years.

2d. The cost of the dam would be much less than at the Quaker Bridge or Cornell site.

3d. The interest on the money saved by building the dam on location No. 2 in preference to either of the other two would almost suffice at the end of 25 years to build a dam on one of those sites.

4th. By deferring the construction of a great reservoir, on the lower Croton, for some years, experience would be obtained in the requirements of the city and the yield of the Croton watershed, which might have an important bearing on the ultimate decision whether a high dam should be built near the Quaker Bridge.

Mr. Fteley stated in his report that "if it were found advisable to build the originally proposed high dam at Quaker Bridge or its vicinity, the merits of Cornell's site should be carefully considered before deciding on a final location." He recommended that a dam be built soon on one of the proposed locations, as he considered that the old Croton Dam, which had been built many years ago, had not that margin of safety which its importance to the city's water-supply required.

Mr. George W. Birdsall, Chief Engineer of the Croton Aqueduct, and Mr. Eugene E. McLean, Engineer of the Finance Department, made reports respectively to the Commissioner of Public Works and to the Comptroller (both members *ex officio* of the Aqueduct

Commission) in which they argued against the immediate necessity of building a dam on any of the sites mentioned above. In case it should be decided, however, to build the proposed structure Mr. Birdsall thought that either the Quaker Bridge or the Cornell site should be chosen.

The Aqueduct Commissioners were divided in opinion with reference to the important question which they had to decide. On January 22, 1891, the Board determined by a divided vote to construct a high dam on the Cornell site. The contract for the work was awarded on August 26, 1892, to James S. Coleman. Mr. Charles S. Gowen was given charge of the construction as Division Engineer. Ground was broken for the "New Croton Dam" (the name given to the structure) on September 20, 1892.

At the site of the dam, which is about 3¼ miles above the mouth of the river and 3.1 miles below the old Croton Dam, the river has approximately a westerly course. The width of the valley at this point is about 450 feet at the level of the south bank of the river and about 1300 feet at the flow-line (elevation 200).

According to the numerous test-borings the bed-rock extends across the valley at about elevation –30, seventy-five feet below the river-bed, but is occasionally deeper in pockets. On the north side of the river the rock rises abruptly to near the surface, cropping out at points. It continues on a steep slope to the top of the hill, about 300 feet high. On the south side of the valley the rock rises gradually with the earth slope, being at first about 70 feet below the surface, but at the south end of the dam at a depth of only 20 feet. At the river-bed the rock is covered with sand, gravel, and boulders. Towards the southern side of the valley the material next to the rock consists of hardpan and compact gravel. On the south side of the valley the rock is limestone, on the north side it is gneiss. The borings indicate that the junction of the two kinds of rock lies about under the old river-bed and is about parallel with it.

The dam is to consist of three parts (see Plates 127 and 128):

1st. A central masonry dam about 600 feet long.

2d. A masonry overflow-weir, nearly 1000 feet long, on the north side of the central structure and nearly at right angles thereto.

3d. An earthen dam with masonry core-wall, about 600 feet long, forming a continuation of the masonry dam to the south side of the valley.

The overflow-weir, masonry dam, and core-wall of the earth bank are all to be founded on rock and will form a continuous masonry wall across the valley.

The masonry dam will have a maximum height of about 260 feet, its top being 10 feet above the flow-line. It will be 18 feet wide on top and will form a roadway which will be continued from the north end of the structure to the side of the valley by a bridge of about 230 feet span. The profile adopted for the dam (see Plate 129) is practically the design made for the proposed Quaker Bridge Dam,* the only essential changes being that it has less height and that the polygonal faces have been rounded off.

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* For theoretical details see "The Design and Construction of Masonry Dams" by the author.

A gate-house for drawing off the water from the reservoir is to be constructed on the up-stream side of the masonry dam near its north end (see Plate 130). The substructure of the gate-house will be divided by brick walls into three separate water-chambers. Each chamber will have an inlet-opening constructed about 30 feet above the original river-bed and just above the embankment that will be made above the dam with the surplus material excavated from the foundation-trench. Sluice-gates for regulating the flow from the reservoir will be placed in each water-chamber. The inlet-openings are to be closed, when required, by stop-planks placed in grooves in the walls of the substructure. Three 48-inch cast-iron outlet-pipes, laid in the masonry of the dam and controlled by stop-cocks placed in a vault constructed on the down-stream face of the dam, will conduct the water from the three chambers mentioned above through the dam and will discharge it into the old river-channel.

At the junction of the earthen and masonry dams a large wing-wall is to be constructed at right angles to the axis of the dam.

The overflow-weir (see Plate 131) is to be built along the hillside, about parallel with the contour-lines, and to be curved to join the north end of the masonry dam. Its height will vary from 10 feet at the end on the hillside to 150 feet at the masonry dam, its top being 4 feet below the flow-line. The down-stream face of the overflow will form a series of steps varying in rise from 2 to 8 feet and in tread from 2 to 6 feet. The up-stream face will be battered below elevation 140. In front of the overflow a waste-channel—50 feet wide at the beginning and 125 feet wide at the masonry dam—is to be excavated in the rock. It will conduct the overflowing water to the old channel of the river.

The earthen dam (see Plate 132) is to have a top width of 30 feet and to rise 20 feet above the flow-line. Its maximum height above the surface will be about 120 feet. Both sides are to be sloped 2 : 1, the down-stream slope being broken, however, by three berms, each five feet wide (made at elevation 130, 160, and 190), which are to be ditched and paved in order to carry the rain-water running down this slope to the hillside. The top of the dam (except where the roadway is formed) and the down-stream slope are to be covered with good soil and to be sodded. The up-stream slope is to be protected by a stone paving two feet deep, placed on 18 inches of broken stone.

The top of the core-wall will reach elevation 200 (the flow-line) and will be 6 feet wide. Both faces will be battered uniformly so as to make the width of the wall 18 feet, about 36 feet below the top. This width is to continue from the point mentioned to the bed-rock. The maximum height of the core-wall above the foundation will be about 225 feet.

The old Croton Aqueduct crosses the line of the earthen dam on the south side of the valley, at about elevation 153. To obtain a good location for a gate-house which is to control the flow through the old Aqueduct, this conduit is to be turned by a new loop further into the hillside. While this change is being made the water is to be conveyed by a temporary line of 12-inch mains, where the old conduit is interrupted, in order to supply the prison at Sing Sing.

The gate-house (see Plates 127 and 128) will be constructed adjoining the core-wall, near the south end of the dam. The substructure of the gate-house will be divided into four water-chambers, the two easterly ones being the inlet-chambers. One of these will be connected with the old aqueduct coming from the present dam, the other will draw water near the new dam by means of three short oval conduits (6 feet high by 10 feet wide) forming a bottom, a middle, and a top inlet, which will enter the gate-house respectively at elevations 152.7, 169, and 185. They are to be built along the new loop for the aqueduct until well away from the toe of the embankment, and will draw water between elevations 70 and 185. Provision will be made for closing all the inlet-openings at the gate-house by means of stop-planks placed in grooves in the side-walls.

The floor of the water-chamber will be at elevation 151.7, one foot below the invert grade of the old aqueduct at this point. Each of the inlet-chambers will be connected with the chamber west of it by openings controlled by sluice-gates operated from the floor of the superstructure. The two westerly chambers will be connected together by openings controlled by sluice-gates in like manner. The outlet will take place from the southwest chamber to which the old aqueduct will be connected.

A system of 12-inch drain-pipes, placed below the floor of the substructure, will serve for draining the water-chambers. The system will be continued by one 12-inch pipe which will follow the aqueduct for a short distance and will then discharge the water at a suitable place.

Details of Construction.—The hearting of the overflow-weir and masonry dam is to be formed of rubble masonry, faced with ashlar, which is to have a depth of at least 28 inches. The courses of the facing (which begin for the overflow at the foundation, but for the masonry wall only above the refilling placed in front and back of the dam) will vary in rise from 30 to 15 inches. The joints for this work are not to exceed ½ inch for 4 inches from the exposed face, and are not to be wider than 2 inches for the remaining depth. In each course every third stone is to be a header, having a length of at least 4 feet. The stretchers are not to be less than 3 feet nor more than 7 feet long. In the successive courses the headers and stretchers are to alternate, approximately, in a vertical plane.

The steps on the down-stream side of the overflow are to be made of block masonry, which generally is to have a greater rise and width than the facing stone, and is to have a sufficient depth to bond under the next step above. The joints in this work are not to be wider than one inch. For the upper steps over which the water passes first, the coping is to be made of granite dimension stone, having the exposed faces roughly pointed.

The heavy cornice of the masonry dam is to be made of granite dimension stone. The roadway on top of this structure will be formed of concrete, covered with asphalt. It will be drained by short pipes, placed under the coping. The large wing-wall at the southern end of the masonry dam will be built of rubble masonry faced, above ground, with ashlar and coped.

The superstructure of the gate-house will be similar in design to those of the other dams constructed by the Aqueduct Commission. The water-chambers will be lined with brick

laid in Portland cement-mortar except at the gate-openings, where granite dimension stone will be used. The grooves for the stop-planks will be formed by castings joined into the brick lining.

Protection Works.—Owing to the great depth to which the foundation-trench for the masonry dam has to be excavated, expensive works were required for turning the river from its former course. A new channel for the river, 125 feet wide and about 1100 feet long, has been excavated in the rock on the north side of the valley. To avoid expense it was kept 5 feet higher than the old bed. The river is confined in its new channel on the north by the slope of the hill, and on the south by a masonry wall continued at both ends by earthen dams which extend across the old channel, the upper one serving to turn the river into its new course.

The wall is built for about 300 feet on each side of the centre-line of the dam. It is 3 feet wide at the top and 13 feet at the base, its height being 23 to 25 feet above the grade of the new channel. The face towards the water-channel is almost vertical. On the other side of the wall (except where it crosses the site of the dam) an earth embankment will be carried up for about half its height. Some portions of the wall which form permanent work have been made stronger than the dimensions given above.

The masonry wall is being continued at each end by an earthen dam, 10 feet wide on top and about 30 feet high. Towards the channel the banks are sloped 1½ : 1, and on the opposite side 2 : 1. Water-tightness is insured in these earthen dams by providing them with a core-wall formed of two courses of 3-inch tongued-and-grooved sheet-piles, which extend 3 feet below the top of the banks to about 20 feet below the original surface. The two courses of sheet-piles are spiked together and are stiffened above the river-bed by frequent courses of horizontal range-timbers, which were fastened to the sheeting as it was put in place. The toe of the slopes on the channel side is formed of heavy crib-work 10 to 12 feet high. In both dams two cribs, each 10 feet wide, are placed 6 feet apart, the space between them being filled with compact earth. The cribs are joined together by frequent cross-ties, extending through the 6-foot spaces. The outer faces of the cribs and those on each side of the filling, just mentioned, are covered with 3-inch tongued-and-grooved sheeting, sunk 3½ to 10 feet into the ground below the bottom of the crib. The cribs are to protect the toe of embankments against the scouring action of the water, which may have a depth of 15 to 19 feet during great freshets. The total length of the masonry and earth dams which bound the new channel of the river on the south is about 1600 feet.

The work which has been accomplished up to January 1, 1895, in constructing the new Croton Dam is as follows:

The new channel for the river has been excavated. The masonry wall on the south of the channel has been carried up to a height of 13 feet. The crib-work for both wing-dams is nearly completed, and the embankments have been commenced. Most of the excavation above the river-bed, required for the masonry dam, has been made. The river having been turned into its new channel, the excavation below its former bed is now in progress. This

work is being done with steam-shovels. The excavation and masonry required for the new loop for the old aqueduct at the new dam has been almost finished. The rock and earth excavation for the channel on the side-hill in front of the overflow-weir, is nearly completed. The total amount of work done under the contract to January 1, 1895, amounts to about $800,000.

The Jerome Park Reservoir.—We have stated on page 114 that the Aqueduct Commissioners decided in 1884 to construct a new receiving reservoir at Jerome Park, in the Annexed District of the city. This site was the only one that could be found within or near the city, where the surface of the ground was near the required elevation to a sufficient extent. Owing to various causes of delay, the plans for the Jerome Park reservoir were not prepared until 1894. A contract for the work was made with John B. McDonald on August 23, 1895.

The basin will be formed by building earthen embankments with masonry core-walls at depressions where they are required to retain the water, and by excavating the high points on the reservoir site. The embankments will generally be of moderate height, the maximum being 35 feet above the surface in the northwest part of the reservoir. The total amount of rock and earth excavation that will be required is estimated at about 7,000,000 cubic yards. In order to insure water-tightness, the whole bottom of the reservoir is to be covered with 3 to 6 inches of concrete. The embankments will be made as shown on Plate 134. The inner slopes are to be covered to an elevation 2 feet above the water-line, with 4 to 8 inches of concrete, the lower part being faced with a 4-inch course of brickwork and the remaining portion with paving-stone, 15 inches deep, laid dry on a bed of mortar.

The reservoir will have a water-surface of about 228 acres, and will store about 1,900,000,000 gallons. This storage will raise the total amount of water in the reservoirs within the limits of the city to 3,234,000,000 U. S. gallons. As these reservoirs cannot be entirely emptied without causing great inconvenience and hardship from the reduction of pressure in the mains that would result, only about half of the above total amount of storage is to be considered available.

The Jerome Park reservoir is to be fed by both the old and the new aqueduct. At present the former passes through the proposed basin on an embankment, while the latter passes beneath it in a tunnel, located about 115 feet below the surface, with which it is connected by shaft No. 21, now closed by a temporary timber bulkhead. According to the plans adopted, the new aqueduct is to be brought to the reservoir by a branch conduit about 7500 feet long, which will leave the aqueduct at station 1268 + 02.5 (see Plate 133) just before the depressed part of the conduit begins, and will follow the line of the old aqueduct to Jerome Park. Both conduits are to be carried into the reservoir on a masonry structure, founded on rock, to a large inlet gate-house (see Plate 133). The masonry structure continues through the reservoir, and divides it into an east and a west basin. The old aqueduct is carried on top of this division-wall through the reservoir. By

means of the arrangement of the gate-houses described hereafter, either of the aqueducts can discharge its water into the reservoir or convey it further into the city.

In order to control the inlet and outlet of the reservoir five gate-houses are to be constructed (see Plate 133), viz.: gate-house No. 1, at the point where the branch conduit leaves the new aqueduct; gate-houses Nos. 2, 3, and 4, at different points on the reservoir embankment for controlling the outlet; gate-house No. 5, at a central point in the reservoir, for regulating the inlet through either or both of the aqueducts.

Gate-house No. 1 (see Plate 135) will form an "L" in plan, the main building being 31 × 35 feet, and the wing 22 × 27 feet. The branch conduit leaves the wing of the gate-house at right angles (westerly) to the direction of the main aqueduct. It is to have a "horseshoe" cross-section, 11.40 feet wide and 13.53 feet high. A central pier in the gate-house will divide the water flowing toward the branch conduit into two streams, each 6 feet wide. Four 2′ × 10′ sluice-gates will control the inlet-openings to the branch aqueduct, which are to be constructed in a cross-wall in the water-chamber of the wing of the building. In the sides of the wing and main water-chambers grooves are to be provided for stop-planks for shutting off the main or branch aqueducts from the city.

Gate-houses Nos. 2, 3, and 4 (see Plate 133) will be constructed to control the outlet from the reservoir. Each is to have two inlet-chambers, one for drawing water from the reservoir at the gate-house at different levels, and the other for drawing water from the further division of the reservoir by means of two 48-inch pipes, which are to be laid on the bottom of the reservoir, and are to be connected with the central inlet gate-house (No. 5), as described hereafter. The two water-chambers of each of the outlet gate-houses are to be connected by an arched passage to be constructed in the partition-wall between them.

Two 48-inch outlet-pipes are to be laid from each of these gate-houses, and are to be connected with the pipe system of the Annexed District. These pipes will be laid in brick culverts through the embankments of the reservoir. Each outlet-pipe will be controlled by a stop-cock, which will be placed in a chamber of the gate-house. At each inlet from the reservoir, grooves will be provided in the masonry. They will ordinarily be used for wire screens, and, in case of necessity, for stop-planks for closing the connection with the reservoir. Drain-pipes for emptying the water-chambers will be laid at each gate-house.

The general plan for gate-houses Nos. 3 and 4 is shown on Plate 137. Each is to have a substructure about 29 × 35 feet in plan. The top inlet of the chamber drawing water from the near division of the reservoir will be at right angles to the bottom and middle inlet.

Gate-house No. 2 (see Plate 136) will be 37 × 40 feet in plan. In addition to the chambers provided for Nos. 3 and 4, it will have a central chamber into which the waste water from the reservoir will pass over three waste-weirs (each 6 feet wide), the height of which will be regulated by stop-planks. One of these weirs will be constructed in the main-wall of the substructure, and the other two in the walls separating the water-chambers from the waste-chamber. A 20-inch waste-pipe will be laid from gate-house No. 5 to the waste-chamber of No. 2. This chamber will be connected by means of a masonry culvert with a sewer near

by. Provision will be made for placing two 2′ × 5′ sluice-gates in the cross-wall of gate-house No. 2 in case they should be required.

Gate-house No. 5 (see Plates 138 to 142, inclusive) is to be constructed on the division-wall of the reservoir at the point shown on Plate 133. It is to serve for the following purposes:

1st. To receive the water from the old aqueduct and the branch of the new aqueduct.

2d. To discharge this water into the east or the west division of the reservoir, or into both; or to let it pass to the city in the new or the old aqueduct without entering the reservoir.

3d. To form a connection between the two divisions of the reservoir.

4th. To control the inlet into the 48-inch pipes laid from gate-houses Nos. 2, 3, and 4, to this gate-house.

5th. To connect the new aqueduct (located in a tunnel 115 feet below the surface) by means of shaft No. 21 with the reservoir.

Gate-house No. 5 will be arranged to maintain a supply to the city when either or both divisions of the reservoir are empty.

The gate-house will have in plan the form of a cross. It will contain a large inlet water-chamber, which will be divided by a central cross-wall, provided with openings controlled by sluice-gates, into an east and a west section. The branch from the new aqueduct will enter the former and the old aqueduct the latter. On the north the inlet-chamber will be connected with a small water-chamber (14 × 18 feet in plan), from which the inlet into a masonry conduit leading to and connected with shaft 21 will be controlled by means of sluice-gates. By this arrangement the water entering the inlet-chamber can be turned into the new aqueduct.

From the west section of the inlet-chamber a new conduit is to be built for the old aqueduct around the gate-house and to be continued on top of the division-wall to the southern extremity of the reservoir, where it is to be joined to the old aqueduct.

A short masonry conduit will lead the water from the east section of the inlet-chamber to the outlet-chamber to be constructed at the south end of the gate-house. From the latter chamber two circular masonry conduits, which are to be constructed in the division-wall, each 12 feet in diameter, will convey the water to a point about 2000 feet south of the gate-house, where the conduits will terminate. Here the water will be discharged from the two conduits respectively into the east and west divisions of the reservoir. By discharging the water in this manner and drawing from gate-house No. 5, a circulation will be produced in the reservoir. The inlet into the conduits just described will be controlled at the outlet-chamber of the gate-house by means of sluice-gates and stop-planks.

Below the bottom of the water-chambers mentioned above, other water-passages are to be provided. Just north of the inlet-chamber of the branch conduit leading to shaft 21, two arched passages will connect the two divisions of the reservoir. For each passage a small chamber, provided with two sets of grooves for stop-planks, will be constructed in the gate-house. Two similar arched passages are to be constructed under the main inlet-chamber.

Provision will be made for closing each of these passages by sluice-gates and by means of stop-planks.

The 48-inch mains to be laid from gate-house Nos. 2, 3, and 4 to No. 5 will terminate at this gate-house and will be continued by arched passages to be constructed in the gate-houses and to be controlled by sluice-gates and stop-planks, as shown on Plate 139. These passages will enable each set of 48-inch mains to draw water from the far side of the gate-house.

In gate-house No. 5 all the sluice-gates are to be either 2 × 10 feet or 2 × 8 feet, placed in pairs. Arrangements will be made for relieving the back-pressure on the gates before they are opened. A complete drainage system will be provided. A 20-inch drain-pipe will convey the waste water to gate-house No. 2, where it will be discharged as described on page 211.

APPENDIX I.

MACHINERY AND APPLIANCES USED IN CONSTRUCTING THE NEW CROTON AQUEDUCT.

Air-Compressors.—Three kinds of air-compressors were used—the Ingersoll, the Rand, and the Norwalk. As great improvements have been made during the past ten years in this kind of machinery, the reader must bear in mind that the compressors described below represent the styles manufactured in 1885 and not the improved machines made now.

The Ingersoll "Straight Line" Air-compressor is shown on Plate 145. The frame or bed-piece, to which the compressor is anchored by eight strong bolts, is made in one casting, the parallel sides being stiffened by heavy transverse ribs. The steam- and air-cylinders are placed in a straight line upon the bed-piece and are connected at the top by heavy tie-rods. The piston-rods of both cylinders are attached to the same cross-head, a solid wrought-iron forging, bearing on the frame and having top and bottom brasses running on guides. In all engines above twelve inches in diameter the piston-rod of the air-cylinder extends through the back-head and is supported outside of the cylinder by an adjustable bearing, which relieves the cylinder from supporting the whole weight of the piston and thus avoids much wear and leakage. The steam- and air-pistons are similar, each being fitted with two anti-friction, self-packing, metallic piston-rings, made of cast-iron for the former and of composition metal for the latter.

Two well-balanced fly-wheels are provided to give a uniform motion to the compressor. They are forced upon and keyed to a heavy main shaft, placed near one end of the frame. The connecting-rods are fastened at one end to the cross-head and at the other to the crank-pins of the fly-wheels.

The smaller engines have ordinary slide-valves, cutting off at three quarters of the stroke, but those over fourteen inches in diameter are provided with Meyer's adjustable cut-off. Eccentrics keyed to the main shaft transmit motion to the steam-valves by means of rockers, fastened to a special rock-shaft, and having their upper arms connected to the valve-stems.

Each head of the air-cylinder is provided with patent inlet- and discharge-valves of the poppet type. They are made of phosphor bronze, and are light and noiseless in motion. As they work in cages screwed to the cylinder-heads from the outside, they can be examined or removed without removing the cylinder-heads. The cooling of the air during compres-

sion is effected, when clear water can be obtained, by a double-acting injection spray-pump fitted to the air-cylinder and moved by a radiating arm having one end fixed and the other moved by the cross-head. Three cubic inches of water are injected against the air-cylinder piston for every cubic foot of free air drawn in by the compressor. When perfectly clear water cannot be obtained for this purpose, which is generally the case, a water-jacket for the air-cylinder is substituted for the spray-pump.

An automatic speed and pressure regulator, placed upon the air-cylinder, prevents the air-pressure from rising above the desired amount by throttling the steam and thus reducing the speed of the machine. It is connected by a small pipe with the air-receiver, and by means of rods and bell-cranks with a balanced regulating-valve in the steam-pipe. In shutting off the steam it closes at the same time, by a suitable attachment, the water-supply and opens a passage permitting the air to flow from one end of the air-cylinder to the other. The machine is thus stopped from compressing any more air. Valves placed upon the regulator serve to throw the air-pressure on either side of the piston of the air-cylinder when the engine is to be taken off the centre.

The Rand Air-compressors (see Plate 146) were all of the duplex non-condensing type. Each of these machines has two steam- and two air-cylinders, 18 inches in diameter by 30-inch stroke. The air-cylinders are placed in the rear of the steam-cylinders, to which they are secured (as also to each other) by a heavy cast-iron sole-plate and by tie-rods. The frames supporting the compressors are of the Corliss type, slightly modified so as to permit the use of bored guides for the cross-heads. The Rand Drill Company claim that with this construction the settling of the foundation or any other disturbance in the alignment has less effect upon the machine than that which occurs with the usual style of planed guides.

The steam-cylinders are fitted with the Meyer valve-gear, which insures an economical use of the steam and seldom gets out of order. The air-cylinders are provided with water-jackets and have spring-pressed poppet-valves. Uniformity of motion in the compressor is obtained by an extra-heavy fly-wheel.

One of the advantages of the Rand Duplex Compressor is that half of the machine (i.e., one steam-cylinder and the air-cylinder tandem with it) can be stopped for inspection or repairs while the other half continues to work.

The Norwalk Compound Air-compressor (see Plate 147) is a compact and efficient machine which was used at some of the shafts. In this compressor the air is first partially compressed in a large intake cylinder and then, a second time, in a smaller compression cylinder, to the required pressure. The piston of the latter has only about one third the area of that of the former. By this arrangement the work performed by the machine varies less at the different points of the stroke than in the ordinary types of compressors.

Each air-cylinder is provided with a water-jacket. In addition to this the air is made to pass through an intermediate cooler in flowing from the first to the second compression cylinders. This cooler consists of a cast-iron pipe, filled with small copper water-tubes, which present a large cooling surface to the air passing between them. By means of the two

water-jackets and the intermediate cooler, the heat generated in compressing air is largely reduced.

The piston of the steam and air-cylinders are connected to the same piston-rod which is provided with a swivel connection for the cross-head which equalizes the work on the two connecting rods. The valves of the air-cylinders are of the Corliss steam-engine pattern. The steam-engine has a cut-off valve which can be regulated by a hand-wheel while the machine is in motion. With sixty to eighty pounds pressure, the steam can be cut off at one quarter to one fifth of the stroke. The point of cut-off is shown by an index. Uniformity of motion is obtained by two light fly-wheels, one on each side of the machine.

The air is delivered to the compressor as cool as possible. It is taken on the north side of the building at the eaves of the roof and led through a tight wooden conduit, which passes under the floor of the engine-house to the air-cylinders. During the hot months the air can be cooled additionally by a spray of water while passing through the conduit under the floor of the building. The connections between the ports of the air-cylinders and the conduit are made by movable wooden hoods.

The Ingersoll "Eclipse" Rock-drill (Fig. 54) is operated by steam or compressed air.

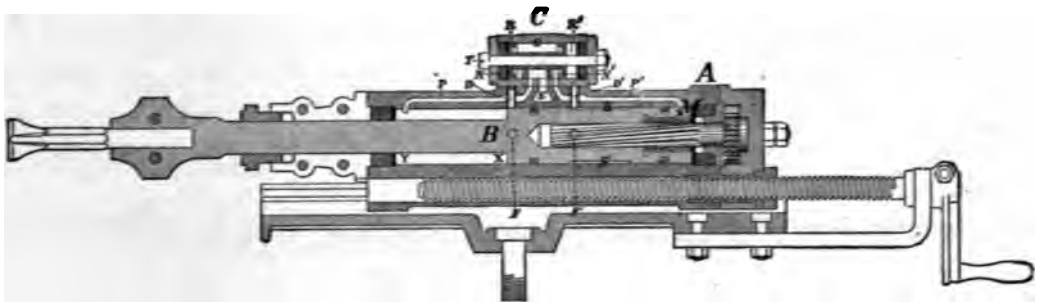

FIG. 54.—INGERSOLL "ECLIPSE" ROCK-DRILL.

It strikes an uncushioned blow, the steam following the piston, without expansion, to the end of the stroke. In raising the drill the machine has the same power as in striking. The valve is thrown by the steam, without the intervention of any mechanical connections, as described below. The stroke of the drill can be made as short as desired by feeding the cylinder closer to the rock,—a great advantage in starting a hole or in drilling in seamy rock.

The cylinder (*A*) has two steam-ports (*P*, *P'*) and an exhaust-port (*E*). Besides these openings, two exhaust-passages for the valve, indicated by the dotted circles *F*, *F'* are provided to connect the interior of the cylinder with the exhaust-port (*E*) and thus with the outer air.

The piston is made in one piece with the rod to which the drills are fastened. It has a long bearing at both ends, but is turned down in the middle so as to form an annular space (*S*) between the piston and the cylinder. This space moves up and down with the piston and is always connected with the outer atmosphere by either passage *F* or *F'*.

The valve is spool-shaped. A bolt (*T*) passing through a longitudinal hole serves as a guide and by means of a spline prevents the valve from rolling. The valve is thrown by the

steam, at the end of the stroke, successively forwards and backwards, in the following manner: D, D' are small brass tubes forming exhaust-ports for the valve, connected by cored passages, crossing each other, respectively, with the spaces R' and R in the steam-chest, at the end of the valve. One of the ports D or D' always exhausts the steam from one side of the valve, through the space S and passage F or F'. The steam surrounding the valve throws it towards the side of the chest at the open exhaust-passage. Rubber buffers receive the shock.

By the simple arrangement described above the valve and piston are moved by reciprocative action without any mechanical means. When the cylinder is brought nearer to the rock by turning the feed-screw, the piston moves only in the back part of the cylinder, and the stroke is thus reduced. A rubber buffer prevents the piston from striking the back cylinder-head.

The crank end of the feed-screw is held in place by a collar attached to the frame of the machine. The other end works in a long nut attached to the cylinder. When the crank is turned the feed-screw moves the cylinder forwards or backwards.

The drill strikes a straight blow, but is made to partially revolve during the up-stroke by the following arrangement:

A spirally-grooved cylindrical steel bar (called the rifle-bar) works in a brass nut having corresponding grooves, which is screwed into the piston at its back-face. A ratchet-wheel is attached at the end of the rifle-bar, the pawls being placed so as to allow the nut to turn the bar during the down-stroke, while on the up-stroke the rifle-bar turns the nut and, consequently, the piston and the drill.

The Sergeant Drill (Fig. 55) is an improved machine designed by Mr. Henry C. Ser-

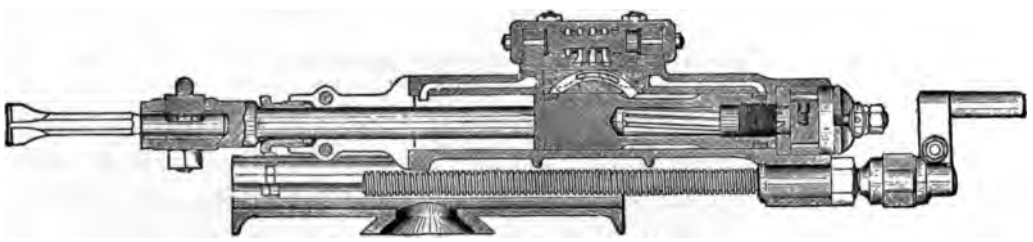

FIG. 55.—SERGEANT ROCK-DRILL.

geant, the inventor of the present Ingersoll drill. It has all the characteristic features of the Ingersoll drill: a steam-thrown valve, a variable stroke, no cushioning of the piston, etc., and, in addition, the following improvements:

(1) An auxiliary valve moving in an arc of a circle and operated by shoulders on the piston, admits and exhausts the steam successively from each side of the valve proper, causing it to move from one side of the steam-chest to the other.

(2) The main valve, a round piston of hardened steel, fitting like a plug at its ends, is perfectly balanced and gives a large opening for a small motion.

(3) The rotating device has a release motion, which prevents the twisting of the rifle-bar or the breaking of the pawls or ratchet-wheel. When a rock-drill strikes a hard blow

on an uneven surface, there is sometimes a tendency to twist the steel in the opposite direction of that in which it rotates. In the Sergeant drill the effect of such a force is simply to turn the back-head of the rifle-bar and, by means of the pawls, the ratchet-wheel, by overcoming the friction of the buffer-spring, which presses, by means of a washer, against the upper surface of the back-head.

(4) The ratchet (Fig. 56) has internal teeth. The pawls are square pieces of steel, pressed into the teeth by springs.

(5) Strong steel springs, attached to the front and back cylinder-heads, serve as buffers by allowing the heads to yield slightly, should they be struck by the piston.

FIG. 56.—RATCHET.

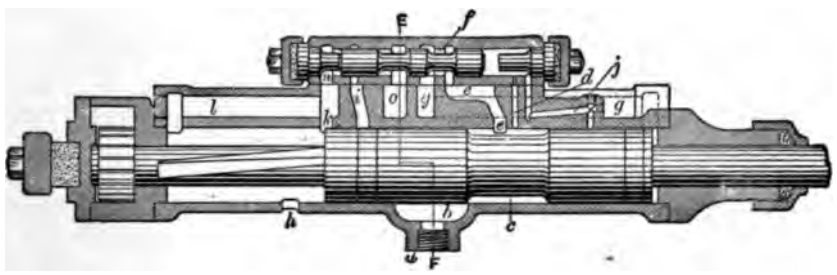

FIG. 57.—RAND ROCK-DRILL.

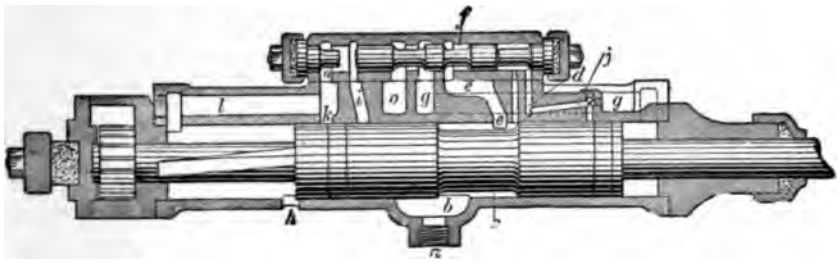

FIG. 58.—RAND ROCK-DRILL.

The Rand drills used (Figs. 57, 58, and 59) were mostly of the "Slugger" pattern, a machine well adapted for hard and heavy work. By means of the ingenious valve-motion described below, this machine strikes an uncushioned blow, although the steam is used to a certain extent expansively. A cushion of exhaust-steam is formed to arrest the motion of the piston on the up-stroke.

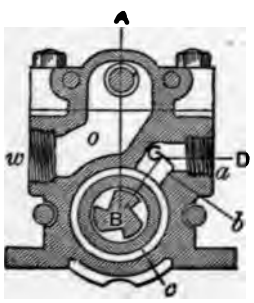

FIG. 59.
RAND ROCK-DRILL.

The valve is a solid spool made of steel. In explaining its action reference will be made to Figs. 57 and 58, which are longitudinal sections taken on the broken line *ABCD* of Fig. 59.

In Fig. 57 the piston is beginning its upward stroke. The steam enters at the supply-nozzle *a* and flows through the longitudinal groove *b*, in the cylinder, to the circumferential groove *c* in the piston (see Fig. 59). From *c* it passes through the port *ce*, the neck of the valve *f*, and the passage *gg* to the lower end of the cylinder. At the same time it enters the lower end of the steam-chest through the port *d* and holds the valve firmly in the position shown.

As the piston moves upward it produces in succession the following effects:

1st. *h*, the exhaust-port of the upper end of the cylinder, is closed. The steam remaining in that part of the cylinder forms a cushion for the piston.

2d. Port *d* is closed. The steam in the lower end of the steam-chest is confined until port *j*, a passage leading to the lower end of the cylinder, is opened.

3d. Port *e* is closed. The steam acts now by expansion.

4th. Port *i* is open, but has no effect until the valve is shifted.

5th. Port *k* is opened. The steam flows into the upper end of the cylinder and assists in arresting the motion of the piston. It passes also through *n* into the upper end of the steam-chest.

As the pressure on the lower end of the valve has been reduced by the expansion in the cylinder, the valve is thrown to the position shown in Fig. 58. The steam in the lower end of the cylinder is now exhausted through the passage *gg* and the exhaust-port *o*.

In making its down-stroke the piston reverses the effects described above. After the port *k* is closed steam flows into the upper end of the cylinder through the passages *i* (opened by the shifting of the valve), *n*, and 1.

In Fig. 58 the port *d*, leading to the steam-chest, has just been opened.

If the piston were stopped in the position shown the valve would be shifted, as the steam on its upper side is being exhausted through *h*. The motion of the machine would thus be reversed. The piston is, however, enabled to make the full stroke (without any cushioning) before the valve is moved by the steam-chest end of *d* being constricted so as to delay the flow of the steam. It is evident that the stroke of the drill can be varied by stopping the piston anywhere between the position shown in Fig. 58 and the end of the cylinder.

Most of the ports opening into the cylinder are arranged in pairs, the ports being diametrically opposite to each other, in order to obviate side-pressure on the piston.

The drills have the usual rotating-ratchet device and are provided with exterior rubber buffers for the main piston and for the steam-valve.

The machines are placed on mountings suited to the different classes of work, the Rand shaft-bar, with universally-adjustable arms, being used for shaft-sinking, columns provided with two jack-screws for driving the heading, and tripods for the bench.

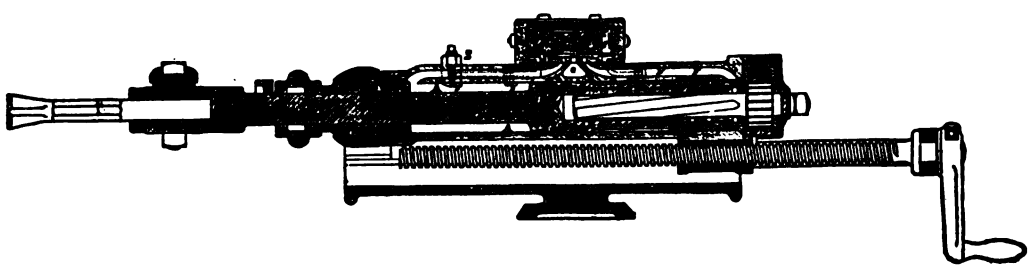

FIG. 60.—"RATTLER" DRILL.

The "Rattler" Drill, invented by Prof. J. E. Denton, is shown in Fig. 60. It operates as follows:

Steam or air enters at either side of the valve-chest into the annular space between

the shoulders on the valve-plunger D, and for the position shown passes through the port F, and acts to force the main piston outward. When the piston packing-ring B^1 passes the point B^2 the air behind the piston has access to the forward end of the plunger D by the passage shown in dotted lines. The plunger is thereby thrown backward, and moves the slide-valve E so as to admit air to the outer end of the main piston. The latter is thereby driven inward, and when the packing-ring B^2 passes the point g^1k, under S, air is sent into the upper end C of the valve-chest to again reverse the plunger and slide-valve. A plug S throttles the port g^1 so that the movement of the valve can be delayed or hastened, and the

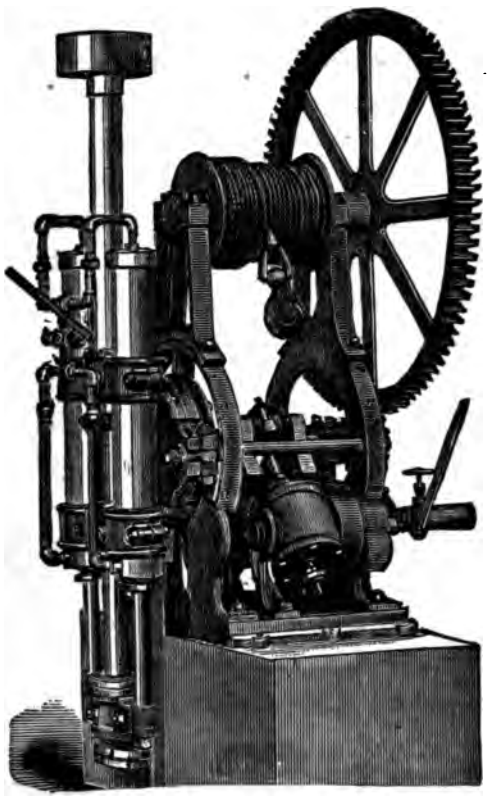

FIG. 61.—DIAMOND-DRILL.

length of the backward stroke thereby adjusted. To effect this adjustment the port g^1 at S must be located too far forward to be used as an exhaust-passage which would require it to connect with the annular space a, on the main piston, when the latter approaches the forward end of the cylinder. Another passage g^1 is therefore provided to exhaust the chamber C. The passage at B^2 serves both to supply and exhaust the chamber at the forward end of the plunger D. This valve-mechanism enables all cushioning of the blow to be avoided, and the full length of the cylinder to be traversed at each stroke.

The "Rattler" drill is a very powerful and effective machine. Some of the work which was performed with it is mentioned on pages 150–152.

Diamond-drills (see Fig. 61).—In establishing the location of the aqueduct tunnel and the sites of the new dams, the Aqueduct Commissioners had a great many test-holes bored with diamond-drills. At first this work was done by the American Diamond Rock-

boring Co., of New York, who were paid six dollars per lineal foot of hole drilled, including the expense of moving the machines from place to place. In 1884 the Commissioners bought a No. 4 and a No. 7 prospecting drill from the above company and had the test-holes bored thereafter by their own men. The cost of drilling (not including transportation, etc.) was found to be about three to four dollars per lineal foot.

The two prospecting drills mentioned above are similar in construction, the No. 4 machine being more powerful than the No. 7. As most of the work was done with the latter, we shall confine our description to that machine.

The motive power is supplied by an oscillating engine having two cylinders, each 4½ inches in diameter by 5 inches stroke, which are mounted upon a cast-iron bed-plate (see Fig. 61). By means of a crank-shaft and bevel-gearing the engine imparts a rotary motion to a hollow spindle and to the drill-rods, which pass through said spindle and are attached to it at the lower end by the drill-rod chuck. One of the bevel-gears is keyed to the crank-shaft. The other one (the sleeve-gear) is attached to the spindle by means of a spline, engaging in a groove, cut nearly the whole length of the spindle. This arrangement permits the spindle to be fed forwards or backwards whether it be rotating or not.

The "feed" of the drill (which is entirely independent of the rotary motion of the engine) is obtained by means of two hydraulic cylinders, one placed on each side of the spindle. The piston-rods of the cylinders are joined together at the top by a cross-head, which is attached to the spindle by means of a collar, a nut, and a roller-thrust bearing. The spindle can rotate freely in the cross-head, but follows its forward or backward motion. A small independent pump supplies the hydraulic pressure, the amount and direction of which is controlled by means of a four-way cock, operated by a small lever. By moving this lever (which is placed in a central position in front of the cylinders) the total hydraulic pressure can be changed from nothing to several thousand pounds. Its amount is indicated by a pressure-gauge attached to one of the hydraulic cylinders.

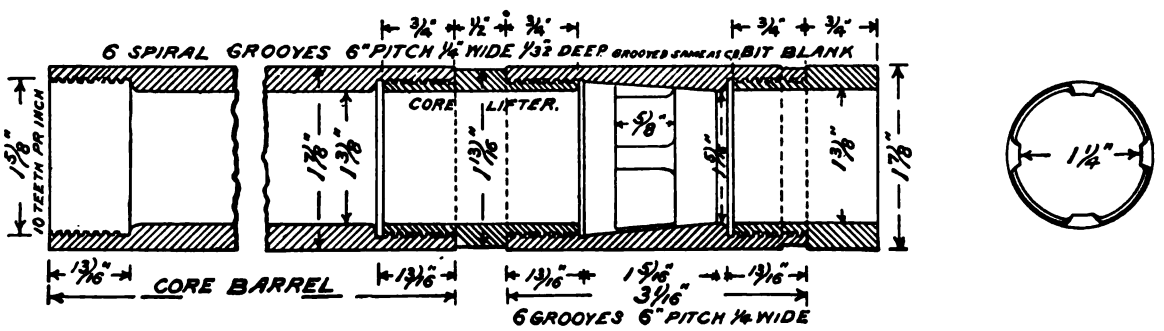

FIG. 62.—DRILL-ROD.

By means of the arrangement described the drill is fed, automatically, slowly or fast according to the hardness of the rock. An experienced drill-runner can judge of the hardness of the rock in which he is boring by the progress made and the pressure indicated.

The drill-rods (see Fig. 62) consist of extra-thick tubes which are joined together by hollow interior sleeves. At the end of the rods are coupled the core-barrel, the core-lifter, and the diamond boring-bit. The core-barrel is a tube 8–16 feet long which receives the

core bored out as the drill advances. The core-lifter is a short tube, about 6 inches long, having its inner surface slightly coned. A split ring, toothed on the inside, is placed in the core-lifter. When the drill-rods are pulled upwards the coned surface of the core-lifter wedges the split ring firmly against the core, which can thus be drawn to the surface.

While the drilling is progressing, water supplied by the pump mentioned above flows through the drill-rod to the bit. Spiral grooves, cut in the outer surface of the core-barrel and core-lifter, provide room for the water to escape from the hole, carrying with it the débris of the boring.

The boring-bit consists of a blank of soft steel or gun-metal into which thirteen black diamonds are set so as to project about 1/32 inch beyond the sides of the blank. Ten of the diamonds are placed at the cutting edge of the bit, six being at its outer and four at its inner surface. Three diamonds (the clearing-stones) are set in the outer surface of the bit above the cutting edge.

The usual manner of fastening the diamonds in the bit is to place each stone in a hole drilled in the blank and to calk the metal around it. This process must be frequently repeated, as the drilling loosens the diamonds. The Aqueduct Commissioners paid 35 cents for resetting each stone. A better manner for holding the diamonds, adopted by the Commissioners for their later work, was invented and patented by a Mr. Jackson. It consists in holding the diamonds by wire loops in the proper position in the mould, while a blank of gun-metal is being poured. A bit prepared in this manner was found on the new aqueduct to drill about fifty per cent more than one with hand-set stones. The cost of casting a bit by the Jackson process was $9.

The diamonds used for boring are usually stones of 1–2 carats, costing $13–$17 per carat. The total cost of a diamond boring-bit for No. 7 drill is $200–$250.

The diamond-drill can be used for boring holes in any direction. This is made possible by the fact that the hydraulic cylinders, the spindle, and the boring parts are attached to the frame of the machine by means of a swivel-head, whose axis of rotation coincides with the axis of the crank-shaft. The bevel gears "engage," therefore, whatever angle the boring parts may make with reference to the bed-plate. The drill-rods are kept at any desired angle by tightening four bolts in the swivel-head.

The front plate of the swivel-head is provided with a hinge, which makes it possible to swing the hydraulic cylinders, the spindle, and its gear-wheel in a circle at right angles with the drill-hole when the drill-rods are to be raised or lowered. Before this form of swivel-head was invented the whole machine had to be moved back on a sliding plate whenever the drill-rods were to be hoisted.

The rods are raised by a hoisting-gear consisting of a drum keyed to a shaft, parallel with the crank-shaft, from which it is driven by spur gearing. A wire rope passes around the hoisting-drum and then over a sheave placed at the top of the derrick. The end of the rope is provided with a swivel-hook, which is attached to a hoisting-plug, screwed into the top rod when the rods are to be raised or lowered. By using a high derrick the rods can be taken out in lengths of 40–50 feet, which saves much time in uncoupling. The hoisting-gear

can be moved over on its supports so as to always pull in line with the hole, at whatever angle it may be. When not in use it is thrown out of gear to avoid useless friction. A slip-drum for driving casing for the drill-hole is keyed to the shaft of the hoisting-drum.

The No. 7 drill bores a two-inch hole, taking out a core 1⅝ inches in diameter. Its engine is capable of handling the drill-rods easily and quickly to a depth of 800 feet. The No. 4 machine bores the same size hole as No. 7, but can drill to a depth of 2000 feet. To handle the heavy weight of the long line of drill-rods required for such a depth, the machine is provided with a compound hoisting-gear.

*Baker Blowers** (Nos. 4, 4½, or 5) were used at most of the shafts on the work of O'Brien & Clark and of Heman Clark (sections 6 to 11, inclusive) to improve the ventilation in the tunnel. Generally only one blower was placed at each shaft and was found sufficient to ventilate the tunnel for about 3500 feet on each side of the shaft.

The arrangement of the Baker blowers is illustrated in Figs. 63 and 64. The casing is made of cast-iron. The inner or working parts consist of three cast-iron drums extending the whole length of the casing. The upper drum, to which a pulley or engine is attached, produces the air-current. It is provided with two vanes which fit closely to the sides and top of the casing. The work of blowing or exhausting is all done by the upper drum to which the power is attached. The two lower drums, having a crescent-shaped section, are

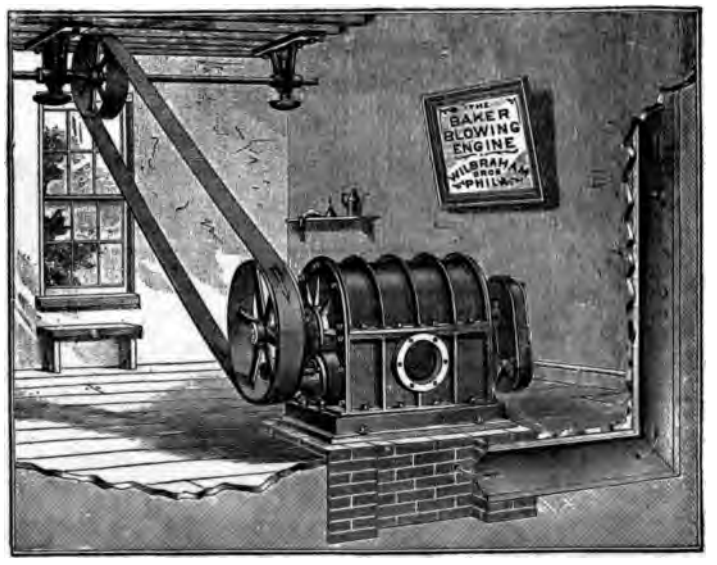

FIG. 63.—BAKER BLOWER.

simply balanced valves which prevent the air from escaping or returning. They are connected with the upper drum by gearing which is encased to prevent accidents. The only work required of the gearing is simply to keep these balanced valves in position.

The Baker blower can be used either for forcing or exhausting air by merely reversing the direction of the motion. It requires no oiling or packing on the inside to make it efficient. Only one pulley is required for driving the largest blower.

* Manufactured by the Wilbraham, Baker Blower Co., Philadelphia, Penna.

At shaft 18 a No. 6 Sturtevant blower,* run by a 10-H. P. engine, was used. Figs. 65 and 66 illustrate the arrangement of this type of blower, known as the "steel pressure" pattern.

The air-current is produced by the centrifugal force caused by the revolution of a blast-wheel 25 inches in diameter, made of steel plates attached to bronze arms. It is provided with vanes inclined backwards and secured between flattened cones of galvanized

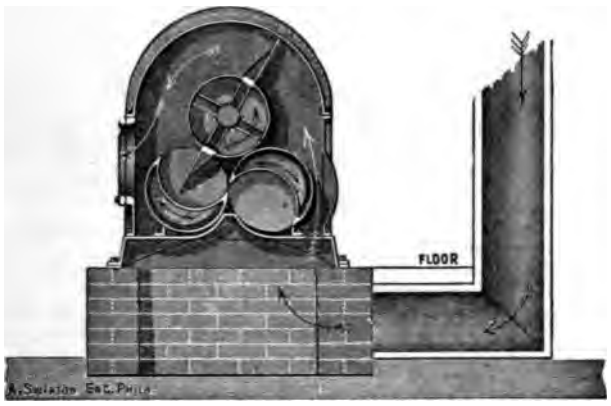

FIG. 64.—SECTION OF BAKER BLOWER.

FIG. 65.—STURTEVANT BLOWER.

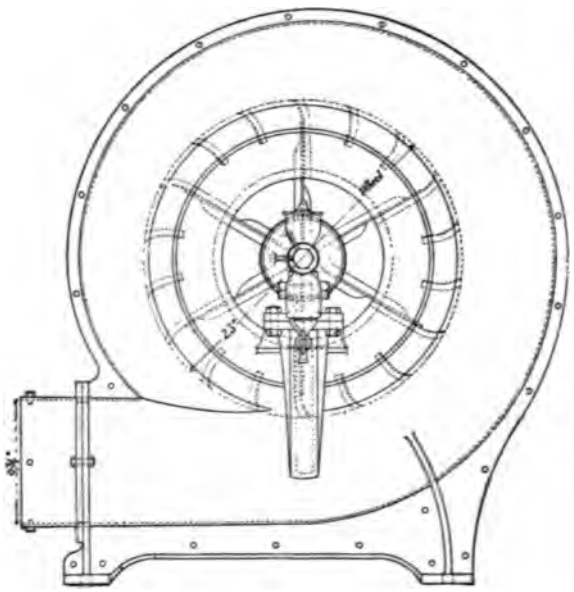

FIG. 66.—SECTION OF STURTEVANT BLOWER.

iron. The shaft of the wheel is made of steel and has extra-long bearings, having continuous oil feed. Two pulleys ($6\frac{3}{4}$ inches in diameter and $4\frac{1}{2}$ inches face) are attached to the shaft, one on each side of the wheel, for the driving-belts.

The wheel is placed in an iron casing, cast in halves and bolted together. Its height is $45\frac{3}{4}$ inches.

* Manufactured by B. F. Sturtevant Company of Boston, Mass.

Openings 12⅝ inches in diameter are left in the sides of the casing and wheel. When in operation the air is sucked in through these holes and forced through an opening 9¾ inches in diameter at the bottom.

Under average conditions the blower shown in Fig. 65 will deliver half a cubic foot of air per revolution. Under the most favorable circumstances this delivery can be increased to one cubic foot per revolution.

By running a No. 6 Sturtevant blower from 560 to 1790 revolutions per minute a pressure of one-half ounce to five ounces per square inch can be obtained.

This style of blower was also used for a short time in sinking shaft 4.

Hoisting-engines.—The hoisting machinery for the work of Brown, Howard & Co., and also the cages for the shafts, were furnished by the Dickson Manufacturing Company, of Scranton, Pa.

Shafts 1, 2, 3, and 4 were each supplied with one pair of horizontal link-motion engines, having cylinders of 13 inches diameter by 18 inches stroke, geared to the drum-shaft in the proportion of 7 to 1. The spur-gear on the drum-shaft had a diameter of 9 feet and a face of 8 inches, the teeth having a 3-inch pitch. Two cast-iron spiral-grooved drums (5 feet in diameter by 31 inches face) were keyed to the wrought-iron drum-shaft, which had a diameter of 8½ inches. A powerful strap-brake, capable of holding a load of 10,000 lbs. at any point in the hoistway, was attached to one of the drums. Each hoisting-rope was fastened to its drum in such a manner that one cage ascended while the other descended, the two cages thus balancing each other.

The throttle, reversing, and brake levers were all placed within easy reach of the engineer.

The hoisting machinery for the other shafts on the work of Brown, Howard & Co. were similar to the one described above, but of different dimensions.

The new Otis hoisting-engine (Fig. 67) was especially designed for blast-furnace work. As it is well adapted for light mine work, it was used by the contractors for a number of the aqueduct shafts.

The engine has two vertical cylinders, provided with piston-valves. No link motion is used, the engine being reversed by a hand-valve, placed on the steam-chest, which changes the steam-ports to exhaust-ports and the exhaust-ports to steam-ports. By throttling the reversing valve, the speed of the engine is controlled.

The crank-shaft is geared by a steel pinion and gear-wheel to an intermediate shaft, which in turn winds the drum through an internal gear (bolted to the drum) and pinion.

When at rest the engine is held by a brake on the crank-shaft. The engine is controlled by a hand-rope, operated from any convenient position.

In most cases the rope was operated from the top of the shaft, the signals being given from below by means of a gong. The engines were usually placed at a considerable distance from the shaft, near the boilers, where they were protected and out of the way.

The engines used in the construction of the new aqueduct had cylinders 8 or 9 inches in diameter by 10 inches stroke.

At shaft 25 a special engine, having 10″ × 10″ cylinders and two drums (one at

each end of the drum-shaft) was used, on account of the great depth of the shaft and the heavy loads which were to be hoisted and lowered. This engine, with the exception of having two drums, was of the standard Otis pattern, described above. After the construction of the new aqueduct had been completed this engine was bought by the Aqueduct Commissioners and made part of the permanent plant at shaft 25.

In addition to the safety appliances on the cage, all Otis winding-engines are provided

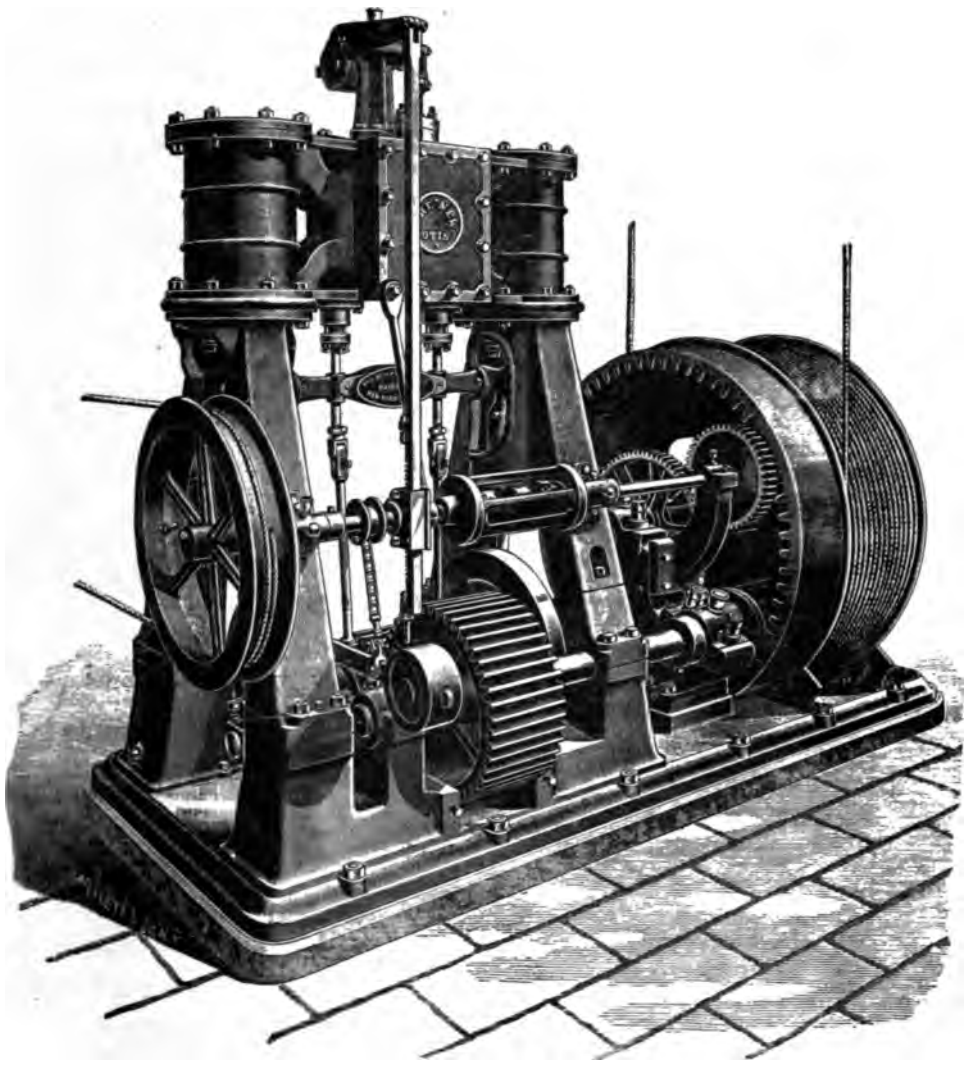

FIG 67.—OTIS HOISTING-ENGINE.

with an automatic top and bottom stop. This device shuts off the steam and applies the brake, automatically and independently of the engineer, when the cage reaches either end of its travel, thus preventing the common accident of running into the overhead timbers.

The Lidgerwood Hoisting-engine used at the shafts for hoisting the cages and for other work is shown in Fig. 68. Both single- and double-cylinder engines were used. They were made according to the same general plan, the only difference being that the former are provided with a fly-wheel, keyed to the crank-shaft.

The cylinders and boilers are attached to a strong cast-iron bed-plate of the box type. The side stands, carrying both the drum and the crank-shaft, are made of the "tee" section, and are strongly webbed.

Each engine is provided with an improved friction-drum. The friction is of the Beekman patent double-cone type. It is composed of sectors of hard wood, which are bolted to the spur-wheel and turned off to suit the flanges of the drum with which the surfaces

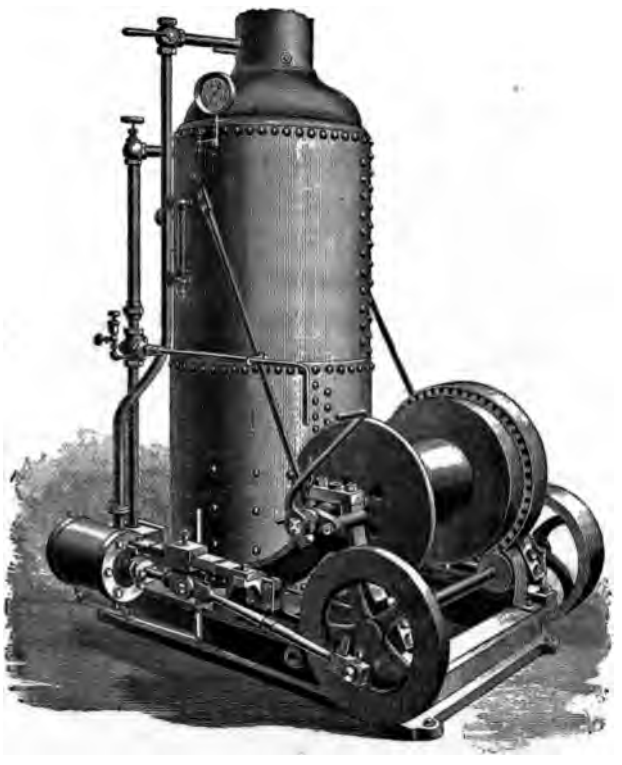

FIG. 68.—LIDGERWOOD HOISTING-ENGINE.

engage when in gear. The drum is loose on the shaft and is thrown into gear by a small end motion along the shaft, which is effected by means of a lever, screw, pin, cross-key, and collar. A very slight pressure will hold the drum in gear against any load the engine can hoist. It is released by means of a spiral spring placed between the drum and the gear-wheel. The end thrust caused by applying the friction is taken up by a thrust-bearing and screw-collar.

In addition to the friction-drum each engine is provided with an independent foot-brake of the band type.

Three styles of cages were used in the shafts of the Croton Aqueduct viz., the Otis, the Dickson, and the Lidgerwood. They were generally arranged in pairs hoisted by the same steam-engine, one descending while the other was being raised. All the cages were provided with safety-appliances, and no accidents occurred from their use in the many shafts of the Aqueduct.

Otis Cages (see Fig. 69) were used in twelve shafts. The frames were made of wrought-iron rolled shapes, the floors of wood, the available space being 6×6 feet. The cages ran on wooden guides (made of 4″×4″ or 4″×6″ yellow or white pine). The hoisting-cable was attached to the cross-head of the cage by means of a turnbuckle and a heavy wagon-spring, the former being used in adjusting the cage to its landing, and the latter to operate the safety-appliances.

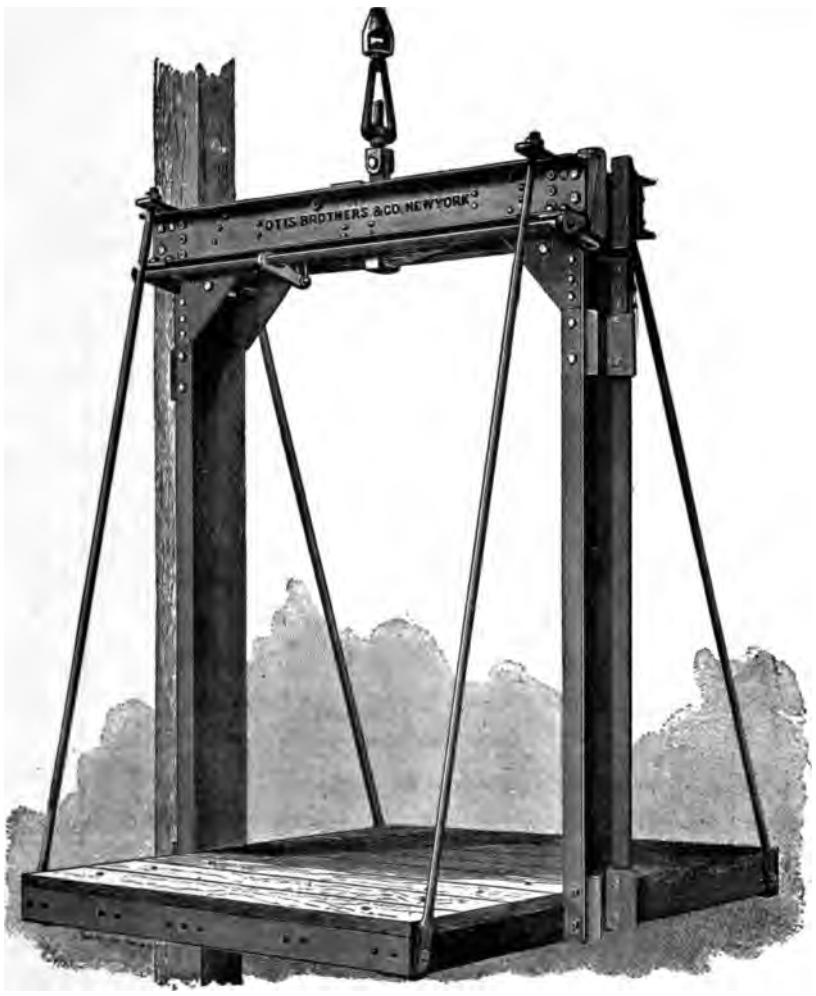

FIG. 69.—OTIS CAGE.

The safety-device consisted of a transverse rod, attached to the spring by a lever, and having at each end a chisel-pointed dog. When the hoisting-cable broke, the wagon-spring forced the dogs into the wooden guides, and the dogs, as the cage descended, pushed steel wedges (one on each side of each guide) against the guides, and thus brought the cage to a stop.

The Dickson Cages (see Figs. 70 and 71) were used in all the shafts on sections 2–5 inclusive. They were made of the best seasoned oak, and were very strong and durable. The available platform space was 5 feet 2½ inches by 6 feet. The main floor-beams had

a section of 6 by 10 inches, and were trussed by $1\frac{1}{4}$-inch rods. The uprights (made of $4\frac{1}{2}'' \times 11\frac{1}{4}''$ beams) were 12 feet high.

The draw-beams had a section of 10 by $11\frac{1}{4}$ inches. Each cage was suspended by a draw-head bolt, which passed through the centre of the draw-beam and through a spring pocket, and was furnished with a clevis and a cone for rope attachment.

The springs were made of special rubber, in three pieces, separated from each other by flanged washers, and enclosed by a case placed under the draw-beam.

Each cage was provided with four safety-catches, formed by eccentric cams (two for

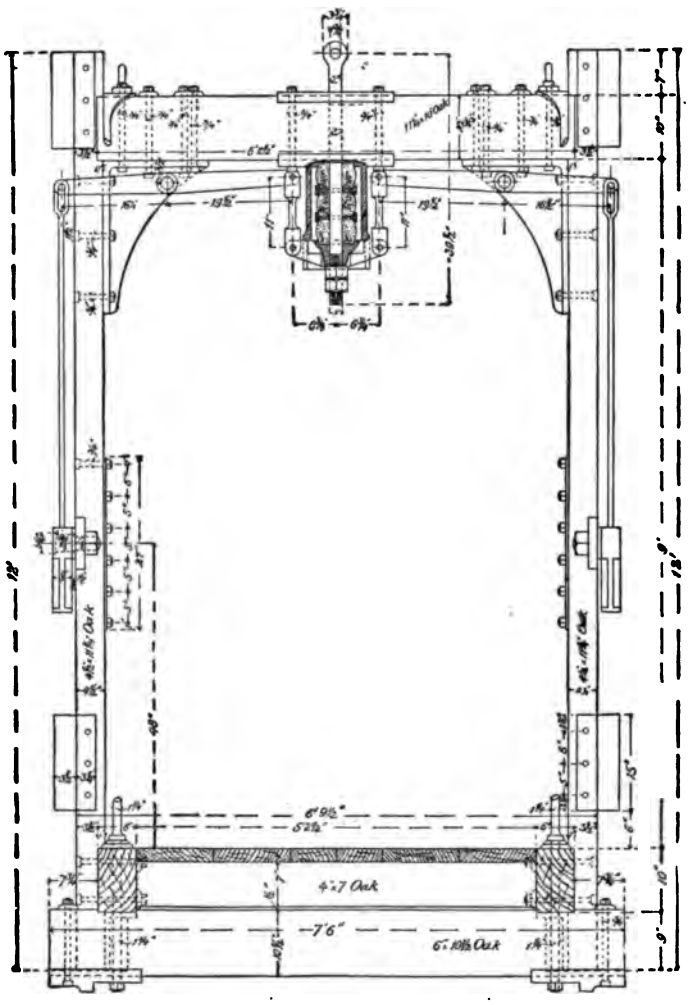

FIG. 70.—DICKSON CAGE.

each guide). The cams were attached by means of rods and levers to the spring under the draw-beam in such a manner that the instant the hoisting-rope slacked or broke, the spring would cause the safety-catches to take a firm grip on the wooden guides, arresting thus the motion of the cage.

An overhead canopy of sheet-iron was placed over each cage to prevent accidents from objects falling down the shafts.

Landing-fans (*k, k, k, k*) were provided to relieve the machinery from strain when a cage had reached a landing, and to act as an additional safeguard against accidents. These fans were thrown forward to support a cage or moved out of the way by means of a hand-lever.

The Lidgerwood Cage (see Figs. 72 and 73) was used in most of the shafts on sections 6–11 inclusive.

The cage runs between two wooden guides, which are attached to the shaft-timbers. On top of the cage there are two iron bars, having iron dogs or cams at both ends. Strong

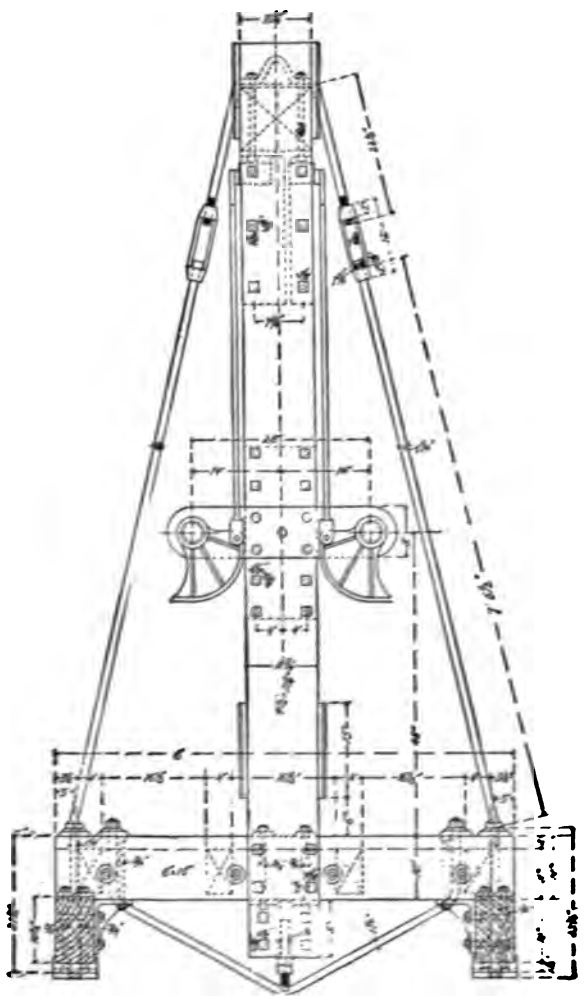

FIG. 71.—DICKSON CAGE.

spiral springs force the cams into the wooden guides and bring the cage to a stop whenever the tension of the hoisting-rope is released. The spiral springs can be wound up to the desired tension.

The platform of the cage has an available space of 5 feet 3½ inches × 6 feet. The landing-fans, which are thrown out by a lever to support the cage when it is at the top of the shaft, are shown in Fig. 72.

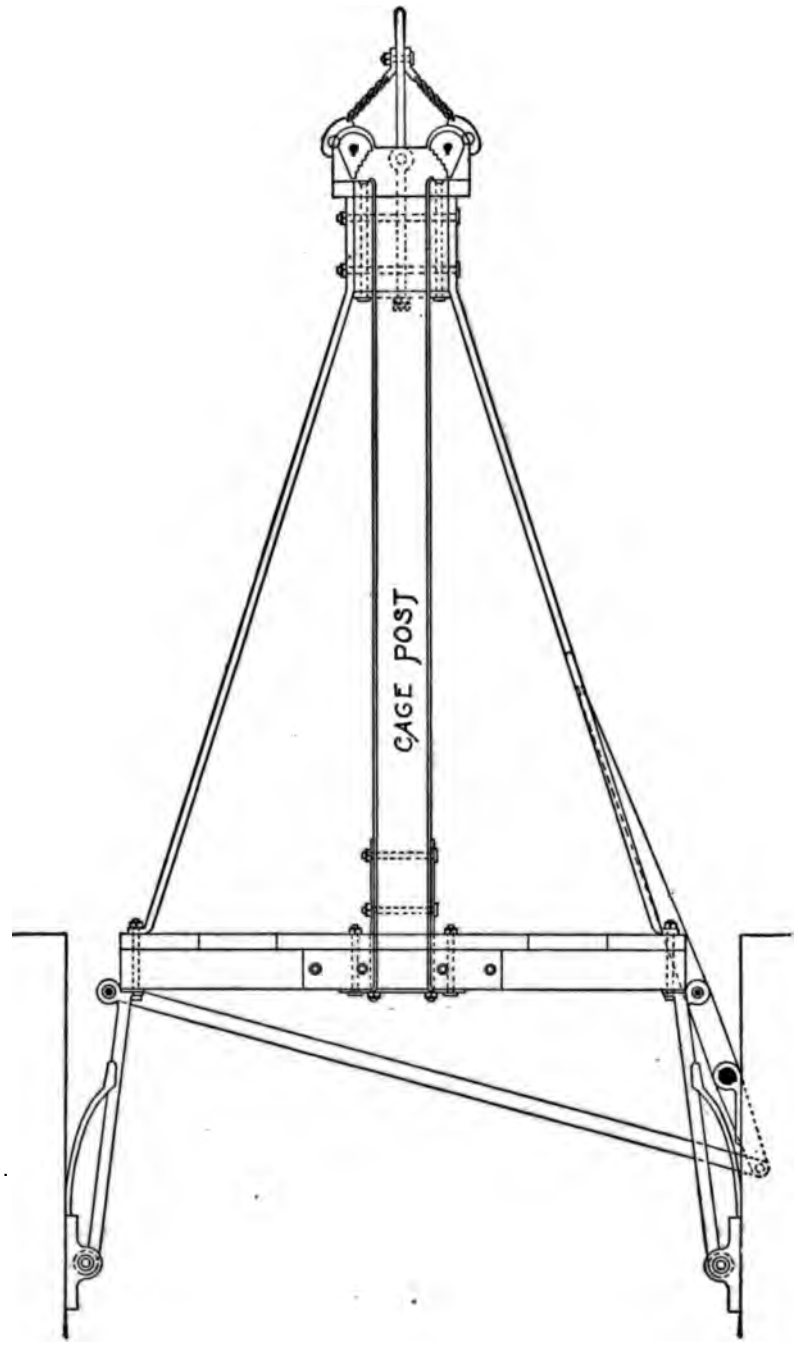

FIG. 72.—LIDGERWOOD CAGE.

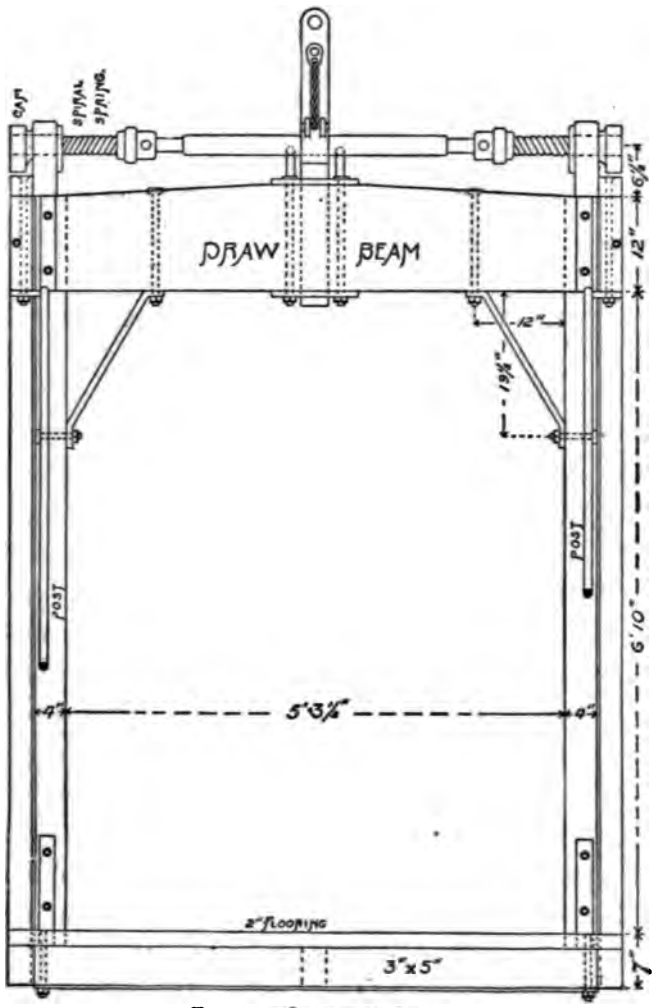

FIG. 73.—LIDGERWOOD CAGE.

[*Extract from "Hudson River Chronicle," Sing Sing, N. Y., Tuesday, January* 12, 1841.]

Great Freshet. Partial Destruction of the Croton Aqueduct Dam. Loss of Life and Destruction of Property.

The rains which commenced in this section of the country on Tuesday of last week continued with but little intermission until Thursday night last. At the time the storm commenced the snow lay upon the earth to the depth of eighteen inches. The melting of this large body of snow, together with the heavy rains, produced the largest freshet that has been witnessed in this part of the country for very many years.

The swelling of the Croton by the numerous streams running into it from the surrounding country became so great that fears began to be entertained on the evening of Thursday that the dam across it for the Croton Aqueduct would not withstand the pressure of the accumulated waters. That part of the dam over which it was designed the surplus waters should flow was constructed of solid masonry. Beyond this on the left bank of the river as you ascend it an embankment of earth, with a protection wall of massive stones, was constructed rising twelve feet above the tumble, as it is called (the space left for the surplus waters to pass off over the mason-work), leaving a passage for the surplus water of ninety feet in width by twelve in height. It was calculated that an opening of such dimensions would be more than sufficient to carry off the waters of the Croton when swelled to a much greater magnitude than they had ever been known to reach. But during the latter part of the freshet of last week the water above the dam, covering a space of about 600 acres, continued to rise at the rate of about one foot an hour, until it reached the astonishing height of seventeen feet above the tumble or fall of the dam and running over the top of the embankment of earth and protection wall to the depth of five feet. The design of the dam was that the water should never reach the top of this embankment, which was raised twelve feet above the tumble, or that part of the dam over which it was designed the water should flow; and when the water reached the height above mentioned, it was at once seen that the embankment must soon give way. But notwithstanding this immense pressure and rushing of water over the embankment it stood for several hours, during which every effort was made to save it by raising a dike on the top of it to a height of three or four feet during the storm. But it was discovered about one or two o'clock on Friday morning that it must soon give way, and messengers were immediately despatched from the dam to warn the people living below, on the banks of the Croton, of their danger.

As was apprehended, about four o'clock on Friday morning the embankment gave way, and the Croton, below the dam already swelled to an unprecedented height, immediately rose, by means of the mighty rush of waters from above the dam, ten to fifteen feet higher, and rushed down its course with resistless force. It first encountered the mills and dwelling-house of Mr. Solomon Tompkins, which it swept away almost in a moment, and Mr. Tompkins, an aged and infirm man, had barely time to escape with the assistance of his family from

his house. Passing on, and tearing up in its course earth, stones, and trees, it next reached the extensive rolling-mills and wire factory of the Messrs. Bailey, situated on the banks of the Croton, which it instantly carried away, together with their dwelling-houses, tenant-houses, etc.—making altogether twelve buildings—and all their machinery, stock, furniture, goods, etc. This was an extensive establishment and employed about fifty men, and was situated about two miles from the dam. They were busily engaged in endeavoring to preserve their property from destruction by the water before the dam gave way. While thus engaged they heard the roaring of the waters as they came rushing down, and fled instantly for the higher grounds in the neighborhood; but so rapid was the approach of the water that some ten or fifteen individuals were overtaken and, to save themselves, were obliged to ascend the surrounding trees for safety. Among them were Mr. Joseph Bailey, Mrs. Mitchell, and a number of women with infant children. In this situation they were obliged to remain for about two hours, until the water in some measure subsided, when they were taken off with the exception of William Evans and Robert Smith, who, overtaken in their flight, were obliged to ascend a cedar of smaller size, which was borne down by the water, ice, and floating timber into the current, and they were carried away amid their unavailing cries for assistance. Their bodies have not yet been found. From this place the accumulated waters dashed furiously onward along the valley of the Croton to its mouth, a distance of about three miles, carrying away in its course Quaker Bridge, Holman's mills, and the old piers of the old Croton Bridge, and fences, timber, portions of orchards, soil, and roads along the banks of the Croton. The damage sustained by the landowners below the dam is variously estimated at from one to two hundred thousand dollars. Among the sufferers are the Messrs. Bailey, Solomon Tompkins, the owners of the Van Courtlandt estate, and Mr. Talbot.

All the bridges below the dam were carried away, and above the dam Pine's Bridge, and we are informed Wood's Bridge also, leaving no bridge over the Croton from its mouth to Golden's Bridge, a distance of twelve to sixteen miles. This we were apprehensive would be productive of very great inconvenience and loss to the community; but we are happy to learn that the Water Commissioners, with a promptitude that reflects credit upon them, have already commenced laying a new bridge upon the abutments and piers of the old Pine's Bridge which remain uninjured, so that the bridge will probably be ready for travel in ten or twelve days.

We are informed that the damage done to the dam is much less than was at first supposed, the mason-work, the most expensive part of it, being but slightly injured, and that the total damage to the dam will not much exceed $40,000.

A number of individuals above the dam have suffered much inconvenience and loss by the rapid rise of the waters of the reservoir. Doctor Gedney, we understand, was driven from the principal story of his house in which the water rose to the depth of six or eight feet to the second story, when his situation was somewhat dangerous, until the dam gave way, when the water settled off so rapidly that his dwelling was entirely freed from it in a few minutes.

It is fortunate that this disaster has been attended with no greater loss of life. But one individual in addition to the two mentioned above lost his life, and he was a laborer at the

dam, of the name of Michael Burke, who was in a shanty below the dam and was carried off in the flood; his body was found on Saturday last, three miles below the dam, much bruised and his clothing nearly all torn off.

We learn that much damage has been done by the freshet in different parts of the country to roads, bridges, etc., the particulars of which we will lay before our readers next week.

The following card that appeared in the *Hudson River Chronicle* Tuesday, January 19, 1841, may be of interest to some persons living in the Croton watershed:

A CARD.

The undersigned return their sincere thanks to their neighbors for the very liberal aid extended to them and their families after the late destruction of their works by the bursting of the Croton Dam, and they would particularly acknowledge the kindness and attention of the Messrs. Henry Lounsbury, Robert Tompkins, Gabriel Purdy, Elias Purdy, William Ryder, Thomas Rowlee, and William Purdy, for the prompt and efficient aid afforded them.

JAMES BAILEY, Sr.
JOHN BAILEY.
ABRAM BAILEY.
JAMES BAILEY, Jr.
JOSEPH BAILEY.

CROTON, January 11, 1841.

BIOGRAPHICAL SKETCHES.

CANVASS WHITE was born on September 8, 1790, at Whitestown, Oneida County, New York. His first employment was as clerk in a store, but he soon retired from business, owing to ill health, and visited Europe.

After returning to America, he raised in 1814 a company of volunteers for the war between the United States and England and was appointed lieutenant. He took part in the assault and capture of Fort Erie, opposite Buffalo, and was severely wounded by one of the enemy's shells while occupying the fort.

Mr. White commenced his career as civil engineer in 1816 by entering an engineer corps that was engaged under the direction of Judge Benjamin Wright in making surveys for the Erie Canal. He remained connected with this work until it was nearly finished.

Mr. White's next engagement was as Chief Engineer of the Delaware and Raritan Canal, a position he held until the work was completed in 1834. While occupied on the above work he was also appointed Chief Engineer of the Lehigh Canal in 1827, and Consulting Engineer of the Schuylkill Navigation Co., of the Delaware and Chesapeake Canal Co., and of many other similar companies. His work in connection with the water-supply of New York has been described on page 14.

Having completed the Delaware and Raritan Canal in the fall of 1834, Mr. White sailed for St. Augustine, Fla., to restore his health, which, naturally poor, had suffered from his arduous duties. He did not recover, however, but died a month after reaching Florida. His remains were brought to New Jersey, and lie buried in the churchyard of Princeton. Although Canvass White died at the early age of 44, he was one of the foremost engineers of his time.

Major DAVID BATES DOUGLASS was born in Pompton, New Jersey, on March 21, 1790. He graduated with high honors at Yale College in 1813, and went directly to West Point to study military science. He soon entered the army as an officer in the Engineer Corps, and took part in the northwestern campaign of 1814 against England. During the siege of Fort Erie, Douglass performed brilliant services for which he was made captain by brevet.

About the year 1816, Major Douglass was appointed Assistant Professor of Natural Philosophy at the West Point Military Academy. He remained one of the professors of this institution for the next fifteen years, during which time he also practised, to some extent, civil engineering.

During 1826 Major Douglass made surveys and estimates for a canal from Conneaut Lake to Lake Erie, and located the Upper Delaware Canal. About the same time he revised the survey of the Sandy and Beaver Canal of Ohio.

In 1828 Major Douglass made an examination of the line of the Morris Canal of New Jersey with reference to employing inclined planes instead of locks. Having resigned as Professor at the Military Academy, he entered the service of the Morris Canal Co. and con-

structed the proposed inclined planes, a piece of work which attracted a great deal of attention at the time.

Major Douglass became connected with the University of the City of New York in 1832, as its first Professor of Natural Philosophy. Owing to his many professional engagements he had to give up teaching about a year later, but was still retained at the University as Professor of Civil Engineering and Architecture, and delivered many lectures on these subjects. While holding this position he made the plans for the old university building (recently taken down to make room for a larger structure), which was the first introduction of the Elizabethan style of architecture into this country.

In 1833 Major Douglass made a survey on Long Island for the Brooklyn and Jamaica Railroad. During the same year he made the surveys for the Croton Aqueduct. His connection with this work has been described in Chapter II of this book.

During 1837–1840 Major Douglass was engaged in laying out Greenwood Cemetery in Brooklyn, Long Island. This beautiful spot attracted his attention while he was surveying for the Brooklyn and Jamaica Railroad, and it is mainly to his efforts that this well-known burial-ground owes its existence.

From 1841 to 1844 Major Douglass held the position of President of Kenyon College, Ohio. Having returned East in 1844, he was engaged in various works, among which we may name the laying out of the Albany Rural and the Quebec Cemeteries, the survey for the Albany Water-works, the investigations for a water-supply for Brooklyn, the plans for the drainage and grading of South Brooklyn, etc., etc.

In 1848 Major Douglass was called to the Chair of Mathematics at Geneva (now Hobart) College. He died at his residence in Geneva, N. Y., on October 21, 1849, from the effects of a paralytic stroke.

JOHN BLOOMFIELD JERVIS was born in Huntington, Long Island, on December 14, 1795. His parents moved, soon after his birth, to Rome, N. Y., where he grew up and acquired an ordinary school education. He commenced life as a farmer, and it was only by chance that he became an engineer. In 1817 Mr. Jervis was offered, by Chief Engineer Benjamin Wright, a temporary position as axeman in one of the engineer corps engaged in locating the Erie Canal near Rome, N. Y. He accepted the offer, became interested in surveying, acquired the use of the instruments, and remained connected with the construction of the Erie Canal, advancing from position to position to that of Resident Engineer, until the work was completed in 1825.

His next engagement, concluded in March 1825, was as Principal Assistant Engineer on the construction of the Delaware and Hudson Canal, under Benjamin Wright as Chief Engineer. In 1827 he was appointed Chief Engineer of this work, and completed it in 1829.

The construction of railroads had just begun in this country about this time. Mr. Jervis was appointed, in 1830, Chief Engineer of the Mohawk and Hudson Railroad, which was to connect Albany with Schenectady, and soon afterwards to a similar position on the Schenectady and Saratoga Railway. Both of these lines were completed by April 1833.

In 1832 Mr. Jervis designed and had built by Robert Stephenson, in England, "The Experiment," a locomotive having a single pair of driving-wheels and a four-wheel swivelling truck. This engine was the forerunner of the present type of American locomotives.

The next engagement of Mr. Jervis was as Chief Engineer of the Chenango Canal, which was constructed by the State. In 1835 he made surveys and estimates for the enlargement and improvement of the eastern division of the Erie Canal, of which he was given charge as Chief Engineer in 1836.

Mr. Jervis was made Chief Engineer of the Croton Aqueduct in October 1837. With regard to this apointment Mr. Jervis states, in "A Memoir of American Engineering" (Transactions of the American Society of Civil Engineers for 1876), that it was a surprise to him, and totally unsolicited. He refused to accept the position, owing to his respect for Major Douglass, until he was assured by the Water Commissioners that a change in the chief-engineership would certainly be made.

In the above memoir Mr. Jervis states that the aqueduct "had been, in the main, well located" by Major Douglass, but that no specifications had been prepared, and that all the principal structures on the line (the Croton Dam, the Sing Sing Bridge, High Bridge, the reservoirs on Manhattan Island, etc.) were constructed according to the designs prepared by himself (Jervis).

Mr. Jervis remained Chief Engineer of this work until the Croton Aqueduct Department was formed in 1849. While connected with the Croton water-works he was consulted about the proposed Cochituate Aqueduct for Boston, Mass., the proposed Hudson River Railroad, and various other works.

In the spring of 1847 he was appointed Chief Engineer of the Hudson River Railroad, and remained connected with this enterprise (during the latter part as Consulting Engineer) until the spring of 1850, when he resigned his position and went to Europe to recuperate his health, which had been much impaired by constant work.

After a four-months' absence he returned and became at once engaged on the construction of the Michigan Southern and Northern Indiana Railway, with which work he remained connected until the spring of 1858. Mr. Jervis was elected President of the Chicago and Rock Island Railway in 1851. He was appointed superintendent of the Pittsburg, Fort Wayne and Chicago Railway in 1861, after the road had been sold under foreclosure of a mortgage. The road was in a very poor condition and the capital stock was very low in the market. In a little over two years Mr. Jervis managed to improve the operation and maintenance of the road to such an extent that the directors were able for years to declare ten-per-cent dividends.

After accomplishing this result Mr. Jervis resigned from the position as superintendent, but remained the engineer of the company until 1866, when he retired from active life. He still retained, however, a lively interest in the advancement of his profession. He was consulted in 1882 about the new aqueduct.

Mr. Jervis was elected an Honorary Member of the American Society of Civil Engineers

on December 21, 1868. He is the author of a book on "Railway Property," and of another on "Labor and Capital." Mr. Jervis died at his home in Rome, N. Y., on January 13, 1885.

HORATIO ALLEN, the son of Dr. Benjamin Allen, Professor of Mathematics at Union College, Schnectady, N. Y., was born in 1802. He graduated at Columbia College, New York, in 1823, ranking high in mathematics, and studied law for about a year. His tastes inclined him, however, towards engineering.

Mr. Allen's first work as a civil engineer was on the Chesapeake and Delaware Canal, under Judge Benjamin Wright as Chief Engineer. In the autumn of 1824 he was made Resident Engineer on this work.

His next engagement was on the Delaware and Hudson Canal under John B. Jervis, Chief Engineer. At this time the use of steam on railroads was attracting great attention. Mr. Allen became much interested in this subject and convinced of the great future of railroads. The Delaware and Hudson Canal Co. determined to try a locomotive on a short railroad they had built into the coal region (the Carbondale Railroad), and sent Mr. Allen, upon the recommendation of Chief Engineer Jervis, to England to buy rails and three locomotives for the above railroad.

Mr. Allen left New York for England in January 1828. One of the first acquaintances he made abroad was that of George Stephenson. Returning to America, he ran the "Stourbridge Lion," one of the locomotives he had purchased, over the Carbondale Railroad on August 9, 1829, which was the first trip made by a locomotive in America.

In September 1829 Mr. Allen was appointed Chief Engineer of the South Carolina Railroad. After finishing this work in 1834, he went abroad with his family in the spring of 1835, and devoted nearly three years to foreign travel. He returned to the United States in the latter part of 1838, and was appointed Principal Assistant Engineer of the Croton Aqueduct under John B. Jervis as Chief Engineer. The plan for a tunnel under the Harlem River instead of High Bridge (see page 41) was strongly advocated by Mr. Allen.

In 1842, after the Croton Aqueduct had been completed, Mr. Allen became one of the proprietors of the celebrated Novelty Works, which became the largest establishment in this country for building marine engines. His connection with these works continued until they were finally closed in 1870. During this period Mr. Allen patented numerous inventions which he had made for improvements in steam-engines. Besides his duties in connection with the Novelty Works, Mr. Allen acted as Consulting Engineer for the Erie Railway, the Panama Railroad, and the Brooklyn Bridge. He served as President of the Erie Railroad Co. for one year.

Mr. Allen retired from active work in 1870 and spent his remaining years at his home in Montrose, New Jersey, occupying himself with various philanthropic matters. He died at his home December 31, 1889. Mr. Allen was a member of the American Society of Civil Engineers, and was elected for one term President of the Society. He was also a member

of the American Society of Mechanical Engineers, and one of the founders of the Union League Club of New York.

ALFRED WINGATE CRAVEN, the second son of Mr. Tunis Craven and the grandson of Commodore Tingey, U. S. Navy, was born on October 20, 1810, in Washington, D. C. When thirteen years of age he entered Yale College, but stayed there only a year. He continued his studies at Columbia College, in New York, and graduated from that institution in 1829. After leaving college Mr. Craven studied law and was admitted to the bar, but did not find the profession he had chosen congenial to his tastes. Being a man of fine physique and practised in all manly exercises, the outdoor life of a civil engineer had attractions for him, and induced him to change his profession.

Mr. Craven commenced his career as civil engineer on the surveys and construction of the Mad River Railroad, in Ohio, advancing to the position of Assistant Engineer.

From this work he went to South Carolina, where he was engaged for three years on the construction of the Louisville, Cincinnati and Charleston Railroad.

He was employed next in succession on the Boston and Albany Railroad, the Erie Railroad, the Mohawk and Hudson Railroad, and the Reading Railroad.

Mr. Craven was appointed Chief Engineer of the Schuylkill Valley Railroad and, at the same time, of the Mine Hill Navigation Railroad. He had charge of constructing the Camden Branch Railroad in South Carolina.

In July 1849 Mr. Craven was appointed Commissioner and Chief Engineer of the Croton Aqueduct Department, a position he held for nineteen years, performing his duties with marked ability and with uncompromising honesty. The work of which he had charge in connection with the water-supply of New York has been described in Chapter IV. In addition to this he projected the present sewerage system and had charge of the paving of the streets, etc.

While Chief Engineer of the Croton Aqueduct Department Mr. Craven was consulted about plans for water-works for Brooklyn, N. Y., Syracuse, N. Y., Newark, N. J., Savannah, Ga., Augusta, Ga., and for many other places.

Mr. Craven resigned from the above position on May 12, 1868, and made an extensive tour in Europe. On returning to New York he opened an office as Consulting Engineer. His failing health induced him to make a second trip to Europe in 1878, but his disease could not be cured. He died at Chiswick, near London, on March 27, 1879. His remains were conveyed to New York and interred with honors.

Mr. Craven became a member of the American Society of Civil Engineers on December 1, 1852, and was elected President for 1870–1871. He was made a member of the British Institution of Civil Engineers on February 1, 1870.

EDWARD H. TRACY was born at Whitesboro, Oneida County, N. Y. in 1817. His early education was acquired at the Academy of the City of Utica, N. Y. At the age of seventeen he obtained the position of rodman on the construction of the Chenango Canal under

John B. Jervis as Chief Engineer. He remained three years on this work, until it was completed, and then renewed his studies at the Academy of Albany, N. Y. In the spring of 1838 Mr. Tracy was appointed Assistant Engineer on the Croton Aqueduct, and given charge of the important section from Fordham to Manhattanville, which included the High Bridge across the Harlem River.

After the Croton Aqueduct Department was formed in 1849, Mr. Tracy remained in charge of the maintenance of the works, under Mr. Alfred W. Craven as Chief Engineer, until 1852, when he resigned and entered into partnership with Mr. Quintard in the Morgan Iron Works.

Two years later he returned again to civil engineering and made the surveys and plans for a ship canal to connect the St. Lawrence River and Lake Champlain. His next work was the improvement of the Des Moines River by slack-water navigation. He made also surveys of the rapids of the Mississippi and gauged this river.

Mr. Tracy became connected with the Cumberland Coal and Iron Co. in succession as engineer, superintendent, and president. His services contributed largely to make this property very valuable.

In 1870, when the Department of Public Works of New York was formed, Mr. Tracy was appointed Chief Engineer of the Croton Aqueduct, a position he held until he died on August 28, 1875. Mr. Tracy became a member of the American Society of Civil Engineers in 1868.

APPENDIX II.

FORM OF CONTRACT* FOR WORK LET BY THE AQUEDUCT COMMISSION.

This Agreement, made and entered into this day of , in the year one thousand eight hundred and eighty-six, by and between the MAYOR, ALDERMEN, AND COMMONALTY OF THE CITY OF NEW YORK, acting by and through the Aqueduct Commissioners, by virtue of the power vested in them by Chapter 490 of the Laws of 1883, of the State of New York, parties of the first part, and part of the second part:

Witnesseth, That the parties to these presents, each in consideration of the undertakings, promises, and agreements on the part of the other herein contained, have undertaken, promised, and agreed, and do hereby undertake, promise, and agree, the parties of the first part for themselves, their successors and assigns, and the party of the second part for and heirs, executors, and dministrators, as follows:

Whenever and wherever in this agreement the phrase "party of the second part," or the word "Contractor," or a pronoun in place of either of them is used, the same shall be taken and deemed to mean and intend the part of the second part to this agreement.

Whenever the word "Engineer" is used in these specifications, or in this contract, it refers to and designates the Chief Engineer of the Aqueduct Commissioners, acting either directly or through any Assistant having general charge of the work, or through any Assistant or any Inspector having immediate charge of a portion thereof, limited by the particular duties entrusted to him.

Whenever the word "City" is used in these specifications, or in this contract, it refers to and designates the parties of the first part to this agreement.

A. The party of the second part will, at own cost and expense, and in strict conformity to the hereinafter contained specifications, furnish all the materials (not herein agreed to be furnished by the parties of the first part), and labor necessary or proper for the purpose; and in a good substantial and workmanlike manner, excavate, etc., etc.

B. To prevent all disputes and litigation, it is further agreed by and between the parties to this contract, that the Engineer shall in all cases determine the amount or the quantity of the several kinds of work which are to be paid for under this contract, and he shall determine all questions in relation to said work and the construction thereof, and he shall in all cases decide every question which may arise relative to the execution of this contract on the part of the said Contractor, and his estimate and decision shall be final and conclusive upon said Contractor; and such estimate and decision, in case any question shall arise, shall be a condition precedent to the right of the party of the second part to receive any money under this agreement.

C. And it is further agreed by the parties to this agreement, that whenever the Chief Engineer aforesaid shall be unable to act in consequence of absence or other cause, then such Engineer, or Assistant, as the Aqueduct Commissioners shall designate, shall perform all the duties, and be vested with all the power herein given to said Chief Engineer.

D. The work to be done under this contract being almost wholly underground, it is impossible now to estimate with accuracy the quantities of the various classes of work to be done, and materials to be furnished. It is therefore expressly understood and mutually agreed, that the estimated quantities stated in the advertisement attached hereto, are only for the purpose of comparing, on an uniform basis, the bids offered for the work under this contract; and the Contractor further agrees, that neither the parties of the first part, nor the Aqueduct Commissioners, or any of them, are to be held responsible that any of the said estimated quantities shall be found even approximately correct in the construction of the work; that he is satisfied with, and will at no time dispute, the said estimated quantities as a means of comparing the bids aforesaid, and that he will make no claim for anticipated profits, or for loss of profit, because of a difference between the quantities of the various classes of work actually done, or of materials actually delivered, and the said estimated quantities; and the Contractor hereby undertakes and agrees that he will complete the entire work to the satisfac-

* This form was based upon those used by the Department of Public Works of the City of New York. Although the language is somewhat antiquated, it was not deemed advisable to change it, as most of the clauses have been tested in the courts, in the language given.

tion of the Aqueduct Commissioners, and in accordance with the specifications and the plans herein mentioned, at the prices herein agreed upon and fixed therefor; except for such extra work, for the performance of which written orders may be received as hereinafter specified.

E. And it is further expressly agreed, that all the work, labor and materials to be done and furnished under this contract, shall be done and furnished strictly pursuant and in conformity with the following specifications, and the direction of the Engineer under them; which specifications form part of this agreement.

F. Specifications.

G. **Condemned Materials.**—And it is further agreed that if the work, or any part thereof, or any material brought on the ground for use in the work, or selected for the same, shall be condemned by the Engineer as unsuitable, or not in conformity with the specifications, the Contractor shall forthwith remove such materials from the work, and rebuild or otherwise remedy such work, as may be directed by the Engineer.

H. **Extra Work.**—No claim for extra work shall be made unless before the performance of such extra work the said Commissioners shall have first authorized, in writing, such extra work; and shall also have first certified in writing, for each and every order, that it is in their opinion for the public interest that such extra work be done; stating in such certificate their reasons therefor; nor unless before the performance of such extra work the price or prices to be paid therefor shall likewise first have been agreed upon, in writing, between the said Commissioners and the Contractor, and done in obedience to a written order from the Engineer, or his authorized agent, given before the performance of such extra work.

The aggregate price to be paid for extra work authorized or ordered under and by virtue of the aforegoing provision of this contract, shall not exceed the sum of five thousand dollars on any one order.

All claim for extra work done in any month shall be made to the Engineer, in writing, before the 15th day of the following month; and failing to make such claim within the time required, all rights of the Contractor to extra pay for such work shall be forfeited.

And the said party of the second part further agrees that if he, the party of the second part, and the said Commissioners are or may be unable to agree, as aforesaid, upon the price or prices to be paid for any extra work which may be authorized as aforesaid, he, the said party of the second part, will not in any way interfere with or molest such other person or persons as the said Commissioners may employ to do such extra work; and that he, the said party of the second part, will suspend such part of the work herein specified, or will carry on the same in such manner as may be ordered by the said Engineer, to afford all reasonable facilities for doing such extra work; and no other damage or claim by the said party of the second part shall be allowed therefor, other than an extension of the time specified in this contract for the performance of said suspended work as much as the same may have been, in the opinion of the Engineer, delayed by reason of the performance of such extra work.

I. **Not to Assign.**—And the said party of the second part hereby further agrees to give his personal attention constantly to the faithful prosecution of the work, and not to assign or sublet the work, or any part thereof, without the previous written consent of the Aqueduct Commissioners indorsed on this agreement; but will keep the same under his personal control, and will not assign, by power of attorney or otherwise, any of the moneys payable under this agreement, unless by and with the like consent of said Commissioners, to be signified in like manner; that no right under this contract, nor to any moneys due or to become due hereunder, shall be asserted against the Aqueduct Commissioners, or any person acting under them, or the Mayor, Aldermen or Commonalty of the City of New York, or any department, officer or officers thereof; by reason of any so-called assignment, in law or equity, of this contract, or any part thereof, unless such assignment shall have been authorized by the written consent of said Aqueduct Commissioners indorsed on this agreement; that no person other than the party signing this agreement, as the party of the second part hereto, now has any claim hereunder; that no claim shall be made excepting under this specific clause of this agreement, or under paragraph S of this agreement, by any person whomsoever; and that the said party of the second part will punctually pay the workmen who shall be employed on the aforesaid work in cash current, and not in what is denominated as store pay.

J. **Suspension of Work.**—The Aqueduct Commissioners reserve the right of suspending the whole or any part of the work herein contracted to be done, if they shall deem it for the interest of the City of New York so to do, without compensation to the Contractor for such suspension, other than extending the time for completing the work as much as it may have been delayed by such suspension.

And if the said work shall be delayed for the reason that the parties of the first part do not own, or have not obtained possession of, the land on which the same is to be performed, then and in that case, and in every such case, the party of the second part shall be entitled to so much additional time wherein to perform and complete this contract on his part, as the said Engineer shall certify in writing to be just. But no allowance, by way of damages, shall be made for such delay.

K. **Competent Men to be Employed.**—And the said party of the second part further agrees to employ only competent, skillful men to do the work; and then whenever the Engineer shall inform said party

of the second part, in writing, that any man on the work is in his opinion incompetent, or unfaithful, or disorderly, such man shall be discharged from the work, and shall not again be employed on it.

L. **Time of Performance.**—And the said party of the second part further agrees to commence the work herein required to be done, within twenty days after the signing of this contract, and that the rate of progress shall be such that the whole work shall be completed in accordance with this agreement on or before .

M. In case the said party of the second part shall fail to fully and entirely, and in conformity with the provisions and conditions of this agreement, perform and complete the said work, and each and every part and appurtenance thereof, within the time hereinbefore limited for such performance and completion, or within such further time as may be allowed by the Aqueduct Commissioners for such performance and completion, the said party of the second part shall and will pay to the said parties of the first part the sum of dollars for each and every day that the said party of the second part shall be in default; which said sum of dollars per day is hereby agreed upon, fixed, and determined by the parties hereto, as the damages which the parties of the first part will suffer by reason of such default, and not by way of penalty. And the said parties of the first part may deduct and retain said sum of dollars per day out of any moneys that may be due or become due under this agreement.

N. But neither an extension of time for any reason beyond that fixed herein for the completion of the work, nor the doing and acceptance of any part of the work called for by this contract, shall be deemed to be a waiver by the said Commissioners of the right to abrogate this contract for abandonment or delay, in the manner provided for in the paragraph marked P in this agreement.

O. **Prices for Work.**—And the party of the second part hereby agree to receive the following prices in full compensation for furnishing all the materials (except the materials herein specified to be furnished by the City) and labor, and for performing and completing all the work which is necessary or proper to be furnished or performed, in order to complete the entire work in this contract described and specified, and in said specifications and plans described and shown, to wit:

(*a.*) For excavation of rock in open trench for drains, etc., including all the work incidental thereto, per cubic yard, the sum of .

(*b.*) For excavation of earth in open trench for drains, etc., including all the work incidental thereto, per cubic yard, the sum of , etc., etc.

P. **If Work be Abandoned or Delayed.**—The said party of the second part further agrees that if the work to be done under this agreement shall be abandoned, or if the conditions as to the rate of progress hereinbefore specfied are not fulfilled, or if this contract shall be assigned by the party of the second part otherwise than as is hereinbefore specified, or if at any time the Engineer shall be of opinion, and shall so certify in writing to the said Commissioners, that the said work or any part thereof is unnecessarily or unreasonably delayed, or that the said Contractor is violating any of the conditions or covenants of this contract, or executing said contract in bad faith, or if the work to be done under this contract be not fully and entirely completed within the time herein stipulated for its completion, the said Commissioners shall have the power to notify the aforesaid Contractor to discontinue all work, or any part thereof, under this contract; and thereupon the said Contractor shall discontinue said work, or such part thereof as said Commissioners may designate, and the said Commissioners shall thereupon have the power to place such and so many persons, and obtain by purchase or hire such materials, animals, carts, wagons, implements and tools by contract or otherwise, as said Commissioners deem necessary to complete the work herein described, or such part thereof, and to procure materials for the completion of the same, and to charge the expense of said labor and materials, animals, carts, wagons, implements and tools to the aforesaid Contractor; and the expense so charged shall be deducted and paid by the parties of the first part out of such moneys as either may be due, or may at any time thereafter become due to the said Contractor under and by virtue of this agreement, or any part thereof: and in case such expense is less than the sum which would have been payable under this contract if the same had been completed by said Contractor, then the said party of the second part shall be entitled to receive the difference; and in case such expense shall exceed the last said sum, then the said party of the second part will pay the amount of such excess to the parties of the first part, on notice from the said Commissioners of the excess so due.

Q. **Prevention of, and Indemnification for, Accidents.**—And the said party of the second part further agrees, during the performance of the work, to take all necessary precautions and to place proper guards for the prevention of accidents; and to put up and keep at night suitable and sufficient lights; and to indemnify and save harmless the said parties of the first part from all damages and costs to which they may be put by reason of injury to the person or property of another resulting from negligence or carelessness in the performance of the work, or in guarding the same; or from any improper materials used in its construction, or by or on account of any act or omission of the said party of the second part, or the agents thereof. And the said party of the second part hereby further agrees that the whole, or so much of the moneys due under and by virtue of this agreement as shall or may be considered necessary by the Aqueduct Commissioners, shall or may be retained by the parties of the first part until all suits or claims for damage as aforesaid have been settled, and evidence to that effect furnished to the satisfaction of the said Commissioners.

S. **Evidence that Work, Labor and Materials are Paid for.**—And it is further agreed by the party of the second part, that said party will furnish the said Aqueduct Commissioners with satisfactory evidence that all persons who have done work, or furnished materials, under this agreement, and who may have given written notice to said Commissioners before or within ten days after the final completion and acceptance of the whole work under this contract, that any balance for such work or materials is due and unpaid, have been fully paid or satisfactorily secured. And in case such evidence is not furnished as aforesaid, such amount as may be necessary to meet the claims of the persons aforesaid may be retained from the money due said party of the second part under this agreement, until the liabilities aforesaid shall be fully discharged, or such notice withdrawn.

T. **Estimates and Partial Payment.**—In order to enable the said Contractor to prosecute the work advantageously, the Engineer shall, once a month, make an estimate in writing of the amount of work done, and of the value thereof, according to the terms of this contract. The first such estimate shall be of the amount or quantity and value of the work done since the party of the second part commenced the performance of this contract on his part. And every subsequent estimate (except the final one) shall be of the amount or quantity and value of the work done since the last preceding estimate was made. And such estimates of amount and quantity shall not be required to be made by strict measurement, or with exactness; but they may, at the option of said Engineer, be approximate only. Upon each such estimate being made, the parties of the first part will pay to the parties of the second part ninety per cent. of such estimated value. And whenever in the opinion of the Engineer the party of the second part shall have completely performed this contract on his part, the said Engineer shall so certify, in writing, to the Aqueduct Commissioners; and in his certificate shall state, from actual measurements, the whole amount of work done by the said party of the second part, and also the value of such work under and according to the terms of this contract. And on the expiration of thirty days after the acceptance by said Commissioners of the work herein agreed to be done by the party of the second part, the said parties of the first part will pay to the said party of the second part, in cash, the amount remaining after deducting from the amount or value contained and stated in the last mentioned certificate, all such sums as shall theretofore have been paid to the said party of the second part under any of the provisions in this contract contained; and also all such sum or sums of money as by the terms hereof they are or may be authorized to reserve or retain; provided that nothing herein contained shall be construed to affect the right hereby reserved of the said Commissioners to reject the whole or any portion of the aforesaid work, should the said certificate be found, or known to be, inconsistent with the terms of this agreement, or otherwise improperly given.

U. And the said party of the second part further agrees not to demand or be entitled to receive payment for the aforesaid work or materials, or any portion thereof, except in the manner set forth in this agreement; nor unless each and every of the promises, agreements, stipulations, terms and conditions herein contained to be performed, kept, observed, and fulfilled on the part of the said party of the second part, has been so far forth performed, kept, observed, and fulfilled; and the said Engineer shall have given his certificate to that effect, and the Aqueduct Commissioners shall have accepted the work.

V. It is further expressly understood and agreed by and between the parties hereto, that the action of the Engineer, by which the said Contractor is to be bound and concluded according to the terms of this contract, shall be that evidenced by his final certificate; all prior partial payments being made merely upon estimates subject to the correction of such final certificate; which final certificate may be made without notice to the Contractor thereof, or of the measurements upon which the same is based.

W. And it is hereby expressly agreed and understood by and between the parties hereto that the said parties of the first part, their successors and assigns, shall not, nor shall any department or officer of the City of New York be precluded or estopped by any return or certificate made or given by any Engineer, Inspector, or other officer, agent, or appointee of said Aqueduct Commissioners, or of said parties of the first part, under or in pursuance of anything in this agreement contained, from at any time showing the true and correct amount and character of the work which shall have been done, and materials which shall have been furnished, by the said party of the second part, or by any other person or persons under this agreement.

In witness whereof, the said Aqueduct Commissioners have hereunto set their hands and seals on behalf of the said parties of the first part, and the said party of the second part ha also hereunto set hand and seal ; and said Commissioners, and party hereto of the second part, have executed this agreement in triplicate; one part of which to remain with said Commissioners, one other to be filed with the Comptroller of the City of New York, and the third to be delivered to the said party hereto of the second part; the day and year herein first above written.

, *Aqueduct Commissioners.*
, *Contractor.*

Signed and sealed in presence of

SPECIFICATIONS OF AQUEDUCT COMMISSION FOR AQUEDUCT IN TUNNEL, SECTION NO. 2.

1. **Plans.**—The plans referred to n these specifications are 16 in number, entitled "The Aqueduct Commission, Westchester County," etc., Nos. , signed by the Chief Engineer, and dated

They show the location of the work, and its *general* character. During the progress of the work, working plans will be furnished by the Engineer.

2. **Work to be Done.**—Section **2** of the Aqueduct to be built under this contract extends from point **P** to point **O**, marked on Sheet No. of the plans, a total distance of about 20,460 feet.

All work, during its progress, and on its completion, must conform truly to the lines and levels given by the Engineer, and must be built in accordance with the plans and directions given by him from time to time, subject to such modifications and additions as he shall deem necessary during its execution; and in no case will any work in excess of the requirements of the plans, or of the specifications, be paid for unless ordered in writing by the Engineer as hereinafter set forth.

The Contractor is to furnish all materials (except such as are obtained from the excavations; and the iron, and station plates, herein specifically agreed to be furnished by the City), and all tools, implements, machinery and labor (necessary or convenient for doing all the work with safety to life and property, and within the time specified herein), required to construct and put in complete working order the section of Aqueduct above specified, and is to perform and construct all the work covered by this agreement; the whole to be done in conformity with the plans and these specifications; and all parts to be done to the satisfaction of the said Aqueduct Commissioners.

3. **Dumping Grounds.**—Dumping grounds will be furnished by the City for the disposal of the materials to be excavated, and not used in the work; and the Contractor shall dump said materials on such grounds under the direction of the Engineer; sufficient ground shall also be furnished by the City for the establishment of the working plant at the shaft sites.

4. **Rights of Way.**—The necessary rights of way between the highways and the shaft sites are to be furnished by the City, but the Contractor is to build, repair, and maintain the roads used by him for the purposes of his work.

5. **Fences.**—The Contractor shall erect and maintain fences along the roadways, and around the grounds occupied by him. These fences must be of such a character as to be sufficient, in the opinion of the Engineer, for the protection of the adjoining property.

6. **Soiling.**—Before beginning the work at the shaft sites the soil covering the location of the work is to be removed whenever directed by the Engineer and put in spoil banks, to be again placed over the restored surface and the embankments, or wasted. The quantities of soil removed will be measured in the spoil banks, and the price herein stipulated to be paid for the removal and replacing of soil is to cover the cost of grubbing and clearing and of removing, storing, replacing and wasting the soil, wherever ordered by the Engineer.

7. **Roads.**—Whenever in the prosecution of the work it is necessary to interfere with roads or railroads, the Contractor shall at his own expense provide suitable bridges or other sufficient crossings for the accommodation of the travel on said roads; and shall maintain the same in good and safe condition until the roads can be restored; when all bridges and other temporary expedients shall be removed, and the roads restored to a condition suitable for use, and satisfactory to the Engineer.

8. **Borings.**—Borings have been made, on portions of the line, to ascertain the nature of the underground strata through which the shafts and tunnel are to be constructed. The results of these borings are shown on the plans; but should the character and extent of the various materials be found to differ from what is indicated, the Contractor shall have no claim on that account, and it is expressly understood that the City does not warrant the indications of the borings to be correct.

SHAFTS.

9. The Contractor is to sink 4 shafts, at the points and to the depths directed by the Engineer; these shafts are indicated on plan sheets Nos. . All shafts will have their longest horizontal dimensions parallel with the axis of the Aqueduct.

10. The position of the shafts may be altered by the Commissioners within the area of the shaft sites on the line of the tunnel before the inception of the work; and if, during its progress, additional shafts are ordered by the Commissioners, such shafts shall be made in the same manner, of the same size, and paid for at the same rate as the shafts mentioned in the specifications and shown on the plans.

11. The supports of the shafts must be so arranged as to leave ample room for all the necessary water steam, air, and other pipes, and for the convenient use of instruments and appliances for the alignment of the tunnel. Their horizontal section is to be 17 feet 6 inches, by 8 feet, in the clear of all rock and of all framing

or other supports, except the necessary cross-bracing used for maintaining the sides of the shafts; but where only one heading is worked from a shaft, the dimensions may be changed to 11 feet by 8 feet.

12. **Measurements, etc.**—The shaft excavation is to be paid for by the vertical linear foot of shaft excavated and completed. The price herein stipulated to be paid for shaft excavation is to cover the cost of all curbing or other support, of all pumping and bailing, and of all work of whatever nature incidental to the excavation and maintenance of the shafts. The number of linear feet in each shaft is to be measured on its centre line, from the point where said centre line strikes the surface of the ground, to the point where it strikes the soffit of the tunnel excavation.

13. **Curbing.**—The curbing, whenever any is found necessary, must be of such a nature as to thoroughly support the sides of the shaft, and to secure vertical faces. Cages must be used for the hoisting of men and materials during the construction of the Aqueduct, and full precautions must be used to ensure perfect safety. Safety catches of tested efficiency and strength must be used in connection with the cages, to hold them in case of accident.

14. **Masonry in Shafts.**—All masonry work in connection with the shafts is to be done as may be directed from time to time by the Chief Engineer. The shafts are to contain masonry into which steps, and other iron pieces are to be built; arches are to be thrown across them, with suitable abutments on the solid rock.

15. **Shaft Filling.**—The shafts shall be refilled, over or about the masonry, as directed by the Engineer, with material of approved quality, from the excavation; the filling material to be carefully lowered, unless otherwise permitted. All the filling must be thoroughly compacted by ramming. Such filling is to be paid for by the cubic yard, and the price per cubic yard herein stipulated for shaft filling is to cover the cost of loading, transporting and placing the material, and of all work incidental thereto.

TUNNEL.

17. The form and area of the cross-section of the tunnel excavation at any place shall be such as the Engineer may determine for that place; but at all points it shall have an area of at least two hundred and one square feet (201).

Various forms of cross-sections of the tunnel excavation are illustrated on sheets Nos. of the plans. On the plans the line limiting the cross-section of the tunnel excavation is designated by the letters *A*, *A*, *A*.

18. Masonry shall be built within the tunnel at such points and of such materials and of such form and dimensions as the Chief Engineer may determine from time to time (See sheets Nos. of the plans for illustrations of some of the proposed forms).

The lower part of the excavation is to be protected with masonry for the whole length of the tunnel; and at all points (except where a circular form is ordered for the masonry) a floor, in the form of a nearly flat inverted arch, is to be built. Where no side-wall masonry is built, skewbacks must be cut in the rock for the invert to abut against, as shown on sheet No. of the plans.

19. Weepers, of the form and dimensions shown on sheets Nos. , are to be built in the side walls and floor. No deductions in the measurement of the masonry will be made for the weepers, which must be built true and smooth.

20. The spaces between the top of the arch and the rock or other material of the excavation, or any other space which may be designated by the Engineer, are to be filled, at the expense of the Contractor, with material excavated from the tunnel, of approved size and quality, and free from all perishable matter. The filling to be carefully and thoroughly compacted, so as to bring an uniform pressure on the masonry.

The extrados of all portions of the arch, when in contact with this filling, is to be covered, at the expense of the Contractor, with a coating of cement mortar, not less than one-half inch thick.

TUNNEL EXCAVATION.

21. The tunnel, at any place, is to be excavated to the line of the cross-section determined by the Engineer for that place.

No payment will be made for any excavation outside of the cross-section of the tunnel excavation determined by the Engineer; but all loose or shaky rock must be removed.

The price per cubic yard, stipulated herein for tunnel excavation, is to cover all expense due to the presence of quicksand or other soft material, rotten rock, boulders, etc.; the cost of all pumping and bailing; of all timbering, and removal of same; of removing all excavated materials; of all ventilation; and of all other work incident to the excavation of the tunnel. Any expense that may arise from loose and shaky rock or from falls or cave-ins, or from unexpected obstacles, shall be borne by the Contractor.

22. **Extra Excavation.**—The Engineer may order at any time additional excavations for the chambers in the shafts, for the skewbacks of arches, for the sump holes, or for any other purpose in the tunnel or

shafts; and the Contractor is to do such excavation, which is to be measured according to the lines of the cross-sections determined by the Engineer, and paid for by the cubic yard as tunnel excavation.

23. If after the excavation has been made of a certain size by direction of the Engineer, he is of opinion that the nature of the rock or other material is such that the form and dimensions of the masonry for which said excavation was intended must be increased, he may order an enlargement of the excavation for the purpose of building masonry of greater thickness, and the Contractor is to make such enlargement, which is to be measured according to the lines given by the Engineer, and paid for at the price per cubic yard herein stipulated for tunnel excavation.

24. In rock excavation, the drilling and blasting must be conducted with all possible care, so as not to shatter the roof and sides of the tunnel outside of the lines determined by the Engineer; and in soft material precautions must be taken not to allow cavities to be formed behind the timbering or other supports; and especially in the vicinity of the existing Croton Aqueduct the blasting and timbering, and any other operation connected with the work, must be so regulated as not to cause injury to said Aqueduct. The Contractor is to be held responsible for all injuries to the said Aqueduct caused by his work.

25. **Excessive Excavation.**—If, in the opinion of the Engineer, the Contractor by the use of too high explosives, bad location of drill holes, defective arrangement of timbers or other supports, or want of proper skill and attention, shall excavate the tunnel or shafts to greater dimensions than is required for the proper building of the masonry, the excess of tunnel or shaft area thus formed shall be filled solid, at the expense of the Contractor, with such kind of masonry (brick, concrete, or rubble masonry, as herein specified), or other material as the Engineer may direct.

TIMBERING, DRAINAGE, POWER, ETC.

26. **Timbering or Other Supports.**—The Contractor shall be responsible for properly supporting the roof and sides of the tunnel, and the sides of the shafts, with timber, or other supports. If, however, the Engineer is of opinion that at any point sufficient or proper supports have not been provided, he may order additional supports, or order them modified or replaced, at the expense of the Contractor; and the compliance with such orders by the Contractor shall not relieve or release him from his responsibility for the sufficiency of such supports.

27. **Timber to be Removed.**—All timber work is to be removed from the excavation; but if in the opinion of the Engineer, any timber work be so located in the tunnel or shafts, that its removal would endanger the safety of the masonry, it shall be left in, and all cavities about it shall be filled with masonry or with such other material as he may order; but no payment is to be made to the Contractor for such timber.

28. **Drainage in Tunnel and Trenches.**—Wherever, in the opinion of the Engineer, special means are necessary for draining the tunnel, a drain is to be cut in the rock below the floor of the excavation, to such a depth as to free entirely from water the portions where the masonry of the floor is to be laid. This drain is to be paid for per linear foot of its length, in rock excavation only. If, in the opinion of the Engineer, a drain pipe is necessary, it shall be laid and paid for per lineal foot of its length. All drain pipe furnished for the work shall be vitrified sewer pipe, equal in quality to the best "Akron" pipe. The pipe must be "socket pipe," perfect in shape, and free from cracks and flaws. The joints must be made tight, to prevent gravel and sand from passing through them. If, in the opinion of the Engineer, it be necessary, they shall be calked with neat cement. No size is fixed, in advance, for the drains; but the Contractor is to be responsible for their sufficiency; and if the Engineer find that they are not of sufficient size to drain the tunnel properly, and for the protection of the masonry, he may order the Contractor to increase the means of drainage; and the Contractor is to do so without any extra compensation.

The drains are to be filled, before the completion of the work, with the kind of masonry that the Engineer may order; and the Contractor is to be paid for such filling at the price stipulated for the kind of masonry ordered.

29. **Power and Appliances.**—The power to be employed in driving the tunnel—except when otherwise allowed—shall be compressed air, to be applied by the most approved method; or some more effective force which shall be approved by the Engineer and the Commissioners. The Contractor is to use such appliances for pumping, drilling, blasting, ventilating, hauling or hoisting materials, and for all other operations connected with the excavation and support of the tunnel and shafts, as will secure the rate of progress herein specified. If at any time before the inception, or during the progress of the work, such appliances appear to the Engineer to be inefficient, or inappropriate, for securing the quality of the work required, or the said rate of progress, he may order the Contractor to increase their efficiency, or to improve their character, and the Contractor must conform to such order; but the failure of the Engineer to demand such increase of efficiency or improvement shall not relieve the Contractor from his obligation to secure the rate of progress established in these specifications. The tunnel must be kept so free from smoke and noxious gases that the Engineer or his assistants can, when necessary, establish the alignment, or do other engineering work, efficiently.

MASONRY.

30. All masonry is to be laid in hydraulic cement mortar, unless otherwise specified.

The Contractor, at his own expense, must conduct the water away from any point where masonry is being laid, by the use of pipes or other efficient means, and must prevent water from flowing over or exerting pressure upon the masonry until it is fully set. Under no circumstances shall masonry be laid in water.

31. The work of masonry in the tunnel must progress simultaneously with the work of excavation; and must follow it at a distance of not less than 200 nor more than 500 feet from the heading, unless otherwise permitted.

32. The work in all cases shall be well and thoroughly bonded; and the system of bonding ordered by the Engineer shall be strictly followed.

33. **Centres.**—Strong centres, made to fit the curves in the line of the masonry, and satisfactory moulds or forms, shall be provided by the Contractor; and when they lose their proper dimensions or shape, they shall be replaced by others. They shall, before use, be scraped free from cement or other dirt. The centres upon which the top arch is formed shall be slightly lowered before the backing is placed on said arch, but not until in the opinion of the Engineer the mortar has sufficiently set.

34. **Change of Shape.**—At all places where there is a change in the shape of the masonry, at all angles, shafts, chambers, etc., and at all other parts that may be ordered, the masonry is to be built carefully to the curves and forms given by the Engineer.

35. **Iron Work.**—All iron steps, and all other iron work for permanent use, also the station plates, will be furnished by the City, and shall be built in the masonry wherever, and in the manner directed by the Engineer, without extra compensation; but all iron piping that may be needed during the progress of the work to facilitate the construction and setting of the masonry, shall be furnished by the Contractor at his own expense; and left in, if so ordered.

36. No mason work of any description is to be laid in the trenches between the first of November and the first of April, except by special permission of the Engineer.

37. **Cement.**—The greater part of the masonry is to be laid in American cement mortar; but Portland cement is to be used whenever directed. The American cement must be equal in quality to the best Rosendale cement; it must be made by manufacturers of established reputation; must be fresh and very fine ground, and in well made casks. The Portland cement must be of a brand equal in quality to the best English Portland cement. To insure its good quality, all the cement furnished by the Contractor will be subject to inspection and rigorous tests; and if found of improper quality will be branded, and must be immediately removed from the work; the character of the tests to be determined by the Engineer. The Contractor shall, at all times, keep in store at some convenient point in the vicinity of the work, a sufficient quantity of cement to allow ample time for the tests to be made without delay to the work of construction. The Engineer shall be notified at once of each delivery of cement. It shall be stored in a tight building, and each cask must be raised several inches above the ground by blocking, or otherwise.

38. **Mortar.**—Mortar shall be prepared from cement of the quality before described, and clean sharp sand free from loam. These ingredients shall be thoroughly mixed *dry*, in the following proportions: one part, by measure, of cement to two parts of sand; and a moderate dose of water is to be afterwards added to produce a paste of proper consistency; the whole to be thoroughly worked with hoes or other tools. In measuring cement, it shall be packed as received from the manufacturer. The mortar shall be freshly mixed for the work in hand, in proper boxes made for the purpose; no mortar to be used that has become hard or set. Whenever the Engineer may order it, the above proportions of cement and sand shall be changed to one part by measure of cement to one part by measure of sand.

39. **Concrete.**—The concrete shall be formed of sound broken stone, not exceeding two inches at their greatest diameter. All stone in any way larger is to be thrown out. The materials to be cleaned from dirt and dust before being used; to be mixed in proper boxes, with mortar of the quality before described, in the proportion of five parts of broken stone to one part of cement; to be laid immediately after mixing, and to be thoroughly compacted throughout the mass till the water flushes to the surface. The concrete shall be allowed to set for twelve hours, or more if so directed, before any work shall be laid upon it; and no walking over or working upon it shall be allowed while it is setting. The concrete used for backing must be placed and compacted with extreme care, and no water is to be allowed to interfere with its setting. When stone obtained from the excavation is of proper quality, it may be used for making concrete. Whenever ordered by the Engineer, the concrete shall be formed of broken stone not exceeding one inch at their greatest diameter, used in the proportion of three parts of broken stone to one part of cement; the mode of mixing, the quality of the materials, and the manner of using, to be the same as above described.

40. **Bricks.**—The bricks shall be of the best quality of hand-made hardburnt bricks; burnt hard entirely through, regular and uniform in shape and size, and of compact texture. To insure their good quality, the bricks furnished by the Contractor will be subject to inspection and rigorous tests, and if found of improper quality, will be condemned; the character of the tests to be determined by the Engineer. They are to be culled on the surface before laying, at the expense of the Contractor; the Engineer to be furnished with

men for this purpose by and at the expense of the Contractor. Specially moulded bricks of the shape shown on sheet No. of the plans, are to be used for the lower corner of the tunnel masonry, of the form shown on sheet No. .

41. **Brick Masonry.**—All brick masonry shall be laid with bricks and mortar of the quality before described. No "bats" shall be used except in the outside ring of the covering arch, and in the backing masonry, where a moderate proportion (to be determined by the Inspector) may be used, but nothing smaller than half bricks. The bricks to be thoroughly wet just before laying. Every brick to be completely imbedded in mortar under its bottom, on its sides, and on its ends, at one operation. Care shall be taken to have every joint full of mortar. Competent mechanics shall be employed for this work; and for the invert, especially, only the best skilled labor shall be employed.

For all brick masonry the bricks shall be laid to a line, with the beds in the line of the radii of the curves; and with as close joints (not exceeding ¼ inch for either face or arch work) as may be from time to time directed. The inside faces of the joints of the bottom arch, and of the sides, shall be neatly pointed; and those of the upper arch, after the centres have been withdrawn, shall have all the mortar projecting beyond the surface of the bricks scraped off, not more than fifteen days after the arch has been covered; and shall be pointed and left in a neat condition: all pointing to be done with neat cement.

42. All unfinished work must be racked back, or toothed, as may be directed by the Engineer in each case; and before new work is joined to its surface the bricks must be scraped thoroughly clean, and scrubbed with a stiff brush, and well moistened.

43. **Stone Masonry.**—All stone masonry is to be built of sound stone of quality and size satisfactory to the Engineer.

44. **Rubble Stone Masonry.**—Rubble stone masonry shall be made of sound, clean stone of suitable size, quality and shape for the work in hand, and presenting good beds for materials of that class. Care must be taken to have the beds and joints full of mortar, and no grouting or filling of joints after the stones are in place will be allowed. The work must be thoroughly bonded.

Rubble stone masonry is to be used in any part of the tunnel, or other part of the work where it may be ordered.

In the tunnel, especially, the size and shape of the stone used must be adapted to the spaces to be filled, in order to secure absolutely compact work.

Stone from the tunnel or other excavation may be used, when suitable.

45. **Cut Stone Masonry.**—A small amount of cut stone masonry is to be used at the upper and lower parts of the shafts; and wherever it may be ordered by the Engineer. It is to be built of granite of first quality, free from all defects, and cut to a ⅛-inch joint, and to the form indicated on the plans; all exposed surfaces to be finished in fine hammered (six cut) work, of the best description. In measuring the stones when they are not rectangular, the dimensions taken for each stone will be those of a rectangular cubical form which will just inclose the same.

46. **Station Plates.**—The City will furnish station plates, and the Contractor is to fasten them in the manner directed by the Engineer. The number and position of these plates cannot be indicated in advance, but there is not to be more than one for each 500 feet of the Aqueduct.

GENERAL CLAUSES.

47. **Grading, Cleaning and Finishing.**—At his own expense, and under the direction of the Engineer, the Contractor is to clear the Aqueduct from all refuse and rubbish, and to do about the shafts all grading that may be ordered; to do all ditching and diverting of streams, and leave in neat condition the grounds occupied by him.

48. The Contractor is to give all facilities to the City or to other Contractors for performing work adjoining his own, and any difference which may arise between two contractors in regard to their adjoining work is to be adjusted by the Engineer, whose decision is to be final in the matter.

49. **Lines and Grades.**—All lines and grades are to be given by the Engineer, who may change them from time to time as he may be authorized and directed by the said Aqueduct Commissioners, even to the extent of lowering or raising the grade line of the Aqueduct, or of ordering vertical or side drifts.

50. **Marks and Stakes.**—The stakes and marks given by the Engineer, and the troughs for the plumb lines, must be carefully preserved by the Contractor, who must give to the Engineer all necessary assistance and facilities for establishing the benches and plugs, and for making measurements.

51. **Engineer to Explain Specifications.**—The plans and specifications are intended to be explanatory of each other, but should any discrepancy appear, or any misunderstanding arise as to the import of anything contained in either, the explanation and decision of the Chief Engineer shall be final and binding on the Contractor; and all directions and explanations required, alluded to, or necessary to complete any of the provisions of these specifications, and give them due effect, will be given by the Engineer.

SPECIFICATIONS FOR GATE HOUSE AT 135TH STREET AND CONVENT AVENUE.

(1.) The plans referred to in these specifications are eighteen in number, entitled "The Aqueduct Commission," etc., sheets Nos. , signed by the Chief Engineer and dated September 4, 1886.

They show the location of the work and its general character. During the progress of the work, working plans will be furnished by the Engineer.

(2.) **Description of Section No 15.**—Section No. 15 of the New Croton Aqueduct is shown on the plans, and in the main is to consist of the foundation walls of a gate house, and the enclosed chambers for gates, screens, drainage, etc.; the necessary excavation for such foundation walls, drains, and the excavation for the vertical end of the Aqueduct; of the trench for receiving one length of eight lines of forty-eight inch pipe; of the sewer, of a portion of the ten feet connection with the Tenth Avenue gate house, of the building or superstructure (excepting windows and doors); of all refilling, grading and wasting of materials, and of all incidental work; the gates, gate houses, gate-hoisting machinery, stopcock and screens are not included or called for in this contract.

(3.) The Contractor is to furnish all materials (except such as are obtained from the excavations; and the iron, herein specifically agreed to be furnished by the City), and all tools, implements, machinery and labor necessary or convenient for doing all the work (with safety to life and property, and within the time specified herein) required to construct and put in complete working order said Section No. 15 of said Aqueduct; and to perform and construct all the work covered by this agreement; the whole to be done in conformity with the plans and these specifications; and all parts to be done to the satisfaction of the said Aqueduct Commissioners.

(4.) **Lines and Grades.**—All work during its progress, and on its completion, must conform truly to the lines and levels given by the Engineer, and must be built in accordance with the plans and directions given by him from time to time, subject to such modifications and additions as he shall deem necessary during its execution; and in no case will any work in excess of the requirements of the plans, or of the specifications, be paid for unless ordered in writing by the Engineer, as hereinafter set forth.

(5.) **Space Available.**—Section No. 14 of the new Croton Aqueduct being now under contract, and the available space for excavating and building operations being somewhat contracted, the Contractor for this section must so conduct his work as not to interfere with adjoining work, or with traffic on the public roads, or streets; and to protect the adjoining property.

EXCAVATION.

(6.) **Two Classes of Excavations.**—Two classes of excavation are required, for each of which a price per cubic yard is herein stipulated.

1st. Earth excavation in open trench, for which a price is stipulated in clause , item .

2d. Rock excavation in open trench, for which a price is stipulated in clause , item .

(7.) **What Prices for Excavation are to Cover.**—The prices herein stipulated to be paid for rock or earth excavation are to cover the cost of sheeting, bracing and other supports, the cost of pumping, draining, ditching, and of building bulkheads, of maintaining the cuts, of making roads and embankments, of disposing of all the materials as ordered in refilling, grading, wasting or otherwise, and all other expenses incident to this class of work.

(8.) **Earth Excavation.**—All excavation except solid ledge and boulders of one cubic yard or more in volume, shall be classed as earth excavation. It must be made to the lines given by the Engineer from time to time, and in estimating the quantities of earth excavation to be paid for under this contract, said lines will be used as the boundaries of the pits, trenches, or other excavations.

(9.) **Rock Excavation in Open Cut.**—All solid ledge excavations and boulders of one cubic yard or more in volume, or rock which is removed by blasting in the pits and trenches required to receive the various masonry structures, and for waterways, will be classed as rock excavation in open trench.

The excavations must be made to the lines given by the Engineer from time to time, and in estimating the quantities of rock excavation in open cut to be paid for under this contract, said lines will be used as the boundaries of the pits, trenches and other excavations.

(10.) No payment will be made for any excavation beyond or outside of said lines.

(11.) The sides of the excavation for the pipe trenches and for the gate-house foundation walls and gate chambers, will be ordered perpendicular to such elevations as shall be indicated.

(12.) The gate-house excavations, and all other pits and trenches, shall be taken out with slopes when ordered by the Engineer, to lines that he shall establish.

(13.) Precautions must be taken to protect the men from accidents, and to that effect loose or shaky rock

must be removed, and shelters if necessary must be provided. The Contractor is to receive no payment for the building of such shelters, nor for the removal of loose rock if it extends beyond the lines given.

(14.) In making the excavations for pipe trenches, and for the foundations of the walls, such moderate blasts shall be used that the rock taken out may be as near as practicable to the lines given.

(15.) **Extra Excavation.**—The Engineer may order at any time additional excavations for any purpose; and the Contractor is to do such excavation, which is to be measured according to the lines of the cross-sections determined by the Engineer, and paid for by the cubic yard.

If after the excavation has been made of a certain size by direction of the Engineer, he is of opinion that the nature of the rock or other material is such that the form and dimensions of the masonry for which said excavation was intended must be increased, he may order an enlargement of the excavation for the purpose of building masonry of greater thickness, and the Contractor is to make such enlargement, which is to be measured according to the lines given by the Engineer, and paid for at the price per cubic yard herein stipulated.

(16.) **Excessive Excavation.**—If, in the opinion of the Engineer, the Contractor by the use of too high explosives, bad location of drill holes, defective arrangement of timbers or other supports, or want of proper skill and attention, shall excavate to greater dimensions than is required for the proper building of the masonry, the excess thus formed shall be filled solid, at the expense of the Contractor, with such kind of masonry (brick, concrete, or rubble masonry, as herein specified), or other material, as the Engineer may direct.

(17.) **Blasting.**—In rock excavation the drilling and blasting must be conducted with all possible care, so as not to shatter the rock outside of the prescribed lines and especially in the vicinity of the existing buildings the blasting must be so regulated as not to cause any injury to said buildings. The Contractor will be held responsible for all injuries to the said buildings caused by his work.

All blasting shall be conducted in conformity with the ordinances of the City of New York directing the manner of blasting and the precautions to be taken.

(18.) **Ground for Plant, Dumping, &c.**—Sufficient ground is to be furnished by the City at or near the excavation for the establishment of the working plant, but no material from the excavation shall be dumped thereon except by order of the Engineer. All excavated material is to be removed by the Contractor (except such as shall be required for the refilling of trenches and for grading about the gate house), who must furnish the necessary dumping grounds for the same. The cost of such removal and of procuring such dumping ground is to be included in the price herein stipulated for excavation. And the Contractor, at his own expense, must provide sufficient and proper drainage for all water discharged from the excavations.

(19.) **Fences.**—The Contractor, whenever so ordered, shall erect and maintain fences along the streets, roadways, and around the grounds occupied by him. These fences must be of such a character as to be sufficient, in the opinion of the Engineer, for the protection of the adjoining property.

(20.) **Prices.**—Two prices only are to be paid for materials excavated in open trench, viz.: One for rock, including solid rock and boulders of one cubic yard or more in volume; and one for earth, including all other materials. Whenever the rock is of such a nature that it can be removed by picking, it shall be classified as earth.

(21.) **Refilling in Trenches.**—All refilling in open trenches for pipes, &c., must, if so ordered by the Engineer, be made with selected materials, in layers of not more than six inches in thickness.

(22.) **Prices.**—The prices bid for rock or earth excavation, in open trench, are to include the cost of sheeting, bracing, and other supports; the cost of pumping, draining, and all other expenses incidental to the excavation, maintenance, &c.

(23.) **Soiling.**—Before beginning the work the soil is to be removed wherever directed by the Engineer and put in spoil banks, to be again placed over the restored surface. The quantities of soil removed will be measured in the spoil bank, and the price paid for soiling will cover the cost of removing, storing and replacing the soil wherever ordered by the Engineer.

(24.) **Refilling.**—A portion of the excavated materials is to be used for refilling between the masonry structures and the sides of the excavations. Such refilling is to be done with care, the material to be tamped whenever ordered, and to be lowered into place, if so directed.

A large quantity of the excavated material is to be used in restoring to grade the grounds about the gate house.

TIMBERING, DRAINAGE, POWER, ETC.

(25.) **Timbering or Other Supports.**—The Contractor shall be responsible for properly supporting the sides of the cuts and trenches or other excavations, with timber or other supports. If, however, the Engineer is of opinion that at any point sufficient or proper supports have not been provided, he may order additional supports, or order them modified or replaced, at the expense of the Contractor; and the compliance with such orders by the Contractor shall not relieve or release him from his responsibility for the sufficiency of such supports.

(26.) **Timber to be Removed.**—All timber work is required to be removed from the excavations; but if in the opinion of the Engineer, any timber work be so located in the pits or trenches that its removal

would endanger the safety of the masonry, it shall be left in; and all cavities about it shall be filled with masonry or with such other material as he may order; but no payment is to be made to the Contractor for such timber.

(27.) **Power and Appliances.**—The Contractor is to use such appliances for pumping, drilling, blasting, hauling or hoisting materials, and for all other operations connected with the excavation and support of the pits and trenches, as will be required to complete the work of this section at or before the time hereinafter specified. If, at any time before the inception, or during the progress of the work, such appliances appear to the Engineer to be inefficient, or inappropriate for securing the quality of the work required, or the rate of progress that will in the opinion of the Engineer insure the completion of the work within the time named, he may order the Contractor to increase their efficiency or to improve their character, and the Contractor must conform to such order; but the failure of the Engineer to demand such increase of efficiency or improvement shall not relieve the Contractor from his obligation to secure the rate of progress established in these specifications.

MASONRY.

(28.) The masonry of the gate house, foundations, gate chambers, inlet and outlet chambers, and other structures and appurtenances, shall be of the class, form and dimensions that may be designated by the Chief Engineer from time to time. The general forms and dimensions of the various structures are shown on the plans.

Prohibition.—No mason work of any description is to be laid between the first of November and the first of April, except by special permission of the Engineer.

(29.) **Weepers.**—Weepers shall be built in the masonry whenever directed.

(30.) All masonry is to be laid in hydraulic cement mortar, unless otherwise specified.

The Contractor, at his own expense, must conduct the water away from any point where masonry is being laid, by the use of pipes or other efficient means, and must prevent water from flowing over or exerting pressure upon the masonry until it is fully set. Under no circumstances shall masonry be laid in water.

(31.) The work in all cases shall be well and thoroughly bonded; and the system of bonding ordered by the Engineer shall be strictly followed.

(32.) **Centres.**—Strong centres, made to fit the curves in the line of the masonry, and satisfactory moulds or forms, shall be provided by the Contractor; and when they lose their proper dimensions or shape they shall be replaced by others. They shall, before use, be scraped free from cement or other dirt. The centres upon which the top arch of the aqueduct connection is formed shall be slightly lowered before the backing is placed on said arch, but not until in the opinion of the Engineer the mortar has sufficiently set.

(33.) **Change of Shape.**—At all places where there is a change in the shape of the masonry, at all angles, wells, chambers, etc., and at all other parts that may be ordered, the masonry is to be built carefully to the curves and forms given by the Engineer.

(34.) **Iron Work.**—All iron work for permanent use will be furnished by the Contractor, with the exception of that above mentioned; it shall be built in the masonry wherever and in the manner directed by the Engineer; but all iron piping that may be needed during the progress of the work to facilitate the construction and setting of the masonry, shall be furnished by the Contractor at his own expense; and left in, if so ordered.

(35.) **Cement.**—The greater part of the masonry is to be laid in American cement mortar; but Portland cement is to be used whenever directed. The American cement must be equal in quality to the best Rosendale cement; it must be made by manufacturers of established reputation; must be fresh and very fine ground; and put in well made casks. The Portland cement must be of a brand equal in quality to the best English Portland cement. To insure its good quality, all the cement furnished by the Contractor will be subject to inspection and rigorous tests; and if found of improper quality will be branded, and must be immediately removed from the work; the character of the tests to be determined by the Engineer. The Contractor shall at all times keep in store at some convenient point in the vicinity of the work, a sufficient quantity of cement to allow ample time for the tests to be made without delay to the work of construction. The Engineer must be notified at once of each delivery of cement. It shall be stored in a tight building, and each cask must be raised several inches above the ground, by blocking or otherwise.

(36.) **Mortar.**—Mortar shall be prepared from cement of the quality before described, and clean sharp sand free from loam. These ingredients shall be thoroughly mixed dry, in the following proportions: one part by measure of cement, to two parts by measure of sand; and a moderate quantity of water is to be afterwards added to produce a paste of proper consistency; the whole to be thoroughly worked with hoes or other tools. In measuring cement, it shall be packed as received from the manufacturer. The mortar shall be freshly mixed for the work in hand, in proper boxes made for the purpose; no mortar to be used that has become hard or set. Whenever the Engineer may order it, the above proportions of cement and sand shall be changed to one part by measure of cement and one part by measure of sand.

(37.) **Concrete.**—The concrete shall be formed of sound broken stone, not exceeding two inches at their greatest diameter. All stone in any way larger is to be thrown out. The materials to be cleaned from

dirt and dust before being used; to be mixed in proper boxes, with mortar of the quality before described, and in the proportion of five parts of broken stone to one part of cement; to be laid immediately after mixing, and to be thoroughly compacted throughout the mass till the water flushes to the surface. The concrete shall be allowed to set for twelve hours, or more if so directed, before any work shall be laid upon it; and no walking over or working upon it shall be allowed while it is setting. When stone obtained from the excavation is of proper quality, it may be used for making concrete. Whenever ordered by the Engineer, the concrete shall be formed of broken stone not exceeding one inch at their greatest diameter, used in the proportion of three parts of broken stone to one part of cement; the mode of mixing, the quality of the materials, and the manner of using, to be the same as above described.

(38.) **Brick.**—The brick shall be of the best quality of hand-made hardburnt bricks; burnt hard entirely through, regular and uniform in shape and size, and of compact texture. To insure their good quality, the bricks furnished by the Contractor will be subject to inspection and rigorous tests, and if found of improper quality will be condemned; the character of the tests to be determined by the Engineer. They are to be culled on the surface, before laying, at the expense of the Contractor; the Engineer to be furnished with men for this purpose by and at the expense of the Contractor.

Face Brick.—Brick equal in shape and quality to Philadelphia front pressed brick shall be used to line the inside face walls of the gate-house superstructure.

That portion of said wall forming the wainscoting shall be laid in red mortar, and that portion of said wall above the wainscoting to be laid with buff-colored brick, with black bands, as shown on sheet No. .

(39.) **Brick Masonry.**—All brick masonry shall be laid with bricks and mortar of the quality before described. No "bats" shall be used; except that in the outside backing masonry a moderate proportion (to be determined by the Inspector) may be used; but nothing smaller than half bricks. The bricks must be thoroughly wet just before laying. Every brick must be completely imbedded in mortar under its bottom, on its sides, and on its ends, at one operation. Care shall be taken to have every joint full of mortar. Competent mechanics shall be employed for this work; and only the best skilled labor shall be employed for all face work.

(40.) For all brick masonry the bricks shall be laid to a line, with the beds in the line of the radii of the curves; and with as close joints (not exceeding ¼ inch for either face or arch work) as may be from time to time directed. All exposed faces shall be neatly pointed; after the centres have been withdrawn, shall have all the mortar projecting beyond the surface of the bricks scraped off, not more than fifteen days after the centres are drawn; and shall be pointed and left in a neat condition; all pointing to be done with neat cement.

(41.) All unfinished work must be racked back, or toothed, as may be directed by the Engineer in each case; and before new work is joined to its surface the bricks must be scraped thoroughly clean and scrubbed with a stiff brush, and well moistened.

STONE MASONRY.

(42.) Stone masonry will be classed under the following heads:

1st. Rubble-stone masonry.

2d. Cut paving.

3d. Cut facing stone masonry.

4th. Granite dimension stone masonry.

5th. Dimension stone masonry for exposed face of base of superstructure, having rock face.

6th. Broken ashler masonry for portion of superstructure.

(43.) All the stones used must be of good shape and quality, of compact texture and free from loose seams or other defects that will impair their strength or durability.

When laid they must be thoroughly cleaned.

(44.) All stone masonry shall be laid in hydraulic cement mortar, made (except when otherwise ordered by the Engineer) with one part of American cement and two parts of clean sand, as before described.

(45.) The stones must be well bedded in the mortar, and care must be taken to fill solid all the joints. No grouting of joints will be allowed.

(46.) Stone masonry is to be measured for payment according to the dimensions specified or ordered but in measuring dimension stone masonry, when the stones are not rectangular, the dimensions taken will be those of a rectangular cubical form which will just inclose the said stones. The prices herein stipulated, for any class of masonry, cover the building in and securing of pipes, steps, railings, and of all other iron work (except the gate machinery) which the Engineer may direct to be built in and secured.

(47.) **Rubble-stone Masonry.**—Rubble-stone masonry is to be made of stone of suitable size and shape for the particular work in hand.

Stones from the excavations may be used when of suitable shape, size and quality. The stones must have good beds; no spauling up under them will be allowed after they are laid.

(48.) **Paving.**—Cut paving will be laid for the floors of the gate chambers, and wherever else the Engineer may direct. The stones are to be rectangular in shape, of the full depth of the paving, and are to be laid in courses not less than 9 inches nor more than 18 inches wide, with joints of not more than half an inch in thickness. The paving, when laid, to present an even and smooth upper surface.

CUT FACING STONE, DIMENSION STONE, AND BROKEN ASHLER MASONRY.

(49.) **Joint Dressing.**—The beds, builds and joints of cut facing stone and dimension stone are to be dressed for the full depth of the stones to surfaces that will allow the stones to be laid with a joint not exceeding three eighths of an inch in thickness. The beds, builds and joints of the granite dimension stone used for trimmings, cornice, coping, &c., to be cut to a quarter-inch joint and to their full depth, also the broken ashler masonry.

No plug-holes or cavities more than six inches long or nearer than three inches to an arris will be allowed; and in any bed, build or joint, the aggregate area of the plug-holes or cavities must not exceed one quarter of the whole area.

(50.) **Headers.**—An adequate number of headers will be required in all masonry—about one in every 25 square feet of face area.

(51.) **Face Dressing.**—The exposed faces of the stones shall be either left with a rock or quarry face, rough pointed or fine hammered (6-cut work), as may be directed by the Engineer.

The various classes of face dressing must be equal in quality and appearance to those on the sample in the office of the Chief Engineer.

(52.) **Payment for Face Dressing.**—The cost of preparing the rock faces is included in the price per cubic yard stipulated for the particular class of masonry, clause , item .

For rough pointed and fine hammered (6-cut) dressing, a price per square foot of dressing will be paid in addition to the price per cubic yard of masonry, viz.:

For rough pointed dressing, the price stipulated in clause , item , and for fine hammered (6-cut) dressing, the price stipulated in clause , item .

(53.) **Rock-face Dressing.**—In rock face work the arrises of the stones inclosing the rock face must be pitched to true lines; the face projections to be bold and from 3 to 6 inches beyond the arrises. The angles of all walls on structures having rock faces are to be defined by a chisel draft not less than one and a half inches wide on each face.

(54.) **Rough-pointed Dressing.**—In rough pointed work the stones shall at all points be full to the true plane of the face, and at no point shall project beyond more than 1-4 inch, the arrises to be sharp and well defined.

(55.) **Fine Hammered (6-cut) Dressing.**—In fine hammered work the face of the stones must be brought to a true plane and fine dressed with a hammer having six blades to the inch; the arrises to be true to line, sharp and well defined.

(56.) **Joints and Pointing.**—Cut facing stones and granite dimension stone masonry for the chambers are to be laid with joints not exceeding 3-8 inch in thickness, and the face of the joints is to be pointed with pure Portland cement. This pointing must be done with the utmost care, in order to secure water tight-joints. The joints are to be raked out and cleaned to a depth of one and a half inches from the face, thoroughly moistened and then filled with pure cement well forced in and rubbed down to a surface even with the face surface of the masonry. Any defects found in the pointing before the work is accepted shall be immediately corrected.

(57.) **Cut Facing Stone Masonry.**—For cut facing stone masonry the stones must be rectangular in shape, except where connections and closures are to be made.

All cut facing stone masonry, except where otherwise shown or specified, is to be laid in rectangular courses not less than 15 inches nor more than 30 inches build, and with a face bond of not less than 12 inches lap.

Where this class of masonry joins with granite dimension stone masonry, the courses must correspond, and the joining with arches and other dimension stone masonry must be accurate and workmanlike. The stones to be not less than 3 feet long, with a bed equal to the height of the course; to be well bonded with the backing by numerous headers, projecting, at least, one foot into the backing, as shown on the plans, or as may be directed from time to time.

The face dressing of this class of masonry in the gate chambers will be generally rough pointed; a portion is to be fine hammer (6-cut).

The coping for the fence about the grounds will be classed as granite dimension stone masonry; all the exposed faces of this coping are to be rough pointed.

(58.) In estimating the quantities of cut facing stone masonry, for payment, the depth of the masonry from the face of the wall will in all cases be taken as 24 inches.

The tails of the headers will be estimated as of the class of masonry into which they project, and to which they must conform.

No payment shall be made for cutting grooves and recesses other than the price paid for the dressing of their surfaces, which are to be equal to fine hammered.

(59.) **Granite Dimension Stone Masonry.**—Granite dimension stone masonry shall be of first quality granite. The stones are to be cut to dimensions required by the detail plans to be given from time to time by the Engineer.

The faces of the stones to which the gates are to be fastened, the exposed faces of the gate openings,

drawings; the struts and heel shoes for the rafters are to be cast iron of the forms shown on the detail drawings, and the heel shoes are to be anchored to the masonry by one-inch wall bolts.

(106.) **The Purlins.**—The purlins to which the slates are fastened are to be two inches by two inches (2x2) angles, fastened to the rafters as shown on sheet No. .

(107.) **Slates.**—The slates to be of the best quality of black slate 3-16 inches thick, 12 inches by 20 inches, laid 9 inches to the weather, with at least 4 inches lap, except at the rafter, where the lap must be 6 inches. The slates are to be laid in mortice and fastened down to the purlins with copper nails, clinched to the under edge of the purlin.

(108.) **Flashings and Gutters.**—The flashings, gutters, hip covers, ventilators, &c., are to be made of the best quality 16-ounce sheet copper, well lapped, riveted and soldered; the gutters are to be properly fastened into the joint at the base of the coping, and formed, as shown on the drawing, and to run up under the slates about 12 inches and turned down over second purlin, requiring a width of about 32 inches; the gutter to be laid on a base of brick and mortar, and to have the proper grade necessary to cause the water to flow to the leaders, which will be built in the masonry as shown on sheet No. .

(109.) **Leaders.**—The leaders will be cast iron pipe; the pipe will be 4 inches, carried down through a recess built in the masonry and connected with the drains below, at points indicated on sheet No. , or as may be ordered during construction. The cast iron leaders will be paid for under clause , item .

(110.) **Ventilators and Skylights.**—If ventilators or skylights are ordered they will be furnished by the City, and they are to be put in the roof by the Contractor, at his expense, as directed by the Engineer.

(111.) **Ceiling to Roof.**—The under side of the roof is to be ceiled with 3 inch by 3-4 inch yellow pine, tongued, grooved and beaded boards, properly fastened to the nailing strips at every fourth purlin, and a 2 inch moulding will be placed against the rafters.

(112.) **Roof to Tower.**—The roof to the tower will be constructed of brick, arched upon I beams, about as shown on sheet No. .

(113.) **Decoration and Painting.**—The under side of roof, ceiling and iron work shall be painted as directed by the Chief Engineer, which painting is included in the price for such wood work, iron work, &c., under clause , items and .

The face brick work shall be arranged for decoration about as shown on sheet No. , and such arrangement is included in the price for face or front brick masonry under clause , item .

(114.) **Stairways.**—Spiral or other stairways will be built (of cast and wrought iron) in the gate vaults or chambers, also in the tower. They will be constructed in the usual way, out of cast and wrought iron, and will be paid for under clause , items and also any cast or wrought iron ladders required for the work and built in the masonry, will be paid for under the above items.

SPECIFICATIONS FOR DOORS, WINDOWS, SCREENS, ETC., 135TH STREET GATE-HOUSE.

The plans or drawings referred to in these specifications are five in number, entitled "The Aqueduct Commission Contract, Detail Drawing," etc., sheets , signed by the Chief Engineer and dated January 4th, 1889.

They show the character and details of the work to be done, and they must be generally followed unless otherwise ordered by the Engineer in writing.

Description of the Work.—The work to be done consists in furnishing all materials, the doing of all work or labor necessary to construct, paint, fit and put in place, in perfect working order, at the New Gate House, 135th Street and Convent Avenue, New York City, two single iron doors two double iron doors, two windows, 4 ft. 9 in. by 8 ft. 7½ in. opening; four windows, 4 ft. by 8 ft. 3 in. opening; five windows, 2 ft. 10 in. by 4 ft. 5 in. opening; two windows, 2 ft. by 7 ft. 3 in. opening; eight "Bulls-eye" windows, 2 ft. 6 in. opening, including netting and wrought-iron guards where required; also sixty-eight 5 ft. by 7 ft. 2 in. No. 10 brass wire screens ¼ inch mesh for gate chamber.

Iron Doors.—The single and double iron doors called for shall be constructed about as shown on the drawings (Sheets) of wrought and cast-iron. The casing to the doors and that of the transoms to be of cast-iron, bolted to the granite as shown, or as the Engineer may direct. The panel to the doors to be of cast iron and ornamented. The transom sash to be of first quality oak, glazed with heavy cathedral stained glass, the colors to be selected and arranged as the Engineer may direct.

The doors are to be hinged as shown on the drawing, and to be provided with heavy bronze bolts, also bronze lock, to be selected or approved by the Engineer.

A wire netting of No. 8 wire ¾ inch mesh shall also be fastened to the exterior face of the transom sashes.

Windows.—The windows are to be constructed about as shown on (Sheets) the drawings.

The frames and sashes to be of first quality oak. Lower portion of window to be glazed with the best quality double-thick German or French glass; the transom sash to be glazed with heavy cathedral stained glass, of selected colors and the arrangement to be approved by the Engineer.

A wire netting of No. 8 wire ¾ inch mesh, to cover the entire opening, also ¾ in. by 1 in. wrought-iron guards, to be provided and put in place as shown on Sheet .

Screens for Chambers.—The screens are 5 ft. by 7 ft. 2 in. over all; the frame shall be constructed of 3 in. by 4 in. first quality oak, put together as shown on Sheet , with brass screws. The wire cloth or screen to be of first class No. 10 brass wire, with a ¼ inch mesh or opening between the wire. The wire cloth to be fastened to the frames with brass screws, spaced about as shown on Sheet of the contract drawings.

Painting.—The materials for the doors, windows, netting, guards, and screens shall be painted with two or more coats of such paint as the Engineer shall direct. Great care shall be taken in painting, so as to prevent rust from forming, and discoloring the granite work of the building, a last coat to be applied to the work after it is in place.

Quality of Work.—All the above work shall be done in a first class and workmanlike manner and to the satisfaction of the Engineer. All materials to be of the first quality of their kind.

SPECIFICATIONS. PIPE-LINE (SECTION 16).

F. (1.) **Plans.**—The plans referred to in these specifications are fifteen in number, entitled "The Aqueduct Commission," etc., Nos. , signed by the Chief Engineer, and dated .

They show the location of the work, and its general character.

During the progress of the work, such working plans will be furnished from time to time by the Engineer, as he may deem necessary.

(2.) **Borings.**—Some test pits have been made to ascertain the nature of the ground where this section is to be built and the result of these tests has been shown on the plans; should the character and extent of the various materials be found to differ from what is indicated, the Contractor shall have no claim on that account, and it is expressly understood that the Corporation of the City of New York does not warrant the indications of the tests to be correct.

(3.) **General Description of the Work.**—All work, during its progress, and on its completion, must conform truly to the lines and levels to be given hereafter and determined by the Engineer, and must be built in accordance with the plans and directions which shall be given by him from time to time subject to such modifications and additions as said Engineer shall deem necessary during the prosecution of the work, and in no case will any work which may be performed, or any materials furnished in excess of the requirements of this contract or of the plans, or of the specifications, be estimated and paid for unless such excess shall have been ordered by the Engineer, as herein set forth.

The Contractor is to furnish all materials (except such as may be obtained from the excavations), and all tools, implements, machinery and labor (necessary or convenient for doing all the work herein contracted for, with safety to life and property in accordance with this contract, and within the time specified herein) required to construct and put in complete working order the section of Aqueduct herein specified, and is to perform and construct all the work covered by this agreement; the whole to be done in conformity with the plans and these specifications; and all parts to be done to the satisfaction of the said Aqueduct Commissioners.

The work to be done is the making, furnishing, delivering and laying of eight (8) lines of forty-eight (48") inch, pipe through Convent and Ninth Avenues from the end of the pipes projecting out of the Gate House (Section No. 15) at One Hundred and Thirty-fifth Street, to One Hundred and Twenty-fifth Street, seven (7) lines of forty-eight (48") inch pipe through Ninth Avenue from One Hundred and Twenty-fifth Street to Manhattan Street; six (6) lines of forty-eight (48") inch, pipe through Ninth Avenue and Morningside Avenue, south from Manhattan Street to One Hundred and Tenth Street, (9) lines of forty-eight (48") inch, pipe through New Avenue, One Hundred and Sixth Street and Eighth Avenue from One Hundred and Sixth Street to One Hundredth Street; and four (4) lines of forty-eight (48") inch pipe through Eighth Avenue to Ninety-seventh Street, and from Eighth Avenue through the Transverse Drive in Central Park to a point near a proposed Gate House located on the northerly side of the large reservoir in Central Park; and of all the pipes, branch pipes, special castings, stop cocks, hydrants, blowoffs, air cocks and all appurtenances connected therewith.

The building of a sewer from the stop cock chamber of the One Hundred and Twenty-fifth Street Gate House to Manhattan Street, and of all other necessary sewers, sewer pipes and drains with the necessary manholes, basins, vaults, culverts and all other appurtenances, also the taking down, refitting and relaying of sewers, sewer basins and drains where made necessary by the laying of the pipes.

The taking down and rebuilding of all walls and other masonry as required by the Engineer.

The taking up and relaying of all water mains and pipes and drains made necessary by the construction of the work. The excavating, filling, grading, trenching, laying of pipes for the sewers, and for the construction of all other structures, also all the embankments, filling and refilling connected with the same.

The furnishing of all materials and labor for taking up and relaying the streets, curbs, gutters, flagging, crosswalks, all in the places and of the dimensions and materials therein set forth in the specifications or shown on the plans. The taking up and replacing of any pipes or work that may be in the way of the laying of the pipes, the taking up and restoring of all work of any kind which may have been destroyed or inter-

fered with during the execution of the work; and the doing of all work necessary to complete Section 16 of the New Croton Aqueduct.

The Contractor must so conduct his work, with the approval of the Engineer, as to interfere as little as possible with the public traffic on the line of the work, and whenever his work requires the removal or alteration of structures and appliances in service, he is not to interfere with them except with the permission and under the direction of the Engineer, and the work of removal or alteration or reconstruction of structures and appliances now in service as culverts, sewers and water mains and service pipes, and the taking up and relaying of the same when necessary, shall be done under the direction and supervision and subject to the inspection and acceptance of the Chief Engineer and his Assistant Engineers of the Department of Public Works.

PIPES.

(4.) **Description of Pipe.**—The pipes shall be circular cylinders, with the inner and outer surfaces concentric, and of the full interior diameter required.

The hub or socket, the spigot end, the branches and all other castings, shall be shaped in exact conformity with the drawings which shall be furnished. The seat or shoulder of the socket and the end of the spigot must be straight and even, so as to make a smooth joint. No pipe will be received whose eccentricity at the spigot and socket ends, or either, exceeds one-eighth ($\frac{1}{8}$) of an inch.

Pipes will be designated by dimensions of the interior diameter.

(5.) **Gauges.**—The sockets and spigots will be tested by circular gauges.

(6.) **Dimensions.**—The straight pipes shall be twelve (12) feet long exclusive of the hub, all others as shall be directed.

(7.) **Straight Pipes.**—The pipes shall be straight in the direction of the axis of the cylinder, and the curves shall be true to the required curvature.

(8.) **Thickness.**—The thickness of the pipes, branches and special castings shall correspond with drawings to be furnished by the Engineer.

(9.) **Tested by Calipers.**—The thickness of the metal of the pipes and special castings will be tested by calipers after the castings have been freed from sand and cleaned. No pipe or casting will be received when the thickness of metal shall be found to be more than one-twelfth ($\frac{1}{12}$) of an inch less than the thickness required by the plans and specifications.

(10.) **Weight.**—The weight of the straight pipes shall be approximately as follows:

The 48-inch, pipes.....8,250 pounds each.
The 20-inch, pipes.....2,000 pounds each.
The 12-inch, pipes.....1,000 pounds each.
The 6-inch, pipes..... 430 pounds each.

(11.) **Variation in Weight.**—No pipe will be received which weighs less than the weight above mentioned by more than two and a half ($2\frac{1}{2}$) per cent of said weights, and no excess of weight in any one pipe of more than two and a half ($2\frac{1}{2}$) per cent above weight, as above estimated, will be paid for.

(12.) **To be Cast Vertically.**—All straight pipes shall be cast vertically with the hub end down.

(13.) All the castings shall be made in such moulding sand or loam as will leave the surface clean and smooth.

(14.) **Marks.**—All the castings shall have the year in which they were cast, the running number of the castings of the same size and form, the letters A. C. and the initials or name of the Contractors and of the foundry where cast, cast on the outer side, in raised letters of not less than two inches in length and one-eighth of an inch in relief, in such manner as the Engineers may designate; and in case any pipe shall be condemned, the letters A. C. shall be erased by the Contractor under the direction of the Engineer.

(15.) **Quality of Metal.**—The metal of which the castings are to be cast (which must be remelted in the cupola or air furnace) shall be pig iron, made without any admixture of cinder iron, or other inferior metal, and shall be of such character as to make a pipe strong, tough, and of an even grain, entirely free from uncombined carbon when examined under the microscope, and such as will bear drilling and cutting satisfactorily; and the iron in the pipes and castings shall have a tensile strength of at least sixteen thousand (16,000) pounds to the square inch.

(16.) The castings shall be free from scoria, sand holes, air bubbles, and all defects and imperfections, and no plugging or filling will be allowed.

(17.) The castings shall be perfectly cleaned, and no lumps shall be left on the inner surface in the barrels or sockets or on the outer surface of the spigot end.

(18.) **Hammer Inspection.**—All castings, after having been perfectly cleaned according to the specifications and the direction of the Engineer, will be subjected to a careful and thorough hammer inspection.

(19.) **Cleaned.**—Every casting shall be thoroughly dressed and made clean and free from earth, sand and dust which adheres to the iron in the moulds. Iron or steel wire brushes must be used, as well as softer brushes, to remove the loose dust, and no acid or other liquid shall be used in cleaning the castings.

(20.) **Coating.**—Every pipe, branch and special casting shall be carefully coated inside and out with coal pitch and oil, and must be entirely free from rust when the coating is applied. If the casting cannot be

dipped immediately after being cleansed, the surface must be oiled with linseed oil to preserve it until it is ready to be dipped; no casting to be dipped after rust has set in. The Contractor shall provide a covered tramway from the casting room to the dipping vat, so that no pipe shall be liable to become wet previous to its being coated.

(21.) The coal tar pitch to be made from coal tar, distilled until the naphtha is entirely removed and the material deodorized with a mixture of five or six (5 or 6) per cent of linseed oil. Pitch which becomes hard and brittle when cold will not answer for this use.

(22.) Pitch of the proper quality having been obtained, it must be carefully heated in a suitable vessel to a temperature of three hundred (300°) degrees Fahrenheit, and must be maintained at not less than this temperature during the time of dipping and bathing. The material will thicken and deteriorate after a number of pipes have been dipped; fresh pitch must therefore be frequently added and occasionally the vessel must be entirely emptied of its old contents and refilled with fresh pitch as often as the Inspector of the Aqueduct Commissioners shall require.

(23.) Every casting must attain a temperature of three hundred (300°) degrees Fahrenheit before being removed from the vessel of hot pitch. After having been in the bath for at least ten minutes, it may then be slowly removed, and laid on skids to drip. Any pipe or casting that is to be recoated shall first be thoroughly scraped and cleaned.

(24.) **Inspection before Dipping.**—No casting shall be dipped until the authorized Inspector has examined it as to cleaning and rust and subjected it thoroughly to the hammer proof. It may then be dipped, after which it will be passed to the hydraulic press to meet the required water proof. The proper coating must be tough and tenacious when cold on the castings, and not brittle or with any tendency to scale off.

(25.) **Proof Hydraulic Press.**—The castings must be capable of sustaining a pressure in the hydraulic press of two hundred (200) pounds to a square inch. After having been dipped and put in the bath, they shall be carefully drained of the surplus pitch, and when dry, subjected to the above-mentioned water pressure, and, if required by the authorized Inspector, they shall be subjected to a careful hammer test, under this pressure. Any pipe or casting showing any defect, by leaking, sweating or otherwise, will be rejected. This proof will be made at the foundry, and at the expense of the Contractor.

(26.) **Tools, etc.**—All tools, machinery, materials and men necessary for the proper testing and inspection of pipes shall be furnished by and at the expense of the Contractor.

(27.) **Weight to be Marked.**—The pipes and castings will be weighed after the application of the coal pitch coating, and also if desired by the Engineer after delivery; the weights must be distinctly marked on the pipes and castings in white paint. The Contractor shall provide proper sealed scales and weights for weighing the castings; which will be done at the expense of the Contractor, under the supervision of the authorized Inspectors.

(28.) **Specimen Rods.**—Specimen rods of the metal used, of a size and form suitable for a testing machine shall be prepared for the Engineer when required. These specimen rods shall be poured from the ladle at any time, either before or after the pipe has been poured as may be required, and shall present a true sample of the iron used for making the pipes. These specimens shall be prepared at the cost of the Contractor.

(29.) **Pipes and Castings to be Moved for Inspection.**—The Contractor shall move the pipes and castings, and place them in such position, either at the foundry or after their delivery, as shall be required for the convenience of inspection.

(30.) **Power of Engineer.**—The Engineer shall be at liberty at all times to inspect the material in the foundry or elsewhere, and the moulding, casting and coating thereof, and he may condemn any of the material or processes used in any state of the preparation or manufacture of the pipes and other castings; he may reject without proving any casting which is not in conformity with the specifications or with the drawings.

(31.) The Contractor shall notify in writing the Chief Engineer at least ten days previously to the beginning of the manufacture of the pipes or other castings of the time and place where the manufacture is to commence, in order that an authorized Inspector may be present to inspect it.

(32.) **Pipes and Castings to be Delivered Sound and Perfect.**—All the pipes and other castings contracted for must be delivered in all respects sound and conformable to the contract. The inspection will not relieve the Contractor of any of his obligations in this respect; and any defective pipe or other castings, which may have passed the inspection at the foundry or elsewhere, will be at all times liable to rejection when discovered until the final adjustment and completion of the contract.

(33.) **Delivery.**—The pipes and other castings, when satisfactory to the Engineer, are to be considered as "delivered" to the party of the first part whenever they have been deposited on the line of the work, in such places as shall be approved by the Chief Engineer. The delivery of the pipes and other castings upon the public streets may be stopped by the Engineer if he is of opinion that they interfere unnecessarily with the public traffic thereon, and he may designate other points of delivery.

(34.) **Special Castings.**—All castings other than straight 48-inch pipe and under shall be denomi-

nated special castings, such as branches, blow-offs, curved pipes, basin heads, boxes, manhole heads and covers, floor plates, posts, beams, braces, steps, and any other castings ordered. Cast-iron shall be built in the masonry by the Contractor, and at the Contractor's expense, whenever ordered by the Engineer.

WROUGHT-IRON WORK.

(35.) Under this head are included all bolts and nuts, washers, sheet and bar iron, all rolled beams, together with all other wrought-iron that may be ordered for permanent use.

(36.) **Quality and Strength.**—All rolled beams, bars, plates, bolts, etc., must be straight and out of wind, free from flaws and other defects.

All wrought-iron must be tough, highly fibrous, and uniform in texture. In its manufacture no old scrap-iron is to be used. Test pieces selected at random by the Engineer or Inspector from any iron designated to be used for this work must show a minimum ultimate tensile strength of 50,000 pounds per square inch of original sectional area before fracture, and an elastic limit of not less than 25,000 pounds per square inch of same sectional area with an elongation before fracture of not less than 15 per centum, measured on a tested length of eight inches; with a reduction of area at the point of fracture of over 20 to 25 per centum. All nuts and bolts to have good, sound and well-fitted threads. If so ordered by the Engineer, the bolts shall be turned.

The price herein stipulated in clause —, item —, for wrought-iron covers the furnishing, finishing, fitting, placing and painting of the same, all in complete working order.

(37.) **Painting.**—The iron work shall be painted in the manner that may be directed by the Engineer.

STOP COCKS, ETC.

(38.) **Stop Cocks, Hydrants, Blow-offs, Branches, Etc.**—The sizes named for the stop cocks apply to the inside diameter of the water-way thereof.

The 48-inch stop cocks and the gearing are to be made according to the detail plans in the office of the Chief Engineer.

The flanges are to be bored as directed by the Engineer and according to templets approved by him.

For a general contract drawing of the 48-inch stop cock, see Sheet No.

The 12-inch and 6-inch stop cocks are shown in a general way on contract drawing sheets Nos. and . All stop cocks are to have outside screws. The hydrants are to have a cast-iron case and are to be furnished with Johnson's waste valve, and are to correspond and conform to the sample at the pipe yard of the Department of Public Works, Twenty-fourth Street, East River. All cast-iron work in stop cocks and hydrants shall be of strong, tough iron, free from all imperfections and thoroughly cleaned inside and outside, and painted with one coat of red lead.

All composition work shall be made of a metal composed of six parts copper and one part tin and one-half zinc, unless otherwise directed. All wrought-iron work shall be made of best quality American refined iron.

All workmanship to be of the best, and the fitting to be perfect.

All lead to be soft refined lead.

(39.) **Blow-offs.**—Blow-off manholes shall be placed at the several low points on the line, and will consist of a piece of 48-inch pipe with a cap on the bottom (see Sheet No. —), into which the connecting pipes from the 48-inch pipe will discharge, and from which will be taken a pipe or masonry outlet, and connected with the sewer. Blow-offs are classed as special castings.

(40.) **Branches, Etc.**—Branches, curved pipe and other special castings shall be laid and set where directed by the Engineer, and will be estimated and paid for according to the number of feet they lay, except that branches will be estimated in addition from the centre of main pipe out.

Connection shall be made with pipes projecting out from the One Hundred and Thrity-fifth Street gate house, also with those near the proposed gate house at Central Park Reservoir; branches, curves and stop cocks are to be laid in One Hundred and Twenty-fifth Street, Manhattan Street, One Hundred and Tenth Street, Eighth Avenue and the Transverse Road and elsewhere, wherever directed by the Engineer.

EARTH AND ROCK EXCAVATION, EMBANKMENTS, ETC.

(41.) **Earth Excavation.**—Under the head of earth excavation will be included all excavation of earth, loose rock and other material which may be necessary for the pipes, chambers, sewers, basins, piers, culverts, and all other work of excavation connected with the work, except excavation of solid rock in place. Any masonry ordered to be removed shall be classified as earth excavation.

(42.) **Rock Excavation.**—Under the head of rock excavation will only be included the excavation of solid rock which may be necessary for the work under these specifications. All boulders measuring less than one-half a cubic yard in volume shall be classed as earth excavation.

(43.) **Disposition of Materials.**—The material excavated from the trench and other excavations shall be placed in such a position as not to impede the travel on the railroads or unnecessarily impede the general travel of the streets and avenues through which the trenches are to be excavated, leaving one side of the trench entirely clear, unless otherwise permitted, so as to facilitate the rolling of the pipes over or in the same, and the laying of the pipes.

(44.) All materials excavated from the trenches, if not used in the work, shall be carted away from the work and disposed of by the Contractor, at his cost and expense.

(45.) **Pipe, and Other Trenches, and Pits.**—The excavations for the pipe trenches shall be two feet wider than the inside diameter of the exterior pipes, and to such depth as the Engineer shall direct. The excavation for the gate chamber piers, culverts, sewers, basins, blow-offs, etc., shall be of such size and depth as the Engineer shall direct. Allowances will be made for slopes in earth or rock excavation where slopes are deemed necessary by the Engineer. All excavations are to be so conducted, as not to interfere unnecessarily with the public traffic.

(46.) If, during the progress of any excavation on the line of this contract, water shall be encountered, it shall be the duty of the Contractor, at his own cost and expense, to provide such machinery, pumps, labor, timber and other materials as shall be necessary to maintain such excavation and to keep it free from water.

(47.) **Sheet Plank to be Removed.**—All the sheet plank and timber used during the progress of the work to support the sides of the trenches shall be removed as the filling proceeds, except where otherwise ordered by the Engineer.

(48.) **Refilling and Embankments.**—Under the head of refilling and embankments is to be included all filling of trenches and other excavations, all grading, and the making of all embankments necessary under and over the pipes, or wherever ordered by the Engineer; the materials for refilling and embankments shall be of a quality satisfactory to him; and if the material from the cuts along the line are not sufficient, other materials must be furnished by the Contractor at his own expense.

In the filling and refilling of trenches and other excavations, and in the making of embankments, the materials must be put in horizontal layers not exceeding six inches in thickness, thoroughly compacted by carts, wagons, heavy grooved rollers or rammers, and they must be amply watered as may be ordered, and must be free from stones.

(49.) Should it be decided to construct any embankments or parts of embankments, or do any refilling with loose rock from the excavation or from the present embankments, such materials shall be deposited in such layers and compacted by such means as the Engineer shall direct; it shall be paid for as "refilling and embankments," and measured according to the lines given by the Engineer.

(50.) The trenches after being filled must be allowed to settle as long a time as the Engineer shall direct before the pavement and flagging are relaid.

(51.) **Clearing up.**—After the pipes have been laid, the trenches filled, the embankments made and the roadways put in order, the refuse and surplus materials which may have been left shall be removed from the line of the work and disposed of by the Contractor at his cost and expense.

(52.) All blasting shall be conducted in conformity with the ordinances of the Corporation of the City of New York directing the manner of blasting and the precautions to be taken therein.

Where a line of the present water pipes intersects the line of trench, the rock necessary to be excavated for a width of five feet in the clear on each side and under such pipe or main shall be in all cases removed without blasting, and the pipes or mains shall in all cases be protected, at the expense of the Contractor, from any injury from blasting in the vicinity, the cost of the same to be included in the price of rock excavation.

In case the trench shall run parallel with, across or near enough to a water main or gas pipe, or water or gas service pipe, to endanger its safety, it shall be protected, as the Engineer may direct, by the Contractor, and at his cost and expense, during the whole of the time the trench may be open and unpaved.

(53.) **Sodding and Soiling.**—Wherever it is deemed necessary, in Central Park or at any other point, to protect the embankment over the pipes, the top and slopes of same shall be sodded.

The whole surface of the ground to be sodded is to be levelled off, all gullies filled up, and covered with good loam to an average depth of four inches above the present surface, so as to make a true and even bearing for the sods to rest on.

The sods to be of good quality of earth covered with heavy grass, sound and healthy, and not less than one foot square, and generally of a uniform thickness of three inches (which sizes may be altered by the Engineer during the progress of the work); to be cut with a bevel on all sides, so that when laid they will lap at the edges; to be properly set, so as to have a full bearing on their whole lower surface; to be padded down firm with a spade or wooden bat made suitable for the purpose; each sod is to be pinned with one wooden pin in each sod, not less than fifteen inches long, so as to be secured to the ground beneath it. No lean, poor or broken sods will be allowed in the work, but on the outside edges of the bank

sods may be cut to such size and shape as will make a proper finish to the same. The sodding that shall have been laid shall be well and carefully sprinkled with water as often as the Engineer shall deem necessary for the benefit of the work during its progress.

All soil wherever ordered shall be removed, stored and replaced on the finished work; one price only (clause —, item —) will be paid for the removal, storing and replacing of the soil, and it will be measured in spoil bank.

LAYING PIPE, ETC.

(54.) All the places where the pipes are to be laid are to be prepared with great care.

(55.) **Piers.**—Where necessary, concrete foundations and rubble-stone masonry piers shall be built under the pipes as the Engineer shall direct.

(56.) **Timbers.**—Where the ground is filled in, and on soft embankments, good sound hemlock timbers twelve inches square and at least twenty-four feet long shall be laid lengthwise of the pipe and under the same, and then filled in with broken stone; on top of these timbers crosswise timbers of good sound hemlock, six inches by twelve inches, shall be placed, on which the pipe is to be laid and levelled up by means of hemlock wedges. The number of lengthwise timbers and length of cross timbers shall be as the Engineer shall direct.

The 12 inches by 12 inches hemlock timbers, and all blocks and wedges ordered under pipe and all sheet piling ordered to be left in place, shall be paid for as hemlock timber put in the work. Between the hemlock timbering the filling must be done with broken stone placed by hand and compacted with rammers. Said filling to be paid for at the price herein stipulated for rubble-stone masonry laid dry.

(57.) **Lowering Pipe.**—After the trenches shall have been excavated or the embankment built up to the required grade the pipes shall be rolled in or over the trenches or on the embankment on skids, and then by means of a derrick and rigging shall be carefully raised off the skids and placed in their proper positions. The Contractor is expressly prohibited from laying any pipe branches or special castings, or laying any masonry except under the direct supervision of an authorized Inspector.

(58.) **Blocks and Wedges.**—Each pipe over six inches inside diameter shall be placed on two blocks and four wedges of hemlock timber, the wedges to rest on the blocks and the pipes on the wedges. The blocks and wedges shall be of sound hemlock timber. Forty-eight-inch pipe shall be laid on blocks four feet long, twelve inches wide and six inches thick, with wedges eighteen inches long, six inches wide, four inches thick on one end, and one-half inch thick on the other. Twenty-inch and twelve-inch pipes shall be laid on blocks two feet long, eight inches wide and four inches thick, with wedges twelve inches long, four inches wide, three inches thick on one end and one-half inch thick on the other.

(59.) **Joints.**—The joints of the forty-eight inch pipe shall be made four inches in depth with lead; all others three inches.

(60.) **Joints.**—The spigot end of the pipes shall be inserted into the hub within from one-fourth to one-eighth of an inch of the full depth of the hub, and the space around the pipe shall be equalized so as to give as nearly as possible an equal space for the packing. The space between the pipe and the hub shall be packed with clean, sound hemp packing yarn, free from tar, far enough to leave the proper space for lead. The remaining space shall then be filled by running it full of lead at one operation, with a bead outside the face of the hub large enough to allow for caulking, so that when the joint is properly caulked the bead will be flush with the hub of the pipe; after the joint shall have been run with lead it shall be caulked by means of proper tools so as to make a water-tight joint.

(61.) **Lead.**—The lead to be used shall be of the best quality of pure, soft lead, and in every respect suitable for the purpose.

(62.) **Cutting Pipe.**—Whenever any pipe requires cutting, the same shall be done by the Contractors without extra charge.

(63.) **Price for Laying.**—The price herein stipulated for laying cast-iron pipes includes the placing of the same in the trench, the placing of the blocks and wedges, the making of the joints, furnishing the lead and all other materials necessary for the same, and putting the pipes in complete working order.

(64.) **Taking up and Relaying Water Mains.**—When it becomes necessary to take up any of the water mains now laid in the streets and avenues to be excavated for this work, they shall be taken up and relaid as hereinbefore directed in clause F, section 3, and the price to be allowed to the Contractor for the said taking up and relaying of such pipes shall be the same as herein stipulated for laying new pipe of the same size.

SPECIFICATIONS FOR 48-INCH STOP COCKS AND GEARING.

F. (1.) **Plan.**—The plan referred to in these specifications is hereto attached and forms part of these specifications, entitled, "The Aqueduct Commission, 48-inch Stop-Cock Valves, Sheet No. —,"* and signed by the Chief Engineer, and dated January 3, 1888.

It shows the work, and its general character.

During the progress of the work such working plans will be furnished from time to time by the Engineer as he may deem necessary.

(2.) **Work to be Done.**—The work to be done consists of furnishing, manufacturing, fitting, facing, painting, shipping, delivering and placing ten (10) forty-eight-inch stop-cock valves and gearing at the Gate House at 135th Street and Convent Avenue, Section No. 15, and four (4) forty-eight-inch stop-cock valves and gearing at the blow-off at shaft No. 25, Section No. 12, and one (1) forty-eight-inch stop-cock valve and gearing at the new Croton Gate House, Section No. 1, in their several places or compartments, properly bolted, braced and secured, and in complete working order.

(3.) The stop-cock valves are to be delivered, put in place, the adjoining pipe connected by lead joints, properly made and the fringes bolted. They are to be properly fastened and braced to the adjoining walls, and put in complete working order, acceptable to the Chief Engineer.

(4.) **Size.**—The size of the stop cock named is to be the inside diameter of the water-way thereof.

(5.) **Sample Showing Quality of Workmanship and Materials.**—In addition to the drawings a sample stop-cock valve may be seen by application to the Chief Engineer, and all the valves must be equal to it in the quality of workmanship and the materials used.

(6.) **Quality of Materials.**—All cast-iron in the stop-cock valves shall be of strong, tough iron, free from all impurities and imperfections, and thoroughly cleaned inside and outside and painted with two coats of red lead and linseed oil, or as the Chief Engineer may direct. All composition work shall be made of a metal composed of six parts copper, one part tin and one-half part zinc, or as the Chief Engineer may direct. All wrought-iron work shall be made of the best quality American refined iron. All lead shall be soft refined lead, or as the Chief Engineer may direct.

(7.) **Engineer to Explain Specifications.**—The plans and specifications are intended to be explanatory of each other, but should any discrepancy appear, or any misunderstanding arise as to the import of anything contained in either, the explanation of the Engineer shall be final and binding on the Contractor; and all directions and explanations required, alluded to, or necessary to complete any of the provisions of these specifications, and give them due effect, will be given by the Engineer.

(8.) **Force to be Employed.**—The work shall be commenced and carried on in such order and at such times and with such force as may from time to time be directed by the Engineer.

SPECIFICATIONS FOR 2′ × 5′ SLUICE GATES.

(1.) **Plans or Drawings.**—The plans or drawings referred to in these specifications are six (6) in number, entitled "The Aqueduct Commission, Contract Drawings, for twenty-two 2′ × 5′ Sluice Gates for the 135th Street and Central Park Gate Houses," Sheets Nos. —,† signed by the Chief Engineer, and dated April 10, 1889.

They show the character and details of the work to be done.

From time to time during the progress of the work, such other working drawings as may be found necessary will be furnished by the Engineer.

All work shall be made in accordance with the drawings, and the directions given from time to time by the Engineer, as the work progresses.

(2.) **Dimensions to be Verified.**—The Contractor must verify to his own satisfaction the correctness of all dimensions given on the drawings, as well as the dimensions of the sluiceways or openings through the walls of the gate chambers.

(3.) **Quality of Materials and Workmanship.**—All the materials and workmanship for the work herein specified must be of the first quality of their kind.

(4.) **Inspection.**—The quality of the materials, the process of manufacture, and the workmanship will at all times be subject to examination or inspection by the Engineer or his Inspector; and shall be subject to rejection, by order of the Engineer, if, in his opinion, it be not of the quality called for. The Contractor, at his own expense, shall furnish the Engineer or Inspector with men, and every facility for moving or handling the various parts of the work, as may be required for convenience of proper inspection.

(5.) **Tests.**—Such tests as the Engineer may require shall be made at the Contractor's expense, and test pieces of all metals used must be furnished to the Engineer on his requisition, of the size and form that he may order.

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* See Plate 90. † See Plates 94 and 95.

(6). **Nuts and Bolts.**—All nuts and bolts to have good, sound and well-fitted threads. If so ordered by the Engineer, the bolts shall be turned.

(7.) **Composition Metal.**—The composition metal shall be formed of six parts copper, one part tin and one-half part zinc, or as the Engineer may order.

(8.) **Bronze or Brass.**—The bronze or brass used must be equal in quality to "quality B metal" made by the Phosphor Bronze Smelting Co. (Limited), of Philadelphia, Pa., or No. 2 metal aluminum brass made by the "Cowles Electric Smelting Aluminum Co.," of Lockport, N. Y., and show, by test pieces from the metal used for this work, a tensile strength of at least 40,000 pounds per square inch sectional area, and free from all flaws, blow-holes, or other imperfections, not only in the test bars but also in the castings when faced or turned down.

(9.) **Rejection.**—The approval by the Engineer or Inspector of any work shall not prevent its rejection for any defect discovered at any time before the final acceptance thereof, or final payment therefor, on the completion of the contract.

(10.) **Painting.**—All the work, except facings or bearing surfaces, shall be painted thoroughly (before rust sets in) with at least three coats of such paint or coating as the Engineer may direct; the third coat to be applied after the work is in place.

(11.) **Sluiceways or Openings.**—The sluiceways or openings through the granite masonry walls of the chambers are approximately 2′ 9″ × 5′ 3″, but the Contractor is to take his own measurements to make his patterns correspond to the actual size of the openings. The faces of these walls about the openings have been "six-cut hammer" faced, also the arrises to the openings have been chamfered off one inch, to receive the frame and give it a perfect bearing; but, wherever the faces are not true, the Contractor shall make them true by such re-cutting as is necessary before the frame is put in place, the cost of such re-cutting to be included in the price bid for each gate.

(12.) At points above the gateways, where stem guides are to be fastened, the face of the wall is to be dressed down to receive such stem guides, which must be so adjusted in size, in each case, as to fit the stone work on which they are to be placed; the cost of such cutting or dressing and adjustment to be included in the price bid for each gate.

(13.) **Gate Frame.**—The gate frame is to be cast-iron, cast in one piece, of the form and dimensions as shown on the drawings.

(14.) **Facing to Frame.**—The seat on the frame for the valve or movable part of the gate, shall be faced with composition metal, the strips to be 1¾″ wide, hammered into a dovetail groove, which is to be planed into the face of the frame, and shall be made to fill said groove perfectly, so as to secure the facing firmly, and prevent any moisture from working in between the two metals.

The strips extend around the opening formed by the frame and also to the top edge of frame (as shown on the drawings). In addition to the dovetail fastening, the strips will be screwed down fast to the cast-iron with composition metal "safe screws" three-eighths inch (⅜″) diameter, the heads then cut down so as to leave no slot in top of screw. This done, the entire surface of the facing strips shall be accurately planed and scraped down to give a true and perfect surface upon which the gate valve is to move.

(15.) **Facing on Valve.**—The facing strips for the valve are to be made of composition metal, put in and fastened, and planed or scraped in the same manner as its seat on the frame.

(16.) **Surfaces Planed for Guides.**—The frame is to be planed true on its face to receive the guides, and the chipping strips which fit against the masonry are also to be planed, as shown on the drawings.

(17.) **Guides.**—The guides on either side of the valve or gate are to be of cast-iron, planed on their seats, where fastened to the frame. The groove which is to receive the edge of the valve shall also be planed, if necessary to make it straight, but will be preferred without planing if it can be made perfectly straight, without breaking the skin of the casting.

(18.) **Wedges and Guides.**—Wedges are to be of brass or bronze, perfectly fitted and fastened to the guides by dovetailing, and also screwed fast by five-eighth (⅝″) inch composition screws.

(19.) **Gate or Valve—Wedges or Inclines.**—The gate or valve is to be of cast-iron, with composition facing strips, secured to the iron as heretofore described. The gate is to have on the back one fixed wedge at the bottom and three adjustable wedges on either side, made of brass or bronze, and fastened by bolts and adjusting screws, as shown on the drawings; these wedges correspond in position with the wedges on the guides. They are to be perfectly fitted and adjusted to each other, until the gate is water-tight.

(20.) **Stem Connection with Gate Valve.**—A hub with bored socket 2¾″ diameter is formed on the back of the gate valve, to receive the gate stem, which is secured by two cast steel cotters.

(21.) **Fitting the Valve to Frame.**—The face of the frame and that of the valve or gate, after having been faced as described above, shall be carefully fitted together by planing and scraping, and made to fit perfectly tight, so that water will not leak through when the gate is closed.

(22.) **Setting and Securing the Frame to the Masonry.**—The holes to receive the anchor

bolts (which secure and fasten the frame to the masonry) shall be carefully drilled to templet, and the bolts set to templet and fastened in the masonry with melted sulphur or brimstone, so as to be strictly perpendicular to the face of the wall or frame.

(23.) **Stone Cutting or Dressing.**—The Contractor shall, if necessary, dress down the face of the stone so as to make an even bearing for the frame, also cut any recesses required to receive the frame, and do all stone cutting required to place the gate and appurtenances in complete working order. The cost of drilling of holes and of all stone cutting in connection with the placing of the gates, lifting machinery, and their appurtenances, is included in the price bid for each gate.

(24.) The above having been done, the frame shall then be placed in position against the masonry, the caulking strip of lead inserted in the "lead sets" (which are to be cast or planed on the edges of the frame, as shown on the drawing), leaving it projecting out sufficiently for caulking; then, the frame being held firmly in its place, the nuts to the anchor bolts are to be screwed on lightly so as to bring the frame to a bearing without (by reason of any unevenness in the casting or masonry) springing or warping it. The nuts must be screwed down before the sulphur around the anchor bolts has thoroughly hardened and the filling is done.

(25.) **Filling Space Behind the Frame.**—The frame having been set in place and the nuts to the anchor bolts screwed slightly down on the frame, the space between the frame and masonry (as shown on the drawings) shall then be filled with melted brimstone or sulphur, Portland cement or any other material approved of by the Engineer. This should be done beginning at the bottom and pouring through the spaces around the bolt-holes and working upwards, completely filling the space behind the frame.

(26.) Should the Contractor wish to set the frame in some other way, he shall first get the approval of the Engineer.

(27.) The space filled, the nuts to the anchor bolts will then be screwed "home," or as tightly as is possible, and then the frame thoroughly caulked around the edges.

(28.) **Guides Put in Place.**—The stud bolts to fasten the guides to the frame (after the above is properly set) may then be screwed in and the guides for the gate bolted on; great care being taken to have a continuous surface from the composition facing on the frame to the faced surface on the guide at the top of frame. The space behind the upper portion of the guides is also to be filled as is done in setting the frame, first fastening the anchor bolts, etc.

(29.) **Gates Seated and Wedges to be Adjusted.**—The bottom wedge is to be set and bolted fast; each gate is to be then adjusted by means of the movable wedges until after repeated trials (under water pressure) the gate is found to be water-tight and satisfactory; the movable wedges are then to be bolted down tight to prevent them from moving.

(30.) The third coat of paint can now be applied to this portion of the work, the above having been properly done.

(31.) **Gate Stems.**—The stem to the gate valve is formed by coupling the lengths of the two and three-quarter inch diameter cold rolled steel together. The ends of stems to be slotted to receive the cast-steel cotters which fasten them to the wrought-iron couplings, to the gate valve, and to the screw section, at upper end of the stem. Stems not to be less than two and three-quarter inches diameter at any point.

(32.) The workmanship on the stem and its coupling connections must be perfectly done, so that when placed in position it will form a true alignment.

(33.) **Couplings.**—The couplings are to be wrought-iron, sleeve connections, with cotters of cast-steel, all to be of the dimensions shown on the plans.

(34.) **Screw End of Stem.**—The screw at the upper end of the stem is to be of the best quality machinery steel, with turned thread three inches diameter, one-half inch pitch.

(35.) The lower end of screw to be turned down to two and three-quarter inches diameter, to fit and fasten to the coupling on the section of stem below, as shown on the drawings.

(36.) **Guides to Stem.**—The guides for the stem are to be of cast-iron, with a composition collar or bushing through which the stem passes (as shown on the drawings). These guides are to be fitted and adjusted in proper position (so that when the stem is perfectly plumb it will not touch or bear upon the bushing), and secured to the face of the masonry walls by four one-inch (4—1″) anchor bolts, sulphured in place.

(37.) **The Pedestal or Stand.**—The pedestal or stand for supporting the gearing is to be of cast-iron. Its base is to be eighteen (18″) inches square, bolted to bed-plate (provided by the City) after the gate stem has been properly centred, with four one and a half inch (4—1½″) tap bolts. These bolts and the drilling required to fasten the stand to the bed-plates to be furnished and the work done under this contract.

The pedestal is to be cast in one piece, the base is to be faced so as to make a perfect bearing when bolted to the bed-plate.

(38.) **Gearing.—The Nut.**—The nut for the gate stem screw to work in is to be of bronze or

brass, equal to "quality B metal," made by The Phosphor Bronze Smelting Co. (Limited), Philadelphia, Pa., or "No. 2 metal" aluminum brass, made by the Cowles Electric Smelting and Aluminum Co., of Lockport, N. Y., carefully threaded so as to run freely over the entire length of the gate stem screw; the collars to be accurately turned, so as to form a perfect bearing on the seat within the pedestal.

(39.) **Nut.**—The nut shall be carefully faced and fitted to the hand wheel and capstan head, as shown on the drawings.

(40.) **Bearing for Nut.**—The bearing to the nut is to be of bronze or brass (as above) and closely fitted to nut, with even bearing on collar, and held in place as shown on the drawings.

(41.) **Testing the Gates under Water Pressure.**—The gates shall be tested under a head of water about equal to the head under which they are expected to work when in service. At the 135th Street Gate House this head will be obtained by placing "stop-planks" in the grooves cut in the stone, and the water necessary will be obtained from the "high-service" hydrant on Tenth Avenue and 136th Street.

(42.) At the Central Park Gate House "stop-planks" will be placed in like grooves, and the water necessary will be obtained by pumping from the Reservoir.

(43.) Each gate, if not found water-tight, is to be made so and tried until satisfactory to the Engineer.

The handling of the water is to take place under the immediate direction of the Engineer, and the Contractor shall not be entitled to any compensation on account of delays that may result from filling or from freeing the chambers of water, and from other operations connected with the said handling of the water.

(44.) The testing shall be thorough and complete, and to the satisfaction of the Engineer; all expense connected therewith, all labor, materials, "stop-planks" and other appliances required for the handling, obtaining or disposing of the water used for such tests shall be included in the price bid for items — and — respectively.

The water to be furnished by the City.

SPECIFICATIONS FOR EARTH AND MASONRY DAM.

F. (1.) **Plans.**—The plans referred to in these specifications are fourteen (14) in number, entitled "The Aqueduct Commission, Contract Drawings, Dam and appurtenances for Reservoir M, on Titicus River, etc., etc., Nos. —" and signed by the Chief Engineer, and dated —.

They show the location of the work, and its general character. During the progress of the work such working plans will be furnished from time to time by the Engineer as he may deem necessary.

(2.) **Test-pits and Borings.**—Test-pits and borings have been made to ascertain the nature of the ground where the work is to built; should the character and extent of the various materials be found to differ from what is indicated by the test-pits and borings, the Contractor shall have no claim on that account, and it is expressly understood that the Corporation of the City of New York does not warrant the indications of the tests to be correct.

(3.) **General Description of the Work.**—The Dam is to be erected on Titicus River, at the place indicated on the plans, and is to be built partly of masonry, partly of earth, approximately, on the lines shown on Sheet No. —; if the character of the materials and other local circumstances render it advisable, the location may be modified by the Engineer. The central part, where it is the deepest, is to be of masonry only, with a Gate House and overflow; on each side of the central part the Dam is to be formed of a heavy earth embankment, with a central wall of rubble-stone masonry. The overflow is to be 200 feet in width. The various parts are separated by wing walls or other contrivances. The water side and other sides of the earth slopes that may be designated are to be protected by broken stones and paving; other slopes to be covered with soil and by sodding.

The work to be done consists in constructing the Dam and foundations, Gate House, overflow, fountain and other appurtenances; in doing all earth, rock and timber work; in constructing all masonry; in building in or in connection with said masonry all iron, timber and other work required or ordered to be built; in laying pipes, gates and other iron work; in building a temporary dam or dams, if required; in performing all other work needed for taking care of the water that may interfere with the operations of construction; and in doing all the work necessary to construct the said Dam, overflow, Gate House, fountain and other appurtenances, complete, in accordance with the plans and specifications.

All work, during its progress, and on its completion, must conform truly to the lines and levels to be given hereafter and determined by the Engineer, and must be built in accordance with the plans and directions which shall be given by him from time to time, subject to such modifications and additions as said Engineer shall deem necessary during the prosecution of the work, and in no case will any work which may be performed, or any materials furnished in excess of the requirements of this contract or of

the plans, or of the specifications, be estimated and paid for unless such excess shall have been ordered by the Engineer, as herein set forth.

The Contractor is to furnish all materials (except such as may be obtained from the excavations), and all tools, implements, machinery and labor (necessary or convenient for doing all the work herein contracted for, with safety to life and property in accordance with this contract, and within the time specified herein) required to construct and put in complete working order the work herein specified, and is to perform and construct all the work covered by this agreement; the whole to be done in conformity with the plans and these specifications; and all parts to be done to the satisfaction of the said Aqueduct Commissioners.

(4.) **Soil.**—The soil is to be removed from the grounds where the Dam, embankments and other works are to stand and the excavation to take place, and wherever directed by the Engineer; said soil is to be hauled and put in spoil banks, to remain until required to be placed over the finished surface of slopes or embankments. The quantities of soil removed will be measured in the spoil banks and paid for as stipulated in clause —, item —.

The slopes of the embankments are to be covered with soil taken from the spoil banks; if any additional soil is needed for the work, it shall be obtained and taken from such grounds as may be designated by the Engineer, and deposited wherever ordered by him; all soil removed from the spoil banks, or from such grounds as the Engineer may designate, shall be measured in embankment after being rolled or otherwise compacted, and paid for as stipulated in clause —, item—.

All surfaces which are required to be afterwards sodded or seeded are to be covered with soil at least six inches in thickness.

(5.) **Sodding.**—The embankments of the Dam and such other surfaces as may be designated by the Engineer, are to be sodded or seeded with grass seed.

All the surfaces to be sodded are to be carefully graded, so as to make a true and even bearing for the sods to rest on.

The sods to be of good quality of earth, etc. (as on page 261).

(6.) If any surface is ordered to be seeded down, it shall be so done with such kind and quality of seed and in such a manner (including rolling and watering) as the Engineer shall direct, at the expense of the contractor.

EARTH EXCAVATION AND EMBANKMENT.

(7.) Earth excavation is to be made for the foundation of the Dam and of its centre wall, for the overflow, pipes, fountain, retaining walls, for the temporary dam or dams and for other protecting work, for grading, for regulating the bed of the brook below the Dam, and for any other work which the Engineer may order.

(8.) **How Made.**—Earth excavation is to be made in accordance with the lines established by the Engineer, and the price herein stipulated for earth excavation (clause —, item —), is to include the work of clearing and grubbing the grounds of all trees, stumps, bushes and roots, and burning or otherwise disposing of the same; of sheeting and bracing and supporting and maintaining all trenches and pits during and after excavation; of all pumping, ditching and draining; of clearing the excavation of all wood or other objectionable stuff, of selecting the materials and of hauling [except as specified in clause —, item —] and of disposing of the excavated materials in making embankments, in filling, refilling and wasting; of rolling and watering, and of all other labor and expenses incidental to the handling of the excavated materials.

(9.) Whenever, in the opinion of the Engineer, the material excavated from the pits and trenches cannot be properly disposed of in embankment or for other work at one hauling, it shall be deposited in spoil banks, and if subsequently ordered to be used in the work, it shall be paid for a second time under clause —, item —.

(10.) **Measurement.**—All earth work paid for under item — shall be measured in excavation.

(11.) **Embankments.**—The embankments for the Dam shall start from a well-prepared base, stepped on sloping ground, and shall be carried up in horizontal layers not exceeding six inches in thickness; every layer to be carefully rolled with a heavy grooved roller, and to be well watered. The earth to be well rammed with heavy rammers at such points as cannot be reached by the roller. Special care shall be required in ramming the earth close to the centre wall, which shall always be kept at least two feet higher than the adjoining embankment, unless otherwise permitted. The embankments of the Dam shall be kept at a uniform height on both sides of the masonry during construction.

(12.) Ample means shall be provided for watering the banks, and any portion of the embankment to which a layer is being applied shall be so wet, when required, that water will stand on the surface. The contractor shall furnish at his own cost the necessary steam or other power for forcing the water upon the bank, if the Engineer find that other means of transportation and distribution of the water are not sufficient.

(13.) **Clearing and Grubbing.**—All the grounds covered by the Dam and by the burrow pits

shall be cleared of all soil which shall be deposited in spoil banks at such points as shall be designated, and of all perishable matters; the stones shall be removed and the trees, stumps and other vegetable matter shall be burned or removed from the grounds of the City.

(14.) **Extra Thickness of Embankments.**—The embankments of the Dam or any slopes that may be so ordered shall be formed with an extra width of twelve inches; this surplus quantity of earth shall be afterwards removed and estimated as excavation, and the surface left shall be dressed smoothly to receive the broken stones supporting the paving, or the soil.

(15.) **Quality.**—The earth used for the embankments shall be free from perishable material of all kinds and from stones larger than three inches in diameter, and it shall be of a quality approved by the Engineer.

(16.) **Selected Materials.**—The Engineer shall decide upon the quality and character of the earth to be used at various places, and it must be selected and placed in accordance with his orders; the most compact material must be used on the up-stream side of the centre wall of the Dam embankments and for the refilling of the wall trenches.

(17. **Refilling.**—The refilling of the trenches and pits shall be made with approved materials free from all perishable matter, deposited in thin layers, rammed and well watered.

(18.) **Mixing.**—When the Engineer finds it necessary to mix the materials to be used for making embankments and for refilling, separate loads of the various materials designated by the Engineer, and in proportions to be determined by him, shall be deposited on the embankments at proper intervals; they will then be thrown with shovels in such a manner as to effect a thorough mixture.

(19.) All excavation of earth, hard pan and other materials, including boulders not exceeding one cubic yard each, shall be classified and estimated as earth excavation, and paid for at the price herein stipulated (clause —, item —).

(20.) **Trenches and Borrow Pits.**—The materials necessary for making the embankments, for refilling and for other purposes are to be taken from the areas adjacent to the Dam, marked — — — on Sheet No. —, and tinted in sienna.

(21.) **Extra Haul.**—If any earth or soil is ordered to be taken from any place outside of the said areas marked BP, BP, BP,.....on Sheet No. 1, an additional price is to be paid for each cubic yard, for each one hundred feet that such material may be hauled from the point of excavation to the nearest point of the boundary line limiting the said areas (clause —, item —).

ROCK EXCAVATION.

(22.) **What is Rock Excavation.**—Rock excavation is to include the excavation of all soli rock which cannot be removed by picking, and of boulders of one cubic yard or more in size; the price herein specified (clause —, item —) to be paid for rock excavation shall include the work of hauling and placing the same in spoil bank or other places.

(23.) **Measurement.**—Rock excavation shall be measured in excavation, and estimated for payment in accordance with the lines given by the Engineer.

(24.) **Where to Take Place.**—Rock excavation is to take place for the foundation of the Dam, Gate-House, overflow and other appurtenances, and wherever the Engineer may order it.

(25.) In the wall and pipe trenches and in the pits for the Gate-House, overflow, tail race and other structures, the rock is to be shaped roughly in steps, or other form that may be ordered by the Engineer.

The price bid for rock excavation is to include the cost of supporting and maintaining the excavations, of pumping and draining, of disposing of the excavated materials as ordered by the Engineer, and all other incidental expenses.

(26.) **Explosives.**—All rock excavation in the wall trenches and at any other place designated by the Engineer is to be made with explosives of a moderate power under his directions, and not with high explosives. Black powder may be ordered by him to be used in special cases.

(27.) **Surface of Rock Foundation.**—All rock surface intended for masonry foundation must be freed from all loose pieces, and be firm and solid, and prepared as directed by the Engineer.

FOUNDATION WORK.

(28.) The foundation work for the centre walls of the Dam and for other structures is to be extended to such a depth and in such a manner as shall be ordered by the Engineer. In bad bottom, sheet piling, tongued and grooved, may be ordered to be driven or placed on one or more sides of the work. Several illustrations of the modes of foundations which may be ordered can be seen on Sheet —, and if the material of excavation is such, in the opinion of the Engineer, as to require especial precaution, the trenches for the centre wall and for other structures may be ordered extended to a great depth, beyond the indications of the plans.

PROTECTIVE WORK.

(29.) The Contractor shall erect all necessary structures, and do all work needed to protect his work from water; he shall erect all temporary dams, coffer dams, sheet-piling and other devices, take care of the river and of the water accumulated behind the temporary dam or dams or other structures, and shall be responsible for all damage that may be caused by the action of water, whether from negligence or any other cause. Such damage is to be repaired, and the work must be restored and maintained at his cost.

(30.) All earth and rock excavation, masonry, timber and other work temporary or permanent, for the purpose of protecting the work from the river, provided that they are not objected to by the Engineer as improper or unnecessary, are to be paid for at the prices stipulated in this contract. All work of this character is to be removed by the Contractor at his own expense, if so ordered by the Engineer.

TIMBER.

(31.) Timber may be ordered used for platforms, for permanent sheet-piling and for other permanent uses. It shall be of the size and placed in the manner ordered by the Engineer.

(32.) All timber and lumber so used shall be spruce, sound, straight-grained, and free from all shakes, loose knots and other defects that may impair its strength and durability. The price bid for timber shall cover all incidental expenses incurred for labor, or for tools and materials used in placing, securing and fastening it.

(33) No payment shall be made to the Contractor for lumber used for bracing, sheeting, scaffolding and other temporary purposes.

(34.) All sheeting and other timber work in the trenches and pits shall be removed unless it is *ordered* left in, in which case such timber shall be paid for as herein stipulated, clause —, item —, for permanent timber work.

(35.) **Tongued and Grooved Timber.**—The timber to be used for sheet-piling in the foundations and other places may be ordered tongued and grooved. Such timber shall be furnished and placed as ordered, and the price herein stipulated, clause —, item —, for tongued and grooved timber is to cover the cost of placing, driving, securing and fastening the same.

MASONRY.

(36.) **Hydraulic Masonry.**—All masonry, except where otherwise specified, shall be laid in hydraulic cement mortar, and shall be built of the forms and dimensions shown on the plans, as directed by the Engineer from time to time, and the system of bonding ordered by the Engineer shall be strictly followed.

(37.) All joints must be entirely filled with mortar, and the work in all cases shall be well and thoroughly bonded.

(38.) Care must be taken that no water shall interfere with the proper laying of masonry in any of its parts.

(39.) All means used to prevent water from interfering with the work, even to the extent of furnishing and placing pipes for conducting the water away from points where it might cause injury to the work, must be provided by the Contractor at his own expense.

(40.) Under no circumstances will masonry be allowed to be laid in water.

(41.) **Ironwork.**—All ironwork, except the sluice-gates, is to be built in the masonry without other compensation than the price herein stipulated to be paid per cubic yard of masonry.

(42.) No masonry is to be built between the 15th of November and the 15th of April, or in freezing weather, except by permission of the Engineer.

(43.) All fresh masonry, if allowed to be built in freezing weather, must be covered and protected in a manner satisfactory to the Engineer, and during hot weather all newly built masonry shall be kept wet by sprinkling water on it with a sprinkling pot, until it shall have become hard enough to prevent its drying and cracking.

(44.) **Cement.**—American cement and Portland cement are to be used. The American cement must be in good condition and must be equal in quality to the best Rosendale Cement. It must be made by manufacturers of established reputation, must be fresh and very fine ground, and in well-made casks for equally safe and tight receptacles approved by the Engineer. The Portland cement must be of a brand equal in quality to the best English Portland cement. To insure a good quality, all the cement furnished by the Contractor will be subject to inspection and rigorous tests, and if found of inferior quality, will be branded, and must be immediately removed from the work; the character of the tests to be determined by the Engineer. The Contractor shall, at all times, keep in store at some convenient point in the vicinity of the work, a sufficient quantity of cement to allow ample time for the tests to be made without

delay to the work of construction. The Engineer shall be notified at once of each delivery of cement. It shall be stored in a tight building, and each cask must be raised several inches above the ground, by blocking or otherwise.

(45.) Cement is generally to be used in the form of mortar with an admixture of sand, and when so used, its use is included in the price herein stipulated for the various kinds of masonry; for the foundation work, however, Portland cement may be ordered by the Engineer to be used without any admixture of sand in exceptionally wet and difficult places, for grouting seams or for such purposes as he may direct; such cement shall be furnished by the Contractor, and if it is used in connection with masonry, it will be paid for in addition to the price herein stipulated to be paid for said masonry. Such cement is to be paid for at so much per barrel of 400 lbs., furnished and delivered by the Contractor at the place where it must be used. See clause —, item —.

(46.) **Mortar.**—All mortar shall be prepared from cement of the quality before described, and clean, sharp sand free from loam. These ingredients shall be thoroughly mixed dry, as follows: The proportion of cement ordered, by measure, with the ordered proportion of sand, also by measure; and a moderate dose of water is to be afterwards added to produce a paste of proper consistency; the whole to be thoroughly worked with hoes or other tools. In measuring cement it shall be packed as received in casks from the manufacturer. The mortar shall be freshly mixed for the work in hand, in proper boxes made for the purpose; no mortar to be used that has become hard or set.

(47.) The price herein stipulated for the various kinds of masonry is contingent on the use of a mortar made of a mixture of one part in volume of American cement to two parts of sand. Additional prices are herein stipulated for the use of mortars formed with a different mixture of cement and sand. Clause —, items —.

(48.) **Concrete.**—The concrete shall be formed of sound, broken stone or gravel not exceeding two inches at their greatest diameter. All stone in any way larger is to be thrown out. The materials to be cleaned from dirt and dust before being used; to be mixed in proper boxes, with mortar of the quality before described, in the proportion of five parts of broken stone to one part of cement; to be laid immediately after mixing, and to be thoroughly compacted throughout the mass by ramming till the water flushes to the surface; the amount of water used for making the concrete to be approved or directed by the Engineer. The concrete shall be allowed to set for twelve hours, or more, if so directed, before any work shall be laid upon it; and no walking over or working upon it shall be allowed while it is setting.

(49.) Whenever ordered by the Engineer, the concrete shall be formed of broken stone not exceeding one inch at their greatest diameter, used in the proportion of three parts of broken stone to one part of cement.

(50.) **Bricks.**—The bricks shall be of the best quality of hand-made, hard-burned bricks; burned hard entirely through, regular and uniform in shape and size, and of compact texture. To insure their good quality, the bricks furnished by the Contractor will be subject to inspection and rigorous tests, and if found of improper quality, will be condemned; the character of the tests to be determined by the Engineer. They are to be culled before laying, at the expense of the Contractor; and all bricks of an improper quality shall be laid aside and removed; the Engineer to be furnished with men for this purpose by and at the expense of the Contractor.

(51.) **Brick Masonry.**—All brick masonry shall be laid with bricks and mortar of the quality before described. No "bats" shall be used except in the backing, where a moderate proportion (to be determined by the Inspector) may be used, but nothing smaller than "half-bricks." The bricks to be thoroughly wet just before laying. Every brick to be completely imbedded in mortar under its bottom and on its sides. Care shall be taken to have every joint full of mortar. The face work inside of the Gate-Houses to be laid with pure Portland cement to a depth from the face of at least one foot.

(52.) **Brick Masonry in Asphaltum Mortar.**—During the progress of the work some brick work in connection with the roof of the Gate-House and stop-cock vaults way be ordered to be laid in asphaltum mortar. In laying such work the bricks must be heated to such a temperature and the mortar must be made of such mixture of Trinidad asphaltum and plaster of Paris as shall be directed. The mixture to be kept stirred up and at the temperature ordered, and the whole operation to take place under the direction of the Engineer.

(53.) **Centering.**—All centering shall be made, put up and removed in a manner satisfactory to the Engineer.

STONE MASONRY.

(54.) All stone masonry is to be built of sound clean quarry stone of quality and size satisfactory to the Engineer; all joints to be full of mortar, unless otherwise specified.

(55.) **Dry Rubble Stone Masonry and Paving.**—Dry rubble masonry and paving are to be laid without mortar, and are to be used for walls, for the slopes of the Dam embankments, and at any other places that may be designated.

(56.) This class of masonry is to be of stone of suitable size and quality, laid closely by hand with as few sprawls as practicable, in such manner as to present a smooth and true surface. The work is to be measured in accordance with the lines shown on the drawings or ordered during the progress of the work. The stones used must be roughly rectangular; all irregular projection and feather-edges must be hammered off. No stone will be accepted which has less than the depth represented on the plans or ordered. Each stone used for paving must be set solid on the foundation of broken stone or earth and no interstices must be left.

(57.) In the dry rubble masonry walls large stones must be used, especially for the faces, and the walls must be bonded with frequent headers, of such frequency and sizes as shall be approved by the Engineer.

(58.) **Rip-Rap.**—Rip-rap may be used in connection with the protective work, and wherever the Engineer may order it. It shall be made of stone of such size and quality and in such manner as he shall direct, and must be laid by hand.

(59.) **Broken Stones.**—After the slopes which are to receive the paving have been dressed, a layer, twelve inches thick, of broken stone is to be spread as a foundation for the paving, wherever ordered. The broken stones must be sound and hard, not exceeding two inches at their greatest diameter. Broken stone, not exceeding one inch in diameter, may be used for forming roadways; it is to be spread to such thickness as ordered and heavily rolled or rammed. Broken stones may be used also wherever the Engineer may direct, rolled if so directed, and paid for under this head, except the broken stone used for making concrete, the cost of which is included in the price hereinbefore stipulated for concrete laid.

(60.) Rubble stone masonry is to be used for the central part of the Dam, for the centre walls of the earth embankments, for most of the structures and appurtenances of the Dam, and wherever ordered by the Engineer.

Rubble stone masonry shall be made of sound, clean stone of suitable size, quality and shape for the work in hand, and presenting good beds for materials of that class. Especial care must be taken to have the beds and joints full of mortar, and no grouting or filling of joints after the stones are in place will be allowed. The work must be thoroughly bonded. The up-stream face of the centre walls shall be closely inspected after they are built, and if any mortar joints are not full and flush, they shall be taken out to a depth of no less than two inches or more, if so ordered, and repointed properly.

(61.) **Central Part of the Dam and Overflow.**—A large quantity of rubble stone masonry in mortar is to be used in the construction of the central part of the Dam and of the overflow.

The stones used therein must be sound and durable; they must have roughly rectangular forms, and all irregular projections and feather-edges must be hammered off. Their beds, especially, must be good for materials of that class, and present such even surfaces that, when lowering a stone on the level surface prepared to receive it, there can be no doubt that the mortar will fill all spaces. After the bed joints are thus secured, a moderate quantity of spauls can be used in the preparation of suitable surfaces for receiving other stones. All other joints must be equally well filled with mortar.

The quality of the beds is to regulate, to a large extent, the size of the stones used, as the difficulty of forming a good bed joint increases with the size of the stones.

Various sizes must be used.

Generally the largest stones are not to measure more than twenty cubic feet, and they are to be used in the proportion of about 25 per cent. of the whole; but they must be omitted partially or entirely if their beds are not satisfactory. It is expected that one-quarter of the stones used in the main body of the Dam, which is built of rubble, will be of such size that two men can handle them, or even smaller. The balance to be composed of intermediate sizes. Regular coursing is to be avoided.

(62.) **Face Work for Rubble Stone Masonry.**—The exposed faces of the wing walls, retaining walls and of any other rubble work that the Engineer may designate, are to be made of broken ashlar with joints not exceeding one-half inch in thickness; the stones not to be less than 12 inches deep from the face, and to present frequent headers. This face work to be equal in quality and appearance, although with smaller stones, to the face of the breast wall in front of the proposed new Gate-House at Croton Dam (section 1), and to be well pointed. This face work is to be paid by the square foot of the superficial area for which it is ordered, in addition to the price paid per cubic yard of rubble stone masonry.

(63.) **Block Stone Masonry.**—Block stone masonry is to be composed mainly of large blocks and is to be used for the steps of the overfall or for other steps, or whenever and wherever ordered by the Engineer. It is to be laid in cement mortar, well pointed, or may be ordered laid dry at the price stipulated in clause —, item —.

This stone, which is to receive the shock of water and ice, is to be especially sound, hard and compact, and of a durable character; it is to be prepared to the dimensions given, so that no joint will in any place be more than one inch wide.

(64.) **Facing Stone Masonry.**—The outer faces of the Masonry Dam and of its gate chamber, of the overflow (except steps), and of any other piece of masonry that may be designated, are to be made of range stones, as shown on the plans, the stone to be of unobjectionable quality, sound and durable, free from all seams, discoloration and other defects, and of such kind as shall be approved by the Engineer.

(65.) All beds, builds and joints are to be cut true (for the gate chamber to a depth of not less than 6 inches from the faces, and for the Dam to a depth of not more than 4 inches, and not less than 3 inches from the faces), to surfaces allowing of one-half inch joints at most; the joints for the remaining part of the stones not to exceed two inches in thickness at any point.

(66.) All cut arrises to be true, well defined and sharp.

(67.) Where this class of masonry joins with granite dimension stone masonry the courses must correspond, and the joining with arches and other dimension stone masonry must be accurate and workmanlike.

Each course to be composed of two stretchers and one header alternately, the stretchers not to be less than 3 feet long nor more than 7 feet long, and the headers of each successive course to alternate approximately in vertical position.

(68.) The rise of the courses may vary from bottom to top from 30 inches to 15 inches in approximate vertical progression, and the width of bed of the stretchers is not to be at any point less than 28 inches. The headers are not to be less than 4 feet in length.

This class of masonry, for the faces of the Dam and gate chamber, including the headers, is to be estimated at 30 inches thick throughout. At other places that may be designated by the Engineer the size of the stones is to be established by him, and the facing stone masonry is to be estimated according to the lines ordered or shown on the plans. In no case are the tails of the headers to be estimated.

The work to be equal in quality and appearance to the facing stone masonry work now being built by the Aqueduct Commissioners for their Masonry Dam across the East Branch of the Croton River near Brewster.

(69.) The coping of the wing walls, of the side walls to the spill-way, and any other copings that may be designated, will be classed as facing stone masonry.

(70.) The price herein stipulated for facing stone masonry is to cover the cost of pointing, of cutting chisel drafts at all corners of the Gate-House Dam and other corners, and of preparing the rock faces; but if any six-cut or rough-pointed work is ordered in connection with this class of masonry it shall be paid for at the prices herein stipulated for such work. Clause —, items — and —.

(71.) The face bond must not show less than 12 inches lap, unless otherwise permitted.

(72.) The pointing of the faces to be thoroughly made with pure Portland cement after the whole structure is completed only; unless otherwise permitted, every joint to be raked out therefor to a depth of at least two inches, and if the Engineer is satisfied that the pointing at any place is not properly made, it must be taken out and made over again.

(73.) **Granite Dimension Stone Masonry.**—Granite dimension stone masonry must be made of first-class granite of uniform color, free from all seams, discoloration and other defects, and satisfactory to the Chief Engineer.

(74.) It is to be used for the arches and gate openings in the gate chamber, for the cornice work of the Dam, for the Gate-House superstructure and for the crest and first step of the overflow, and at any other place that may be designated by the Engineer.

(75.) The stones shall be cut to exact dimensions, and all angles and arrises shall be true, well defined and sharp.

(76.) All beds, builds and joints are to be dressed, for the full depth of the stone, to surfaces, allowing of one-quarter ($\frac{1}{4}$) inch joint at most. No plug-hole of more than 6 inches across or nearer than 3 inches from an arrise is to be allowed, and in no case must the aggregate area of the plug-holes in any one joint exceed one-quarter of its whole area.

(77.) The stone shall be laid with one-quarter ($\frac{1}{4}$) inch joints, and all face joints shall be pointed with mortar made of clear Portland cement, applied before its first setting. All joints to be raked out to a depth of one inch before pointing; the cost of pointing to be included in the price stipulated for cut stone masonry.

(78.) **Face Dressing.**—The exposed faces of the cut stone are to be finished in various ways, in accordance with the various positions in which they are placed. They shall be either left with a rock or quarry face, rough-pointed, or fine-hammered (six-cut work).

(79.) The various classes of face dressing must be equal in quality and appearance to those on the sample in the office of the Chief Engineer.

(80.) **Rock Face Dressing.**—In rock face work the arrises of the stones inclosing the rock face must be pitched to true lines; the face projections to be bold, and from 3 to 5 inches beyond the arrises. The angles of all walls on structures having rock faces are to be defined by a chisel draft not less than $1\frac{1}{2}$ inches wide on each face.

(81.) **Rough Pointed Dressing.**—In rough-pointed work, the stones shall at all points be full to the true plane of the face, and at no point shall project beyond more than $\frac{1}{4}$ inch, the arrises to be sharp and well defined. Each stone to have its arrises well defined by a chisel draft, which is included in the price for rough-pointed dressing.

(82.) **Fine Hammered (Six-Cut) Dressing.**—In fine-hammered work the face of the stones must be brought to a true plane and fine-dressed, with a hammer having six blades to the inch.

(83.) In measuring cut stone masonry, when the stones are not rectangular, the dimensions taken for

each stone will be those of a rectangular, cubical form which will just inclose the same. The price herein stipulated for granite dimension stone masonry is to cover the cost of preparing the rock faces, and of making the chisel drafts, of preparing all holes and recesses and grooves and of pointing.

(84.) No payment will be made for cutting grooves and recesses other than the price paid for the dressing of their surfaces, which are to be fine-hammered.

(85.) For rough-pointed and fine-hammered (six-cut) dressing, a price per square foot of dressing will be paid in addition to the price per cubic yard of masonry, viz.:

(86.) For rough-pointed dressing, the price stipulated in clause —, item (—), and for fine-hammered (six-cut) dressing, the price stipulated in clause —, item (—).

(87.) The broken ashlar in the superstructure of the gate chamber and the cut paving in the Gate-House, are to be estimated as granite dimension stone masonry.

(88.) The exposed parts of the cut stone, including the ashlar masonry of the superstructure, are generally to be prepared with rock face.

(89.) The inside surfaces and copings are generally to be rough-pointed.

(90.) All the gateways, grooves, sills, floors, and all other surfaces designated by the Engineer are to be fine-hammered.

Ironwork, stop-cocks, sluice-gates, doors and windows (similar to the specifications given on pages 258, 263, and 256).

SPECIFICATIONS OF DEPARTMENT OF PUBLIC WORKS FOR PUMPING-ENGINES, BOILERS AND APPURTENANCES. (NEW PUMPING STATION AT 179TH STREET AND 10TH AVENUE.)

The work to be done consists in furnishing all of the material and labor and performing all the work necessary to build and erect complete, in a building to be erected at the New Aqueduct, between Tenth Avenue and Harlem River, two vertical triple expansion ten-million gallon pumping-engines, boilers and appurtenances complete, and two vertical triple expansion four-million gallon pumping-engines, boilers and appurtenances complete.

Capacity.—Each reservoir service engine shall have capacity to deliver 10,000,000 United States gallons of water in twenty-four hours.

Each tower service engine shall have capacity to deliver 4,000,000 United States gallons of water in twenty-four hours.

Pressures.—The water pressure on the plungers will be, in the case of the reservoir service engines, 56 pounds per square inch.

In the case of the tower service engines, the water pressure will be 105 pounds per square inch.

This includes friction in the pipes. There will be a pressure on the suction of about 15 pounds in both cases.

The steam pressure in each case shall be 160 pounds above atmosphere at the boilers.

Condensers.—The condensers shall be of the surface type, and there will be one for each engine, situated in the suction main and so arranged that the water, or part of the water, pumped by the main engine will pass through it, so that no water will be wasted for injection.

The tubes will be of brass or copper, and there shall be some arrangement to permit of the necessary expansion and contraction of tubes.

There must be provided some arrangement by which the temperature of the condensed water can be kept practically constant during such variations in the temperature of the cooling water as are liable to occur.

The air pump may be independent or attached, but must be of ample capacity to handle all leakages and maintain a satisfactory vacuum.

There must also be furnished a cast-iron hot well with proper vapor-pipe, to collect the discharge from the air-pump.

Foundations.—The City will provide concrete sub-foundations for the boilers to a level with the bottom of boiler saddles or ash-pits, and for the engines to a level 21 feet below the engine-room floor.

All foundations and masonry of any character for either engines or boilers above this point must be provided by the Contractor and included in the proposition.

Space.—The engines and boilers will be generally located as shown in accompanying plan.

Bidders must show a plan of the engine and boiler rooms to scale showing dimensions, etc., necessary for the machinery offered.

Pipes.—The suction-pipes with tees and stop-cocks left for provisional engines shall be furnished, connecting the engines with tank in building.

The delivery pipes with blank tees and stop-cocks left for provisional engines shall be furnished,

connecting the engines with 30-inch stop-cock in vault on main leading to tower at High Bridge and with the stand-pipe.

There shall be an outside screw gate-valve in the suction, and an outside screw-gate and a check-valve in the delivery pipe of each engine.

Arrangements must be made for provisional engines as shown on the plans by dotted lines.

The Contractor must also furnish the necessary filters for feed-water and the steam, injection, drain, drip, priming, starting, blow-off, feed and other necessary and usual pipes within the engine and boiler-house.

Fixtures.—Each engine shall be supplied with a revolution-counter, a sight-feed lubricator, a steam, a water and a vacuum gauge, a set of drip pans, polished brass oilers, a full set of wrenches and all necessary attachments and appurtenances.

Platforms.—Platforms for conveniently reaching every part of the engines shall be furnished, fitted with finished brass hand-railings and suitable stairs for reaching the same.

Jackets.—All steam cylinders must be steam-jacketed, and proper arrangements must be made for returning the condensed water from the jackets back to the boilers.

Covering.—The steam cylinders, and all heated parts of the engines, and all live steam pipes must be covered with some non-conducting material to be approved by the Chief Engineer, and such pipes as are not lagged shall be inclosed in canvas and painted.

Lagging.—The steam cylinders and all heated parts of the engines and the main steam-pipe in the engine-room will be inclosed in an ornamental lagging of black walnut.

All parts of the machinery excepting the bright work must receive a good coat of paint before leaving the shops of the Contractor, and, after being erected at the pumping-station, two additional coats of Dixon's silico-graphite paint.

Boilers.—There shall be one or more boilers for each engine. They must be capable of carrying a working pressure of 160 pounds above the atmosphere.

Dimensions.—Each boiler, or set of boilers for each engine, shall have not less than 900 square feet of heating surface. The ratio of grate to heating surface shall be not less than 1 to 35.

Tubes.—The tubes shall be best lap-welded tubes not less than 3 inches diameter, with sufficient space between them to insure proper circulation. No tube to be nearer the shell than 3 inches.

Plates.—All plates used in the boilers shall be of open-hearth steel, of not less than 55,000 nor more than 60,000 pounds tensile strength, with an elongation of not less than 25 per cent. in 8 inches and a reduction of area of not less than 50 per cent. Name of maker, brand and tensile strength to be plainly stamped on each plate.

The thickness of the plate shall be not less than that given by the rules at present in force of the Board of United States Inspectors of Steam Vessels.

Flanges.—All flanges to be turned in a neat manner to an internal radius of not less than 2 inches, and to be clear of cracks, checks or flaws, and all plates on which any heated work has been done shall be properly annealed before assembling in the boiler.

Riveting.—Rivet-holes to be punched or drilled so as to come fair when in position. No drift-pin to be used in construction of boilers. A reamer to be used in all cases to bring the holes "fair."

Braces.—All braces to be best quality of wrought iron and properly set in accordance with the rules of the United States Inspectors of Steam Vessels at present in force.

Manholes.—Boilers to have necessary manholes and hand-holes of suitable size, with strong internal frames and suitable plates, yokes and bolts, the proportion of the whole such as will make them as strong as any other section of the shell of like area.

Fittings, etc.—Each boiler to be fitted with all necessary connections, including fire-door fronts, front smoke-box, grate-bars, grate-bearers, together with proper setting for each boiler or sets of boilers; also bolts, door-frames and door for the back smoke-box. Also, all necessary and usual try-cocks, water and steam-gauges, pot safety-valve, blow-off cocks, dampers and firing tools.

Covering.—Boilers shall be properly covered with approved non-conducting material, to the satisfaction of the Engineer.

Flue Connections.—The boilers shall be connected with the chimney by a smoke-flue, of proper area, with damper regulator for each boiler, of a make to be approved by the Chief Engineer.

Boiler Connections.—The boilers shall be so connected to the main, steam and other pipes that any one boiler or sets of boilers may be thrown out of commission and disconnected without interfering with the working of the rest of the plant, and also connected with the boilers now on the ground.

Feed Pumps.—There shall be two feed pumps, either of which shall have capacity to supply feed water for the whole boiler plant.

Connections.—The feed pumps will be connected to take suction from hot well, and also have an independent suction from the main influent pipe to the pumping station.

They will be so arranged that either pump will be able to feed any or all boilers.

DRAWINGS AND SPECIFICATIONS.

Bidders must submit drawings of engines and boilers and their setting, showing dimensions and detailed specifications of the machinery offered.

It is the intent of these specifications to call for a complete engine-house plant of four engines and four boilers or sets of boilers, with all connections, appurtenances and fittings necessary to the operation of the same, the whole to be erected complete and ready for regular service.

When completed each reservoir pumping-engine shall run continuously for twenty-four hours to ascertain whether it does the maximum work required of raising each twenty-four hours 10,000,000 gallons of water in the stand-pipe 100 feet above the level of delivery in supply-tank, and shall be run continuously for twenty-four hours to ascertain whether it does the minimum work required of raising each twenty-four hours 5,000,000 gallons of water into the stand-pipe 100 feet above the level of delivery in supply-tank.

When completed, each tower pumping-engine shall be run continuously for twenty-four hours, to ascertain whether it does the maximum work required, of raising each twenty-four hours 4,000,000 gallons of water into the tower, 230 feet above the level of delivery in supply-tank, and shall be run continuously for twenty-four hours to ascertain whether it does the minimum work required of raising each twenty-four hours 2,000,000 gallons of water into the tower 230 feet above level of delivery in supply-tank.

After the first tests of twenty-four hours, each of the pumping-engines shall be run fifty days on the actual consumption of water to ascertain the durability of the same and its workings under the variable amounts of water necessary, ranging from 10,000,000 to 5,000,000 gallons each day for reservoir engines, and from 4,000,000 to 2,000,000 gallons each day for tower engines, and of its capacity to obtain a duty of 90,000,000 foot pounds, per 100 pounds of coal fed on the grates of boilers under these conditions.

Quantity of water pumped to be calculated from the size of pumps and revolutions of same, less five per cent. for slippage, and to be between the maximum and minimum quantities.

The height of water pumped to be determined by pressure-gauges on main supply and delivery pipes near pumps and to include steam used for heating purposes, auxiliary pump pumping condensed water, feed pumps and all uses, during the regular running of the station. Coal to be the same as now used, no deduction for ashes, clinkers, etc.

Details, plans and drawings for all of the work shall be submitted to the Engineer for his approval, and a copy of same furnished the Department of Public Works before work on same is commenced.

Every facility shall be given Contractors that will have work to be done in connection with and adjacent to this work, as directed by the Engineer.

All materials to be of the best quality, and all of the work shall be done in a skillful and workmanlike manner, and to the satisfaction of the Engineer.

Any doubt as to the meaning of these specifications, or any obscurity as to the wording of them, will be explained by the Engineer, and all directions and explanations required, alluded to or necessary to complete any of the provisions of these specifications and give them due effect, will be given by the Engineer.

SPECIFICATIONS FOR TANK AND STAND-PIPE FOR HIGH SERVICE. (179TH STREET AND 10TH AVENUE.)

The receiving-tank in engine-house will be 8 feet in diameter outside, and 47 feet high, and shall be built with a cast-iron base, three 36-inch cast-iron flange connections, one manhole and a homogeneous soft steel superstructure.

The two bottom sheets shall be $\frac{3}{4}$ inch thick, and the upper part $\frac{5}{8}$ inch thick.

The stand-pipe in engine-house will be 6 feet in diameter, and 138 feet high, and shall be built with cast-iron base, two 48-inch cast-iron flange connections, one manhole and a soft homogeneous steel superstructure.

The bottom sheets for 50 feet shall be $\frac{3}{4}$ inch thick; $\frac{5}{8}$ inch thick for the next 50 feet, and top $\frac{1}{2}$ inch thick.

The bottom sheet shall be leaded inside and out in the groove of the bottom casting.

The receiving and stand-pipe shall be made of the best quality soft homogeneous steel, name of maker, brand and tensile strength to be plainly stamped on each sheet; horizontal joints to be planed and butted and plate-riveted on stand-pipe and on beams of the tower where they join to act as stediments.

They shall be placed in the building after the foundations are completed and guyed where necessary until the tower is completed.

Concrete foundations will be made for the tank and stand-pipe on which the cast-iron base shall be properly set.

The rock and masonry at the bottom of the tower at High Bridge shall be excavated without blasting to set the stand and waste-pipe and to pass the connections through and outside of the tower at least 10 feet.

The stand-pipe will be cast-iron, 20 inches inside diameter, and the waste-pipe 12 inches diameter.

The waste-pipe will be connected outside the tower with the present 20-inch reservoir pipes, and both the stand-pipe and waste-pipe shall be connected with and through the tank on top of tower, and proper composition slip joints made in same, and wrought-iron braces at top of tank and at each landing; all connections to be made by working night and day. All of the work of cutting out and making connections to be included in the price bid for cast and wrought-iron work.

All cast-iron used in the work shall be good machinery iron of a tensile strength of at least 25,000 pounds per square inch; and all joints faced, turned and bored where necessary and properly bolted together.

All wrought-iron work shall be of best quality, American refined iron.

All steel work shall have a tensile strength of at least 50,000 pounds per square inch.

All composition work shall be composed of six parts copper, one part tin and one-half part zinc.

All lead shall be of the best quality soft, refined lead.

All as per plans on file in the office of the Chief Engineer of the Croton Aqueduct.

When necessary, as the work progresses, further detail plans will be furnished. Every facility shall be given Contractors that will have work to be done in connection with and adjacent to this work, as directed by the Engineer.

RULES AND REGULATIONS FOR THE SANITARY PROTECTION OF THE CROTON RIVER AND ITS TRIBUTARIES,

In the Counties of Westchester, Putnam and Dutchess, and of so much of the Bronx and Byram Rivers and their Tributaries in the County of Westchester, as are now used for the Supply of Water for the City of New York.

PRIVIES ADJACENT TO LAKES, PONDS OR RESERVOIRS, AND WATER-COURSES.

First.—No privy, or place for the deposit or storage of human excreta, shall be constructed, located or maintained within fifty (50) feet, horizontal measurement, of the high-water mark of any lake, pond or reservoir, or within thirty (30) feet, horizontal measurement, of the high-water mark or precipitous bank of any spring, stream or water-course of any kind, tributary to said lakes, ponds or reservoirs on the entire water-shed of the Croton River, or on those portions of the water-sheds of the Bronx and Byram rivers now used for the water supply of the City of New York.

Second.—No privy vault, pit or cesspool, or non-transportable receptacle of any kind for the reception or storage of human excreta shall be constructed, located or maintained within two hundred and fifty (250) feet, horizontal measurement, of the high-water mark of any lake, pond or reservoir, or within one hundred and thirty (130) feet, horizontal measurement, of the high-water mark or the precipitous bank of any spring, stream or water-course of any kind on the entire water-shed of the Croton river, or on those portions of the water-sheds of the Bronx and Byram rivers now used for the water supply of the city of New York.

Third.—Every privy, or place for the deposit of human excreta, which is constructed, located or maintained between the aforesaid limits of fifty (50) feet and two hundred and fifty (250) feet, horizontal measurement, of the high-water mark of any lake, pond or reservoir, or within the limits of thirty (30) feet and one hundred and thirty (130) feet, horizontal measurement, of the high-water mark or precipitous bank of any spring, stream or water-course tributary to such lakes, ponds or reservoirs, on the entire water-shed of the Croton River, or on those portions of the water-sheds of the Bronx and Byram rivers now used for the water supply of the city of New York, and from which the said excreta are not at once removed automatically, by means of suitable water-tight pipes or conducts, to some proper place of ultimate disposal, as hereinafter provided; shall be arranged in such manner that all said excreta shall be received and temporarily maintained in suitable vessels or receptacles, which shall at all times be maintained in an absolutely water-tight condition, and which will admit of convenient removal to some place of ultimate disposal, as hereinafter set forth.

Fourth.—Whenever it shall be found that, owing to the porous character of the soil, the height and flow of the surface and subsoil waters, the steepness of the slopes, or other special condition of the locality, the excremental matter from any privy, cesspool or other receptacle for human excreta, situated within the limits hereinbefore provided, may be washed over the surface or through the subsoil into any lake, pond or reservoir, or into any spring, stream or water-course tributary to such lake, pond or reservoir on said water-shed of the Croton river, or on those portions of the water-sheds of the Bronx and Byram rivers now used for the water supply of the city of New York, without having been thereby, in the judgment of the State Board of Health, sufficiently purified, then the said privy, cesspool or other receptacle for human excreta shall, after due notice to the owner thereof, be removed to such greater distances from said high-water marks as shall be considered safe and proper by the State Board of Health.

Fifth.—All said receptacles for human excreta must be provided with tightly-fitting covers, which shall be securely applied during the process of removal, so that no portion of the contents of said receptacle shall escape therefrom while being transported from the privy to the place of ultimate disposal.

Sixth.—A sufficient number of duplicate receptacles of said general description or character shall be provided, so that when one of the same is removed from the privy an empty receptacle may at once be substituted in its place.

Seventh.—All such receptacles, when filled, shall be removed to some place of ultimate disposal as hereinafter provided, and said receptacles themselves shall be thoroughly cleansed and deodorized as often as may be found necessary to maintain the privy in proper sanitary condition, and to prevent an overflow of the excreta upon the soil or floor of said privy.

Eighth.—The excreta collected in the aforesaid receptacle shall be removed to some convenient place of ultimate disposal, which shall not be less than two hundred and fifty (250) feet from the high-water mark or precipitous bank of any lake, pond, or reservoir and not less than one hundred and thirty (130) feet from the high-water mark or precipitous bank of any stream, spring or water-course of any kind on the entire water-shed of the Croton river, or on those portions of the water-sheds of the Bronx and Byram rivers now used for the water supply of the city of New York, and from which they cannot be directly washed

by rain, or melting snow, or otherwise over the surface of the ground into any lake, pond or reservoir, or into any spring, stream, water-course, channel or well which is tributary thereto on the entire water-shed of the Croton river, or on those portions of the water-sheds of the Bronx and Byram rivers now used for the water supply of the city of New York.

Ninth.—In the absence of any other manner of disposal of the excreta collected as aforesaid, which is not specifically approved by the State Board of Health after due submission to said Board, the said excreta shall be disposed of by digging the same into the surface soil or by burial in trenches of moderate depth in places where the character of the subsoil and the depth of the ground-water level will afford ample security both against the undue pollution of such ground-water and the soil itself, and for the efficient filtration of the liquid contents of the said receptacles.

Tenth.—The removal of the aforesaid receptacles from the privies shall be conducted in such manner as to cause as little inconvenience or annoyance to the occupants of the premises as is compatible with proper management of the work.

HOUSE SLOPS, SINK WASTES, LAUNDRY WATER AND OTHER SIMILAR SEWAGE.

Eleventh.—Nose wage, house slops, sink wastes, water in which clothes or bedding have been washed or rinsed, nor any other polluted water or liquid shall be thrown or discharged directly into any lake, pond or reservoir as aforesaid, or into any spring, stream or water-course tributary thereto, nor shall any such aforesaid liquid or solid matter or other polluted liquid be thrown or discharged upon the surface of the ground or into the ground below the surface in any manner whereby the same may flow into any lake, pond or reservoir, or into any spring, stream or water-course tributary thereto, within fifty (50) feet, horizontal measurement, or the high-water mark in any lake, pond or reservoir, or within thirty (30) feet of the high-water mark or the precipitous bank of any spring, stream or water-course tributary to said lakes, ponds or reservoirs.

Twelfth.—The foregoing rule shall be considered applicable only where the quantity of such polluted water or liquid wastes is small, such as may be derived from a single family, but when relatively large quantities of such wastes are produced and are thrown or discharged upon or below the surface of the ground at any point beyond the aforesaid limits, in such manner or volume as to cause the same to flow over the surface of the ground, or through it below the surface, into any lake, pond or reservoir, or into any spring, stream or water-course tributary thereto, without having been thereby, in the judgment of the State Board of Health, sufficiently purified; then, upon due notice to the owners or occupants of the premises from which such discharge comes, the aforesaid distances shall be increased respectively to such other limit as shall appear justified to said State Board of Health.

Thirteenth.—In case that human excrement is mingled with any of the aforesaid polluted water or other sewage, the discharge of the same upon or below the surface of the ground will be governed by the rule relating to privies.

Fourteenth.—No clothes or unclean objects of any kind shall be washed in any lake, pond or reservoir, or in any spring, stream or water-course tributary thereto.

GARBAGE AND REFUSE.

Fifteenth.—No garbage or putrescible refuse of any kind shall be thrown or discharged directly into any lake, pond or reservoir, or into any spring, stream or water-course tributary thereto; nor shall any such substances be placed in large quantities upon or below the surface of the ground where they may be washed into any lake, pond or reservoir, or into any spring, stream or water-course tributary thereto, within one hundred (100) feet of the high-water mark in any lake, pond or reservoir, or within fifty (50) feet of the high-water mark or precipitous bank of any spring, stream or water-course tributary to said lakes, ponds or reservoirs.

Sixteenth.—The State Board of Health shall have the right to increase the aforesaid distances in all cases where, in its judgment, it may appear that injury to the purity of the water results from the deposit or storage of garbage or putrescible refuse as aforesaid.

Seventeenth.—Where it becomes impracticable to comply with the foregoing rules so far as the disposal of garbage or putrescible refuse upon or below the surface of the ground is concerned, then suitable water-tight receptacles must be provided and be so located and maintained on the premises that none of the contents thereof shall escape and pollute the waters as heretofore indicated.

MANURES, COMPOSTS AND SIMILAR MATTER.

Eighteenth.—No stable, pig-sty, hen-house, barn-yard, hog-yard, hitching or standing place for horses or cattle or other place where animal manure accumulates, shall be constructed, located or maintained within

one hundred (100) feet of the high-water mark in any lake, pond or reservoir, or within fifty (50) feet of the high-water mark or precipitous bank of any spring, stream or water-course tributary to said lakes, ponds or reservoirs.

Nineteenth.—No stable, pig-sty, hen-house, barn-yard, hog-yard, hitching or standing place for horses or cattle or other place where animal manure accumulates, shall be arranged or maintained in such manner that the washings or drainage therefrom may flow through open or covered drains or channels into any pond, lake or reservoir, or into any spring, stream or water-course tributary thereto, without having undergone proper purification.

Twentieth.—The foregoing rules shall also apply to composts and to masses of fermented or decayed fruit, vegetables, roots, grain, sawdust, leaves or other vegetable substances, which may be used either alone or in combination with other matter as manure, or as food for domestic animals.

DEAD ANIMALS, VEGETABLE REFUSE AND MANUFACTURING WASTES.

Twenty-first.—No dead animal, bird, fowl, fish or reptile, or parts thereof, nor any filthy or decaying matter of animal or vegetable origin derived from human habitations, barns or stables, nor any putrescible matter or waste product or polluted liquid from any slaughter-houses, creameries, condensed milk factories, cheese factories, breweries, distilleries, cider-mills, wine or beer vaults, sugar or glucose factories, tanneries, woolen mills, paper mills, pulp-mills, saw-mills, or other manufactories, shall be thrown, discharged, drained or washed into any lake, pond or reservoir, or into any spring, stream or water-course tributary thereto.

Twenty-second.—No dead animal, bird, fish, fowl or reptile, or any part thereof, shall be buried in the ground within two hundred and fifty (250) feet of the high-water mark of any lake, pond or reservoir, or within one hundred and thirty (130) feet of the high-water mark or precipitous bank of any spring, stream or water-course tributary thereto.

Twenty-third.—No live sheep or other animal shall be washed in any lake, pond or reservoir, or in any spring, stream or water-course tributary thereto; neither shall any person swim, bathe or wash in any of said lakes, ponds or reservoirs, or in the streams tributary thereto.

Twenty-fourth.—The waste liquids which may be polluted with putrescible or deleterious organic matter from any of the operations above indicated shall all be thoroughly filtered or otherwise purified before being allowed to escape into any lake, pond or reservoir, or into any spring, stream or water-course tributary thereto.

CEMETERIES.

Twenty-fifth.—No interment shall be made in any cemetery or other place of burial on the entire water-shed of the Croton river, or on those portions of the water-sheds of the Bronx and Byram rivers now used for the water supply of the city of New York, within two hundred and fifty (250) feet, horizontal measurement, of the high-water mark in any lake, pond or reservoir, or within one hundred and thirty (130) feet, horizontal measurement, of the high-water mark or precipitous bank of any spring, stream or water-course tributary to such lakes, ponds or reservoirs.

Twenty-sixth.—Whenever it shall be brought to the notice of the State Board of Health that, owing to the porous character of the soil, the height and flow of the subsoil waters, the steepness of the slopes or other special conditions of the locality, the percolation or drainage from any cemetery or place of burial is polluting the waters of any lake, pond or reservoir, or of any spring, stream or water-course tributary thereto, the aforesaid limits within which the interments are not permitted shall be extended as much further from said high-water marks as shall be considered safe and proper by the State Board of Health

PROVISION FOR APPEALS TO STATE BOARD OF HEALTH.

Twenty-seventh.—Wherever any system of treating excremental matter from any dwelling, hotel, stable, factory or other building from which such matter may be discharged, by means of subsurface irrigation, filtration, chemical process or otherwise, has already been established, and now discharges the effluent liquid or solid matter anywhere within two hundred and fifty (250) feet, horizontal measurement, of the high-water mark in any lake, pond or reservoir, or within one hundred and thirty (130) feet, horizontal measurement, of the high-water mark or precipitous bank of any spring, stream or water-course tributary to such lakes, ponds or reservoirs, on said water-sheds, such discharge shall no longer be permitted, but must be carried to some suitable point beyond said limits respectively, unless especially allowed by the State Board of Health.

Twenty-eighth.—Wherever any system of treating house-slops, sink-wastes, laundry water, stable drainage, factory wastes or refuse, garbage or any other putrescible waste matter or the drainage therefrom by means of subsurface irrigation, filtration, chemical process or otherwise, has already been estab-

lished and now discharges the effluent liquid or solid matter anywhere within fifty (50) feet, horizontal measurement, of the high-water mark in any lake, pond or reservoir, or within thirty (30) feet, horizontal measurement, of the high-water mark or precipitous bank of any tributary spring, stream or water-course, such discharge shall no longer be permitted, but must be carried to some suitable point beyond said limits respectively, unless specially allowed by the State Board of Health.

PENALTY.

In accordance with section 2 of chapter 543 of the Laws of 1885, a penalty of not less than fifty nor more than one hundred dollars is hereby imposed upon any corporation, person or persons, guilty of a violation of, or non-compliance with, any of the above given mandatory rules or regulations, to be recovered under said act.

At a special meeting of the State Board of Health, held on the 15th of March, 1889, at the Capitol, in the city of Albany, the foregoing rules and regulations were made, ordained and established, pursuant to chapter 543 of the Laws of 1885, for the protection of the water-shed of the Croton river and its tributaries in the counties of Westchester, Putnam and Dutchess, and of so much of the Bronx and Byram rivers and their tributaries in the County of Westchester as are now used for the supply of water for the city of New York.

THOS. NEWBOLD,
President,
LEWIS BALCH, M.D.,
Secretary and Executive Officer.

The above Rules and Regulations were amended by the State Board of Health, on August 25th, 1893, as follows:

"That, taking into consideration the character of the soil, and of the substrata of the soil, and the angle of slopes, the distance at which privy vaults, slaughter-houses, hog-pens, barn-yards, or any and all places or things which tend to pollute and render impure and dangerous water taken from the several sources enumerated and set forth in said rules, may be maintained, is increased to 300 feet, horizontal measurement, of the high-water mark in any lake, pond or reservoir in said water-shed, and to 250 feet, horizontal measurement, of the high-water mark or precipitous bank of any spring, stream or water-course tributary to said lakes, ponds or reservoirs."

REGULATIONS ESTABLISHING A SCALE OF WATER RENTS AND RULES GOVERNING THE USE OF WATER, FOR THE CITY OF NEW YORK.

By order of THOMAS F. GILROY, *Commissioner of Public Works.*

Under chapter 410, Laws of 1882, sections 350, 351, 352 and 353, and as amended by chapter 559, Laws 1887, as follows:

"The Commissioner of Public Works shall, from time to time, establish scales of rents for the supplying of water, which rents shall be collected in the manner now provided by law, and which shall be apportioned to different classes of buildings in said city in reference to their dimensions, values, exposure to fires, ordinary uses for dwellings, stores, shops, private stables and other common purposes, number of families or occupants, or consumption of water, as near as may be practicable, and modify, alter, amend and increase such scale from time to time, and extend it to other descriptions of buildings and establishments. All extra charges for water shall be deemed to be included in the regular rents, and shall become a charge and lien upon the buildings upon which they are respectively imposed, and if not paid, shall be returned as arrears to the clerk of arrears. Such regular rents, including the extra charges above mentioned, shall be collected from the owners or occupants of all such buildings, respectively, which shall be situated upon lots adjoining any street or avenue in said city in which the distributing water-pipes are or may be laid, and from which they can be supplied with water. Said rents, including the extra charges aforesaid, shall become a charge and lien upon such houses and lots, respectively, as herein provided, but no charge whatever shall be made against any building in which a water-meter may have been, or shall be placed as provided in this act. In all such cases the charge for water shall be determined only by the quantity of water actually used as shown by said meters. * * * The said Commissioner of Public Works is hereby authorized to prescribe a penalty not exceeding the sum of five dollars for each offense, for permitting water to be wasted, and for any violation of such reasonable rules as he may, from time to time, prescribe for the prevention of the waste of water, such fines shall be added to the regular water rents."

The regular annual rents to be collected by the Department of Public Works shall be as follows, to wit:

Croton Water Rates for Buildings from 16 *to* 50 *feet, all others not specified subject to Special Rates.*

Front Width.	1 Story.	2 Stories.	3 Stories.	4 Stories.	5 Stories.
16 feet and under	$4 00	$5 00	$6 00	$7 00	$8 00
16 to 18 feet	5 00	6 00	7 00	8 00	9 00
18 to 20 feet	6 00	7 00	8 00	9 00	10 00
20 to 22½ feet	7 00	8 00	9 00	10 00	11 00
22½ to 25 feet	8 00	9 00	10 00	11 00	12 00
25 to 30 feet	10 00	11 00	12 00	13 00	14 00
30 to 37½ feet	12 00	13 00	14 00	15 00	16 00
37½ to 50 feet	14 00	15 00	16 00	17 00	18 00

The rent of all tenements which shall exceed in width fifty feet shall be the subject of special contract with the Commissioner of Public Works.

The apportionment of the regular rents upon dwelling-houses are on the basis that but one family is to occupy the same, and for each additional family, one dollar per year shall be charged.

Meters will be placed on all houses where there is an extra use of water; where required to ascertain the amount used and where waste of water is found, and they will be charged at rates fixed by the Department for all the water passing through them.

The extra and miscellaneous rates shall be as follows, to wit:

Bakeries.—For the average daily use of flour, for each barrel, three dollars per annum.

Barber shops shall be charged from five to twenty dollars per annum each in the discretion of the Commissioner of Public Works; an additional charge of five dollars per annum shall be made for each bath-tub therein.

Bathing-tubs in private houses, beyond one, shall be charged at three dollars per annum each, and five dollars per annum each in public houses, boarding-houses and bathing establishments. Combination stationary wash-tubs, having a movable division in the centre and capable of use for bathing, shall be charged the same as bathing-tubs.

Building Purposes.—For each one thousand bricks laid, or for stone work—to be measured as brick—ten cents per thousand. For plastering, forty cents per hundred yards.

Cows.—For each and every cow one dollar per annum.

Dining saloons shall be charged an annual rate of from five to twenty dollars, in the discretion of the Commissioner of Public Works.

Fish Stands (retail) shall be charged five dollars per annum each.

For all stables not metred, the rates shall be as follows:

Horses, Private.—For two horses there shall be charged six dollars per annum; and for each additional horse, two dollars.

Horses, Livery.—For each horse up to, and not exceeding thirty in number, one dollar and fifty cents each per annum; and for each additional horse, one dollar.

Horses, Omnibus and Cart.—For each horse, one dollar per annum.

Horse Troughs.—For each trough, and for each half-barrel or tub on sidewalk or street, twenty dollars per annum; each trough to be fitted with a proper ball-cock to prevent waste.

Hotels and Boarding-houses shall, in addition to the regular rate for private families, be charged for each lodging-room, at the discretion of the Commissioner of Public Works.

Laundries shall be charged from eight to twenty dollars per annum, in the discretion of the Commissioner of Public Works.

Liquor and Lager Beer Saloons shall be charged an annual rate of ten dollars each. An additional charge of five dollars per annum shall be made for each tap or wash-box.

Photographic galleries shall be charged an annual rate of from five to twenty dollars, in the discretion of the Commissioner of Public Works.

Printing Offices, when not metered, shall be charged at such rates as may be determined by the Commissioner of Public Works.

Soda, Mineral Water and Root Beer Fountains shall be charged five dollars per annum each.

Steam Engines, where not metered, shall be charged by the horse-power, as follows: For each horse-power up to and not exceeding ten, the sum of ten dollars per annum; for each exceeding ten, and not over fifteen, the sum of seven dollars and fifty cents each, and for each horse-power over fifteen, the sum of five dollars.

Water-Closets and Urinals —To each building on a lot one water-closet having sewer connections is allowed without charge; each additional water-closet or urinal will be charged as hereinafter stated. All closets connected in any manner with sewer shall be charged two dollars for each seat per annum, whether in a building or on any other portion of the premises. Urinals shall be charged two dollars per annum each.

Water-Closets of every description that are supplied with water from a *measuring* tank or cistern from which only a limited quantity can be drawn, say about three gallons at each pull, two dollars.

Water-Closets of every description that are supplied with water from a tank other than a *measuring* tank, from which an unlimited quantity can be drawn by holding or fastening the valve open, or when the supply is received direct from the Croton supply, five dollars.

Cistern answering this description can be seen at this Department.

METERS.

Under the provisions of section 352, Consolidated Act 1882, water-meters of approved pattern shall be hereafter placed on the pipes supplying all stores, workshops, hotels, manufactories, public edifices, at wharves, ferry-houses, stables, and in all places where water is furnished for business consumption, except private dwellings.

It is provided by section 352, Laws of 1882, that "all expenses of meters, their connections and setting, water rates, and other lawful charges for the supply of Croton water, shall be a lien upon the premises where such water is supplied, as now provided by law." * * *

All manufacturing and other business requiring a large supply of water shall be fitted with a meter.

Water measured by meter, ten cents per one hundred cubic feet.

The rate charged for steam-vessels taking water daily, or belonging to daily lines, is one-half cent per ton (Custom House measurement) for each time they take water.

Steamers taking water other than daily, one cent per ton (Custom House measurement).

Permits for tugs, etc., to take water are granted for six months.

No extensions will be granted on permits for tugs that have been laid up.

No unexpired permits will be transferred to other boats.

Attention is called to chapter 6, article III., section 26, Revised Ordinances, New York, 1880:

"IN RELATION TO THE OPENING OF HYDRANTS WITHOUT PERMISSION."

"No person or persons, except the Mayor and Aldermen of the respective districts, shall, without previous permission in writing from the Commissioner of Public Works, unscrew or open any hydrant belonging or attached to the Croton Aqueduct Works, erected for the extinguishment of fires, except in cases of fires in the neighborhood; nor shall leave said fire hydrant open for a longer time than shall be limited in said permission; nor shall use the water for other purposes than may be mentioned in said permission, under the penalty of not less than five dollars nor more than twenty-five dollars for each offense, in the discretion of the magistrate before whom the complaint shall be made."

All matters not hereinbefore embraced are reserved for special contract by and with the Commissioner of Public Works.

HYDRANTS, HOSE, TROUGHS, FOUNTAINS, ETC., ETC.

No owner or tenant will be allowed to supply water to another person or persons.

All persons taking water from the city must keep their own service-pipes, street tap, and all fixtures connected therewith, in good repair, protected from frost, at their own risk and expense, and shall *prevent all waste of water.*

The use of hose to wash coaches, omnibuses, wagons, railway cars or other vehicles or horses, cannot be permitted.

No horse-troughs or horse-watering fixtures will be permitted in the street or on the sidewalk, except upon a license or permit taken out for that purpose. All licenses or permits must be annually renewed on the first of May. Such fixtures must be kept in good order and the water not allowed to drip or waste by overrunning the sidewalk or street, or to become dangerous in winter by freezing in and about such troughs or fixtures.

No hydrant will be permitted on the sidewalk or in the front area, and any hydrant standing in a yard or alley, attached to any dwelling or building, must not be left running when not in actual use, and if the drip or waste from such hydrant freezes and becomes dangerous in winter, the supply will be shut off in addition to the penalty of five dollars imposed.

Taps at wash-basins, water-closets, baths and urinals must not be left running, under the penalty of five dollars for each offense, which will be strictly enforced.

Fountains or jets in hotels, porter-houses, eating saloons, confectioneries or other buildings are strictly prohibited.

The use of hose for washing sidewalks, stoops, areas, house-fronts, yards, court-yards, gardens, and about stables, is prohibited. Where premises are provided with wells, special permits wil be issued for the use of hose, in order that the police or inspectors of this Department may understand that the permission is not for the use of Croton water.

Opening fire-hydrants to fill hand-sprinklers or other vessels will not be allowed.

The penalty for a violation of any of the preceding rules and regulations will be five dollars for each offense, and if not paid when imposed will become a lien on the premises in like manner as all other charges for unpaid water rents.

By order,

THOMAS F. GILROY,
Commissioner of Public Works.

ANALYSES OF WATERS IN THE CITY OF NEW YORK.

WATER FROM THE PUMP OF THE MANHATTAN COMPANY.*

The sample was obtained from the pump at the works (see Plate 4. page 12) before its entrance into the cistern. Its specific gravity was 1011.

One wine quart was slowly evaporated to dryness. The dry mass weighed 31.45 grains, equal to 125.80 grains of solid matter in the gallon. It consisted of

Solid Matter.	In one Gallon Water.
Muriate of soda	45.20 grains.
Muriate of magnesia	40.00 "
Sulphate of magnesia	6.00 "
Carbonate of lime with a little carbonate of magnesia	12.80 "
Sulphate of lime	4.00 "
Extractive matter with combined water	17.80 "
Total	125.80 grains.

Analysis made by George Chilton, Chemist, Nov. 25, 1831.

VARIOUS SAMPLES OF MINERAL AND PUMP WATERS.

Solid Matter in a Pint of Water.	No. 1.	No. 2.	No. 3.	No. 4.
	grains.	grains.	grains.	grains.
Muriate of magnesia	3.50	2.00	2.00	....
Muriate of soda	4.00	2.00	1.00	1.00
Sulphate of lime	0.25	1.00	....	0.25
Carbonate of lime and magnesia	1.25	1.25	....	....
Carbonate of potassium and extractive matter	0.75	....	....	....
Carbonate of lime	....	....	1.00	1.00
Sulphate of lime and extractive matter	....	....	0.50	....
Muriate of lime, magnesia, and extractive matter	....	....	....	1.80
Extractive matter and loss	....	0.75	....	....
Loss	0.25	....	....	....
Total	10.00	7.00	4.50	4.05

* From King's "Memoir of the Croton Aqueduct," New York, 1843.

RESULTS OF ANALYSES OF CROTON WATER.

Results calculated for 100,000 parts of water.

Complete Analyses of Croton Water.	Analyst, Prof. J. C. Booth.	Analyst, Dr. J. R. Chilton.		Analyst, C. F. Chandler.		Analyst, E. Waller.	
	1	2	3	4	5	6	7
	1843.	1843.	August, 1859.	Summer, 1869.	May, 1872.	May, 1879.	Nov., 1881.
Sodium chloride	.....	0.629	0.577	0.690	0.487	0.351	0.351
Calcium sulphate	.....		0.504	0.272	0.041	1.239	.....
Alkaline chlorides	0.276	.....	.....	.....	.....	.....	.....
Potassium sulphate	.....	.....	.....	0.309	0.351	0.322	0.345
Sodium sulphate	.....	.....	.....	0.449	0.041	0.343	0.371
Alkaline carbonates	1.183	.....	0.386	.....	.....	.....	0.092
Magnesium chloride	.....	1.286	0.210	.....	.....	.....	.....
Calcium chloride	.....		0.149	.....	.....	.....	.....
Magnesium carbonate	1.341	1.200	0.557	(1.888)	(1.320)	1.575	1.174
Calcium carbonate	3.276	2.171	0.194	(2.826)	(2.467)	2.830	2.262
Magnesium bicarbonate	.....	.....	.....	3.280	2.294	.....	.....
Calcium bicarbonate	.....	.....	.....	4.578	3.996	.....	.....
Ferric and Aluminic oxides	0.157	0.657	0.243	Trace	0.100	0.300	0.078
Silica	0.513			1.060	0.380	0.470	3.360
Organic and volatile	0.394		1.309	1 150	1.500	0.960	0.400
Total	.....	.....	5.129	11.788	9.190	.....	.....
Solids by evaporation	7.140	5.943	5.293	8.200	6.600	8.390	5.432
Chlorine	.....	.....	0.508	0.416	0.294	0.213	0.213

Nos. 1 and 2. From Illustrations of the Croton Aqueduct. F. B. Tower, N. Y., 1843, p. 135.
No. 3. Report of Water Commissioners of Albany for 1865, p. 50.
Nos. 4 and 5. Report of Board of Health for 1871. New York, p. 371.
No. 6. Report on Croton Water. New York, 1881, p. 45.

The above table, extracted from a pamphlet, "The Water Supply of the City of New York," by E. Waller Ph.D., is taken from the Ninth Annual Report of the Board of Health of the State of New York.

ANALYSIS OF CROTON WATER, JANUARY 4, 1895.*

Result expressed in parts per 100,000.

Appearance	Very slightly turbid.
Color	Light yellow brown.
Odor (at 100° Fahr.)	Faint marshy.
Chlorine in chlorides	0.280
Equivalent to sodium chloride	0.560
Phosphates, phosphoric acid (P_2O_5) in	None.
Nitrogen in nitrites	None.
Nitrogen in nitrates (method of Gladstone and Tribe)	0.0284
Free ammonia	0.0005
Albuminoid ammonia	0.0085
Hardness equivalent to carbonate of lime — before boiling	3.82
Hardness equivalent to carbonate of lime — after boiling	3.82
Organic and volatile (loss on ignition)	1.90
Mineral matter (non-volatile)—lost carbonic acid not restored	6.40
Total solids (by evaporation, at 230° Fahr.)	8.30
Temperature at hydrant, 42° Fahr.	

* Given in the Weekly Report of the Health Department of the City of New York.

PRINCIPAL CONTRACTS FOR WORK DONE UNDER THE AQUEDUCT COMMISSION.

Section.	Description of Work.	Contractors.	Superintendents or Assignees.	Date of Contract.	Final Estimate.
1	Substructure New Croton Gate-house	Smith & Brown	.....	August 4, 1885	$649,964.62
2	Tunnel Section	Brown, Howard & Co.	.....	December 20, 1884	2,490,829.35
3	" "	" " " "	.....	" 20, 1884	1,836,215.99
4	" "	" " " "	.....	" 20, 1884	1,805,244.83
5	" "	" " " "	.....	" 20, 1884	810,066.15
6	" "	O'Brien & Clark	Reilly & McLaughlin	" 20, 1884	748,852.97
7	" "	" " "	Paige, Cary & Co.	" 20, 1884	1,777,610.99
8	" "	" " "	Denton, Breuchaud & Co.	" 20, 1884	1,454,157.36
9	" "	" " "	Rider & Dougherty; Paige, Cary & Co.	" 20, 1884	1,922,100.89
10	" "	Heman Clark	Collins & Farwell	" 20, 1884	1,515,916.07
11	" "	" "	Rodgers, Shanly & Co.	" 20, 1884	1,105,778.60
12	" "	O'Brien & Clark	Charles Peterson & Co.	February 3, 1886	541,923.04
13	" "	John Brunton & Co.	Rodgers, Shanly & Farrell	" 3, 1886	427,641.42
14	" "	" " " "	" " " "	" 3, 1886	647,869.75
15	135th Street Gate-house	Richard A. Malone	.....	" 18, 1887	156,358.20
15½	Connection with Old Aqueduct at 135th Street	Robert Hanna & Co.	.....	April 17, 1887	27,416.82
16	Pipe Line	O'Brien & Clark	.....	May 17, 1888	1,013,220.54
17	Central Park Gate-house	Richard J. Malone	.....	January 14, 1889	37,621.69
	Deepening and Finishing Shaft No. 24	O'Brien & Clark	.....	August 7, 1888	91,904.59
	Iron-lined Masonry Aqueduct, Shaft No. 30	Breuchaud, Pennell & Co.	.....	October 16, 1888	69,369.20
	Superstructure of Pocantico Gate-house	John Peirce	.....	December 12, 1887	21,717.92
	" " Ardsley Gate-house	O'Brien & Clark	.....	October 5, 1887	4,900.00
	" " Gate-house at South Yonkers	" " "	.....	February 15, 1888	21,785.00
	" " Croton Dam Gate-house	Smith, Brown & Coleman	.....	March 18, 1890	51,783.01
	Masonry Head-houses for Shafts	Breuchaud, Pennell & Co.	.....	October 16, 1890	40 251.28
	Blow-off at Shaft No. 24	John M. Waddle	Reilly & McLaughlin	April 25, 1891	21,694.18
	Masonry Head-house, Shaft No. 25	William H. Baker	John Peirce	June 27, 1891	43,605.80
	Masonry Dam for East Branch Reservoir	Sullivan, Rider & Dougherty	.....	December 30, 1887	436,499.05
	Dams Nos. 1 and 2 at Bog Brook Reservoir	David R. Paige & Co.	.....	January 12, 1889	329,870.29
	Highways, Roads, and Fences for East Branch Reservoir	Clinton Stephens	.....	September 4, 1889	90,851.69
	Earth and Masonry Dam for Reservoir "M"	Washburn, Shaler & Washburn	.....	February 18, 1890	To Jan. 1, 1895. 959,379.85
	Highways and Appurtenances for Reservoir "M"	John Twiname	.....	May 31, 1893	66,866.83
	Main Dam for Reservoir "D"	M. S. Coleman	Coleman, Washburn & Washburn	September 19, 1890	372,944.37
	Auxiliary Dam for Reservoir "D"	" "	" " " "	" 18, 1890	144,602.76
	Highways and Appurtenances, Reservoir "D"	John Flanagan	.....	April 11, 1893	99,404.62
	Constructing New Highways, etc., Reservoir "D"	John Flanagan & Son	.....	September 25, 1894	22,546.00
	New Croton Dam	Jas. S. Coleman	.....	August 31, 1892	776,593 97
	Highways, Retaining-wall, etc., New Croton Dam	Augustine M. Newton	.....	" 6, 1891	16,717.09

WAGES PAID DURING THE CONSTRUCTION OF THE NEW CROTON AQUEDUCT AND NEW RESERVOIRS.

Classification.	New Aqueduct, 1884-1891.	New Reservoirs, 1890-1895.
	Per day of 10 hours.	Per day of 10 hours.
Superintendents	$6.00 to $10.00	.....
Foremen	3.00 " 4.00	$3.00 to $5.00
Hoisting engineers	2.50	2.25
Firemen	2.00	.....
Coal passers	1.50	.....
Machinists	2.50 to 3.00	2.50 to 3.00
Pipe-fitters	2.00	.....
Blacksmiths	2.50	2.50 to 3.00
Blacksmiths' helpers	1.50	.....
Carpenters	2.50	2.25 to 2.75
Bricklayers	5.00	.....
Stone-masons	2.50 to 3.50	3.00 to 3.50
Masons' helpers	1.50 " 1.75	.....
Stone-cutters	.....	2.50 to 3.00
Quarrymen	.....	1.75
Drill-runners	2.50	2.25
Drill-runners' helpers	1.75	1.75
Hammersmen	1.75	1.75
Riggers, tagmen, brakemen, etc	.....	1.50 to 1.75
Stable boss	1.75 to 2.00	.....
Teams, with driver	4.50	4.00
Drivers	2.00	1.25 to 1.50
Watchmen	1.50	.....
Time-keepers	2.00	.....
Book-keepers	3.00 to 4.00	.....
Intelligent labor	.....	1.50 to 1.60
Common labor, white	.....	1.30 " 1.50
" " colored	.....	1.25 " 1.40
" " Italian	.....	1.15 " 1.25
Electric-light men	2.00 to 3.00	.....
Powderman	1.75 " 2.00	.....
Bell and hoist, top-man	2.00 " 2.25	.....
Bell and pump, bottom-man	1.50	.....
Top-men and muckers	1.50	.....
Heading foreman	3.00	.....
Muck boss	2.00	.....
Nippers	1.50	.....
Water boys	1.25	.....

Item.		Section 1.	Section 2.	Section 3.	Section 4.	Section 5.	Section 6.	Section 7.	Section 8.	Section 9.
Earth excavation in open cut	per cub. yd.	.30	....	....	.90	1.75	.80	.80	.80	.80
Soiling	" " "	....	.75	.75	.75	.75	.40	.40	.40	.40
Removing and replacing soil	" " "	....	....	....	....	....	....	....	....	....
Refilling	" " "	....	....	....	....	....	....	....	....	....
" over pipes	" " "	....	....	....	....	....	....	....	....	....
Embankments	" " "	....	....	....	....	....	....	....	....	....
Sods, furnished and laid	per sq. yd.	....	....	....	....	....	....	....	....	....
Rock excavation in open cut	per cub. yd.	2.50	....	....	2.00	2.50	1.75	1.75	1.75	2.00
" " deep	" " "	....	....	....	....	....	....	....	....	....
Additional haul for each 100 feet over 500 feet	" " "	....	....	....	....	....	....	....	....	....
Tunnel excavation	" " "	5.00	7.00	6.50	6.40	6.25	7.00	7.00	7.00	6.75
Drain excavation, in tunnel	" " "	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Shaft excavation, 16′ 6″ × 33′ 0″	per lin. ft.	....	....	....	....	....	....	....	....	....
" " 16′ 6″ × 16′ 6″	" " "	....	....	....	....	....	....	....	....	....
" " 16′ 0″ × 16′ 0″	" " "	....	....	....	....	....	....	....	....	....
" " 8′ 0″ × 17′ 6″	" " "	....	120.00	100.00	100.00	100.00	150.00	150.00	150.00	150.00
" " 8′ 0″ × 11′ 0″	" " "	....	60.00	....	....	90.00	140.00	140.00	140.00	140.00
Shaft filling	per cub. yd.	....	1.00	.80	.75	.75	.40	.40	.40	.40
Brick masonry	" " "	10.00	11.00	10.00	11.00	11.00	10.00	10.00	10.00	10.00
" " lining	" " "	....	....	....	....	....	....	....	....	....
" " backing	" " "	....	....	....	....	....	....	....	....	....
" " front brick	" " "	....	....	....	....	....	....	....	....	....
" " in asphaltum mortar	" " "	....	....	....	....	....	....	....	....	....
Rubble masonry	" " "	5.40	5.00	5.00	6.00	5.50	5.00	5.00	5.00	5.00
" " lining	" " "	....	....	....	....	....	....	....	....	....
" " backing	" " "	....	....	....	....	....	....	....	....	....
" " dry	" " "	....	....	....	....	....	....	....	....	....
Concrete masonry, 5 stone to 1 cement	" " "	4.00	5.75	5.75	5.00	5.50	5.00	5.00	5.00	5.00
" " 3 " " 1 "	" " "	5.00	6.75	6.75	6.00	6.50	5.50	5.50	5.50	5.25
" " lining, 5 stone to 1 cement	" " "	....	....	....	....	....	....	....	....	....
" " " 3 " " 1 "	" " "	....	....	....	....	....	....	....	....	....
" " backing, 5 stone to 1 cement	" " "	....	....	....	....	....	....	....	....	....
" " " 3 " " 1 "	" " "	....	....	....	....	....	....	....	....	....
Add. for all kinds masonry laid in Amer. cem. mort., 1 : 1	" " "	.50	1.00	1.00	1.00	1.00	1.25	1.25	1.25	1.50
" " " " " " " Port. " " 1 : 1	" " "	....	....	....	....	....	....	....	....	....
" " " " " " " " " " 2 : 1	" " "	1.50	2.50	2.50	2.50	2.50	1.50	1.50	1.00	1.50
" " " " " " " " " " 3 : 1	" " "	....	....	....	....	....	....	....	....	....
Dimensions stone masonry, granite	" " "	....	....	....	....	....	....	....	....	....
Cut-stone masonry	" " "	40.00	60.00	60.00	50.00	60.00	40.00	40.00	40.00	35.00
Cut facing-stone masonry	" " "	11.00	....	....	....	....	....	....	....	....
Block-stone masonry	" " "	....	....	....	....	....	....	....	....	....
Broken ashlar masonry	" " "	....	....	....	....	....	....	....	....	....
Split-stone masonry in mortar	" " "	....	....	....	....	....	....	....	....	....
" " " dry	" " "	....	....	....	....	....	....	....	....	....
Fine-hammered (6 cut) face for cut stone	per sq. ft.	.25	....	....	.75	....	....	.90	....	.90
Rough-pointed face-dressing for cut stone	" " "	.15	....	....	.25	....	....	.80	....	.80
Face-work for rubble masonry	" " "	.15	....	....	.20	....	....	.80	....	.80
Rectangular paving	per cub. yd.	6.00	....	....	15.00	....	....	2.50	....	2.50
Dry rubble masonry and paving	" " "	....	....	....	7.50	....	....	2.00	....	2.00
Riprap	" " "	....	....	....	....	....	....	....	....	....
Broken stone, placed	" " "	....	....	....	....	....	....	....	....	....
Tile drain, 6″	per lin. ft.	....	.30	.30	.30	.30	.30	.30	.30	.40
" " 8″	" " "	....	.45	.45	.45	.45	.40	.40	.40	.65
" " 10″	" " "	....	.60	.60	.60	.60	.65	.65	.65	.90
" " 12″	" " "	....	.70	.70	.70	.70	.90	.90	.90	.90
" " 15″	" " "	....	1.15	1.15	1.15	1.15	1.25	1.25	1.25	1.25
" " 18″	" " "	....	1.25	1.25	1.25	1.25	1.50	1.50	1.50	1.50
Yellow pine, planks furnished and placed	per 1000 ft. B.M.	....	....	....	....	....	....	....	....	....
" " matched boards, mouldings, etc., painted	" " "	....	....	....	....	....	....	....	....	....
Hemlock timber, furnished and placed	" " "	....	....	....	....	....	....	....	....	....
Lumber, furnished and placed	" " "	....	....	....	50.00	50.00	30.00	30.00	30.00	30.00
Timber, tongued and grooved, furnished and placed	" " "	....	....	....	....	....	....	....	....	....
Piles, driven and prepared	per lin. ft.	....	....	....	.50	.50	.25	.25	.25	.25
Fencing, stone-wall	" " "	....	....	....	....	....	....	....	....	....
" post and rail	" " "	....	....	....	....	....	....	....	....	....

* See notes

CROTON AQUEDUCT AND RESERVOIRS.*

Section 10.	Section 11.	Section 12.	Section 13	Section 14	Section 15.	Section 15½.	Section 16.	Section 17.	Blow-off at Shaft 24.	Masonry Dam, East Branch Reservoir.	Dams Nos. 1 and 2, Bog Brook Reservoir.	Roads and Fences, East Branch Reservoir.	Earth and Masonry Dam, Titicus Reservoir.	Highways, etc., Titicus Reservoir.	Main Dam, Carmel Reservoir.	Auxiliary Dam, Carmel Reservoir.	New Croton Dam.*	Jerome Park Reservoir.*
.50	.50	.30	.70	.70	.50	.45	.30	.75	.34	.35	.26	.29	.25	.26	.30	.30	.61	.23½
.50	.50	.20	.42	.42	....	....	....	....	....	....	....	....	....	....	....	....	.50	.25
....	....	....	....	....	.70	.70	.20	.50	....	.40	.55	....	.65	....	.60	.60	....	....
....	....	....	....	....	.50	.35	....	.75	.20	.25	....	....	....	....	....	....	.25	....
....	....	....	....	....	....	.35	.25	.75	.20	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	.25	....	....	....	....	....	....	....	....	....	.25	....
....	....	....	....	....	....	....	.20	1.25	.32	.30	.20	....	.30	....	.40	.40	.30	.15
1.75	1.75	2.50	2.00	2.00	2.50	1.73	1.45	3.00	1.75	1.50	.90	1.00	2.25	1.20	.80	.80	1.95	.86
....	....	....	....	....	....	....	....	....	....	2.00	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	.015	.05	....	.015	....	.05	.05	....	....
7.00	7.50	8.00	6.44	6.44	....	....	....	....	....	....	5.50	....	....	....	....	....	....	....
1.00	1.00	2.00	.75	.75	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	200.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	100.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
150.00	150.00	....	90.00	90.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	140.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
.40	.40	.40	1.00	1.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	11.00	11.75	10.00	13.00	11.25	9.50	9.00	13.00	12.00	12.00	12.00	12.00	....	10.00
10.00	10.00	11.00	8.90	8.90	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8.50	8.50	9.35	7.57	7.57	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	30.00	....	....	70.00	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	20.00	....	10.00	20.00	....	13.00	....	15.00	15.00	....	....
....	....	....	....	....	6.00	....	....	6.00	4.75	3.75	3.50	5.00	3.40	4.50	4.00	4.00	4.05	3.20
5.00	5.00	4.50	4.60	4.60	....	4.50	6.00	....	....	....	....	....	....	....	....	....	....	....
4.25	4.25	3.83	3.91	3.91	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	1.50	3.00	....	....	....	....	....	....	....	....	....	....	....
5.00	5.00	....	....	....	5.00	5.75	5.00	....	....	4.50	5.00	6.00	4.00	4.50	5.00	5.00	4.55	3.75
5.50	5.50	....	....	....	6.00	6.00	6.00	7.00	5.00	5.00	5.00	....	4.50	....	6.00	6.00	....	....
....	....	4.00	5.40	5.40	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	5.00	6.40	6.40	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4.25	4.25	3.40	4.59	4.59	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4.68	4.68	4.25	5.44	5.44	....	....	....	....	....	....	....	....	....	....	....	....	....	....
1.25	1.25	1.50	1.00	1.00	.75	1.00	1.00	....	....	.30	.75	....	.70	....	.75	.75	....	....
....	....	....	....	....	....	....	....	....	....	1.00	2.50	....	2.50	....	2.00	2.00	....	....
1.50	1.50	1.12	2.00	2.00	1.00	1.75	2.00	....	1.25	.75	1.25	1.50	1.75	1.00	1.50	1.50	....	.96
....	....	....	....	....	....	....	....	....	....	.50	.75	....	1.00	....	1.00	1.00	....	.64
....	....	....	....	....	30.00	....	50.00	51.00	32.00	23.00	30.00	12.00	20.00	25.00	35.00	35.00	35.00	35.00
40.00	40.00	40.00	32.00	32.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	18.00	....	....	....	....	10.00	....	....	12.00	....	15.00	....	13.50	....
....	....	....	....	....	....	....	....	....	....	....	....	....	15.00	....	20.00	....	15.00	....
....	....	....	....	....	25.00	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	8.50	4.00	6.00	....	5.00	....	....	....	....
....	....	....	....	....	....	....	....	....	....	8.00	4.00	6.00	....	5.00	....	....	....	....
....	....	.80	....	....	.75	....	.85	.80	....	.75	.60	.50	.50	.50	.75	.75	.65	.60
....	....	.50	....	....	.25	....	.45	.45	....	.20	.40	.40	.20	.25	.40	.40	.40	.55
....	....	....	....	....	....	....	....	....	....	.30	.40	.40	.30	.30	.50	.50	.40	.25
....	....	....	....	....	18.00	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	3.00	1.50	4.00	2.00	2.50	2.75	2.75	2.50	2.50
....	....	....	....	....	....	....	....	....	....	1.50	2.00	1.50	1.75	1.00	1.50	1.50	1.75	1.50
....	....	....	....	....	....	....	....	....	....	2.00	1.50	....	2.00	....	1.75	1.75	1.50	2.00
.30	.30	.30	.40	.40	.50	....	.50	....	....	....	....	....	....	....	....	....	....	.20
.40	.40	.40	.50	.50	.50	....	....	....	....	....	....	....	....	....	....	....	....	.30
.65	.65	.60	.60	.60	....	....	.75	....	....	....	....	....	....	....	....	....	....	....
.90	.90	1.50	.75	.75	....	....	1.00	....	.50	....	....	....	....	....	....	....	....	.40
....	....	....	....	....	....	....	1.70	....	....	....	....	1.50	....	.80	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	33.00	....	....	....	....	....	....	....	....	....
....	....	....	....	....	60.00	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	30.00	20.00	....	....	....	....	30.00	....	30.00	....	....	....	....
....	....	....	....	....	....	....	....	....	....	50.00	30.00	50.00	30.00	35.00	35.00	35.00	....	50.00
....	....	....	....	....	....	....	....	....	....	....	40.00	....	32.00	....	45.00	45.00	45.00	65.00
....	....	....	....	....	....	....	....	....	.37	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	.70	....	.70	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	.12	....	.15	....	....	.50	....

on page 298.

Item.	Section 1.	Section 2.	Section 3.	Section 4.	Section 5.	Section 6.	Section 7.	Section 8.	Section 9.
Cast-iron hub and spigot pipe, 48", furnished...per ton of 2000 lbs.	....	....	....	....	....	....	....	....	....
" " " " " 20", " ... " " " " "	....	....	....	....	....	....	....	....	....
" " " " " 12", " ... " " " " "	....	....	....	....	....	....	....	....	...
" " " " " 6", " ... " " " " "	....	....	....	....	....	....	....	....	....
Laying cast-iron pipe, 48"....per lin ft.	....	....	....	....	...	....	....	....	....
" " " 20" .... " " "	....	....	....	....	....	....	....	....	....
" " " 12"....." " "	....	....	....	....	....	....	....	....	....
" " " 6"....." " "	....	....	....	....	....	....	....	....	....
Cast-iron hub and spigot pipe, furn. and placed, 48", per ton 2000 lbs.	....	....	....	....	....	....	....	....	....
" " " " " " " " 36", " " " "	....	....	....	....	...	....	....	....	....
" " " " " " " " 30", " " " "	....	....	....	....	....	....	....	....	....
" " " " " " " " 12", " " " "	....	....	...	....	....	....	....	....	....
Special castings furnished..... " " " "	....	....	....	....	....	...	....	....	....
Special castings, furnished and placed. ..... " " " "	....	....	....	...	....	....	....	....	....
Cast iron, furnished and placed..... .... " " " "	....	....	....	...	....	....	....	....	....
Cast-iron shaft and tunnel-lining, furn. and placed.. " " " "	....	....	....	....	....	....	....	....	....
" 48" reducers, furnished and placed ..... " " " "	....	....	....	....	....	....	....	....	....
Wrought iron, furnished and placed..... " " " "	....	....	....	....	...	....	....	....	....
Stop-cocks, complete, furnished and placed, 48".....each	....	....	....	....	....	....	....	....	....
" " " " " 36"..... "	....	....	....	....	....	....	....	....	....
" " " " " 20"..... "	....	....	...	....	....	....	....	....	....
" " " " " 12"..... "	....	....	....	...	....	....	....	....	....
" " " " " 6"..... "	....	...	....	....	....	....	....	...	....
Hydrants, furnished and placed..... "	....	....	....	....	....	....	....	....	....
Ventilators, copper, furnished and placed, 12" ..... "	....	....	....	....	....	....	....	...	....
" " " " " 6"..... "	....	....	....	....	....	....	....	....	....
Gutters, etc., copper, 16 oz.....per sq. ft.	....	....	...	....	....	...	....	....	....
Leaders, copper, furnished and placed.....per lin. ft.	....	....	....	....	....	....	....	....	....
Roofing, slate, furnished and placed.....per 100 sq. ft	....	....	....	....	....	....	....	....	....

NOTE.—In addition to the principal contract prices given in the table the following prices for special work may be of interest:

(1) NEW CROTON DAM.—Earth excavation in vertical trench, 95 cents per cubic yard; permanent timber-work, placed and fastened, $40 per 1000 feet B. M.; crib-work, placed in complete order, including timber, iron, etc., $3 per cubic yard; brick masonry laid in Portland cement mortar (2 : 1), $10 per cubic yard.

(2) JEROME PARK RESERVOIR.—Excavation for the branch aqueduct: earth, 25 cents per cubic yard; rock, $1.50 per cubic yard; with 1 cent per cubic yard for extra haul of earth or rock beyond the limits fixed in the contract. Concrete masonry with Portland cement mortar (3 : 1) for bottom and sides of reservoir, if less than 4" thick, $4.80 per cubic yard; if over 4" thick, $4.60 per cubic yard.

CROTON AQUEDUCT AND RESERVOIRS—(*Continued*).

Section 10.	Section 11.	Section 12.	Section 13	Section 14	Section 15.	Section 15½.	Section 16.	Section 17.	Blow-off at Shaft 24.	Masonry Dam, East Branch Reservoir.	Dams Nos. 1 and 2, Bog Brook Reservoir.	Roads and Fences, East Branch Reservoir.	Earth and Masonry Dam, Titicus Reservoir.	Highways, etc., Titicus Reservoir.	Main Dam, Carmel Reservoir.	Auxiliary Dam, Carmel Reservoir.	New Croton Dam.	Jerome Park Reservoir.
....	....	....	....	....	24.00	....	25.00	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	25.00	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	25.00	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	25.00	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	1.93	1.70	2.50	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	.75	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	.40	1.25	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	.40	....	....	....	....	....	....	....	....	....	....	....
....	....	40.00	....	....	....	....	....	....	....	100.00	....	....	38.00	....	40.00	....	....	30.00
....	....	....	....	....	....	....	....	....	36.00	....	50.00	....	....	....	....	40.00	....	....
....	....	....	....	....	....	....	....	....	36.00	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	100.00	....	....	....	....	....	....	....	....
....	....	....	....	....	....	46.50	54.00	60.00	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	60.00
....	....	....	....	....	60.00	....	....	....	67.50	120.00	40.00	....	100.00	....	100.00	100.00	....	....
....	....	80.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	45.00	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	120.00	....	....	90.00	....	100.00	100.00	....	160.00	50.00	....	100.00	....	100.00	100.00	....	80.00
....	....	....	....	....	....	....	1500.00	....	....	1200.00	....	....	1500.00	....	1500.00	....	....	....
....	....	....	....	....	....	....	....	....	765.00	850.00	800.00	....	....	....	....	800.00	....	....
....	....	....	....	....	....	....	....	....	225.00	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	100.00	....	....	75.00	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	50.00	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	70.00	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	65.00	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	35.00	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	.25	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	1.00	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	12.00	....	....	....	....	....	....	....	....	....	....	....	....	....

NOTE.—*The sluice-gates with the lifting machinery*, furnished and placed, cost as follows: 3′ × 6′ gates, each, $1225; 3′ × 4′ gates, each, $675; 2′ × 5′ gates, $595 to $893.

	Boiler.	Engines.	Compressors.	Receivers.
Gate-house at Croton Lake.	Two Ingersoll, 60"x 16', 80 H.P. each One boiler in inlet	Five Lidgerwood hoists, cylinders 8"x12" One Lidgerwood hoist, cylinders 10"x12" One Copeland & Bacon hoist, cylinders 8"x10" One 10 H.P. Westinghouse (for dynamo) One 20 H.P. Westinghouse	One Ingersoll, 14"x24"	One upright Ingersoll, 42"x10'
Shaft or Portal. 0	Two Ingersoll, 60"x16', 80 H.P. each Two Ingersoll, 60"x14', 100 H.P. each One upright Ingersoll, for hoist, 30 H.P.	One Bacon & Copeland hoist	One Ingersoll, cylinders 24"x30" One Ingersoll, cylinders 20"x30" One Ingersoll, cylinders 12"x18"	One Ingersoll 3'x21' horizontal Two 42"x10' upright
1	One Ingersoll, 60"x16', 60 H.P. " " 60"x13', 40 H.P.	One Dickson hoist, 12"x18" cylinder Two Dickson mining cages		
2	Two Ingersoll, 66"x14' One 10 H.P. upright, for water supply	One Dickson hoist, 12"x18" cylinders, 50 H.P. Two Dickson mining cages One Payne, 8"x9" (for dynamo)	One Ingersoll, 24"x30" cylinders, 200 H.P.	One Ingersoll, 3'x20'
3	Three Ingersoll, 56"x18', 60 H.P.	One Dickson hoist, 12"x18" cylinders Two Dickson cages One Payne, 8"x9" (for dynamo)	Two Ingersoll, 18"x30" cylinders	One horizontal, 3'x17'
4	Two Ingersoll, 60"x14', 90 H.P. each One upright, 10 H.P., to supply water	One Dickson hoist, 12"x18" cylinders, 50 H.P. Two Dickson cages One 9"x9" Lidgerwood (for dynamo)	One Ingersoll, 24"x30" cylinders	One horizontal, 3'x20'
5	Two Ingersoll, 66"x14', 87 H.P. each One 10 H.P. upright, to supply water	One Dickson hoist, 10"x10" cylinders, 30 H.P. One Lidgerwood (for dynamo)	Two Ingersoll, 18"x30" cylinders	Two Ingersoll, 11' 6"x 48"
6	Two Ingersoll, 66"x14' One 10 H.P. upright, 3'x7', for water supply	One Dickson hoist, 12"x12" cylinders, 35 HP. One Payne 10"x12" automatic (for dynamo)	Two 18"x30"	One Ingersoll, 42"x 17'
7	One Ingersoll, 54"x14', 55 H.P.	One Dickson hoist, cylinders 10"x12"		
9	Two Ingersoll, 66"x14', 90 H.P. each Two Ingersoll, 54"x16', 70 H.P. each One portable, 30 H.P.	One Portable 30 H.P. One Blake crusher One engine, cylinder 12"x16", N. Y. S. S. P. Co. (for dynamo)	Two Ingersoll, 20"x30" One Ingersoll, 24"x30"	One, 52"x11' 8" One, 52"x6' 6"
10	Two Ingersoll, 66"x14', 80 H.P. each One 8 H.P. upright	One Double Dickson hoist, 40 H.P., 12"x12" Two Dickson cages One Lidgerwood, 10"x12" (for dynamo)	Two Ingersoll, 18"x30"	Two Ingersoll, 42"x 10' Two, 42"x12'

NOTE.—This Table is condensed from Table 13 of the

PLANT.*

	Blowers.	Pumps.	Electric Light.	Drills.
Gate-house at Croton Lake.		Two No. 5 Worthington, in inlet One No. 2 Cameron (feed) One No. 22½ Hancock inspirator for boiler One No. 17½ Hancock inspirator for boiler	Two Ball 10-light dynamos Fourteen Ball arc lamps	Three 3½" Ingersoll drills and tripods Two 3⅛" Ingersoll drills and tripods Three 3½" Ingersoll drills and tripods One 4¼" Ingersoll drills and tripods One 4" Rand drills and tripods One 3½" Sargent drills and tripods
Shaft or Portal. 0		Two No. 8 Cameron feed, for boiler One No. 6 Cameron, in tunnel		Three 3½" Ingersoll drills and tripods
1		Two No. 9 Cameron One No. 4 "		Ten 3½" Ingersoll Six 3⅛" "
2		One No. 6 Cameron, for water supply One No. 4 " feed One No. 4, in shaft One No. 6, " One No. 9	One Ball 10-light dynamo, 12,000 candle power	Nine 3½" Ingersoll, complete Five 3⅛" Ingersoll, complete
3		Three No. 9 Cameron, in shaft One No. 6 Cameron feed	One Ball 10-light dynamo, 12,000 candle power	Ten 3½" Ingersoll, complete Six 3⅛" Ingersoll, complete
4		One No. 6 Cameron One No. 9 " One No. 6 feed	One Thomson-Houston 10-light dynamo, size No. 9	Seven 3½" Ingersoll Four 3⅛" "
5		One No. 6 Cameron, for water supply One No. 9 " in sump One No. 4 " feed, for boiler	One Thomson-Houston 10-light dynamo	Ten 3½" Ingersoll Five 3⅛" "
6		One No. 6 Cameron, for water supply One No. 6 " in sump One No. 4 " feed, for boiler	One Ball dynamo electric machine	Eleven 3½" Ingersoll Five 3⅛" "
7		One No. 9 Cameron, in sump One No. 4 " feed, for boiler		Eleven 3½" Ingersoll Six 3⅛" "
9		Three No. 6 Cameron	One Schuyler dynamo, No. 1, Type No. 2	Twelve 3½" Ingersoll Four 3⅛" "
10		Two No. 9 Cameron One No. 6 "	One Thomson-Houston 10-light dynamo	Twelve 3½" Ingersoll, complete Six 3⅛" Ingersoll, complete

Aqueduct Commissioners' Report of January 1, 1887.

	Boilers.	Engines.	Compressors.	Receivers.
11A	One Ingersoll, 66"x14', 90 H.P. Two Ingersoll, 66"x14', 90 H.P. each	One Lidgerwood hoist, double cylinders, 10"x12", 30 H.P. One Dickson cage One Greenfield upright, 10"x 12", 15 H.P. One engine, N. Y. S. S. P. Co. (for dynamo)	One Ingersoll, 20"x30" cylinders One Ingersoll, 18"x30" cylinders	Two 48"x12' upright
11B	One Ingersoll, 54"x14', 55 H.P.	One Lidgerwood hoist, double cylinder, 10"x12", 30 H.P. One Dickson cage		
12A & 12B	Two, 60"x16', 80 H.P. each One, 60"x14', 60 H.P.	Four single drum Lidgerwood hoists Two Lidgerwood hoists, 10"x 12" double cylinders One Greenfield upright, 15 H.P. Two Sullivan & Ehler, 15 H.P. each One Blake crusher, 9x15 jaw	One half of one duplex Rand, 18"x30" One compound Norwalk, 20" x 24", 90 H.P.	One air, 4'x14'
13	Two Delamater, 5'x12', 50 H.P. each One Lidgerwood	One double cylinder Lidgerwood hoist, cyls. 8"x12" One Sullivan & Ehler, 8"x12" One Lidgerwood, 8"x12"	One duplex Rand air, 18"x30"	One Rand air, 3½'x9'
14 & 14A	Two Delamater, 5'x12', 50 H.P. each	One Sullivan & Ehler, No. 5, 8"x10" One Lidgerwood, 8"x10"	One duplex Rand, 18"x 30" One Davies, 12"x24"	One air
15	Two Delamater, 5'x12', 50 H.P. each	One Sullivan & Ehler, 8"x12" One Otis hoisting, 10"x12" One Lidgerwood, 8"x12"	One duplex Rand air, 18"x30"	One air
16	Two Delamater, 5'x12', 50 H.P. each	One Westinghouse, 10"x11" One " 6"x6½" One Lidgerwood hoist, 8"x12"	One duplex Rand air, 18"x30"	One air
17	Two Delamater, 5'x12', 50 H.P. each	One Westinghouse, 10"x11" One " 6"x6½" One Lidgerwood hoist, 8"x12"	One duplex Rand air, 18"x30"	One air
18 & 18½	Two Sullivan & Ehler, 5'x14', 75 H.P. each Two Sullivan & Ehler, 5'x14', 75 H.P. each One upright tubular, 20 H.P. " " " 15 H.P. One steam, 40 H.P. " " 20 H.P.	One Sullivan & Ehler, 8"x10" Two double drum hoisting, 8"x10" Two single hoisting, 6"x12" One double hoisting, 6"x12" One No. 4 Westinghouse One engine for fan, 10 H.P. One Blake stone crusher One Payne, 15 H.P.	One half duplex Rand air, 18"x30" One single Rand, 12"x 16" One half duplex Rand air, 18"x30" One single Rand, 12"x 16"	One air, 5'x 14'
19	Two Delamater, 5'x12', 75 H.P. each	One 10 H.P., 12"x12" One Westinghouse, 6"x6½" One Dixon hoisting, No. 5	One duplex Rand, 18"x 30"	One air, 5'x12'
19½	One horizontal return tubular, 2'6"x11'6", 25 H.P.	One Lidgerwood single cylinder hoist, double drum cylinder, 8¼"x10"		
20	Two horizontal return tubular, 5'x12', 75 H.P. each	One Lidgerwood double cylinder hoist, cyls. 8¼"x12" One Sullivan & Ehler reversible, 12"x12" One Sullivan & Ehler, 8"x10"	One half of one Rand duplex, 18"x30" One Rand single, 12"x 16"	One horizontal, 13' 9"x4'

PLANT—(*Continued*).

	Blowers.	Pumps.	Electric Light.	Drills.
11A		One No. 9 Cameron One No. 4 " One No. 6 "	One Schuyler 10-light dynamo, No. 6, Type No. 2	Nine 3½" Ingersoll
11B		One No. 9 Cameron One No. 3 "		Nine 3½" Ingersoll
12A & 12B	One No. 5½ Baker	One Pulsometer, No. 5, 4" discharge One No. 5, Blake feed, 5"x8" cylinder Two centrifugal, No. 4, 4½" discharge Two No. 9 Cameron One No. 11 "	Two Ball 10 light dynamos	Ten 3½" Ingersoll, complete Four 3½" Ingersoll, complete Four 3½" Rand "Slugger" complete Two 3½" Sergeant
13	One No. 4½ Baker	One Davidson, No. 4 Two Blake One Delamater	One Thomson-Houston 15-light dynamo	Twelve Rand
14 & 14A	One No. 4½ Baker	One Blake, No. 4½ One Davidson feed, No. 3 One Blake, No. 3	One Thomson-Houston 15-light dynamo	Ten Rand "Slugger"
15	One No. 4½ Baker	One Davidson feed, No. 3 Two Blake, No. 8	One Thomson-Houston 15-light dynamo	Five Rand "Slugger"
16	Two No. 4½ Baker	One Blake	One Ball 10 light dynamo	Eight No. 3 dynamic
17	Two No. 4½ Baker.	One Blake	Two U. S. Electric Light Co. dynamos, 6-light power each	Five "Rattler"
18 & 18½	One No. 6 Sturtevant	One No. 4 Dean One No. 4 pulsometer One No. 2 Blake One No. 2 Blake feed One No. 6 pulsometer One No. 4 double plunger Dean	One Thomson-Houston 13-light dynamo One Ball 13-light dynamo	Ten Rand Three Ingersoll
19	One No. 5½ Baker	Two Dean One Delamater feed, No. 5	One Ball 13-light dynamo	Six Rand Six Ingersoll
19½		One Cameron No. 9 horizontal steam		
20	One Baker, No. 5	One Cameron No. 8 horizontal steam One Delamater No. 4 horizontal piston, for boiler feed	One Thomson-Houston 10-light dynamo	Thirteen Rand

	Boilers.	Engines.	Compressors.	Receivers.
21	Two Delamater, 5'x12', 75 H.P. each One horizontal, 4'x16'9", 50 H.P. each	One Lidgerwood double cylinder hoisting, cylinder 8"x12" One Sullivan & Ehler reversible, 12"x12" One Sullivan & Ehler, 8"x10"	One Rand duplex, 18"x 30"	One horizontal, 13'9"x4'
22	Two Delamater, 5'x12', 75 H.P. each One Porter, 5'x14', 60 H.P.	One Otis double cylinder reversible hoisting One Sullivan & Ehler, 8"x10" One " " 7"x9" One N. Y. S. S. P. Co. vertical, 7"x9"	One half of one Rand duplex air, 18"x30" One Norwalk air, 14"x 16"	One horizontal, 13'6"x4'
23	Two Sullivan & Ehler, 5'x15', 65 H.P. One Kings County, 5'x15'	One Otis double cylinder reversible hoisting One N. Y. S. S. P. Co. vertical, 8"x9" One Sullivan & Ehler horizontal, 8"x10"	One half of one Rand duplex air, 18"x30" One Norwalk, 14"x16"	One horizontal air, 13'9"x4'
24	Two Delamater, 5'x12'	One Lidgerwood double cylinder reversible hoisting, 8½"x12" One single cylinder hoisting 6"x10" One N. Y. S. S. P. Co. vertical, 7"x9" One N. Y. S. S. P. Co., 10"x14"	One Norwalk air, 20"x 24"	One air, 8'x3'
25 & 26	Three horizontal "Bay State," 5½'x14', 100 H.P. each Two upright	One Otis hoisting, 2 cylinders, 10"x10" One Otis hoisting, 2 cylinders, 7"x10" One Mandy, 1 cylinder, 6"x10" One Sullivan & Ehler, 2 cylinders, 6"x6" One Copeland & Bacon, 2 cylinders, 6"x6" One Sullivan & Ehler, 1 cylinder, 8"x14"	One Ingersoll, 24"x30"	One Ingersoll air, 13½'x20'
27	One Bigelow, 54"x9', 50 H.P.	One Otis double cylinder hoisting, 8"x10"		
28	Two horizontal Bigelow, 5'x16', 100 H.P. each	One Otis double cylinder hoisting, 8"x10"	One Ingersoll, 24"x26"	One air, 54"x12'
29	One horizontal, 5'x16', 100 H.P.	One Otis double cylinder hoisting, 8"x10"	One Norfolk compound, 22"x24"	One air, 3'x7'
30	One vertical, 54"x9', 50 H.P.	One Otis double cylinder hoisting, 8"x10"		
31	Two horizontal return flue, 5'x16' 00 H P each	One Otis double cylinder hoisting, 8"x10"	One duplex Rand, 18"x 30"	One air, 4'x16'
32	One Sullivan & Ehler vertical, 4'x8' 30 H.P	One Sullivan & Ehler hoisting, 2 cylinders, 5"x12"		

PLANT—(*Continued*).

	Blowers.	Pumps.	Electric Light	Drills.
21	One Baker, No. 5	One Blake horizontal piston steam, No. 9 One Cameron horizontal piston steam, No. 10 One Delamater No. 4 horizontal (boiler feed)	One Thomson-Houston 10 light dynamo	Thirteen Rand "Slugger"
22	One Baker, No. 5	One Cameron vertical sinking, No. 7 One Blake " " One Davison No. 2 horizontal piston (for feeding boiler)	One Thomson-Houston 14-light dynamo	Twelve Ingersoll
23	One Baker, No. 5	One Davison deep well One Cameron vertical sinking, No. 7 One Davison No. 3 horizontal piston	One Thomson-Houston 14-light dynamo	Twelve Ingersoll 3½"
24	One "Korting's patent" air inspirator	Two Dean vertical sinking One Davison No. 3 horizontal piston	One Thomson-Houston 15-light dynamo	Five Ingersoll 3½"
25 & 26		One Knowles (steam cyl. 6"x12")	One Thomson-Houston 15-light dynamo	Seven Ingersoll
27		One Deane hanging (steam cyl. 7"x10")		Four Ingersoll
28		One No. 7 Cameron		Four Ingersoll
29		One Deane hanging (steam cyl. 7"x10")		Four Sergeant
30		One Deane hanging (steam cyl. 7"x10")		Six Ingersoll
31		One Deane hanging (steam cyl. 7"x10")		Six Rand No. 3 "Slugger"
32		One Deane vertical		Three Rand "Little Giant"

Week Ending	0	1	2	3	4	5	6	7	10	11A	11B	12A	12B	13	14	15	16
1885																	
January 10		6				8			7	8		7	7	5			
" 17			3	6			4	3		8	6		8	5		2	4
" 24				7						10		5				8	6
" 31				7	8					2		5	8			9	4
February 7	7			15	8				2	3	4	6	6	5		9	5
" 14	8			16	17			4	11		10	4		8	10	8	4
" 21	5			14	14	10		14	10		3	6	3	7	3	5	4
" 28	9	17	9	8	19	3	3	6	9		3	4	4	7	3	8	9
March 7	41	5	9	8	13	14	16	15	10		6	5	3	6	8	10	8
" 14	42	12	17	1	14	13	12	15	6		3			7	3	10	3
" 21	30	9	9	8	5	12	10	6	10					10	1	11	3
" 28	25	13	14	6	17	10	13	10	3					7		9	10
April 4	28	16	6	16	10	12	9	8	13					9		5	9
" 11	15	12	17	8	17	11	12	11	12					10		7	3
" 18		14	5	12	4	11	9	10	10					10		10	
" 25		13		3	2	5	4	7	6					6		7	
May 2		14		6	6		5	10	9					13		9	
" 9		9	14	6	6		6	7	7					10			
" 16		10	6	2	9		6	7	1					13			
" 23		15	10	10	8		3	8						12			
" 30			4		13			6						4			
June 6				14	12			13									
" 13		13	3	13	14			2									
" 20		12	10	9	15		5										
" 27		14	10	5	8		3										
July 4		16	12	7			6										
" 11		14	10	16			3										
" 18		9	8	15			2										
" 25		4	9	18			8										
August 1		18		13			11										
" 8		16	4	18			9										
" 15		20	10	18			12										
" 22		18	9	11			8										
" 29		14	12	12			1										
September 5			10	10													
" 12			12														
" 19			13														
" 26			13														
October 3			10														
" 10																	
" 17																	
" 24			3														
" 31			11														
November 7			10														
" 14			11														
" 21			15														
" 28			7														
December 5			9														
" 12			5														
1886																	
February 27																	
March 6																	
" 13																	
" 20																	
" 27																	
April 3																	
" 10																	
" 17																	
" 24																	
May 1																	
" 8																	
" 15																	
" 22																	
" 29																	
June 5																	
" 12																	
" 19																	
" 26																	
July 3																	
" 10																	
" 17																	
" 24																	
" 31																	
Total	210	333	349	331	246	109	180	162	126	31	35	42	39	154	28	127	72
Av. per work'g week	21.0	12.8	9.4	10.3	10.7	9.9	7.2	8.5	7.9	6.2	5.0	5.2	5.6	8.1	4.7	7.9	5.5

NOTE.—By July 31st, 1886, all shafts

IN SHAFT EXCAVATION (LINEAL FEET).

Week Ending	17	17½	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1885																
January 10				13	6	6	7	16								
" 17	11		8	1	7	1	1									
" 24	7		1	3	3	7	5	14								
" 31	3		5	3	4	6	5	8								
February 7	9		7	6	8	5	3	7								
" 14	7		10	5	1	4	5	7								
" 21	5		3	8	2	5	6	6								
" 28	7		5	10		6	5	5								
March 7	6		13	6	1	3	3	5								
" 14	5		12	9	4	5	2	3								
" 21			4	4	8	4	3	5								
" 28				8	7	3	4	3								
April 4				11	5	7	6	3								
" 11				15	6	6	6	5								
" 18				11	6	9	4	2								
" 25				2	12	4		3								
May 2					9			4								
" 9					11			4								
" 16					2			5								
" 23								4								
" 30								3								
June 6								9								
" 13		12						6								
" 20		8						4								
" 27		2						4								
July 4								7								
" 11								3								
" 18								9								
" 25								4								
August 1								7								
" 8								1								
" 15								6								
" 22								4								
" 29																
September 5																
" 12																
" 19																
" 26																
October 3																
" 10																
" 17																
" 24																
" 31																
November 7																
" 14																
" 21																
" 28																
December 5																
" 12																
1886																
February 27											4	4	7	5	6	6
March 6									4		5	12	6	3	10	7
" 13									7		5	4	1	7	7	6
" 20									4		7	4	3	11	8	12
" 27									5		6	7	11	8	12	13
April 3									7		6	2	7	4	5	3
" 10									6	10	2	2	1	11	12	10
" 17									10	13	5	5	7	7	10	6
" 24									7	8	7	5	5	7	8	7
May 1									8	4	6	8	3	7		10
" 8									8	11	3	5	9	10		3
" 15									6	9	7	3	7			
" 22									7	12	12	6	5			
" 29									8	10	8	4	9			
June 5									6	13		12	10			
" 12									10	14	10	7	8			
" 19									2	11	10	3	11			
" 26									10	1	11	7	4			
July 3									8		8	8				
" 10									9		8	6				
" 17									11		12	8				
" 24									6		1	1				
" 31									10							
Total	60	22	68	115	102	81	65	176	159	116	143	123	114	80	78	83
Average per working week	6.7	7.3	6.8	7.2	5.7	5.1	4.3	5.5	7.2	9.7	6.8	5.6	6.3	7.3	8.7	7.5

were sunk except No. 25.

NEW CROTON AQUEDUCT—WEEKLY PROGRESS IN TUNNEL EXCAVATION (LINEAL FEET)—1885.

1885.		Brown, Howard & Co.					Brown, Howard & Co.						Brown, Howard & Co.						Brown, Howard & Co.				O'Brien & Clark.				
		Shaft 0.	Shaft 1.		Shaft 3.		Shaft 4.		Shaft 5.		Shaft 6.		Shaft 7.		Shaft 9.		Shaft 10.		Shaft 11A.		Shaft 11B.		Shaft 12A.		Portal.		Shaft 12B.
Week Ending		S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	S.
March	7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	40	24	...	...	...	...	...	...	...
"	14	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	...	...	13	...	...	...	...	...	...	...	...
"	21	...	...	...	...	...	...	...	...	...	...	...	...	...	...	34	...	...	35	...	...	...	13	...	...	...	14
"	28	...	...	...	...	...	...	...	...	...	...	...	...	...	...	15	...	...	20	...	...	...	20	...	...	...	19
April	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12	15	...	...	...	...	16
"	11	21	...	...	...	...	...	...	...	...	...	...	...	...	...	14	...	...	7	...	12	...	7	...	...	...	10
"	18	29	...	...	...	...	...	...	...	...	...	...	...	...	...	51	...	...	25	...	6	15	5	28	...	...	5
"	25	31	...	...	...	...	...	...	...	...	...	...	...	...	...	32	...	...	38	...	2	26	2	8	...	...	4
May	2	30	...	...	...	...	...	...	3	...	...	...	...	...	...	47	...	...	23	...	3	19	9	8	...	...	...
"	9	28	...	...	...	...	...	...	21	12	...	...	...	...	...	41	...	...	29	...	8	17	22	13	...	...	11
"	16	34	...	...	...	...	...	...	11	17	...	...	...	...	...	32	...	...	9	...	1	32	7	...	...	...	25
"	23	...	...	...	...	...	...	...	...	...	...	...	...	...	...	26	...	...	32	...	...	10	2	1	...	...	12
"	30	...	...	...	...	...	...	...	...	1	...	...	...	...	...	35	20	17	43	...	...	29	19	...	...	...	9
June	6	37	...	...	...	...	...	...	...	...	...	...	...	...	...	32	...	...	33	...	...	36	14	...	...	...	36
"	13	32	...	...	...	...	...	...	...	...	...	...	...	...	...	30	...	...	48	...	...	40	29	...	...	...	15
"	20	40	...	...	...	...	...	...	...	...	...	...	...	...	...	36	9	...	42	...	...	44	19	...	...	...	11
"	27	40	...	...	...	...	...	...	4	10	...	...	...	...	5	41	3	9	47	...	...	36	27	...	...	...	31
July	4	47	...	...	...	...	8	15	21	16	...	...	...	...	12	36	23	3	44	...	...	42	12	...	...	...	42
"	11	41	...	...	...	...	15	9	17	19	...	...	...	...	31	40	16	23	48	...	...	39	19	...	...	...	23
"	18	3	...	...	...	...	3	13	27	12	...	...	...	...	36	37	21	23	48	...	...	39	14	...	...	...	17
"	25	34	...	...	...	...	4	7	11	7	...	...	4	4	44	51	27	22	47	...	...	41	5	...	...	...	13
August	1	35	...	...	...	...	7	...	17	20	...	...	19	22	41	45	23	21	50	...	...	47	24	...	...	...	...
"	8	37	...	...	...	...	...	...	26	31	...	...	7	8	34	36	...	2	57	...	...	53	25	...	...	...	30
"	15	36	...	...	...	...	...	...	24	32	...	...	20	16	37	54	34	19	64	...	...	53	38	10	...	...	16
"	22	42	...	...	...	...	...	...	31	40	...	...	12	6	34	48	24	31	55	...	...	49	17	10	...	...	...
"	29	45	...	...	...	...	...	...	28	10	...	...	24	15	36	47	29	41	58	...	...	61	...	8	...	...	23
September	5	45	14	14	...	...	...	...	47	4	12	12	15	16	41	35	25	46	54	...	...	42	9	19	...	...	55
"	12	47	...	...	...	...	50	21	71	17	...	2	10	17	38	37	31	65	59	...	...	57	22	...	...	...	37
"	19	52	...	...	...	...	4	25	63	17	10	8	32	31	31	...	27	25	34	...	...	36	26	10	...	...	23
"	26	40	...	...	...	...	18	15	22	20	...	...	...	...	41	5	55	20	59	...	...	55	30	13	...	...	26
October	3	52	4	6	...	...	14	4	27	34	9	10	7	10	49	...	60	49	65	...	...	56	16	32	...	...	43
"	10	22	12	7	...	...	27	31	39	9	7	8	42	49	25	...	61	55	49	...	...	48	26	8	...	...	...
"	17	45	20	22	...	...	50	55	33	16	10	14	40	31	54	31	13	55	54	...	...	49	26	50	...	...	...
"	24	43	3	...	...	...	31	28	46	40	14	16	41	39	48	57	50	35	45	...	...	44	24	9	...	...	24
"	31	50	9	10	...	...	22	24	43	37	15	12	35	40	50	53	58	37	54	...	...	55	19	3	19	18	...
November	7	55	15	18	14	18	42	44	43	35	27	32	45	41	51	54	55	57	24	...	...	53	36	8	...	...	...
"	14	61	18	17	6	8	54	60	52	47	23	24	...	...	50	48	49	52	48	...	...	54	39	9	...	51	28
"	21	36	10	6	12	11	56	65	43	39	...	...	55	43	51	54	44	37	55	...	...	46	43	2	...	43	39
"	28	61	...	2	1	14	51	36	15	31	...	...	56	39	...	51	51	46	51	...	...	49	53	...	...	...	6
December	5	49	10	10	10	9	43	29	48	53	41	41	46	44	...	67	57	36	33	...	...	48	42	...	...	6	35
"	12	10	...	...	4	2	54	21	37	46	53	43	49	50	...	67	54	41	44	...	...	63	35	...	...	22	17
"	19	54	8	9	8	12	60	23	49	40	34	14	48	46	4	70	49	52	59	...	...	41	60	...	...	...	28
"	26	39	17	10	11	9	29	28	17	10	33	26	33	25	39	58	27	18	43	...	...	46	25	...	...	...	17
Total.....		1403	140	131	66	83	642	553	936	722	288	262	640	592	882	1554	995	937	1785	24	44	1585	880	249	19	140	760
Aver. per working week. ...		39	12	11	8	10	31	28	31	24	22	19	30	28	37	41	36	33	43	24	6	42	23	13	19	28	22

1885. Week Ending	O'Brien & Clark. Shaft 13. N.	Shaft 13. S.	Shaft 14. N.	Shaft 14. S.	Shaft 14A. S.	Shaft 15. N.	Shaft 15. S.	O'Brien & Clark. Shaft 16. N.	Shaft 16. S.	Shaft 17. N.	Shaft 17. S.	Shaft 17½. N.	Shaft 17½. S.	O'Brien & Clark. Shaft 18. N.	Shaft 18. S.	Shaft 18½. N.	Shaft 18½. S.	Shaft 19. N.	Shaft 19. S.	Heman Clark. Shaft 20. N.	Shaft 20. S.	Shaft 21. N.	Shaft 21. S.	Heman Clark. Shaft 22. N.	Shaft 22. S.	Shaft 23. N.	Shaft 23. S.	Shaft 24. N.	Shaft 24. S.
March 7	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 14	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 21	....	....	....	....	12	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 28	....	....	....	....	15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
April 4	....	....	6	6	....	....	....	....	....	39	30	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 11	....	....	6	10	11	....	....	....	....	....	....	....	....	....	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....
" 18	....	....	12	5	22	....	....	9	9	2	2	....	....	....	....	....	....	10	10	....	....	....	....	....	....	....	....	....	....
" 25	....	....	4	2	11	....	....	....	7	9	11	....	....	12	52	....	....	21	21	....	....	....	....	....	....	....	....	....	....
May 2	....	....	6	10	13	....	....	19	7	13	18	....	....	84	29	....	....	16	17	15	22	....	....	7	13	14	14	....	....
" 9	....	....	11	....	16	9	9	2	14	17	9	....	....	23	20	....	....	7	10	9	9	....	....	22	12	8	7	....	....
" 16	....	....	3	....	17	6	5	....	....	17	29	....	....	33	29	....	....	10	6	2	16	....	....	19	21	23	19	....	....
" 23	....	....	8	....	23	11	11	....	....	21	22	....	....	24	23	....	....	10	8	1	9	19	20	20	16	18	19	....	....
" 30	....	....	15	....	23	21	19	....	....	16	16	....	....	29	12	....	....	16	19	6	....	6	11	15	9	14	13	....	....
June 6	....	....	19	....	23	6	5	13	22	26	25	....	....	36	17	....	....	8	8	7	....	15	9	3	....	....	2	....	....
" 13	23	23	13	....	21	....	....	9	14	29	26	....	....	29	13	....	....	6	8	7	1	21	16	7	13	....	2	....	....
" 20	5	2	15	....	29	....	....	15	16	35	42	....	....	13	23	....	....	13	15	9	4	8	11	14	15	15	9	....	....
" 27	12	10	14	....	26	....	....	18	18	45	48	....	....	45	22	....	....	15	10	6	....	15	18	26	17	18	17	....	....
July 4	....	5	15	....	28	....	....	21	22	25	39	15	....	34	15	....	....	12	12	1	5	8	13	6	16	17	17	....	....
" 11	3	....	23	....	32	....	....	28	28	38	....	5	7	....	31	....	....	27	19	35	23	....	....	4	....	18	20	....	....
" 18	....	....	39	....	26	....	....	39	36	42	15	8	5	22	....	....	....	15	11	34	10	10	....	25	22	16	15	....	....
" 25	9	10	13	....	28	....	....	27	34	35	14	2	8	50	....	....	....	42	15	54	6	19	20	27	7	4	....	....	....
August 1	....	....	30	....	39	7	8	39	53	42	74	....	....	43	....	....	....	....	19	48	10	26	20	28	19	4	....	....	....
" 8	....	....	33	....	38	36	35	32	21	33	6	....	....	31	....	....	....	17	17	59	35	21	18	24	23	17	27	....	....
" 15	....	....	44	....	47	34	21	36	53	55	9	....	....	65	....	....	....	19	28	67	48	31	34	24	26	19	15	....	....
" 22	....	....	50	....	39	26	....	35	34	59	6	....	....	13	21	....	....	6	14	50	31	34	20	30	25	19	18	....	....
" 29	....	....	21	....	31	33	....	25	17	45	26	....	....	32	....	....	....	10	30	53	43	31	22	34	29	24	20	8	8
September 5	....	....	26	....	53	10	....	47	49	45	33	....	....	38	15	....	....	22	25	27	46	25	43	34	32	30	30	12	6
" 12	....	....	60	....	50	3	8	41	46	47	35	....	....	25	16	....	....	....	30	49	45	32	29	40	33	27	36	10	9
" 19	8	7	59	....	56	35	10	51	51	34	55	....	....	35	34	....	....	....	22	52	67	57	45	36	34	35	34	7	6
" 26	16	14	32	....	23	....	13	38	34	9	48	....	....	34	20	....	....	....	26	42	....	25	40	43	34	18	24	....	16
October 3	25	28	39	....	29	13	21	34	48	3	39	....	....	36	6	....	....	26	42	48	15	27	31	42	43	30	44	...	25
" 10	32	20	21	10	31	9	52	39	40	11	....	....	....	33	32	....	....	16	18	40	20	31	32	44	39	47	41	20	4
" 17	51	53	63	8	34	....	8	34	39	8	....	....	....	38	....	....	....	....	16	38	33	35	26	58	49	42	29	28	....
" 24	18	31	10	3	....	....	....	13	16	13	9	....	....	46	....	....	....	13	16	50	35	37	41	47	39	35	31	40	....
" 31	35	36	43	....	....	3	....	36	45	23	7	....	....	38	....	41	42	6	18	45	28	29	25	51	40	39	39	9	....
November 7	25	28	8	....	15	11	....	37	36	22	27	....	....	59	....	14	25	28	29	36	19	44	33	43	42	40	40	31	1
" 14	33	42	7	....	3	3	33	4	9	33	52	....	....	36	....	16	5	38	39	38	25	45	23	33	33	49	57	31	....
" 21	5	4	....	1	6	8	60	....	10	28	52	....	....	46	....	....	....	....	....	40	33	51	44	36	31	47	47	28	....
" 28	....	....	33	....	10	20	12	28	14	36	58	....	....	37	....	11	15	....	....	30	36	29	25	29	47	45	51	29	....
December 5	47	61	33	....	18	46	34	20	17	39	44	....	....	27	....	31	21	30	42	47	30	42	40	38	37	40	61	14	....
" 12	81	40	52	....	13	5	31	45	49	50	....	....	....	26	....	34	21	36	34	36	33	48	44	44	45	38	58	....	....
" 19	58	13	54	....	30	30	46	40	57	56	43	....	....	28	....	46	....	41	43	....	42	34	21	39	32	45	62	....	....
" 26	20	....	13	....	....	26	23	8	10	27	14	....	....	30	....	27	2	26	18	14	25	40	25	17	17	31	28	23	....
Total.....	506	427	953	55	941	411	464	882	975	1127	983	30	20	1230	450	220	131	562	715	1095	804	895	799	1009	910	886	946	290	75
Aver. per working week..	27	24	25	6	25	17	22	28	29	30	29	8	7	35	23	28	19	19	20	32	26	29	27	29	28	27	29	21	9

NEW CROTON AQUEDUCT—WEEKLY PROGRESS IN TUNNEL EXCAVATION (LINEAL FEET)—1886.

Week No.	1886. Week Ending	Brown, Howard & Co. Shaft 0. S.	Shaft 1. N.	Shaft 1. S.	Shaft 2. N.	Shaft 2. S.	Shaft 3. N.	Shaft 3. S.	Brown, Howard & Co. Shaft 4. N.	Shaft 4. S.	Shaft 5. N.	Shaft 5. S.	Shaft 6. N.	Shaft 6. S.	Brown, Howard & Co. Shaft 7. N.	Shaft 7. S.	Shaft 9. N.	Shaft 9. S.	Shaft 10. N.	Shaft 10. S.	Brown, How'd & Co. Shaft 11A. N.	Shaft 11B. S.	O'Brien & Clark. Shaft 12A. N.	Shaft 12A. S.	Shaft 12C. N.	Shaft 12C. S.	Shaft 12B. N.	Shaft 12B. S.	O'Brien & Clark. Shaft 13. N.	Shaft 13. S.	Sh'ft 14. N.	Sh'ft 14A. S.	Shaft 15. N.	Shaft 15. S.
1	Jan. 2	40	28	....	....	....	....	8	36	43	37	49	46	40	30	34	43	55	44	32	46	43	34	....	....	....	....	20	36	....	26	8	23	32
2	" 9	56	0	....	14	15	....	11	64	48	43	65	43	40	42	44	37	57	41	54	53	51	59	....	....	....	....	67	58	....	39	19	50	42
3	" 16	47	26	....	6	4	....	....	58	64	49	54	49	53	47	50	57	61	52	33	57	50	6	....	....	....	....	15	66	....	56	32	53	51
4	" 23	42	56	....	....	....	....	9	64	22	44	53	48	47	41	48	52	51	39	25	54	52	51	....	....	....	....	36	34	11	38	24	17	9
5	" 30	53	41	....	....	....	....	17	42	37	11	47	39	43	50	34	52	21	57	63	47	49	40	....	....	....	....	44	37	9	51	38	59	29
6	Feb. 6	48	34	....	....	....	....	27	55	60	36	65	42	51	35	36	43	62	59	43	34	45	45	....	....	....	....	47	29	14	32	21	39	37
7	" 13	52	52	....	5	5	....	32	56	73	52	50	31	27	48	35	28	31	63	31	46	54	58	....	....	....	....	51	28	....	47	7	47	38
8	" 20	55	6	....	14	15	....	32	52	45	31	42	53	52	49	34	39	47	19	50	42	41	41	....	....	....	....	....	42	....	52	3	37	41
9	" 27	43	37	....	20	21	....	18	43	47	12	25	49	49	29	40	51	70	18	26	50	46	16	....	....	....	....	7	3	....	45	22	43	26
10	Mar. 6	47	46	....	25	25	....	33	58	46	33	40	54	53	27	25	28	47	54	51	46	48	....	....	....	....	....	....	18	....	32	23	48	48
11	" 13	51	56	....	16	33	....	29	60	57	40	22	43	44	35	58	54	51	34	48	48	51	....	....	....	....	....	35	35	....	63	47	49	49
12	" 20	42	49	....	7	15	....	18	42	40	24	18	31	36	35	16	38	47	28	47	50	42	....	....	....	....	....	41	29	....	38	30	31	30
13	" 27	40	34	....	2	5	....	26	25	15	15	9	49	30	36	36	44	41	34	38	51	45	....	....	....	....	....	35	42	....	10	30	4	41
14	April 3	54	38	....	....	....	....	18	63	55	15	17	37	27	40	38	40	8	51	48	50	49	....	....	....	....	....	8	34	....	33	33	40	29
15	" 10	27	23	....	15	11	....	2	25	27	39	59	41	44	51	43	53	33	51	43	57	59	....	....	....	....	....	23	11	....	10	....	....	....
16	" 17	7	33	....	24	19	....	8	59	62	21	16	48	40	39	40	50	51	50	53	50	48	9	....	....	....	....	....	39	....	29	33	27	33
17	" 24	16	25	....	27	25	....	20	45	39	25	34	47	36	34	18	46	17	32	38	47	49	39	....	....	....	....	....	23	....	17	34	25	32
18	May 1	4	33	....	20	15	....	24	49	53	34	27	49	53	38	32	31	44	37	46	45	50	26	....	....	....	....	9	9	....	11	41	28	35
19	" 8	17	48	....	....	....	....	43	48	39	34	44	51	31	36	37	37	44	29	53	34	28	33	....	....	....	....	5	27	....	....	21	37	34
20	" 15	29	45	....	....	....	....	42	57	54	38	39	57	47	43	37	6	57	37	23	49	47	47	....	....	....	....	32	37	....	....	29	43	37
21	" 22	....	47	....	28	36	....	37	33	29	41	36	38	34	39	39	24	23	32	20	45	43	35	....	....	....	....	17	31	....	....	31	36	42
22	" 29	18	49	....	39	56	....	47	31	27	26	28	48	40	31	25	2	27	18	29	30	35	28	....	....	....	....	31	43	....	....	23	33	25
23	June 5	27	55	....	51	44	....	56	30	32	24	37	52	47	40	14	....	37	33	26	31	28	40	....	....	....	....	38	61	....	....	34	39	41
24	" 12	52	41	....	50	27	....	55	30	29	24	29	26	26	33	39	....	46	28	30	35	26	39	....	....	....	....	38	59	....	....	24	44	27
25	" 19	57	11	....	55	58	....	52	34	34	30	28	25	34	42	46	....	20	24	26	28	32	45	....	....	....	....	44	63	....	....	37	9	33
26	" 26	34	23	....	6	20	....	22	17	9	11	16	28	14	8	9	....	20	11	13	20	15	33	....	....	....	....	42	68	....	....	31	14	32
27	July 3	45	7	6	32	42	40	44	33	29	22	32	....	....	34	28	....	39	36	24	27	27	28	....	....	....	....	29	42	....	....	35	8	23
28	" 10	27	13	31	56	57	41	42	25	21	25	22	29	18	31	31	....	5	20	19	29	22	27	....	....	....	....	29	46	....	....	....	9	27
29	" 17	50	38	47	....	55	47	51	30	32	28	34	50	46	49	44	....	35	31	24	34	30	50	....	....	....	....	34	54	....	....	47	9	46
30	" 24	19	4	25	42	28	27	44	28	33	23	28	35	24	27	23	....	30	29	28	38	29	41	....	....	....	....	43	46	....	....	27	14	22
31	" 31	....	....	30	63	53	18	39	34	35	24	30	52	49	42	32	....	25	35	32	30	31	42	....	....	....	....	42	37	....	....	36	14	31
32	Aug. 7	33	15	51	32	19	38	56	44	28	23	27	39	31	33	40	....	18	26	27	43	26	27	....	....	....	....	36	44	....	....	29	23	29
33	" 14	40	35	48	43	43	49	69	18	36	21	32	59	56	50	38	....	21	38	22	22	31	34	....	....	....	....	42	63	....	....	49	13	43
34	" 21	44	27	4	22	40	59	63	22	35	18	26	40	29	48	28	....	21	34	24	33	27	21	....	....	....	....	33	49	....	....	39	12	39
35	" 28	32	8	12	....	33	12	14	14	35	25	20	37	34	45	43	....	22	22	24	23	29	....	....	....	....	....	33	40	....	....	26	9	21
36	Sept. 4	28	38	20	....	34	57	59	5	28	22	22	29	33	59	....	....	35	23	25	36	25	7	5	....	....	....	45	37	....	....	30	21	33
37	" 11	57	45	4	18	46	41	41	....	31	22	32	49	31	35	....	....	12	35	27	29	38	31	9	....	....	....	45	8	....	....	43	30	43
38	" 18	45	52	....	51	57	51	79	33	13	27	24	49	32	25	....	....	17	25	28	35	26	46	7	....	20	9	2	....	....	....	40	47	41
39	" 25	49	53	19	35	38	21	10	29	35	25	22	31	24	43	....	....	19	23	18	19	25	40	....	4	19	....	....	....	....	....	14	18	30
40	Oct. 2	53	28	38	24	20	47	33	31	30	24	24	74	36	49	....	....	21	31	20	29	31	28	....	....	6	....	....	....	....	....	47	6	46
41	" 9	57	43	27	....	13	42	45	23	25	20	19	56	33	59	....	....	31	23	20	29	33	38	7	....	14	....	....	....	....	....	56	32	50
42	" 16	46	50	22	....	....	27	25	22	12	23	17	45	28	52	....	....	38	17	28	33	27	36	23	....	....	....	....	....	....	....	36	52	47
43	" 23	....	....	34	29	27	53	36	26	29	22	23	58	34	56	....	....	18	25	21	29	26	36	17	....	....	....	....	....	....	....	....	53	50
44	" 30	....	....	43	....	11	61	34	26	22	18	18	41	29	53	....	....	13	29	24	30	26	27	15	....	....	....	....	....	....	....	....	45	45
45	Nov. 6	....	....	39	....	26	51	31	25	26	18	29	42	37	52	....	....	29	22	22	20	37	35	8	....	....	....	....	....	....	....	....	53	51
46	" 13	....	....	38	14	26	52	46	32	31	20	32	44	40	45	....	....	15	31	14	24	25	36	....	....	....	....	....	....	....	....	9	55	47
47	" 20	....	....	29	17	....	28	28	20	20	19	35	39	34	46	....	....	22	29	17	24	27	32	....	....	....	....	....	....	....	....	59	65	51
48	" 27	....	....	36	12	....	42	28	25	26	22	25	47	37	37	....	....	28	24	10	29	24	25	....	....	....	....	....	....	....	....	45	61	38
49	Dec. 4	....	....	35	20	....	26	30	9	25	24	22	35	31	27	....	....	27	26	22	25	26	28	....	....	....	....	....	....	....	2	....	41	42
50	" 11	....	....	41	29	....	30	33	32	29	29	19	19	16	43	....	....	30	24	26	28	28	34	19	50	....	....	....	....	....	9	....	56	47
51	" 18	....	....	38	39	....	30	30	31	35	22	26	10	30	43	....	....	20	37	25	24	28	34	5	9	....	....	....	....	....	7	....	70	43
52	" 25	....	....	41	20	16	29	33	27	23	15	25	20	25	33	....	....	24	27	17	21	20	31	....	....	3	....	....	....	....	15	....	54	43
Jan. 1, '87		....	....	27	....	30	14	20	11	18	13	14	20	19	24	....	....	16	16	16	17	21	28	....	....	9	....	....	....	....	....	....	....	31
Total.....		1583	1393	785	1022	1163	1033	1749	1831	1828	1383	1628	2173	1874	2118	1214	855	1699	1713	1593	1905	1871	1566	115	63	71	9	1098	1428	34	662	1342	1745	1932
Average per work'g w'k		40	31	30	27	29	38	34	35	34	26	31	42	36	40	35	39	32	32	30	36	35	34	12	21	12	9	32	38	11	30	31	34	37

Week No.	O'Brien & Clark.				O'Brien & Clark.						Heman Clark.						Heman Clark.					O'Brien & Clark.				John Brunton & Co.				John Brunton & Co.						
	Shaft 16.		Shaft 17.		Shaft 18.		Shaft 18½.		Shaft 19.		Shaft 19½.		Shaft 20.		Shaft 21.		Shaft 22.		Shaft 23.		Sh'ft 24.	Shaft 25.		Shaft 26.		Shaft 27.		Shaft 28.		Shaft 29.		Shaft 30.		Shaft 31.		Sh'ft 32.
	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.
1....	24	39	29	27	35	....	....	22	29	31	....	....	....	45	7	6	32	30	46	51	15	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
2....	42	49	32	32	15	....	....	41	28	27	....	....	20	15	26	24	37	36	48	62	25	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
3....	35	60	....	....	....	....	23	47	49	41	....	....	33	24	44	40	45	50	52	57	28	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
4....	45	59	61	....	....	....	32	24	35	30	....	....	42	45	38	40	42	40	42	47	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
5....	23	22	54	47	33	5	....	33	22	36	....	....	....	41	32	36	45	52	53	58	37	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
6....	....	53	62	60	43	12	14	36	5	27	....	....	28	47	53	50	41	41	40	35	26	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
7....	12	48	58	51	39	....	33	29	17	23	....	....	25	40	39	40	42	42	33	36	31	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8....	7	47	51	41	27	....	5	49	21	25	....	....	20	45	35	45	51	35	44	22	34	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
9....	12	50	11	22	5	23	16	23	14	19	....	....	5	45	27	10	32	23	34	30	32	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
10....	16	35	10	29	58	22	35	45	37	35	....	....	15	43	43	32	40	36	43	40	32	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
11....	36	38	19	22	36	19	30	33	31	27	....	....	32	30	36	23	45	36	38	39	25	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
12....	10	61	33	32	32	5	32	41	25	39	....	....	31	40	22	20	36	36	40	42	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
13....	....	5	39	41	29	12	8	....	25	35	....	....	22	32	31	30	36	34	42	39	23	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
14....	19	14	12	17	23	2	9	24	17	21	....	....	10	25	41	29	51	45	42	53	32	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
15....	....	3	....	....	....	....	8	....	....	15	....	20	18	18	27	22	48	35	49	49	29	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
16....	....	26	16	19	23	8	21	....	....	32	40	5	16	36	20	21	50	44	52	46	32	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
17....	25	9	24	26	54	14	25	23	....	45	....	2	8	24	23	25	36	43	37	36	22	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
18....	36	43	8	45	33	16	21	10	32	40	....	....	11	44	32	27	51	26	51	58	21	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
19....	....	54	25	21	34	13	....	27	32	33	....	....	23	37	47	29	52	49	49	46	22	....	....	....	....	....	....	....	....	....	....	....	4	10	....	....
20....	34	33	54	47	43	21	37	46	24	38	....	....	32	40	36	20	53	45	54	66	....	....	....	....	....	....	....	....	....	....	....	....	11	8	....	....
21....	37	49	42	44	40	26	18	45	43	35	....	....	17	46	34	26	44	47	52	48	27	....	....	....	....	....	....	....	....	....	....	....	14	16	11	....
22....	19	43	42	28	31	3	10	34	36	42	....	....	22	42	39	23	39	42	39	35	17	....	....	....	....	....	....	....	....	....	....	....	20	20	22	....
23....	54	62	55	56	58	....	22	53	33	42	....	....	22	31	35	22	38	47	42	51	23	....	....	....	....	....	....	....	....	....	21	14	34	22	23	....
24....	45	55	61	48	62	14	....	42	47	55	23	11	24	32	40	24	36	42	55	55	20	....	....	....	....	....	....	....	....	....	9	8	2	....	39	....
25....	13	42	34	44	29	....	....	38	45	46	10	5	27	37	46	27	46	....	83	75	31	....	22	....	....	....	....	....	....	....	9	2	....	....	....	....
26....	62	56	16	37	73	....	....	41	31	30	....	2	16	21	33	22	53	6	22	61	24	....	....	16	15	....	....	....	....	....	6	11	....	....	....	....
27....	47	51	25	....	....	....	....	14	18	42	20	....	....	32	31	44	36	....	....	40	23	....	....	14	11	....	....	....	....	....	21	16	....	....	....	....
28....	23	40	10	26	18	....	....	38	20	24	19	....	....	19	38	36	20	....	....	32	20	....	....	4	5	....	....	....	....	8	18	....	....	....	....	....
29....	59	63	35	40	50	....	....	22	14	35	12	23	....	40	45	42	44	....	....	54	24	....	....	9	....	....	....	....	....	15	7	2	....	....	....	25
30....	48	5	15	41	53	....	....	17	31	39	26	20	45	40	51	37	34	....	....	39	19	....	....	5	9	....	....	....	....	2	5	4	5	....	....	11
31....	8	18	10	29	43	....	....	38	26	35	15	12	25	30	20	30	34	....	....	46	22	....	....	16	10	13	8	22	13	5	15	....	....	....	....	18
32....	35	35	8	37	44	....	....	....	34	46	19	18	19	25	41	38	40	....	....	46	29	....	....	....	15	6	12	8	16	14	13	....	....	12	12	22
33....	47	19	11	22	47	....	....	40	35	45	16	15	9	21	38	32	34	....	....	50	7	....	....	....	....	19	6	12	16	16	17	....	....	....	12	11
34....	56	40	15	44	51	....	....	42	30	21	14	14	31	33	40	33	43	....	....	60	....	....	....	....	....	7	15	16	7	20	17	18	13	30	28	25
35....	41	46	30	34	30	....	....	47	26	37	14	21	23	27	24	2.	40	....	....	59	....	....	....	....	....	20	16	5	18	....	....	17	13	20	19	25
36....	22	53	27	46	30	....	....	39	21	36	16	11	23	27	36	61	48	....	....	58	....	....	....	....	....	25	18	17	15	....	....	18	14	28	29	25
37....	48	45	21	47	45	....	....	41	36	36	15	19	25	22	44	8	38	....	....	53	....	....	....	12	....	14	12	....	6	....	....	12	21	34	26	24
38....	....	48	25	38	39	....	....	50	35	40	10	19	28	25	48	40	45	....	....	58	....	....	....	40	....	....	....	....	....	8	8	33	33	31	33	29
39....	4	59	19	37	41	....	....	14	35	....	28	12	42	37	54	....	54	....	....	27	....	....	....	54	....	....	....	....	....	....	....	32	21	26	30	21
40....	41	54	19	3	40	....	....	32	40	....	10	11	21	40	44	38	40	....	....	55	....	....	....	57	....	....	....	6	....	....	....	31	33	14	25	28
41....	54	65	40	35	49	....	....	37	31	....	17	14	25	33	44	30	46	....	....	56	....	....	....	58	....	....	....	....	....	....	....	32	37	28	17	11
42....	52	50	45	33	43	....	....	43	22	29	8	8	6	33	50	40	40	....	....	61	....	....	....	69	....	....	....	....	....	....	....	....	....	....	....	....
43....	37	52	44	38	39	....	....	48	42	63	20	18	40	44	62	41	47	....	....	61	....	....	....	69	....	....	....	....	....	....	....	31	40	35	35	29
44....	58	56	52	31	38	....	....	37	7	47	18	20	48	47	70	40	49	....	....	51	....	....	....	73	....	....	....	....	....	....	....	45	33	41	49	46
45....	35	70	62	33	49	....	....	48	22	11	6	5	38	32	38	47	41	....	....	66	....	28	....	....	25	....	....	....	....	....	....	7	29	28	12	30
46....	38	40	62	23	56	....	....	43	20	....	....	34	40	36	44	40	51	....	....	43	....	50	....	....	61	4	5	....	....	....	....	49	42	28	28	39
47....	39	64	36	27	45	....	....	50	40	25	....	22	51	53	60	45	48	....	....	....	....	63	....	....	24	....	....	....	....	22	12	5	23	31	25	28
48....	45	43	40	20	53	....	....	45	37	27	....	31	....	22	76	45	40	....	....	....	....	49	....	....	....	29	30	....	....	19	33	13	16	22	15	6
49....	54	59	32	43	52	....	....	42	26	47	....	33	17	38	54	40	51	....	....	....	....	43	....	....	....	32	25	....	....	26	34	21	...	24	23	30
50....	47	51	50	36	53	....	....	50	35	59	....	11	35	37	35	21	60	....	....	....	....	60	....	....	....	17	16	9	2	12	7	38	....	46	26	36
51....	56	53	57	42	40	....	....	57	48	73	....	18	29	20	15	27	60	....	....	....	....	23	....	....	....	22	15	21	21	22	19	19	....	15	26	29
52....	49	52	40	38	32	....	....	45	40	43	....	16	32	....	....	....	58	....	....	....	....	....	....	....	....	10	12	15	17	23	19	13	....	15	18	28
Jan. 1, '87	30	38	43	38	31	....	....	35	19	36	....	10	32	....	....	....	34	....	....	....	....	....	....	....	....	18	22	5	....	....	....	18	....	8	11	28
Total.	1677	2324	1721	1717	1966	215	399	1820	1468	1765	376	480	1203	1738	1988	1590	2302	962	1182	2252	792	316	22	496	175	236	212	136	131	212	224	524	424	601	575	699
Av. per w'g w'k	36	44	34	35	40	13	21	37	29	36	17	15	26	34	39	32	43	38	45	49	25	45	22	35	19	17	15	12	13	15	16	20	21	23	22	25

NEW CROTON AQUEDUCT—WEEKLY PROGRESS IN TUNNEL EXCAVATION (LINEAL FEET)—1887.

1887.	Brown, Howard & Co.						Brown, Howard & Co.						Brown, Howard & Co.						Brown, How'd & Co.		Brown, Howard & Co.				O'Brien & Clark.		
Week Ending	Shaft 0.	Shaft 1.	Shaft 2.		Shaft 3.		Shaft 4.		Shaft 5.		Shaft 6.		Shaft 7.	Shaft 8.		Shaft 9.	Shaft 10.		Shaft 11A.		Shaft 11B.	Shaft 12A.	Shaft 12C.	Portal.	Sh'ft 13	Shaft 13A.	
	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	N.	S.	S.	N.	S.	N.	S.	S.	N.	S.	N.	S.	N.	S.
January 8	.....	47	28	30	29	27	26	19	21	20	23	26	16	..	....	23	31	33	36	....	33	28	3	.....	.....	...	....
" 15	.....	56	27	33	31	21	28	28	24	24	46	26	20	....	....	31	31	42	24	....	28	38	3	.....	...	...	....
" 22	.....	55	32	41	40	40	28	22	24	32	46	32	41	....	...	28	31	37	28	....	28	18	9	.....	...	...	....
" 29	.....	50	38	24	31	32	10	8	24	24	33	27	43	..	....	28	33	39	23	....	36	44	.....	.....	...	...	....
February 5	.....	59	29	4	32	21	27	20	23	22	31	23	42	....	...	36	30	42	30	...	19	22	.....	.....	...	...	....
" 12	.....	40	34	9	29	35	25	21	21	13	28	22	52	....	....	28	29	53	30	....	16	51	.....	.....	...	...	....
" 19	.....	55	26	15	28	30	32	28	24	26	29	51	39	...	....	27	33	40	29	....	31	62	.....	.....	...	...	....
" 26	.....	51	31	34	29	39	30	29	15	26	26	20	57	....	....	27	35	34	24	....	17	53	12	.....	...	...	....
March 5	.....	47	22	32	31	31	22	9	19	23	35	11	43	....	....	.....	....	31	32	....	7	54	.....	4	...	...	....
" 12	.....	51	33	28	50	30	34	23	21	21	35	15	58	31	....	.....	....	30	13	....	20	52	4	.....	...	...	....
" 19	.....	41	20	37	44	31	35	30	17	22	35	15	45	17	....	.....	...	46	31	..	27	50	.....	.....	...	...	....
" 26	.....	39	41	4	29	36	31	17	15	19	32	23	55	17	....	.....	....	42	47	....	34	45	.....	.....	...	...	....
April 2	.....	57	31	24	27	21	19	19	7	12	34	44	42	23	...	.....	....	39	50	....	33	50	.....	.....	...	...	....
" 9	.....	48	36	25	44	21	7	24	14	18	29	31	58	10	...	.....	..	38	51	....	16	50	.....	.....	...	...	....
" 16	.....	21	34	55	38	30	30	25	23	25	20	37	43	30	....	.....	....	36	48	....	.....	40	.....	....	...	...	....
" 23	.....	52	27	34	56	34	10	10	28	30	33	42	54	3	9	.....	....	48	45	....	.....	45	.....	.....	...	...	....
" 30	.....	36	40	30	30	42	8	4	20	18	35	27	25	....	....	.....	....	32	39	....	.....	45	13	.....	...	...	....
May 7	.....	50	5	....	19	62	...	....	18	25	46	....	.....	....	....	.....	..	35	30	....	.....	45	17	.....	...	...	....
" 14	.....	46	25	4	36	56	7	32	19	30	33	...	.....	3	....	.....	....	23	21	....	.....	47	.....	5	...	...	....
" 21	.....	40	64	60	45	47	43	53	21	33	53	....	.....	7	...	.....	....	....	....	44	.....	45	.....	4	...	...	....
" 28	.....	35	52	45	41	45	31	48	15	23	60	....	.....	5	...	.....	....	....	....	7	.....	44	.....	.....	...	...	....
June 4	.....	29	49	48	48	29	20	40	20	33	55	....	.....	30	....	.....	...	....	...	22	.....	38	.....	.....	...	...	....
" 11	.....	33	58	59	50	42	39	47	26	22	45	....	.....	25	...	.....	....	....	....	17	.....	60	.....	10	.....	34	37
" 18	.....	33	60	47	38	50	26	42	16	30	56	...	.....	24	....	.....	....	....	....	30	.....	75	.....	23	.....	7	4
" 25	.....	33	64	54	50	40	33	42	17	28	57	...	.....	41	....	.....	....	....	....	41	.....	59	.....	29	...	13	11
July 2	.....	38	45	45	43	38	....	29	19	29	48	....	.....	25	...	.....	....	....	....	22	.....	70	.....	115	.....	6	25
" 9	.....	35	45	48	42	31	....	20	11	8	41	....	.....	20	....	.....	....	....	....	20	.....	21	.....	9	.....	...	....
" 16	.....	20	60	61	55	16	....	23	20	12	21	....	.....	18	....	.....	....	....	....	....	.....	71	.....	.....	.....	...	....
" 23	.....	32	53	58	34	43	17	31	40	....	....	....	.....	15	....	.....	....	....	....	....	.....	.....	.....	.....	7	...	19
" 30	.....	42	55	39	48	40	19	29	42	....	....	....	.....	8	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	27
August 6	.....	21	51	53	33	30	11	37	34	....	....	....	.....	8	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	17
" 13	.....	14	53	58	28	35	37	37	39	....	....	....	.....	11	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	41
" 20	.....	56	45	48	33	4	34	25	41	....	....	....	.....	12	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	36
" 27	.....	53	46	50	34	..	37	29	42	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	39
September 3	.....	49	44	45	47	....	43	32	39	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	....
" 10	.....	42	51	42	29	8	44	39	43	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	....
" 17	.....	27	54	...	60	36	42	31	34	....	....	....	.....	8	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	....
" 24	.....	30	51	24	36	36	38	....	....	....	....	....	.....	10	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	....
October 1	.....	28	45	48	19	33	46	....	....	....	....	....	.....	2	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	....
" 8	.....	23	37	46	41	45	39	....	....	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	10
" 15	.....	35	46	50	39	....	....	....	....	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	33
" 22	.....	27	33	52	51	...	....	....	....	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	18	...	24
" 29	.....	24	41	50	45	...	..	...	....	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	8	34
November 5	.....	22	36	...	20	...	....	....	....	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	39
" 12	.....	29	41	....	....	....	....	....	....	....	....	....	.....	....	....	.....	....	....	....	....	.....	.....	.....	.....	.....	10	36
" 19	.....	27	40	....	....	...	....	.	....	....	...	....	.....	...	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	35
		4	....	....	....	....	....	....	....	....	....	....	.....	...	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	41
				....	....	....	....	....	....	....	....	....	.....	...	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	38
							....	....	....	....	....	....	.....	20	....	.....	....	....	....	....	.....	.....	.....	.....	.....	...	41
									....	....	....	....	.....	38	32	.....	....	....	....	....	.....	.....	.....	.....	8	....	35
												....	.....	38	23	.....	....	....	....	....	.....	.....	.....	.....	.....	....	50

1887. Week Ending		O'Brien & Clark.						O'Brien & Clark.				O'Brien & Clark.				Heman Clark.			Heman Clark.	O'Brien & Clark.	Brunton & Co.				Brunton & Co.							
		Shaft 13½.		Sh'ft 14.	Sh'ft 14A.	Shaft 15.		Shaft 16.		Shaft 17.		Shaft 18.		Shaft 19.		Sh'ft 19½.	Sh'ft 20.	Sh'ft 21.	Shaft 22.	Shaft 25.	Shaft 27.		Shaft 28.		Shaft 29.		Shaft 30.		Shaft 31.		Shaft 32.	
		N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	S.	N.	S.	N.	N.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
Jan.	8	....	..	4	....	65	71	40	55	50	16	20	36	41	18	26	....	....	46	....	16	19	16	12	28	16	32	....	40	30	....	....
"	15	....	..	18	....	70	70	50	63	52	....	76	52	71	....	38	44	....	66	....	13	14	15	14	21	20	21	....	19	19	....	....
"	22	....	..	15	....	63	90	54	65	49	....	40	82	73	73	34	80	....	52	....	20	15	...	17	17	10	17	....	24	19	....	....
"	29	....	..	24	....	64	63	58	51	61	....	66	86	72	19	7	50	....	32	....	23	23	30	26	26	24	37	....	27	41	....	....
Feb.	5	....	.	30	....	68	71	60	48	50	....	67	65	59	20	....	57	....	32	....	....	5	....	....	5	6	....	....	....	....	....	....
"	12	....	..	2	....	71	82	58	58	57	....	39	64	....	29	....	....	....	....	....	19	17	22	22	27	24	6	....	17	16	12	....
"	19	....	..	26	...	77	83	54	54	60	....	29	62	16	60	....	....	48	....	....	25	36	36	35	17	32	28	9	26	37	....	....
"	26	....	..	....	....	26	71	49	54	53	....	57	58	59	56	...	....	44	....	....	29	30	35	32	38	36	40	16	22	20	....	....
March	5	....	..	....	....	34	65	42	23	49	....	47	10	45	27	...	....	33	....	....	27	27	19	23	45	32	22	....	24	....	....	....
"	12	....	..	....	....	40	70	38	....	2	....	50	30	42	29	....	....	....	....	....	27	20	24	25	49	34	50	....	35	....	....	....
"	19	....	..	....	....	....	61	36	....	....	4	38	36	38	42	....	...	34	....	....	32	43	36	40	36	17	32	1	38	....	....	....
"	26	....	..	....	....	....	102	43	....	....	15	7	64	65	48	....	....	46	....	....	25	27	26	35	36	27	23	5	27	....	....	...
April	2	....	..	19	....	....	49	47	....	....	2	....	50	49	38	....	....	40	....	....	26	28	27	36	26	22	28	15	27	....	....	....
"	9	....	..	....	23	....	60	48	...	....	3	....	70	45	40	....	....	47	....	....	28	35	30	32	51	36	32	21	34	....	....	....
"	16	....	..	....	31	..	54	47	....	....	14	....	50	58	43	....	....	45	....	....	29	37	20	31	44	35	31	2	40	....	....	....
"	23	....	..	8	30	....	62	54	....	....	13	....	76	63	20	....	....	35	....	....	29	38	30	17	42	45	47	13	37	....	....	....
"	30	....	..	8	11	7	63	37	....	....	....	....	74	55	34	....	....	30	....	....	25	32	19	24	29	13	20	4	30	....	....	....
May	7	....	..	23	....	15	46	41	....	....	16	...	....	....	33	....	....	40	....	....	29	22	20	24	38	43	34	7	29	....	....	....
"	14	....	..	22	25	22	45	48	..	....	7	....	40	35	49	....	....	41	....	....	35	16	23	24	36	....	33	20	29	....	....	33
"	21	....	..	12	40	37	20	48	....	....	9	....	38	60	....	....	....	43	....	....	19	15	26	42	35	19	24	18	34	....	...	31
"	28	....	..	4	39	23	65	49	....	....	15	....	52	10	....	....	....	30	....	....	4	3	4	....	3	....	....	....	...	....	....	....
June	4	....	..	....	41	49	40	41	....	....	....	....	....	....	....	....	...	35	....	....	....	....	....	....	....	....	7	....	5	....	....	5
"	11	....	..	....	21	36	....	60	...	....	7	....	....	....	...	...	....	40	....	....	24	6	13	8	....	....	10	10	15	....	....	5
"	18	....	..	....	34	39	....	39	....	...	....	....	....	....	....	....	....	45	....	....	24	20	19	30	34	13	21	15	22	..	....	34
"	25	....	..	....	24	36	....	51	....	....	....	....	....	....	....	....	....	43	....	....	24	17	27	28	28	....	34	17	28	....	....	32
July	2	....	..	....	25	53	....	55	....	....	....	....	....	...	....	....	....	25	....	....	14	23	18	19	27	....	25	....	36	....	....	...
"	9	....	..	....	28	38	....	27	....	....	...	....	....	....	....	....	....	35	....	....	....	29	21	26	30	7	15	9	29	....	....	11
"	16	...	..	....	73	54	....	51	....	....	11	....	....	....	....	....	....	41	....	....	....	30	29	39	39	15	33	34	41	....	....	15
"	23	....	..	....	57	58	....	127	....	....	....	....	....	....	....	....	....	35	....	....	....	29	25	29	27	20	35	42	37	...	....	16
"	30	....	..	....	....	....	....	39	....	....	....	36	...	...	....	....	....	30	....	....	...	23	34	32	28	23	28	34	38	....	....	....
Aug.	6	....	..	....	....	....	....	....	....	....	41	52	....	...	....	....	....	41	....	....	....	15	23	36	23	35	30	19	13	....	....	....
"	13	....	..	....	....	....	....	...	....	....	....	38	....	....	..	....	....	40	....	.....	..	27	27	36	49	26	30	....	....	....	....	....
"	20	....	..	....	....	....	....	....	....	....	....	....	...	....	....	....	....	32	....	12	....	27	32	37	40	....	....	....	....	....	....	...
"	27	....	..	....	....	...	....	....	....	....	1	....	....	...	....	....	....	....	....	....	....	28	29	32	41	....	....	....	....	....	....	...
Sept.	3	....	..	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	24	23	28	30	....	....	....	...	....	....	8
"	10	....	..	....	....	....	...	....	...	....	....	...	....	...	....	....	....	....	....	35	....	29	39	48	37	....	....	..	...	....	....	..
"	17	....	..	....	....	..	....	....	....	...	....	....	....	....	....	....	....	....	....	43	....	35	45	....	....	....	....	....	....	....	....	11
"	24	....	..	20	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5	....	33	50	....	....	....	....	....	....	....	....	....
Oct.	1	....	..	4	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5	....	24	40	....	....	....	....	....	....	....	....	....
"	8	25	28	14	...	....	....	....	...	....	....	....	....	....	....	....	....	....	....	....	....	31	38	...	....	....	....	....	....	....	....	....
"	15	24	11	5	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	28	48	....	....	...	....	....	....	....	....	....
"	22	...	..	5	....	....	....	...	..	....	....	....	....	....	....	....	....	....	....	28	....	5	56	....	....	....	....	....	....	....	....	....
"	29	....	..	12	....	....	....	...	....	....	....	....	....	....	....	....	....	....	....	25	....	....	38	....	....	....	....	....	....	....	....	....
Nov.	5	8	6	12	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	39	....	...	9	...	....	....	....	....	....	....	....	....
"	12	6	..	9	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	43	....	....	46	....	....	....	....	....	....	....	....	....
"	19	9	13	10	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	45	....	....	40	...	....	....	....	....	....	....	....	....
"	26	28	10	27	....	....	....	....	....	....	....	24	....	....	....	....	....	....	....	33	....	....	12	....	....	....	....	....	....	....	....	....
Dec.	3	11	15	19	...	....	....	....	....	....	....	49	....	....	....	....	....	....	....	34	....	....	23	....	....	....	....	....	....	....	....	....
"	10	....	10	32	....	...	....	....	....	....	....	43	....	....	....	....	....	....	....	29	....	....	7	...	....	....	....	....	....	....	....	....
"	17	8	5	35	....	...	...	...	....	....	....	44	....	....	....	....	....	....	....	57	....	....	...	....	....	....	....	....	....	....	....	....
"	24	....	..	33	....	...	....	....	...	....	....	44	....	....	....	....	....	....	....	40	....	....	30	....	....	....	....	...	....	....	....	....
"	31	....	..	11	....	....	....	...	....	....	....	32	...	....	....	....	....	....	....	44	....	....	44	....	....	....	....	....	....	....	....	....
Total.....		119	98	463	502	1045	1403	1491	471	483	174	898	1095	956	678	105	231	998	228	517	566	985	1343	939	1082	630	825	311	823	182	12	201
Average per work'g w'k		15	12	16	33	45	64	50	52	48	12	43	55	50	38	26	58	38	46	32	24	24	28	28	32	24	28	16	28	26	12	18

NEW CROTON AQUEDUCT—WEEKLY PROGRESS IN TUNNEL EXCAVATION (LINEAL FEET), 1888.

1888.	Shaft 13.		Shaft 13A.		Shaft 13½.		Shaft 14.		Shaft 17.		Shaft 18.		Shaft 25.		Shaft 28.	
Week Ending	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.	N.	S.
January 7	....	....	13	41	....	....	...	....	....	....	4	....	62	....	54	....
" 14	...	....	....	53	...	....	42	....	....	....	....	....	62	....	....	....
" 21	...	....	....	58	....	....	63	....	...	14	....	....	64	....	....	....
" 28	....	....	....	50	15	14	36	....	....	....	....	....	59	...	....	....
February 4	....	....	....	44	17	20	5	....	....	24	....	....	63	....	....	....
" 11	....	....	....	48	27	23	8	....	....	20	....	....	52	....	...	....
" 18	....	14	15	58	39	29	7	....	....	....	....	....	73	....	....	....
" 25	....	....	....	....	....	45	36	....	....	7	....	....	48	....	....	....
March 3	....	....	....	....	....	32	11	....	....	13	....	....	63	....	....	....
" 10	....	....	....	....	....	44	15	....	....	7	....	....	51	....	....	....
" 17	...	....	....	....	....	13	33	....	....	10	....	....	30	....	...	....
" 24	....	....	....	....	....	24	16	....	....	17	....	....	55	....	....	....
" 31	....	....	....	....	....	38	28	....	....	8	....	....	45	....	....	....
April 7	....	10	20	....	....	28	14	....	....	12	....	...	35	....	....	....
" 14	....	....	....	....	....	34	9	....	....	11	....	....	....	....	....	....
" 21	....	....	....	....	....	34	....	....	....	10	....	....	....	...	....	....
" 28	....	....	....	....	....	30	....	....	....	....	....	....	....	....	....	...
May 5	....	....	...	....	....	29	...	....	....	....	....	....	...	....	....	....
" 12	....	....	....	....	....	33	....	....	....	....	....	....	....	...	....	....
" 19	....	....	....	....	....	15	9	...	....	32	....	...	....	....	....	....
" 26	....	...	....	....	....	17	8	....	....	22	....	....	....	....	....	....
June 2	....	....	....	....	....	....	2	....	....	31	....	....	....	...	....	....
" 9	....	....	....	....	....	10	12	....	....	18	....	...	....	....	....	....
" 16	....	....	....	....	....	40	27	....	....	....	....	....	....	....	....	...
" 23	....	....	....	....	....	40	31	....	....	....	....	....	....	....	....	....
" 30	....	....	....	....	....	45	37	....	....	....	....	....	....	....	....	....
July 7	....	....	....	....	....	21	17	....	....	....	....	....	....	....	....	....
Total	....	24	48	352	98	658	466	....	....	256	4	....	762	....	54	....
Average per working week	...	12	16	50	25	29	21	....	....	16	4	....	54	....	54	....

Note.—By July 7, 1888, all the tunnel excavation was completed.

NEW CROTON AQUEDUCT.

Table of Flowing Capacities for Various Depths of Water.

Depths Above Centre of Invert, in Feet.	Velocity in Feet per Second. V.	Cubic Feet per Second. Q.	Gallons per Day of 24 Hours.	Depths Above Centre of Invert, in Feet.	Velocity in Feet per Second. V.	Cubic Feet per Second. Q.	Gallons per Day of 24 Hours.
1.0	0.95934	7.7131	4,985,100	7.0	2.9130	252.30	163,065,000
.1	1.0969	10.135	6,550,500	.1	2.9242	257.24	166,259,000
.2	1.1981	12.532	8,099,600	.2	2.9352	262.20	169,467,000
.3	1.2850	14.995	9,691,800	.3	2.9459	267.13	172,653,000
.4	1.3615	17.549	11,342,000	.4	2.9559	272.06	175,840,000
.5	1.4338	20.245	13,084,000	.5	2.9662	277.01	179,038,000
.6	1.4998	23.022	14,880,000	.6	2.9761	281.96	182,233,000
.7	1.5607	25.877	16,724,000	.7	2.9858	286.91	185,432,000
.8	1.6191	28.852	18,648,000	.8	2.9953	291.87	188,638,000
.9	1.6736	31.916	20,628,000	.9	3.0045	296.79	191,819,000
2.0	1.7241	35.017	22,632,000	8.0	3.0132	301.65	194,964,000
.1	1.7731	38.246	24,719,000	.1	3.0218	306.56	198,135,000
.2	1.8178	41.481	26,810,000	.2	3.0298	311.40	201,264,000
.3	1.8639	44.900	29,020,000	.3	3.0375	316.21	204,369,000
.4	1.9064	48.328	31,235,000	.4	3.0457	321.08	207,518,000
.5	1.9465	51.816	33,490,000	.5	3.0532	325.90	210,633,000
.6	1.9860	55.411	35,813,000	.6	3.0604	330.67	213,721,000
.7	2.0234	59.044	38,161,000	.7	3.0673	335.41	216,783,000
.8	2.0596	62.735	40,547,000	.8	3.0747	340.22	219,890,000
.9	2.0945	66.501	42,981,000	.9	3.0814	344.97	222,957,000
3.0	2.1281	70.313	45,444,000	9.0	3.0879	349.64	225,978,000
.1	2.1609	74.204	47,959,000	.1	3.0935	354.24	228,948,000
.2	2.1926	78.143	50,505,000	.2	3.0989	358.80	231,896,000
.3	2.2222	82.089	53,055,000	.3	3.1042	363.32	234,817,000
.4	2.2516	86.101	55,648,000	.4	3.1094	367.84	237,740,000
.5	2.2802	90.183	58,287,000	.5	3.1143	372.28	240,611,000
.6	2.3079	94.301	60,948,000	.6	3.1187	376.68	243,455,000
.7	2.3343	98.463	63,638,000	.7	3.1236	381.11	246,316,000
.8	2.3603	102.65	66,344,000	.8	3.1277	385.43	249,109,000
.9	2.3857	106.90	69,094,000	.9	3.1317	389.70	251,872,000
.0	2.4102	111.21	71,875,000	10.0	3.1352	393.88	254,570,000
4.1	2.4343	115.53	74,671,000	.1	3.1382	397.96	257,205,000
.2	2.4569	119.87	77,476,000	.2	3.1411	402.06	259,856,000
.3	2.4795	124.27	80,319,000	.3	3.1437	406.01	262,410,000
.4	2.5012	128.69	83,174,000	.4	3.1456	409.88	264,911,000
.5	2.5226	133.17	86,068,000	.5	3.1475	413.74	267,407,000
.6	2.5432	137.66	88,975,000	.6	3.1493	417.51	269,843,000
.7	2.5634	142.19	91,902,000	.7	3.1504	421.18	272,215,000
.8	2.5829	146.74	94,837,000	.8	3.1508	424.64	274,454,000
.9	2.6022	151.34	97,817,000	.9	3.1514	428.12	276,700,000
5.0	2.6204	155.91	100,769,000	11.0	3.1519	431.58	278,940,000
.1	2.6382	160.53	103,756,000	.1	3.1515	434.81	281,025,000
.2	2.6560	165.20	106,774,000	.2	3.1509	438.01	283,095,000
.3	2.6732	169.88	109,799,000	.3	3.1491	440.90	284,962,000
.4	2.6901	174.59	112,840,000	.4	3.1478	443.87	286,880,000
.5	2.7066	179.32	115,894,000	.5	3.1463	446.80	288,778,000
.6	2.7230	184.10	118,988,000	.6	3.1438	449.43	290,477,000
.7	2.7388	188.89	122,086,000	.7	3.1412	452.05	292,169,000
.8	2.7541	193.67	125,170,000	.8	3.1374	454.29	293,615,000
.9	2.7693	198.50	128,295,000	.9	3.1338	456.60	295,105,000
6.0	2.7838	203.26	131,372,000	12.0	3.1299	458.81	296,534,000
.1	2.7979	208.11	135,504,000	.1	3.1247	460.64	297,720,000
.2	2.8120	212.98	137,653,000	.2	3.1193	462.47	298,905,000
.3	2.8258	217.87	140,815,000	.3	3.1127	463.86	299,800,000
.4	2.8392	222.76	143,974,000	.4	3.1058	465.22	300,677,000
.5	2.8522	227.66	147,144,000	.5	3.0977	466.37	301,420,000
.6	2.8650	232.58	150,323,000	.6	3.0917	467.65	302,248,000
.7	2.8772	237.46	153,473,000	.7	3.0789	467.74	302,309,000
.8	2.8894	242.39	156,660,000	.8	3.0676	468.00	302,477,000
.9	2.9013	247.33	159,855,000	.842	3.0625	467.99	302,467,000

Note.—This table has been computed by formula (2), page 178, with values of "c" varying as per diagram on page 183. It has been condensed from the table given in the Report of the Aqueduct Commission of December 31, 1894.

SUPPLY FROM CROTON RIVER.

AVERAGE DAILY YIELD OF THE CROTON RIVER, AT CROTON DAM, INCLUDING DELIVERY OF AQUEDUCT (1870 TO 1895).

Flow given in U. S. gallons.

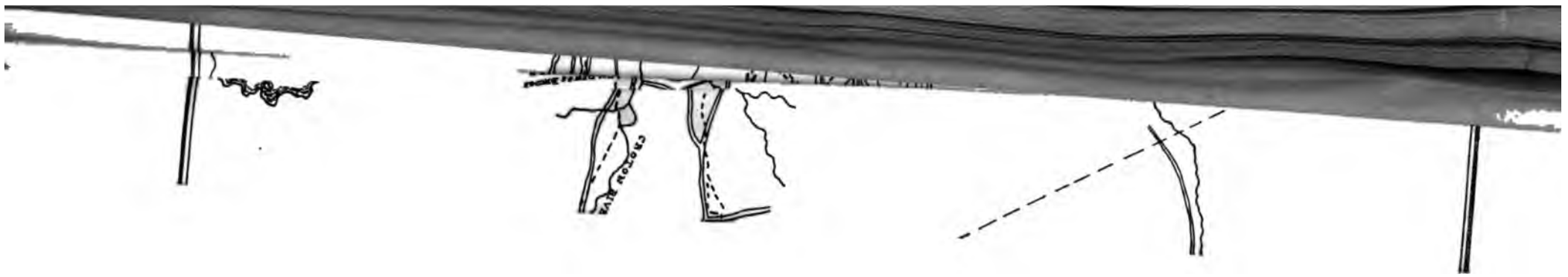
MONTHS.	1870	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881	1882
Jan.	756,229,400	112,583,600	394,276,000	812,602,600	1,233,336,000	123,527,800	301,113,400	159,028,400	539,308,700	275,120,200	520,688,800	143,763,600	454,825,900
Feb.	896,929,400	462,455,300	253,181,000	360,965,900	586,552,800	857,896,100	728,973,300	324,992,800	821,825,000	580,582,800	604,796,000	906,294,200	886,908,100
March	671,864,100	666,064,000	330,750,400	762,445,200	573,137,700	612,838,600	1,355,247,300	1,320,707,600	737,172,300	814,817,100	570,695,500	1,152,429,800	897,801,000
April	802,776,900	394,827,900	608,712,400	1,393,287,500	709,111,900	1,092,060,900	1,249,862,000	591,526,300	330,723,500	1,002,137,400	411,193,300	367,615,200	279,251,500
May	351,170,800	390,004,700	243,054,100	414,505,700	603,902,300	352,818,500	385,070,200	168,523,700	297,982,400	335,352,200	185,883,000	262,429,100	416,778,500
June	162,371,100	280,268,300	238,754,100	106,574,200	180,835,000	114,646,500	138,482,800	122,003,100	297,458,800	183,484,700	102,469,400	325,929,600	333,547,600
July	97,124,500	139,484,900	116,501,400	93,195,700	271,481,000	110,094,000	104,386,700	97,075,700	140,585,200	137,715,000	102,165,600	109,261,200	131,090,100
August	96,156,900	161,562,700	311,423,300	134,929,700	168,529,200	1,098,582,800	95,197,300	93,257,400	129,178,300	281,198,400	97,725,300	98,918,800	99,087,500
Sept	69,401,200	123,146,000	244,752,900	101,025,700	114,362,200	176,436,000	72,876,300	66,184,600	416,331,500	213,818,100	97,911,100	98,997,800	636,747,000
Oct	79,740,400	364,430,400	213,242,100	273,813,200	153,681,000	161,400,700	72,001,400	215,300,400	175,885,400	126,713,000	97,023,100	98,950,900	430,396,000
Nov	121,677,800	666,509,900	522,527,700	354,724,300	143,985,600	401,289,500	138,949,000	817,730,000	408,939,800	160,206,300	112,545,300	93,015,600	187,987,300
Dec	121,823,300	398,819,000	274,445,500	639,659,000	185,200,900	348,299,600	224,774,000	372,613,300	1,468,254,500	383,371,100	101,778,900	327,267,800	243,382,700
Daily av.	352,272,150	346,679,725	312,635,075	453,977,392	410,342,967	454,157,583	405,577,808	362,411,942	480,303,783	374,543,025	250,406,275	332,072,800	416,483,600

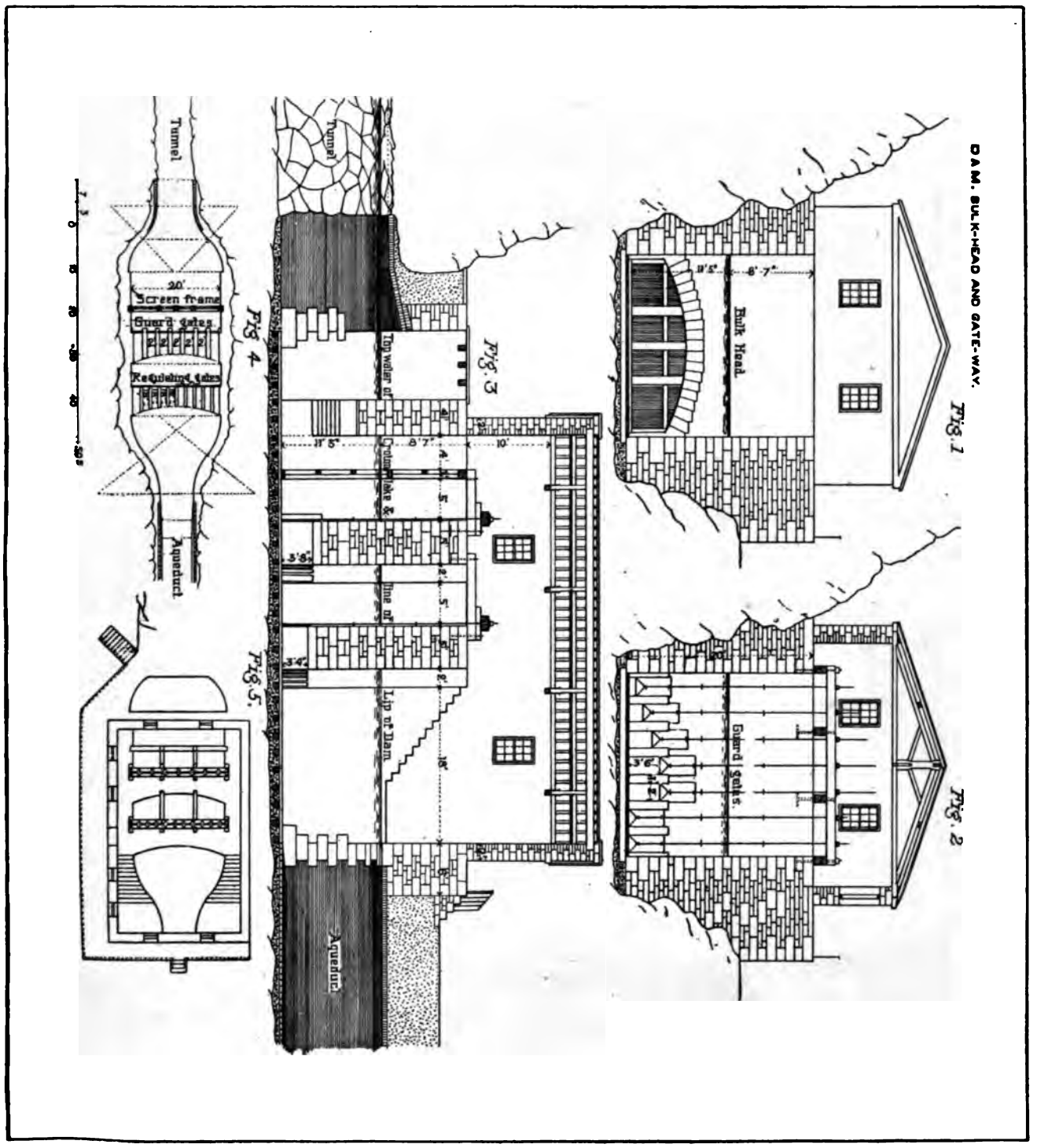
MONTHS.	1883	1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	Average Daily Flow, 1870 to 1894.
Jan.	200,965,100	404,998,700	780,057,300	646,957,500	518,187,500	758,526,200	833,928,600	443,789,500	1,295,833,226	840,806,452	308,427,000	326,831,000	540,331,160
Feb.	797,647,500	1,001,081,500	510,180,000	1,025,720,700	1,043,348,500	1,002,011,600	493,997,300	668,148,300	1,202,320,107	294,862,069	671,353,820	450,363,000	706,156,920
March	572,851,500	949,297,400	388,174,600	473,000,000	698,792,700	888,220,600	396,855,200	892,823,700	828,522,193	367,967,742	1,366,436,613	987,931,000	771,073,720
April	533,060,300	587,228,100	512,912,000	883,077,400	637,929,300	949,308,500	504,476,200	643,834,600	566,897,033	268,500,000	697,991,900	478,173,000	671,658,984
May	261,920,000	361,167,700	298,389,500	406,993,300	245,708,000	505,426,500	333,316,300	517,465,300	168,904,903	306,322,580	1,147,814,000	355,315,000	372,648,760
June	123,568,000	136,199,500	115,722,200	153,141,800	227,348,300	272,243,300	278,682,700	300,111,400	150,000,000	224,833,333	188,083,200	289,503,500	201,850,700
July	99,221,600	154,060,900	98,488,000	115,078,100	496,951,000	126,209,400	308,473,700	134,058,000	120,709,677	143,387,097	132,613,000	110,064,500	147,539,060
August	98,985,000	223,479,200	109,133,600	110,366,300	673,828,700	209,871,400	763,507,700	112,644,700	107,774,193	168,258,065	158,202,387	167,709,700	230,780,356
Sept	99,417,500	144,276,500	82,592,500	99,041,600	175,127,200	608,460,600	444,593,000	398,321,700	108,866,667	140,800,000	133,566,666	135,596,100	200,105,988
Oct	124,183,000	107,058,200	104,721,900	98,948,000	194,817,100	487,535,700	365,224,600	636,074,100	128,670,968	92,032,258	215,779,839	134,129,000	206,070,152
Nov	134,260,300	191,757,800	429,373,200	171,643,900	185,925,400	594,833,000	1,035,063,100	408,078,800	129,019,333	255,466,666	361,478,567	583,078,100	344,402,612
Dec	120,366,600	714,959,900	395,240,500	225,019,600	470,085,100	995,160,600	861,123,600	311,894,700	273,880,548	248,258,064	731,928,774	486,555,400	432,995,656
Daily av.	263,870,533	414,630,450	318,748,775	367,415,683	460,967,490	616,173,000	551,922,400	454,054,200	419,072,934	279,827,869	509,942,219	374,863,778	400,157,703

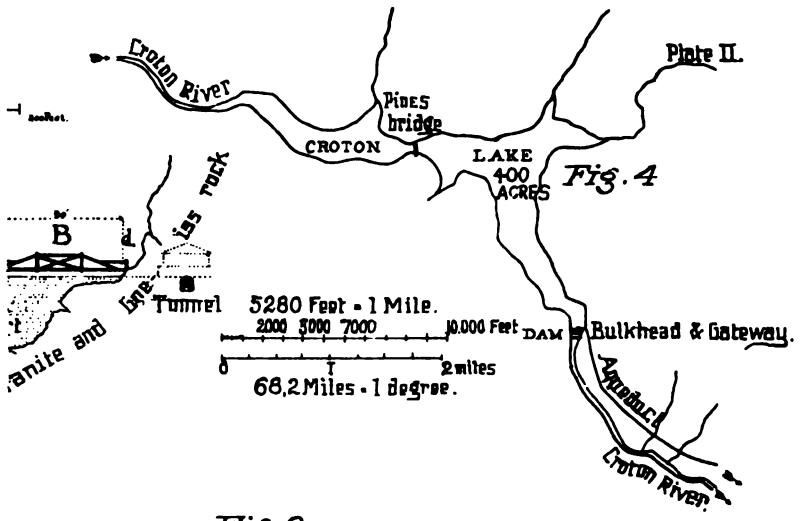
PIPES LAID IN THE CITY OF NEW YORK TO JANUARY 1, 1895.

YEAR.	48"	36"	30"	24"	20"	16"	12"	10"	6"	4"	MILES.
Prev. to July 1849..	.....	60,333	25,796	5,400	20,275	13,125	225,140	5,875	668,107	.....	193.95
July to Dec. (inclusive) 1849.....	.....	.....	.....	.....	.....	958	2,430	.....	9,402	7,451	3.83
1850	.....	545	2,040	.....	4,860	.....	2,375	.....	30,539	969	7.83
1851.....	.....	.....	.....	.....	2,721	.....	18,739	.....	42,817	923	12.35
1852.....	.....	.....	.....	.....	3,650	.....	12,171	.....	47,714	.....	12.03
1853.....	3,500	.....	5,125	.....	.....	.....	999	.....	24,161	.....	6.40
1854.....	587	.....	.....	.....	1,765	.....	5,000	.....	23,223	.....	5.80
1855.....	.....	.....	10,582	.....	1,492	.....	6,063	.....	18,784	.....	6.97
1856.....	.....	.....	1,319	.....	102	.....	2,731	.....	25,702	129	5.70
1857.....	.....	.....	.....	.....	.....	.....	3,089	.....	20,131	.....	4.40
1858.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1859.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
1860.....	.....	.....	.....	.....	.....	.....	6,602	.....	26,331	.....	6.24
1861.....	.....	.....	.....	.....	.....	.....	5,205	.....	34,567	.....	7.53
1862.....	27,900	.....	.....	.....	.....	.....	3,610	.....	21,713	.....	10.08
1863.....	.....	.....	.....	.....	.....	.....	7,560	.....	20,986	.....	5.41
1864.....	.....	.....	.....	.....	.....	2,080	4,880	.....	14,999	.....	4.15
1865.....	.....	.....	.....	.....	.....	.....	6,520	.....	12,938	.....	3.68
1866.....	.....	.....	.....	.....	7,050	.....	3,670	.....	11,100	.....	4.13
1867.....	.....	.....	.....	.....	1,665	.....	6,276	.....	17,660	.....	4.85
1868.....	.....	.....	.....	.....	2,531	.....	8,268	.....	21,453	.....	6.11
1869.....	.....	.....	.....	.....	11,300	.....	9,681	.....	18,171	.....	7.41
1870.....	.....	.....	.....	.....	10,770	.....	18,500	.....	35,282	1,183	12.45
1871.....	2,220	3,050	.....	.....	3,557	.....	19,404	.....	33,481	4,432	12.52
1872.....	82	16,402	.....	.....	3,098	.....	25,372	.....	52,750	9,431	20.34
1873.....	17,332	481	.....	1,626	38,132	.....	34,129	.....	57,855	3,477	28.98
1874.....	9,513	109	2,177	.....	8,059	.....	18,055	754	27,436	3,344	13.15
1875 } 1876 }	2,032	.....	235	.....	22,108	.....	32,771	.....	45,206	.....	19.34
1877.....	9,407	.....	.....	.....	14,998	.....	20,663	.....	34,142	.....	15.00
1878.....	6,916	5,880	.....	.....	16,181	.....	35,699	.....	58,405	.....	23.31
1879	607	3,536	353	.....	889	.....	14,207	.....	65,033	.....	16.03
1880.....	.....	.....	.....	.....	9,100	.....	26,164	.....	87,133	1,018	23.37
1881.....	.....	.....	.....	.....	490	.....	16,826	.....	29,989	.....	9.00
1882.....	.....	2,500	.....	.....	1,757	.....	42,026	.....	56,783	415	19.60
1883.....	.....	13,138	.....	.....	.....	.....	15,928	.....	57,136	2,945	16.88
1884.....	.....	.....	.....	.....	.....	.....	33,257	.....	42,700	.....	14.37
1885.....	.....	.....	.....	.....	38	.....	34,666	.....	54,919	250	17.02
1886.....	.....	.....	.....	.....	.....	.....	51,098	.....	78,400	.....	24.53
1887.....	.....	.....	.....	.....	.....	.....	24,873	.....	56,571	.....	15.42
1888.....	.....	9	.....	.....	937	.....	25,936	.....	74,487	.....	19.20
1889.....	7,513	860	.....	.....	169	.....	22,057	.....	69,369	.....	18.93
1890.....	2,569	7,400	.....	.....	4,530	.....	8,669	.....	60,255	3,130	16.38
1891.....	.....	10,962	.....	.....	1,219	.....	31,853	.....	52,526	.....	18.29
1892.....	9,035	1,378	.....	.....	133	.....	15,739	.....	53,698	96	15.17
1893.....	11,215	1,120	61	.....	727	.....	8,268	.....	48,138	118	13.19
1894.....	6,269	7,990	189	.....	780	.....	9,758	.....	69,529	350	17.97
Total.....	116,697	135,693	47,877	7,026	195,083	16,163	926,927	6,629	2,411,721	39,661	739.29
Less am't taken up.	10,355	437	5,854				10,646		54,152	8,452	11.33
Am't now in use...	106,342	135,256	42,023	7,026	195,083	16,163	916,281	6,629	2,357,569	31,209	727.96

NOTE.—During 1888 and 1889 71,716 lineal feet of 48" mains were laid by the Aqueduct Commission. This is not included in the above table.


EAST ROLLING
CAMPUS


DAM. BULK-HEAD AND GATE-WAY.
Fig. 1
Bulk Head
Fig. 2
Guard Gates.
Fig. 3
Tunnel
Top water of
Column Gate &
Line of
Lip of Dam
Aqueduct
Fig. 4
Tunnel
Screen frame
Guard gates
Regulating gates
Aqueduct
Fig. 5.


Croton River
Pines bridge
CROTON
LAKE
400 ACRES
Plate II.
Fig. 4
B
Tunnel
5280 Feet = 1 Mile.
2000 5000 7000
10,000 Feet
0 1 2 miles
68.2 Miles = 1 degree.
DAM
Bulkhead & Gateway.
Croton River.

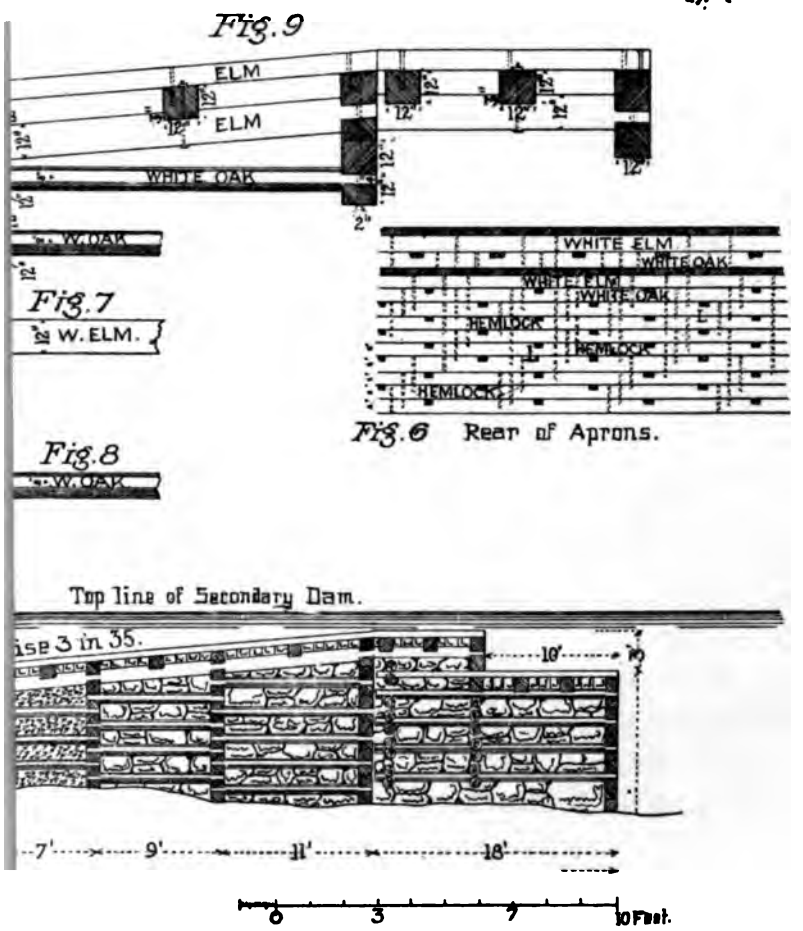
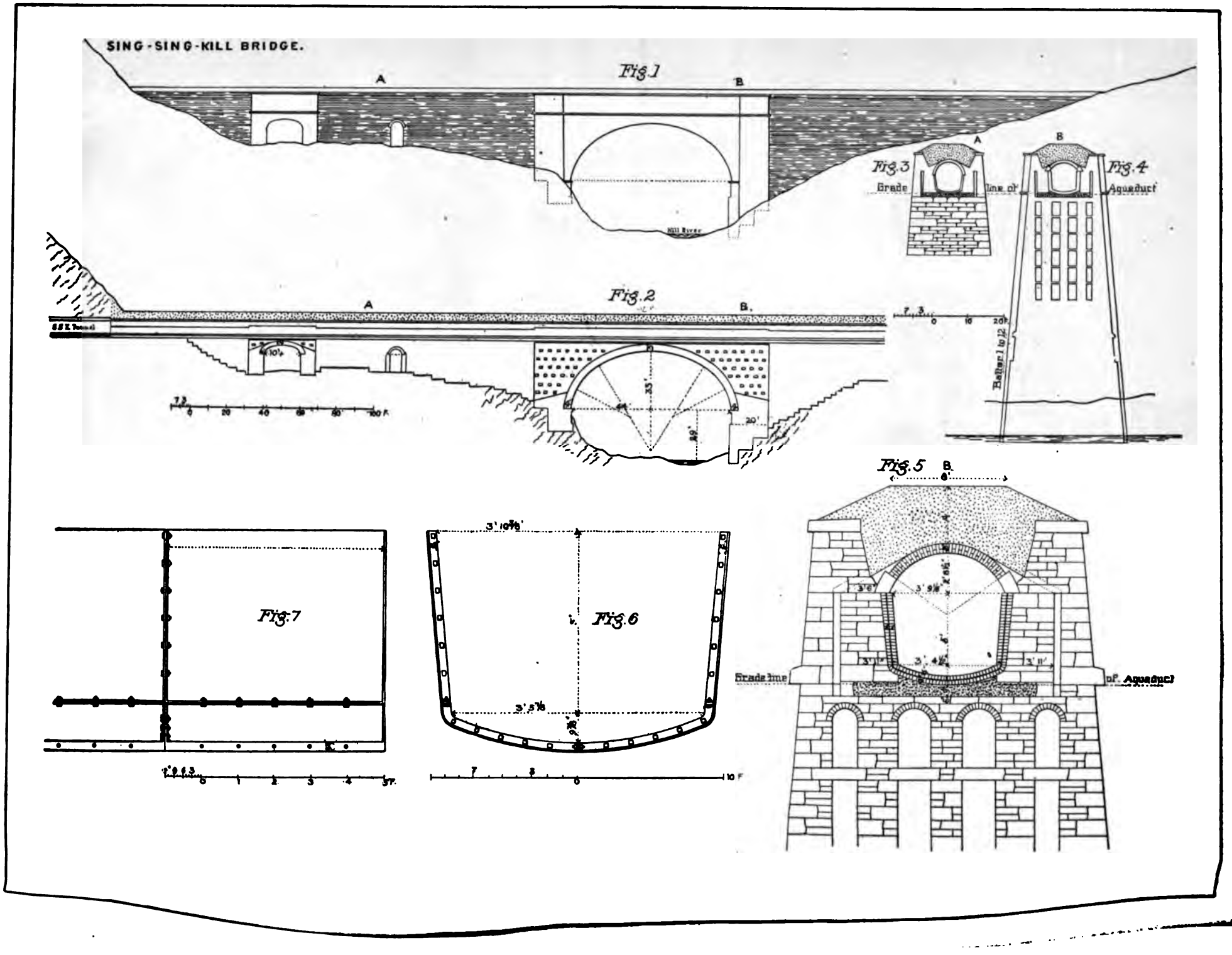


Fig. 9
ELM
ELM
WHITE OAK
W. OAK
Fig. 7
W. ELM.
Fig. 8
W. OAK
WHITE ELM
WHITE OAK
WHITE ELM
WHITE OAK
HEMLOCK
HEMLOCK
HEMLOCK
Fig. 6 Rear of Aprons.
Top line of Secondary Dam.
Rise 3 in 35.
10'
7'
9'
11'
18'
0 3 7 10 Feet.

PLATE 35.


SING-SING-KILL BRIDGE.
Fig. 1
A
B
Fig. 2
Fig. 3
Grade
line of
Fig. 4
Aqueduct
Batter 1 to 12
Fig. 5
Grade line
of Aqueduct
Fig. 6
Fig. 7

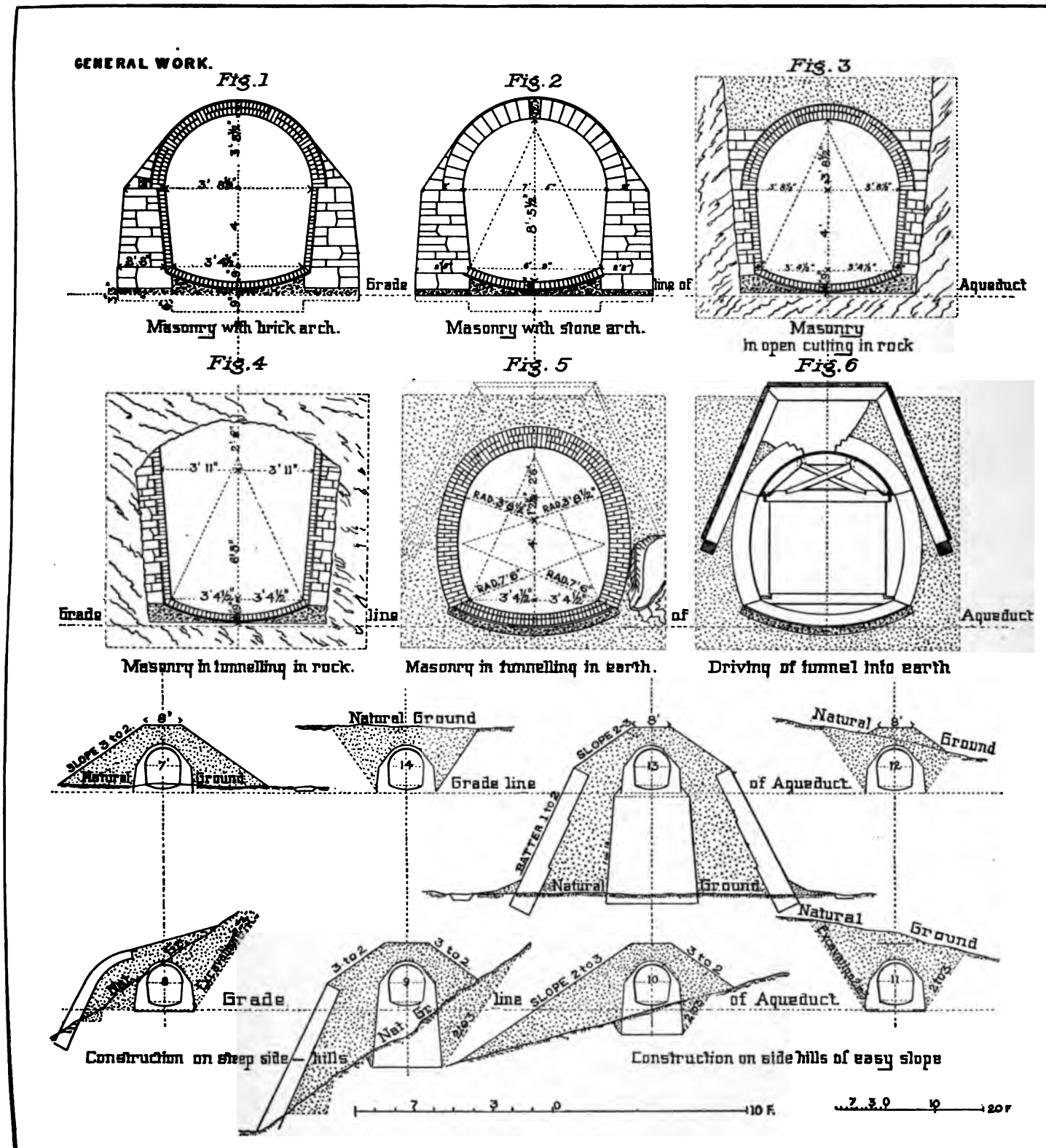

GENERAL WORK.
Fig. 1
Fig. 2
Fig. 3
Grade line of Aqueduct
Masonry with brick arch.
Masonry with stone arch.
Masonry in open cutting in rock
Fig. 4
Fig. 5
Fig. 6
Grade line of Aqueduct
Masonry in tunnelling in rock.
Masonry in tunnelling in earth.
Driving of tunnel into earth
Natural Ground
Grade line of Aqueduct
Natural Ground
Construction on steep side-hills
Construction on side hills of easy slope
10 F.
20 F.

PLATE 34.

CULVERTS.

Fig. 1

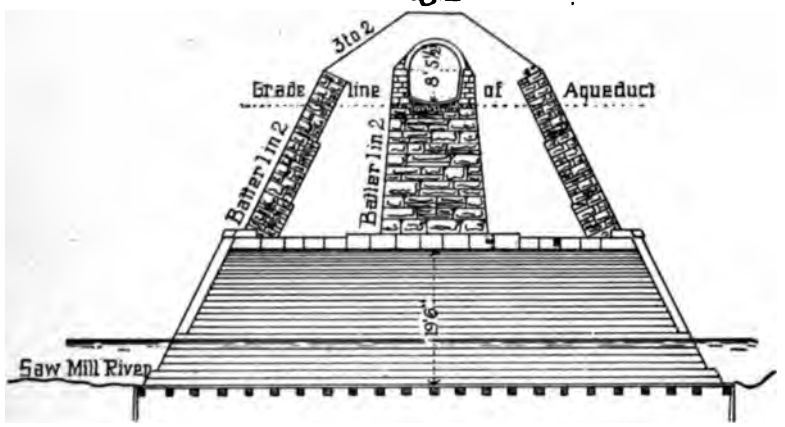


Fig. 2

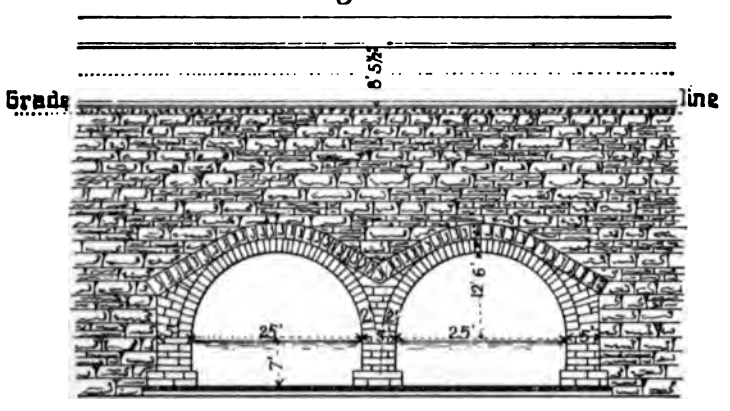


Fig. 3

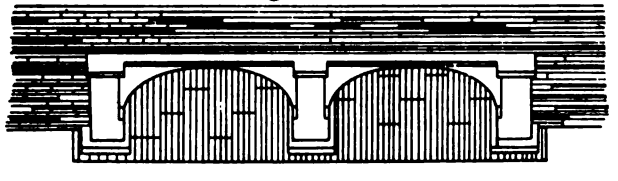


Fig. 4

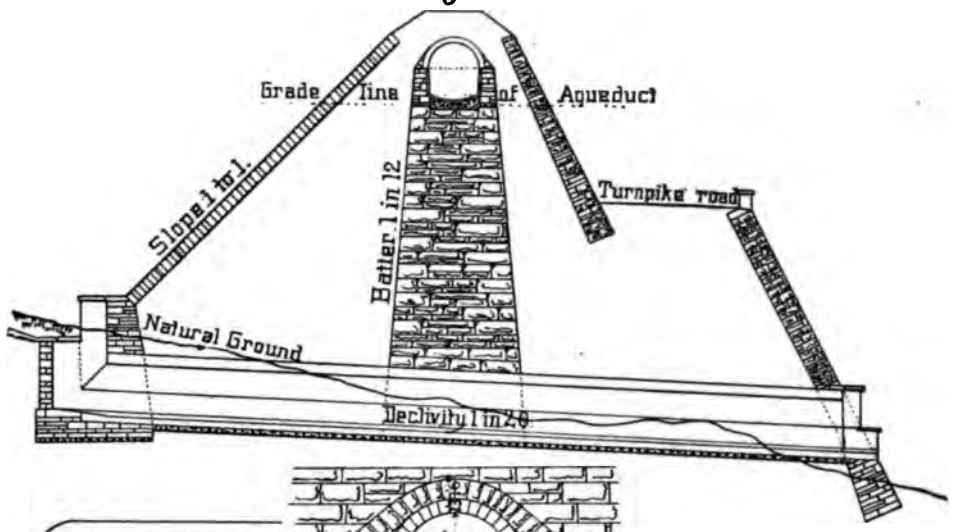
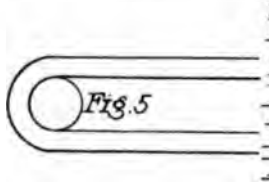


Fig. 5



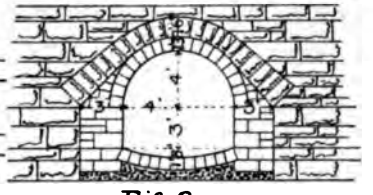


Fig. 6

Fig. 7

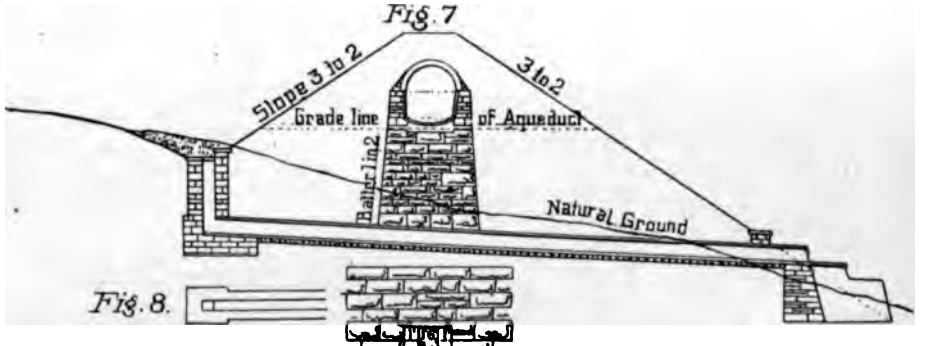


Fig. 8.

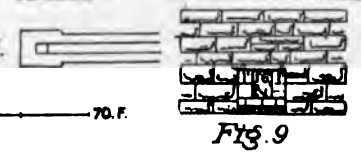
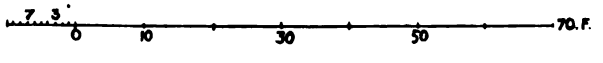
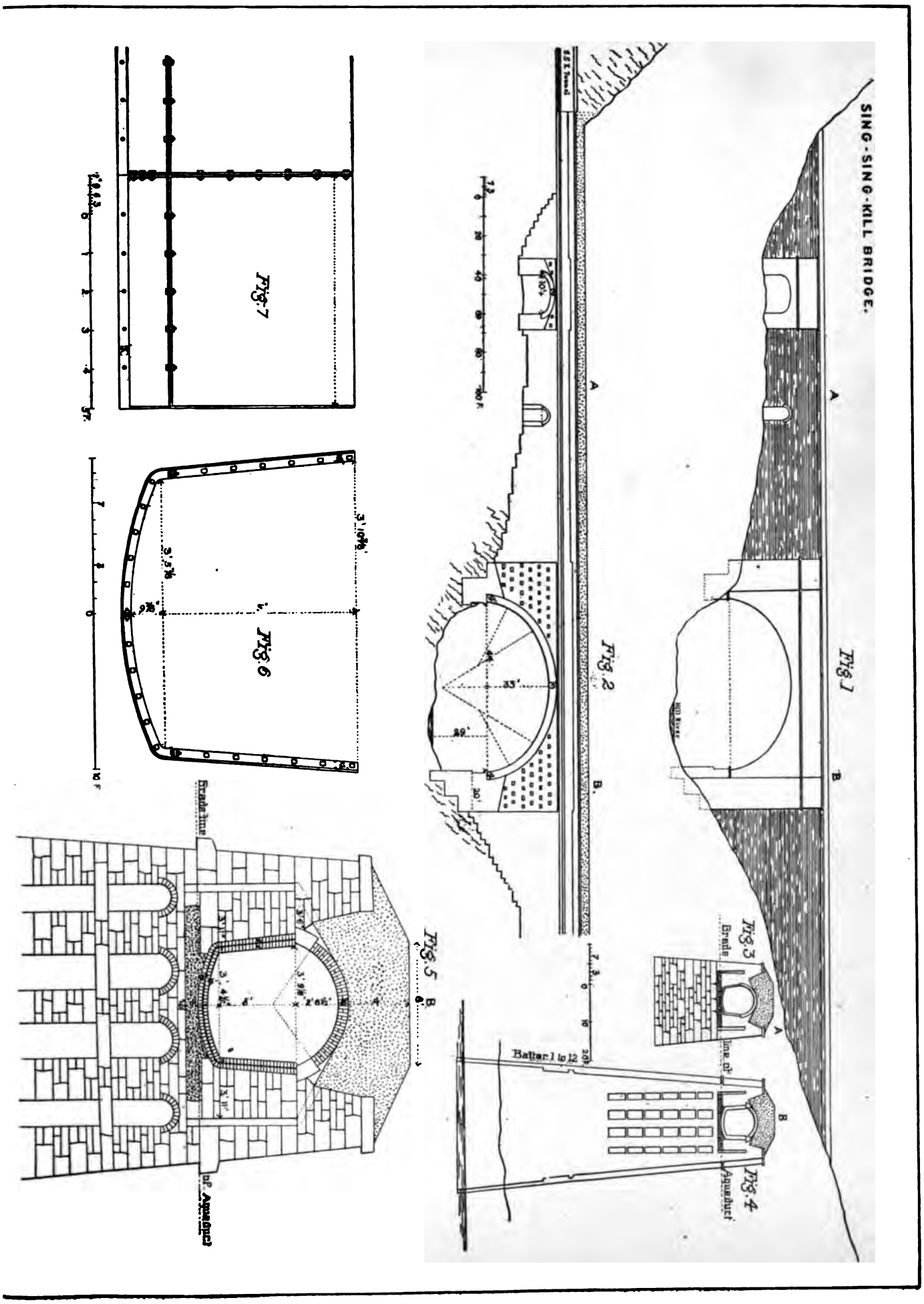
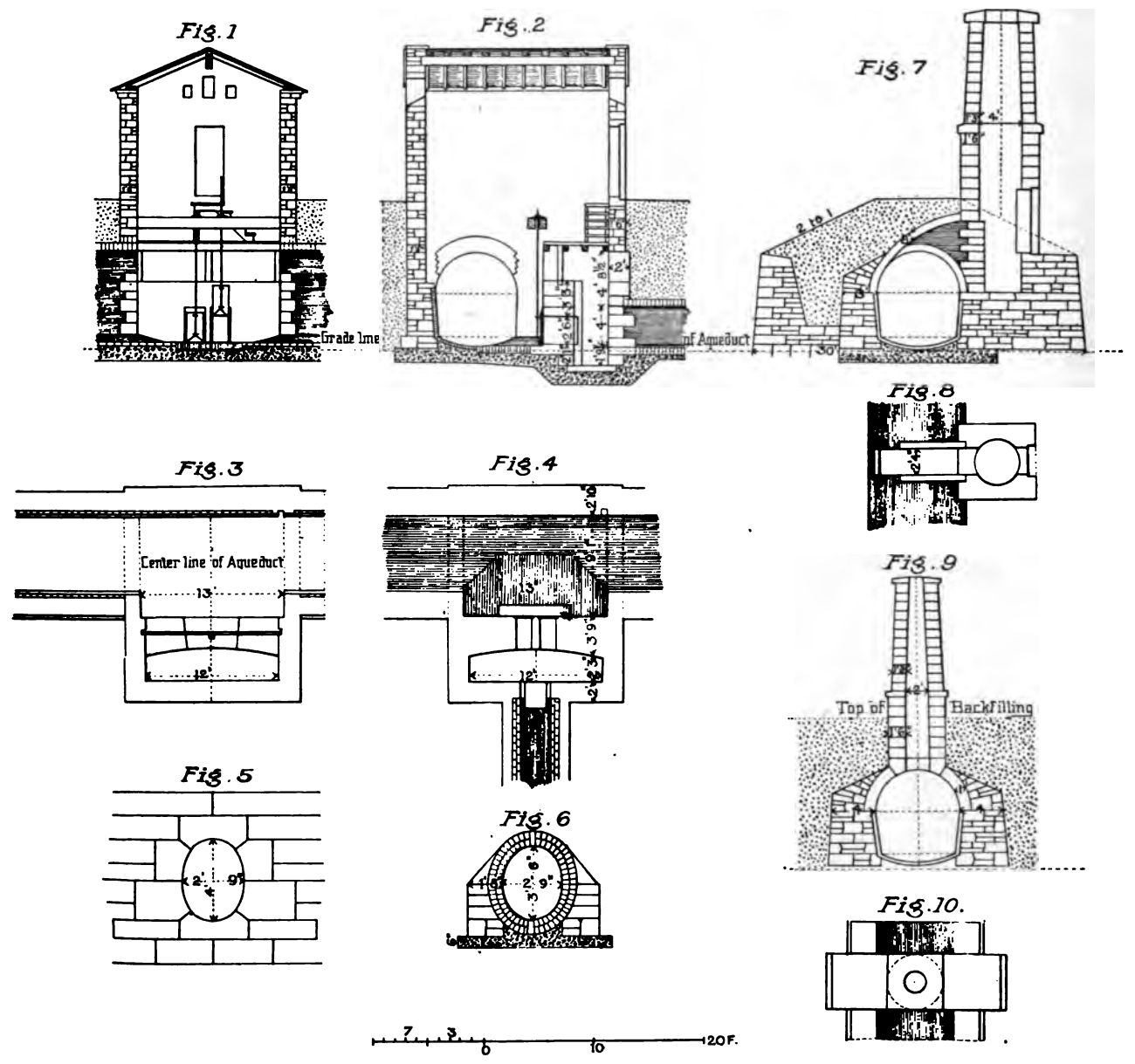


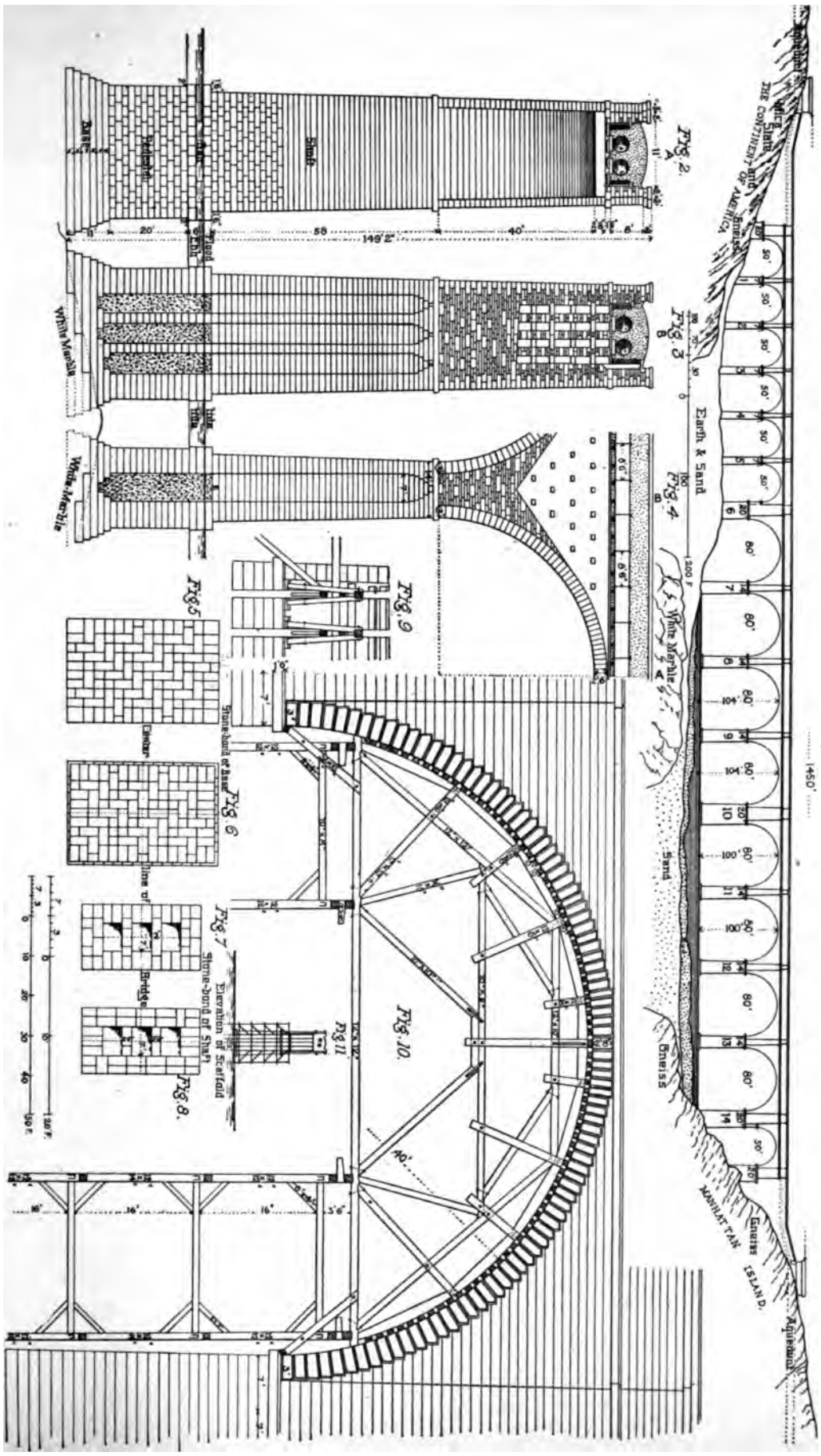
Fig. 9



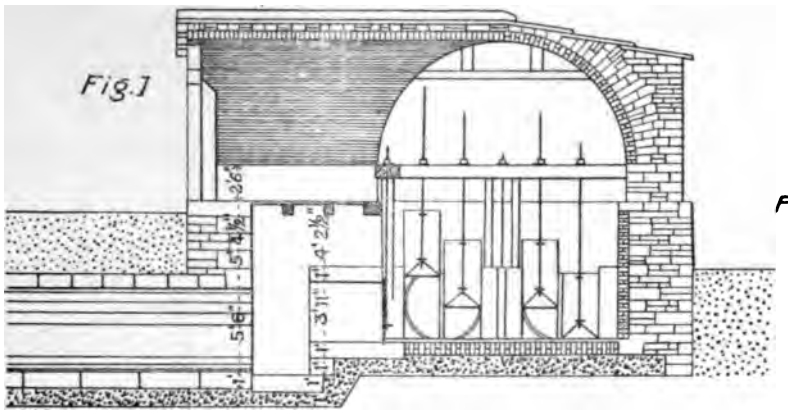

SING-SING-KILL BRIDGE.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Grade line
Aqueduct
Batter 1 to 12
Mill River

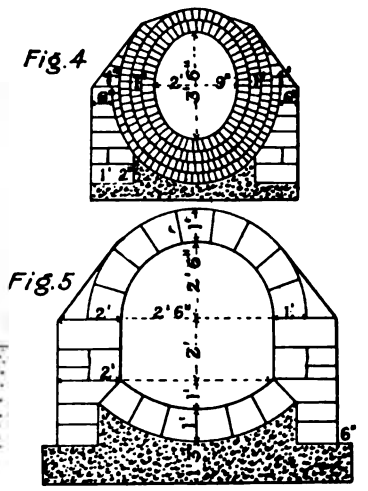
WASTE-WEIRS AND VENTILATORS.

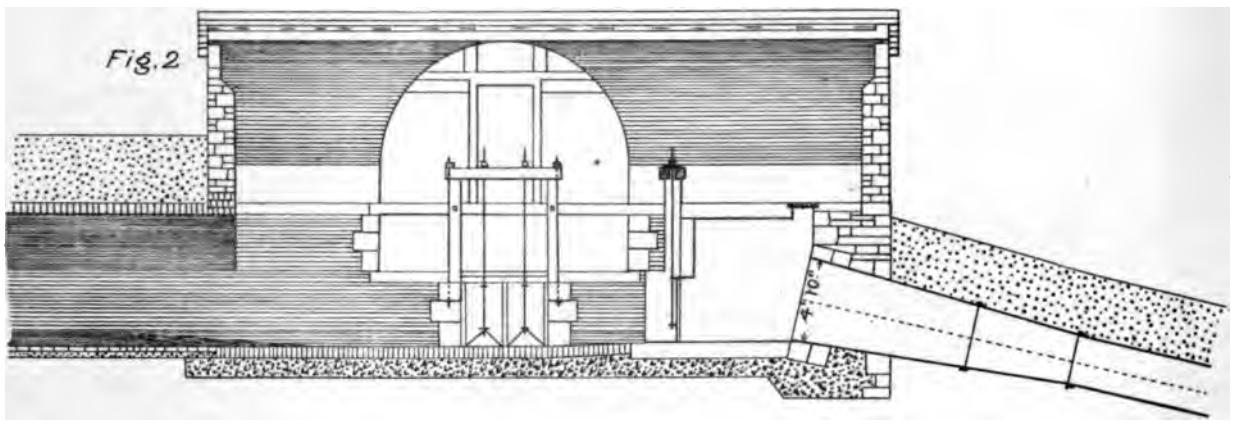


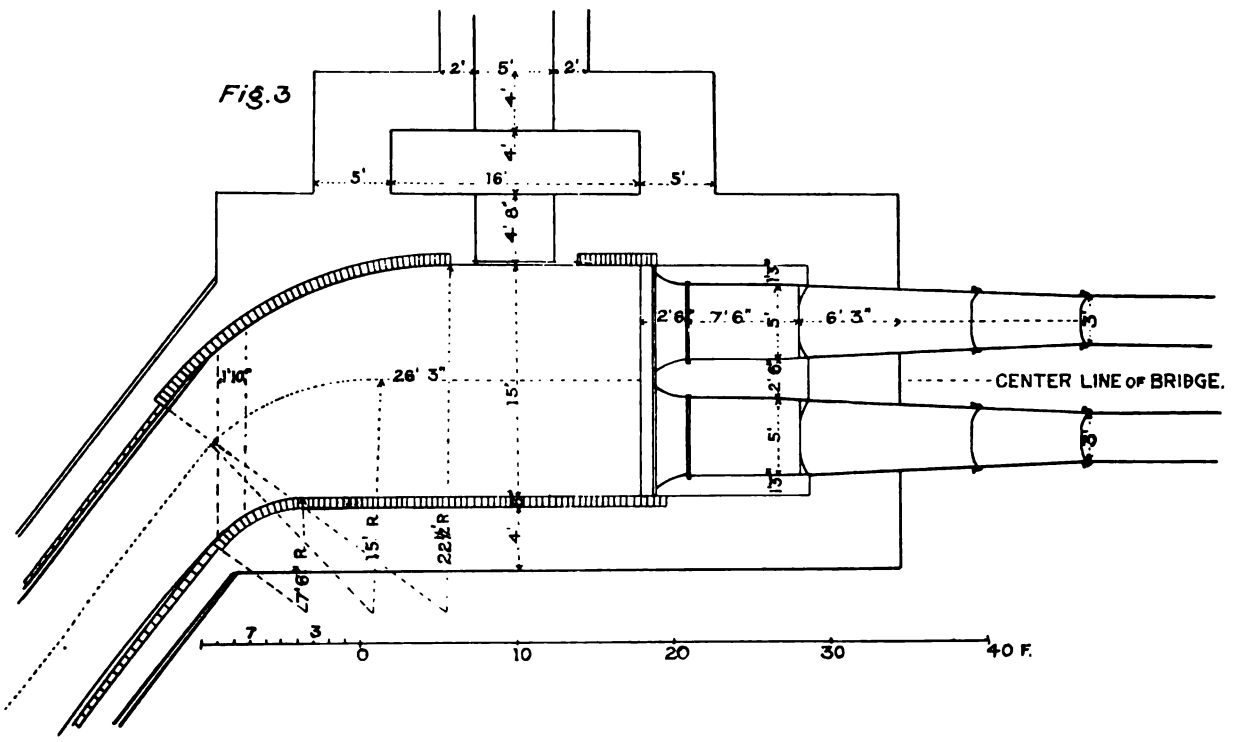

HARLEM RIVER BRIDGE.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
Fig. 9
Fig. 10
Fig. 11
Earth & Sand
Sand
Gneiss
White Marble
Stone-bond of Base
Stone-bond of Shaft
Elevation of Scaffold
Bridge
Dam
Sluice
Aqueduct
MANHATTAN ISLAND.
THE CONTINENT OF AMERICA
1450'

HARLEM RIVER BRIDGE. GATE HOUSE.

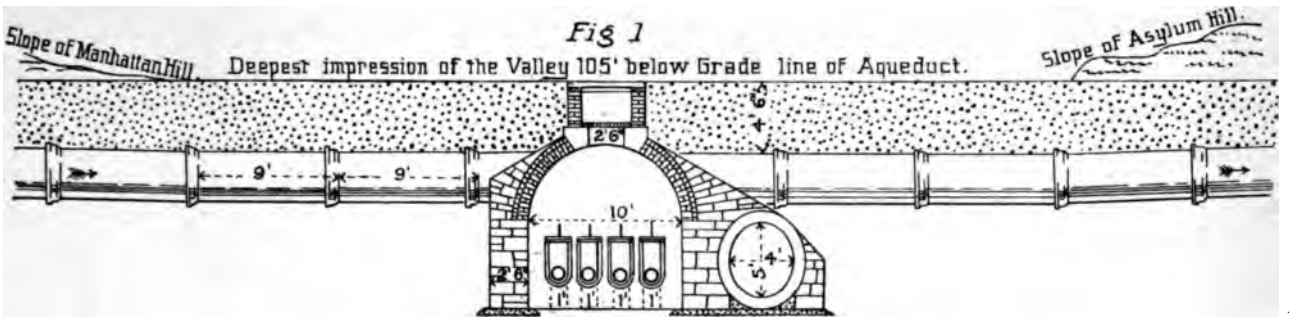


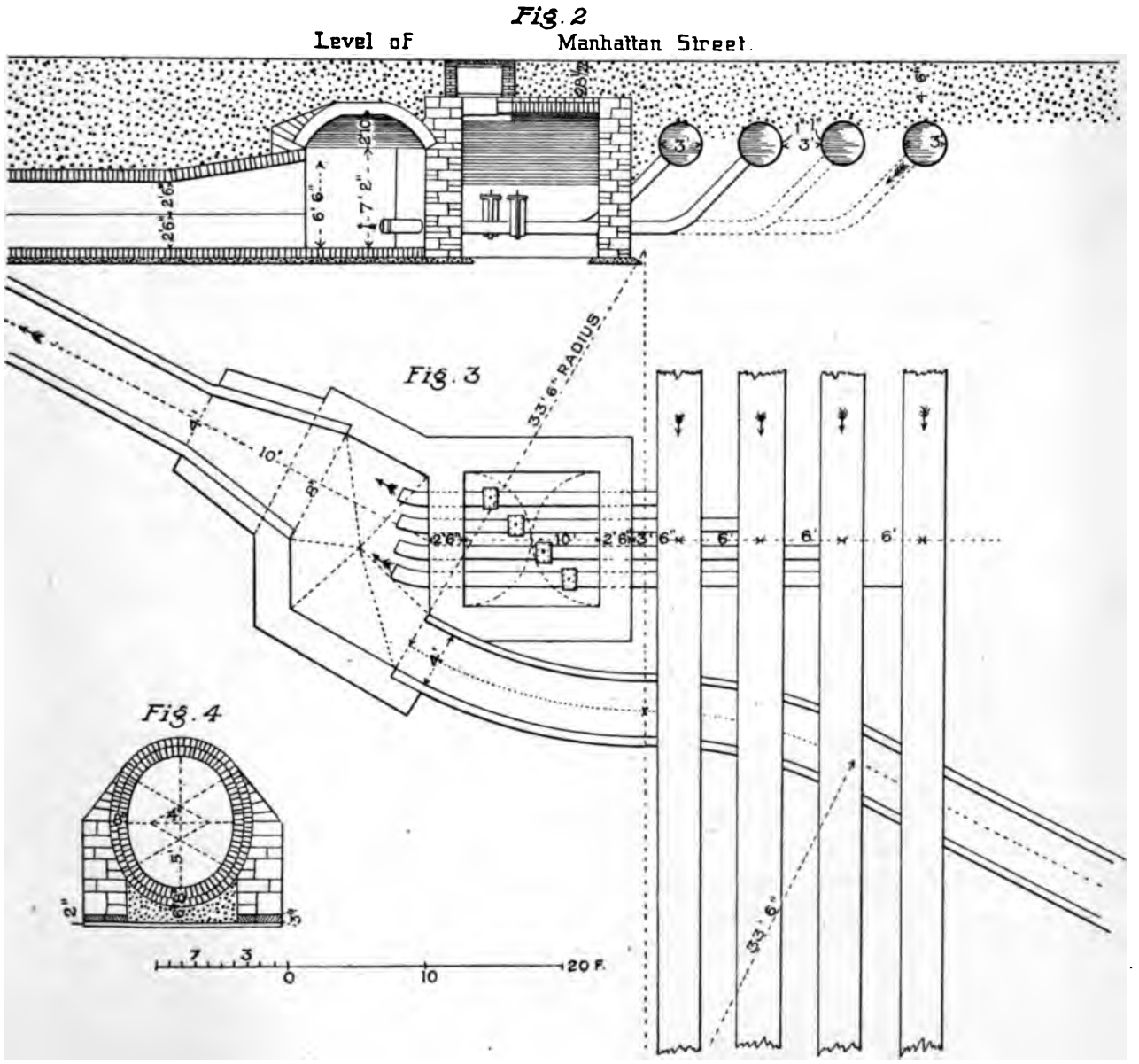






MANHATTAN VALLEY.





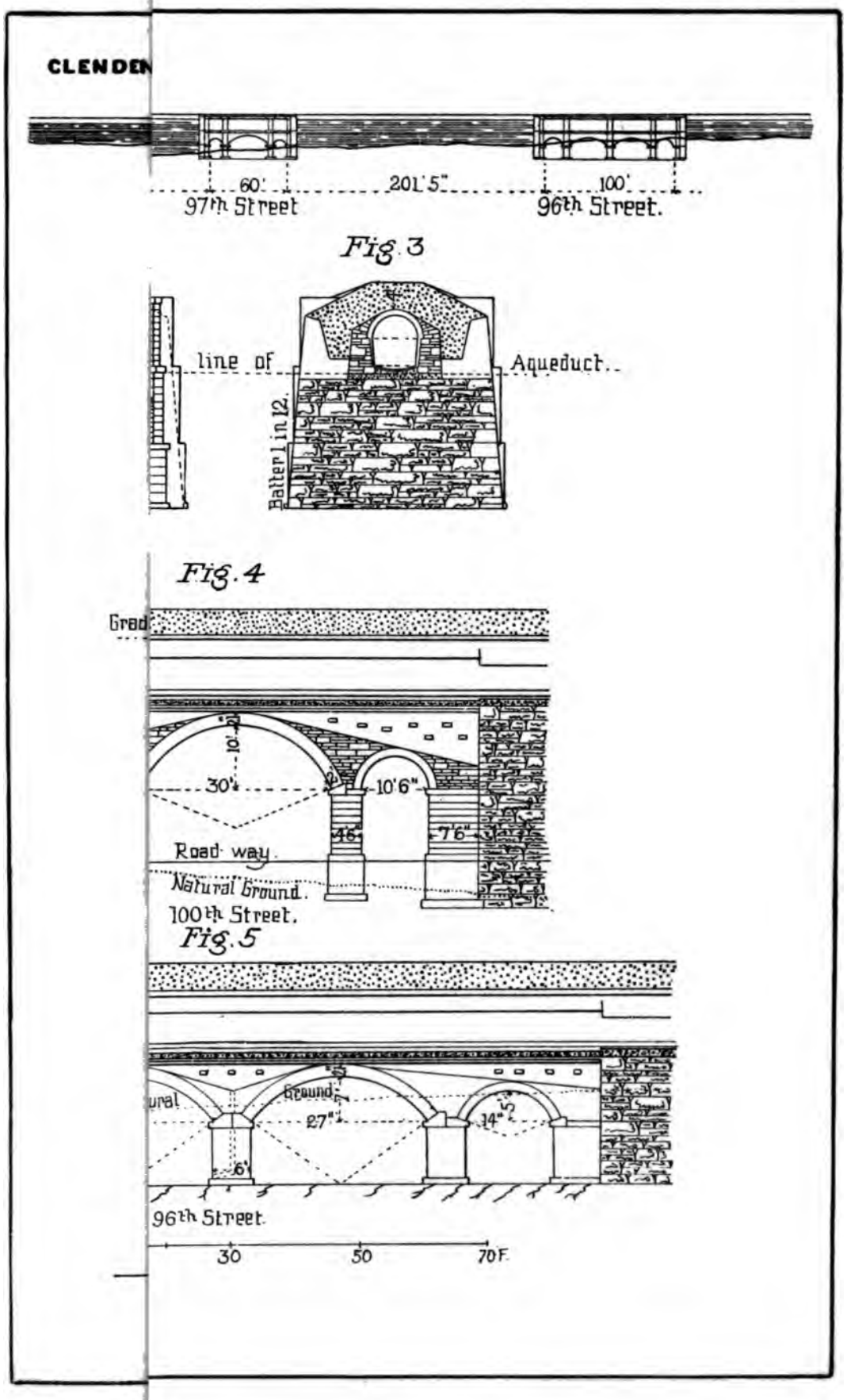

CLENDEN
60'
201'5"
100'
97th Street
96th Street.
Fig. 3
line of
Aqueduct.
Batter 1 in 12.
Fig. 4
Grad
10'
30'
10'6"
4'6"
7'6"
Road way.
Natural Ground.
100th Street.
Fig. 5
ural
Ground
27"
14"
6'
96th Street.
30
50
70 F.

PLATE 42.

RECEIVING RESERVOIR.

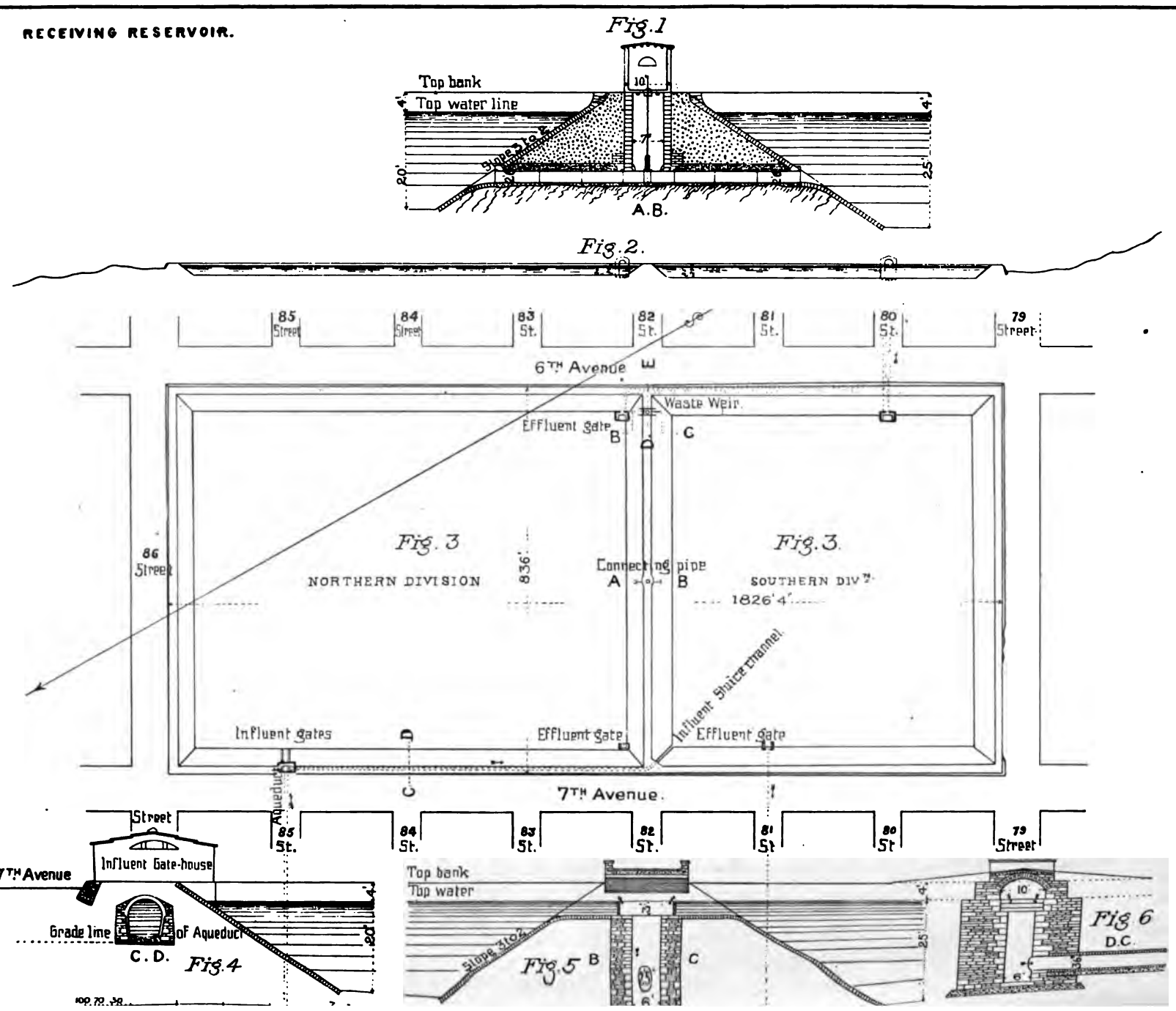
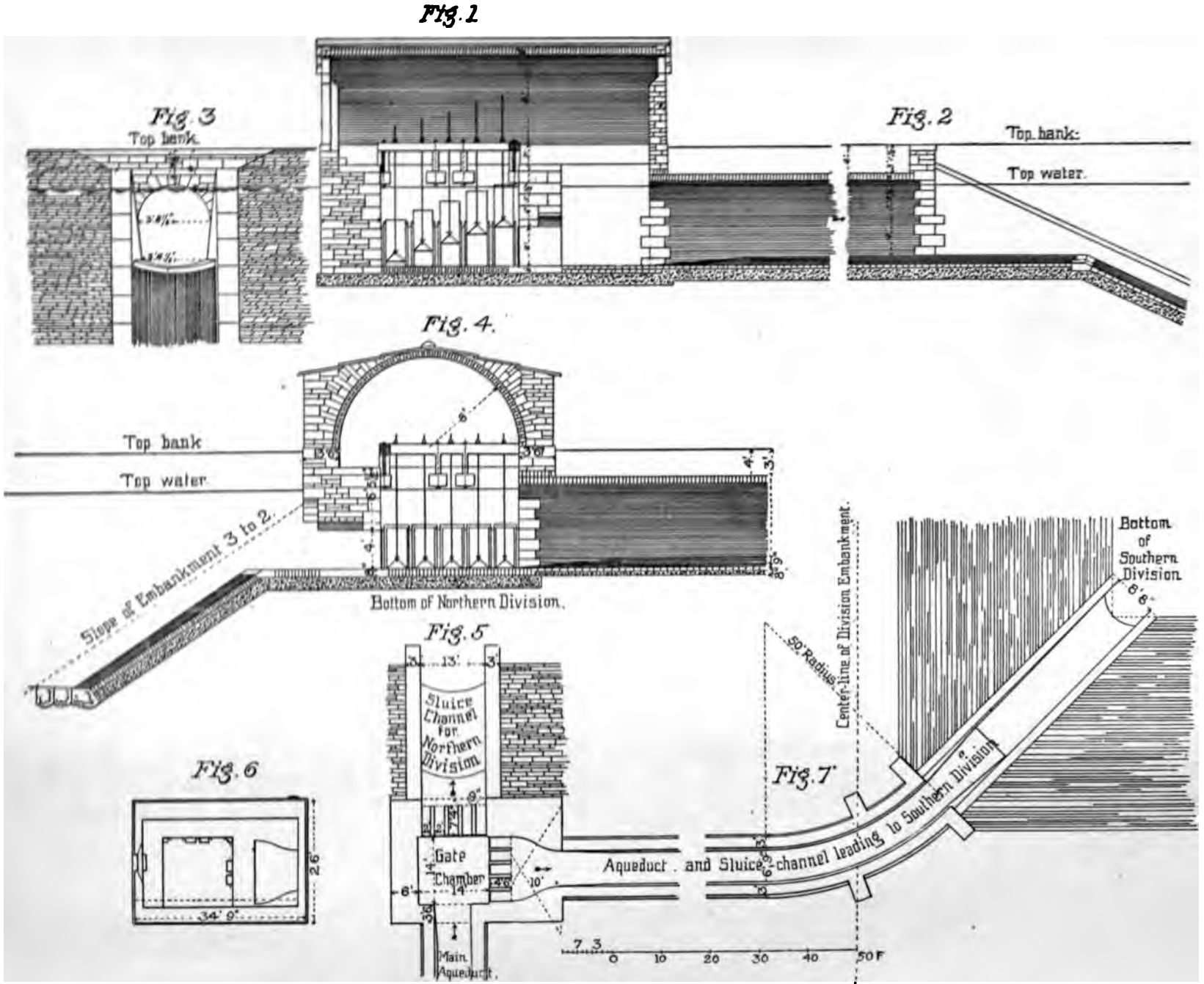


PLATE 48.

RECEIVING RESERVOIR. INFLUENT GATE HOUSE



DISTRIBUTING RESERVOIR.

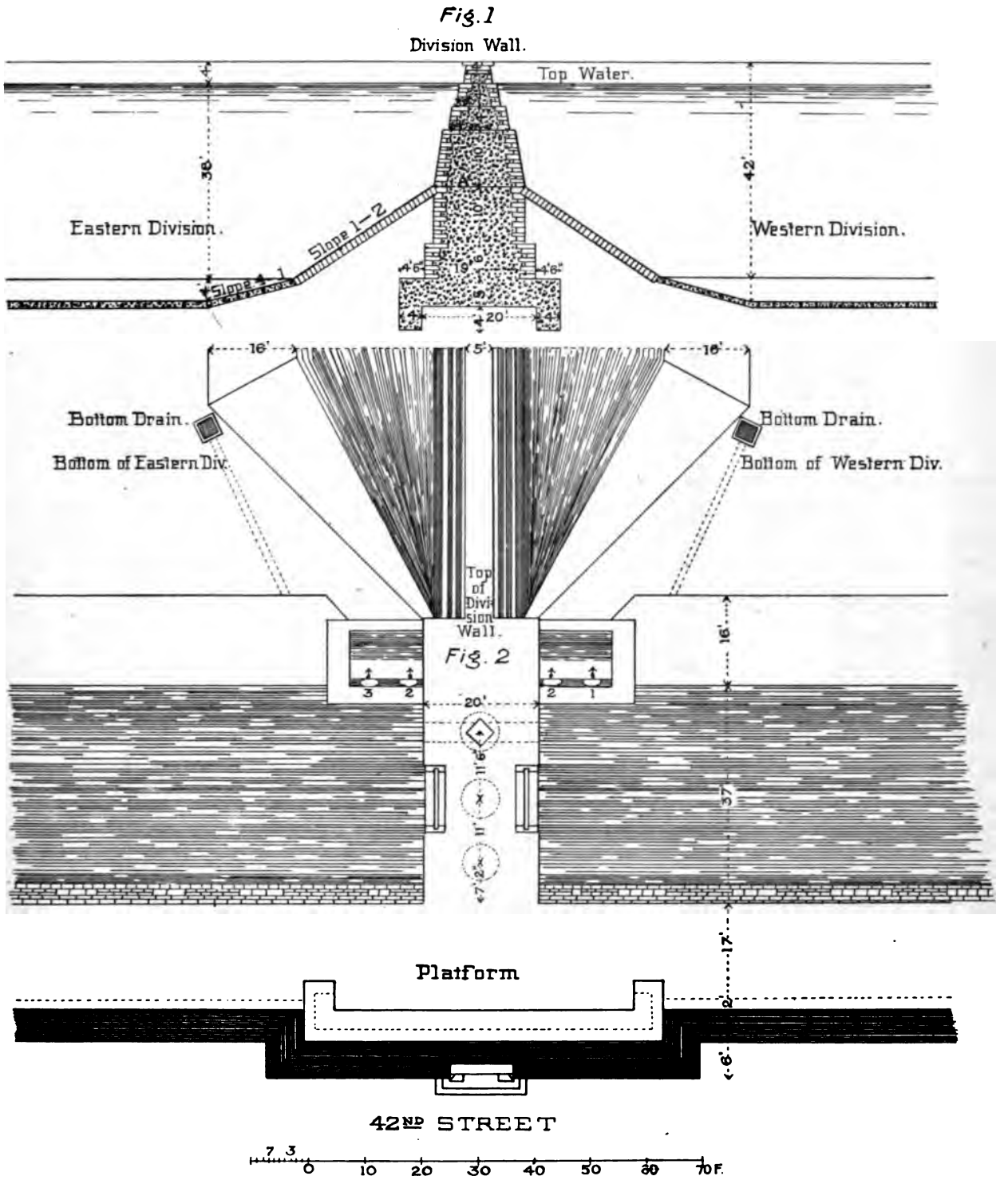
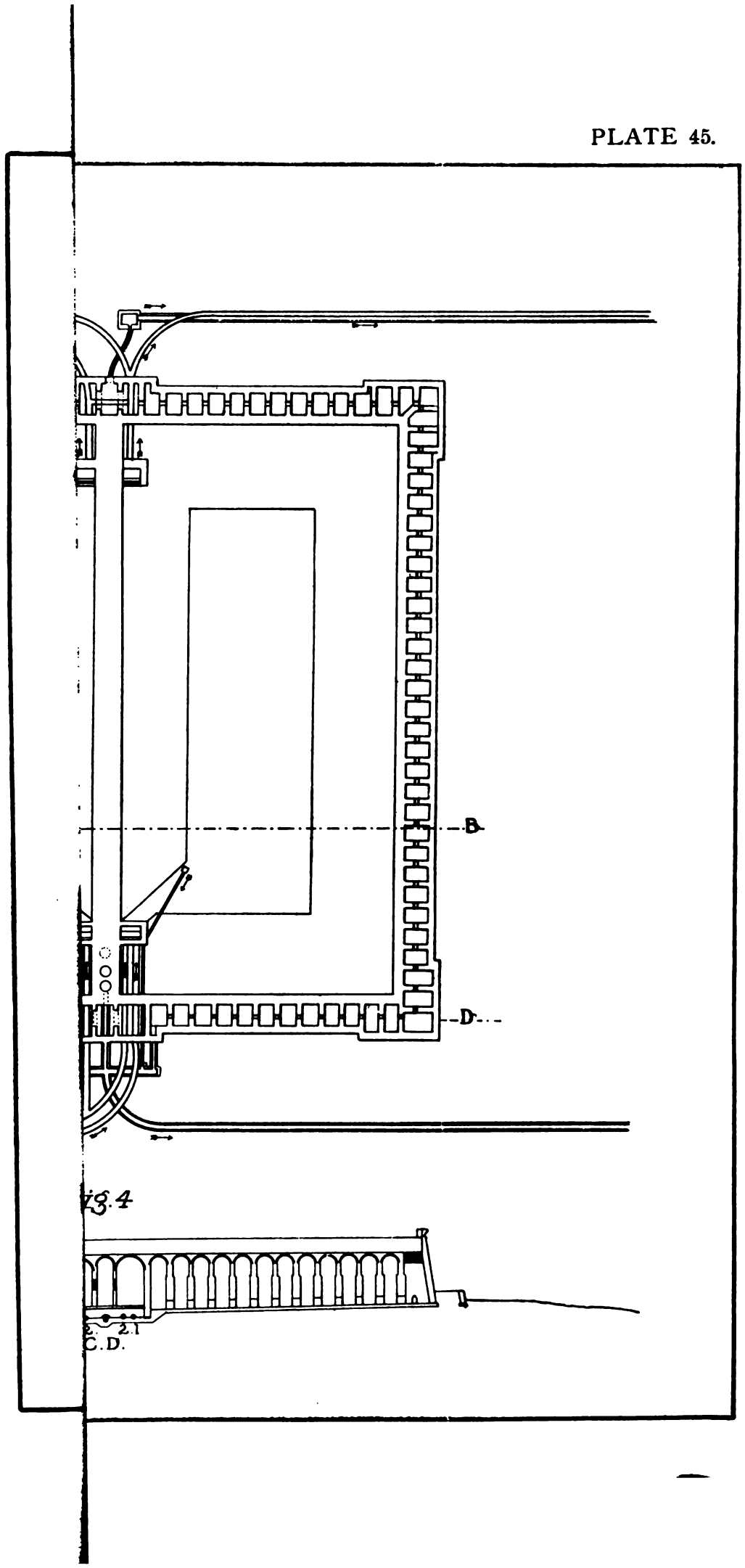
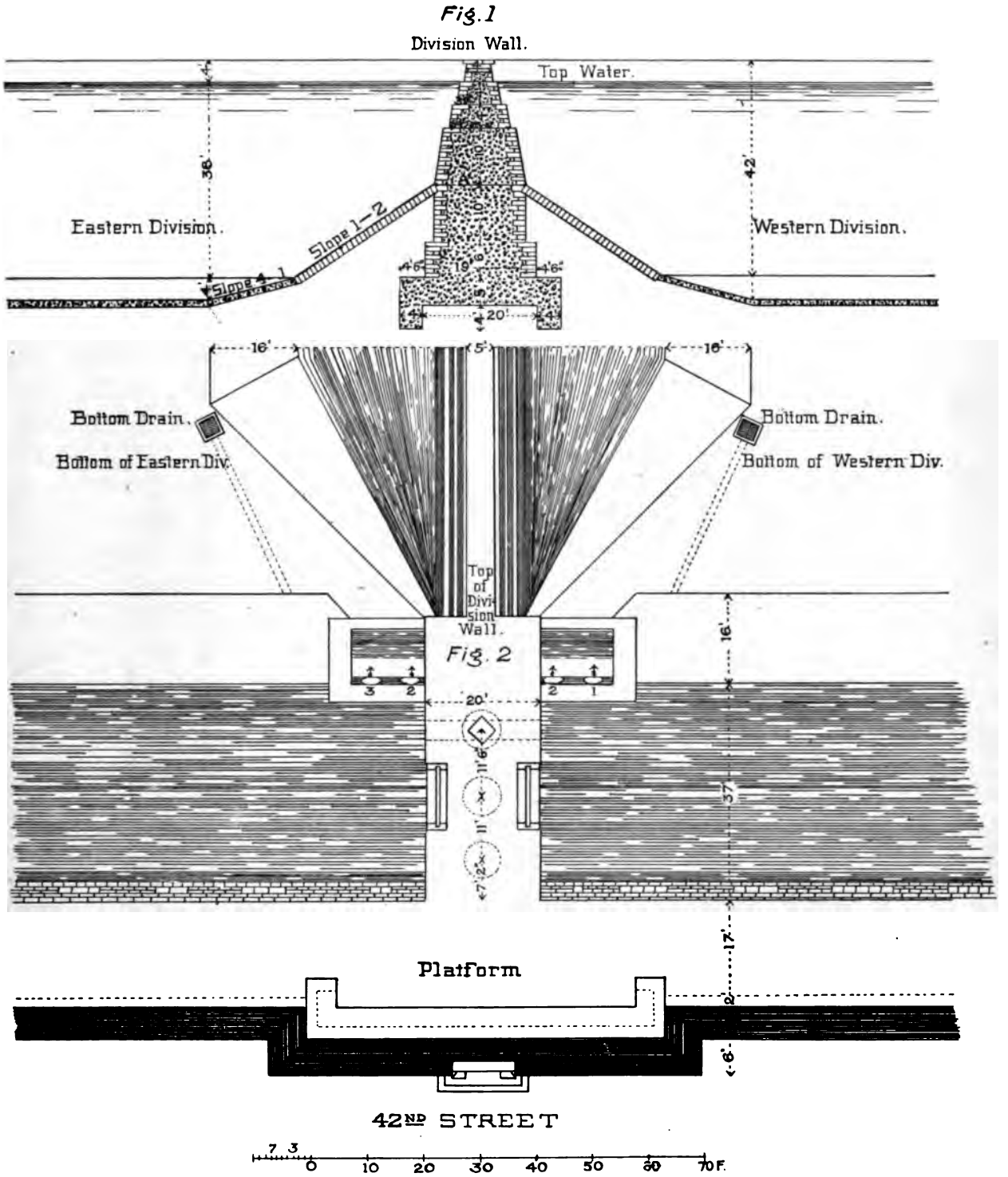


PLATE 45.



DISTRIBUTING RESERVOIR.



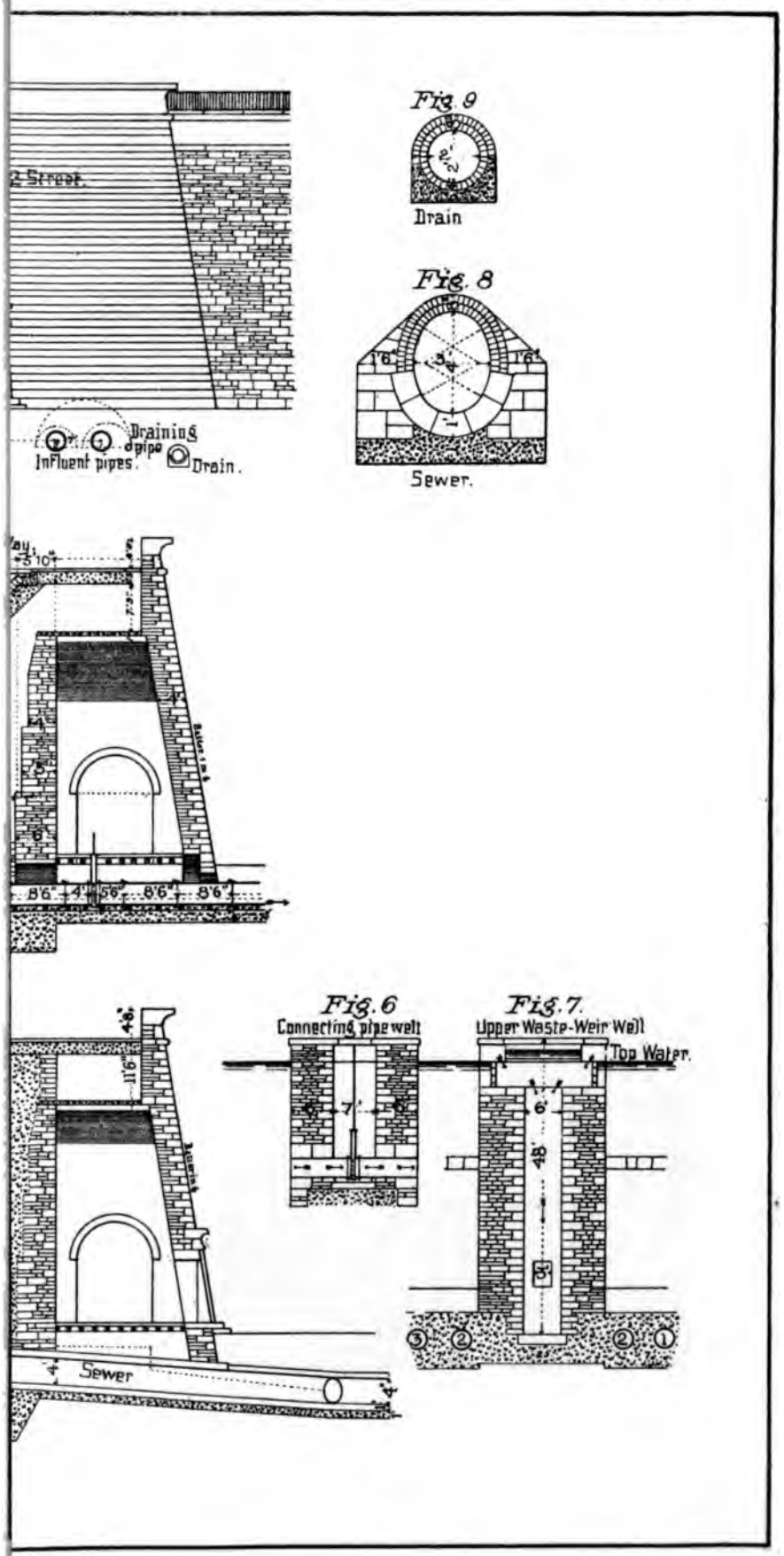
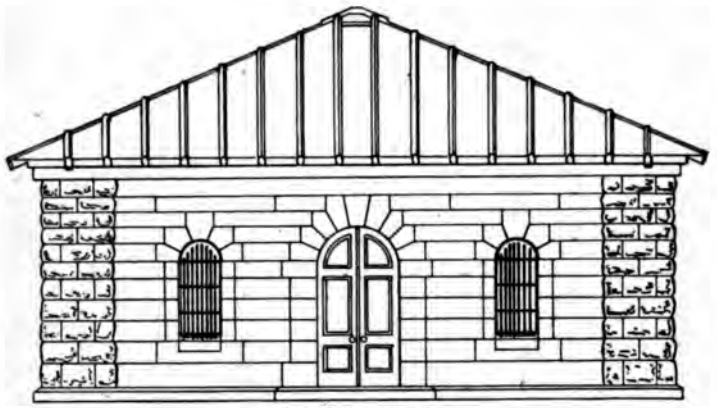
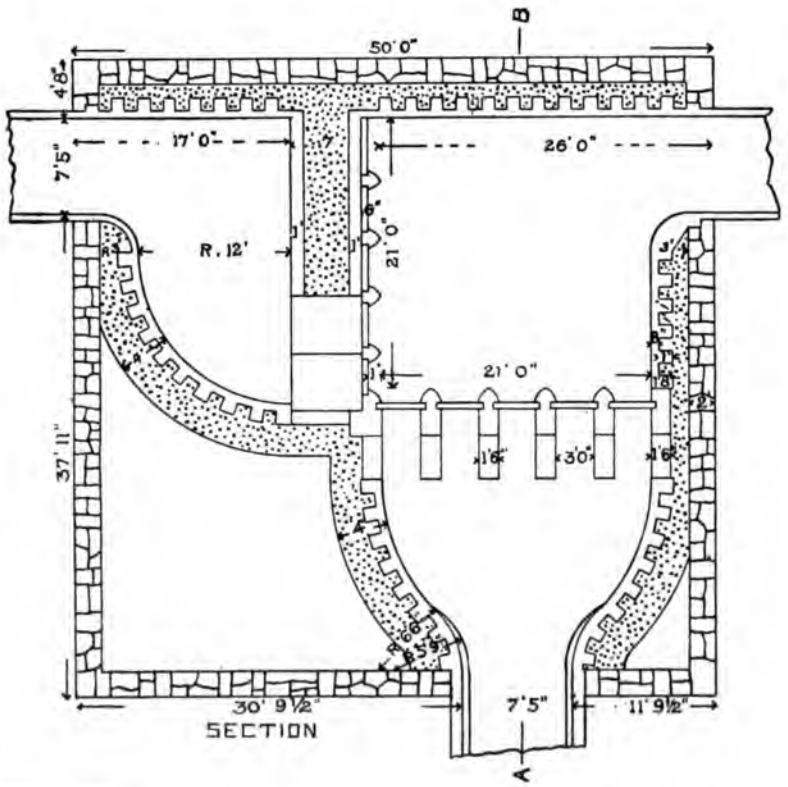

Street.
Draining pipe
Influent pipes.
Drain.
Fig. 9
Drain
Fig. 8
Sewer.
8'6"
4'
5'6"
8'6"
8'6"
Fig. 6
Connecting pipe well
Fig. 7.
Upper Waste-Weir Wall
Top Water.
48'
Sewer

PLATE 49.

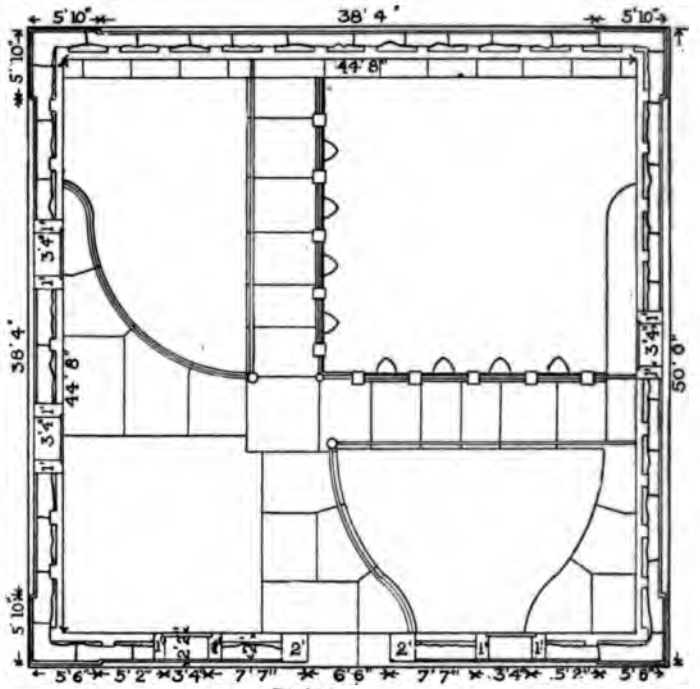
JUNCTION GATE-HOUSE, NINTH AVENUE AND NINETY-SECOND STREET.



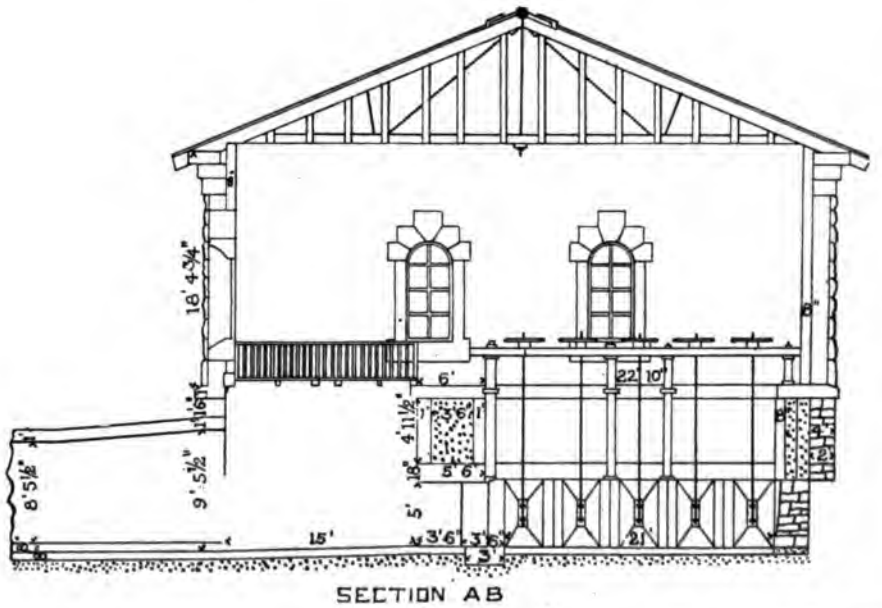
FRONT ELEVATION



SECTION



PLAN



SECTION AB

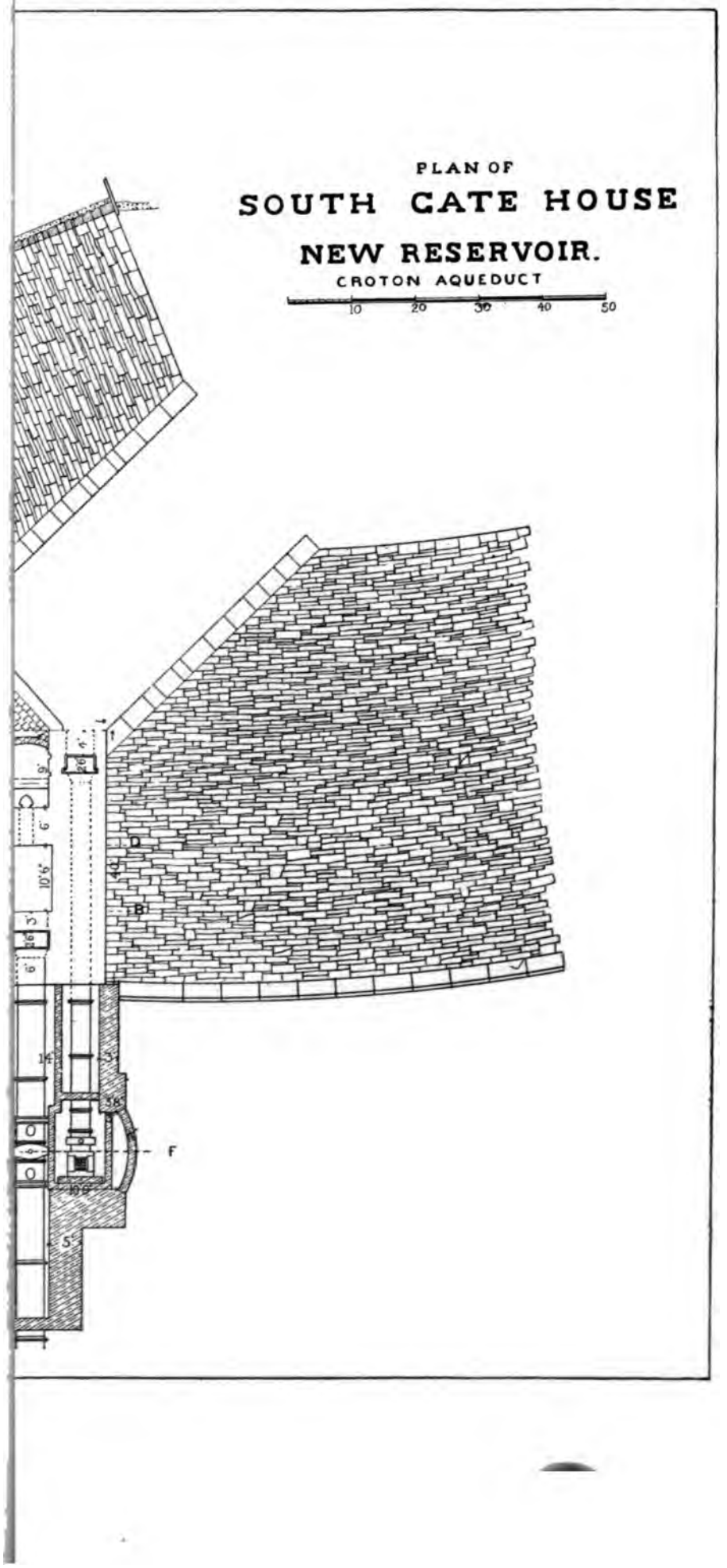
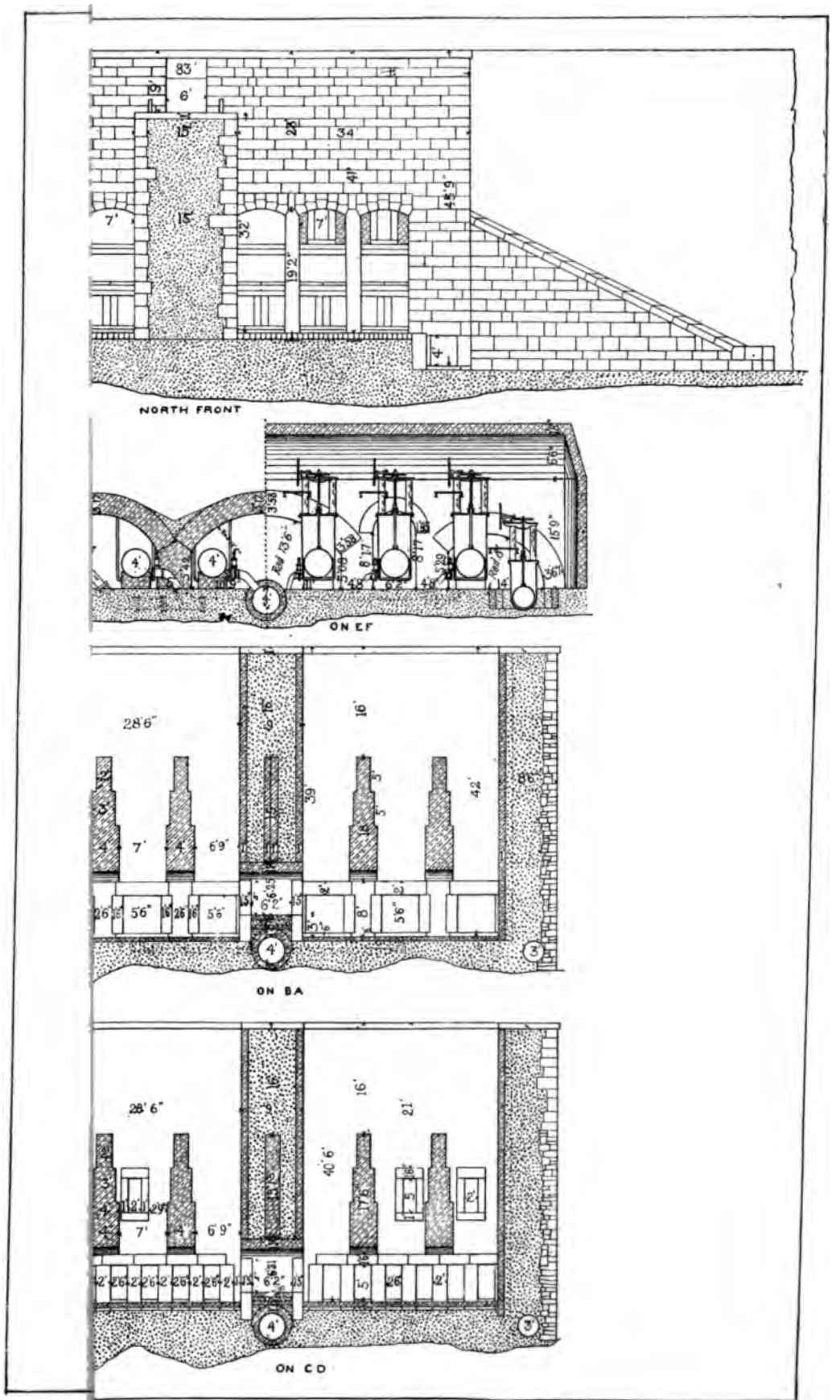

PLAN OF
SOUTH GATE HOUSE
NEW RESERVOIR.
CROTON AQUEDUCT
10
20
30
40
50
F

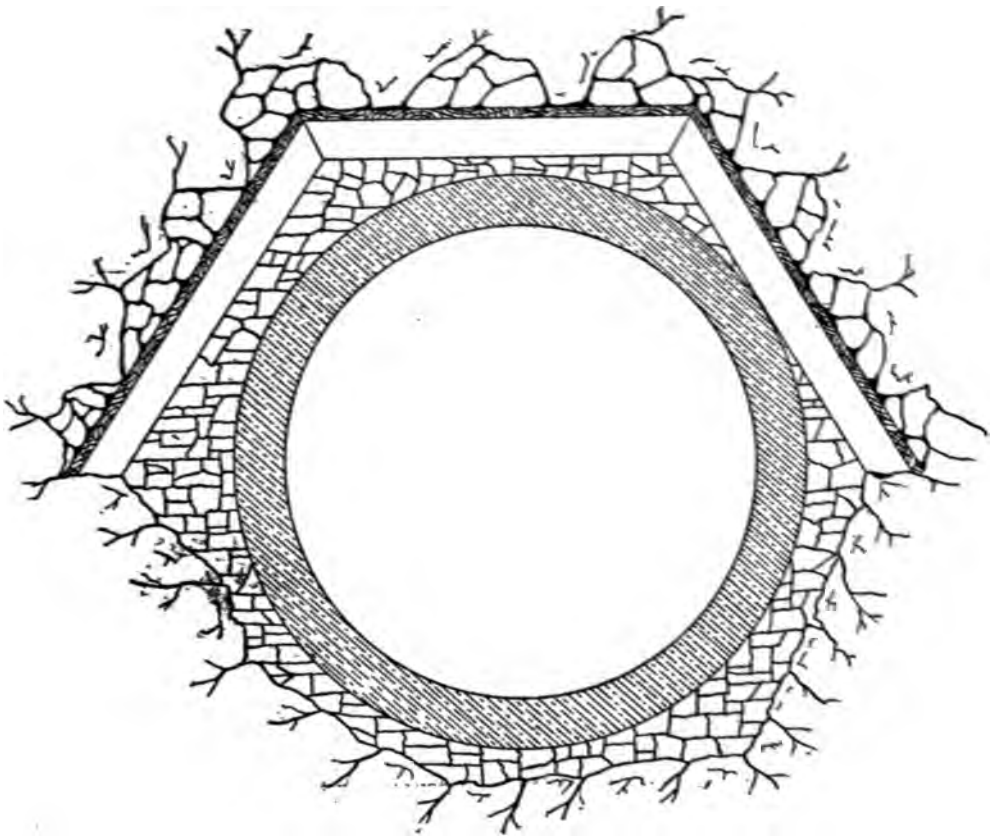
PLATE 51.

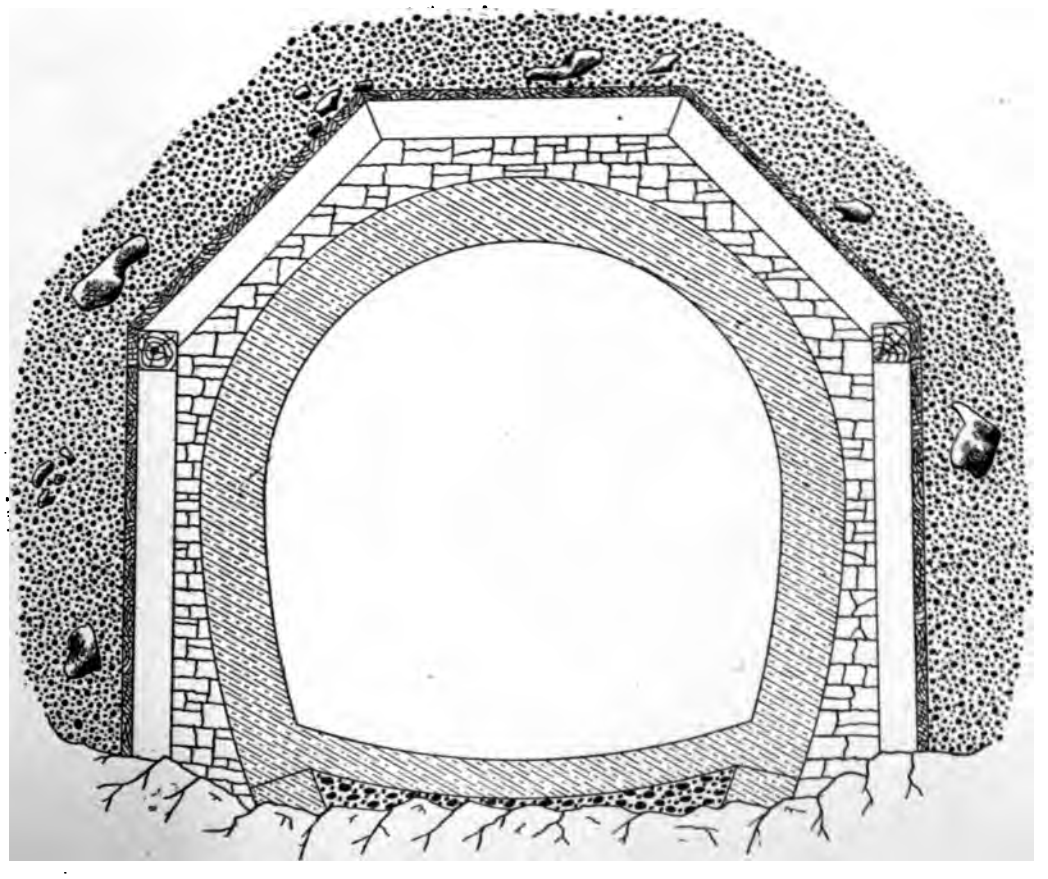


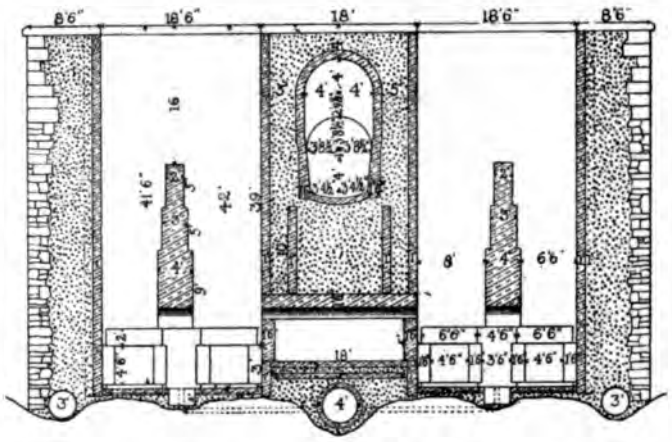
THE AQUEDUCT COMMISSION

AQUEDUCT IN LOOSE ROCK AND SOFT MATERIAL

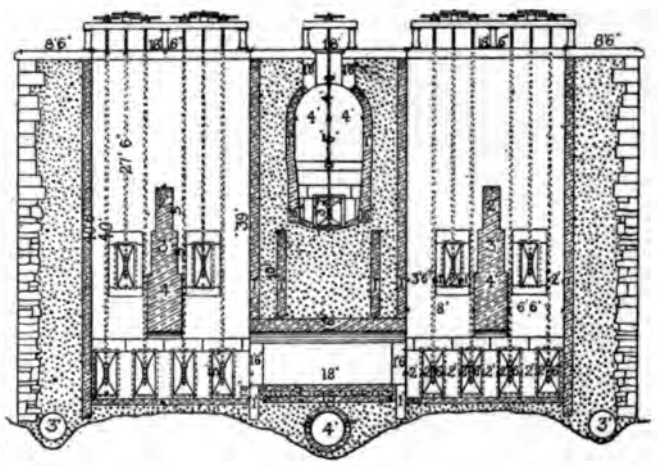
SCALE



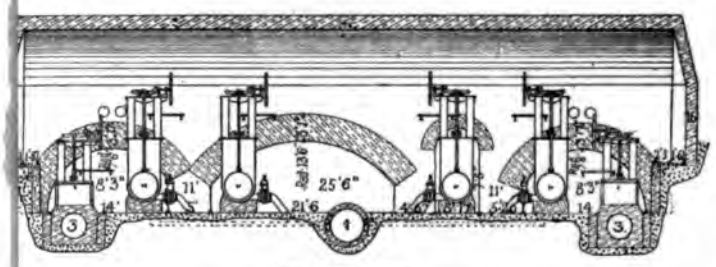




SECTION ON BA



SECTION ON CD



SECTION ON GH

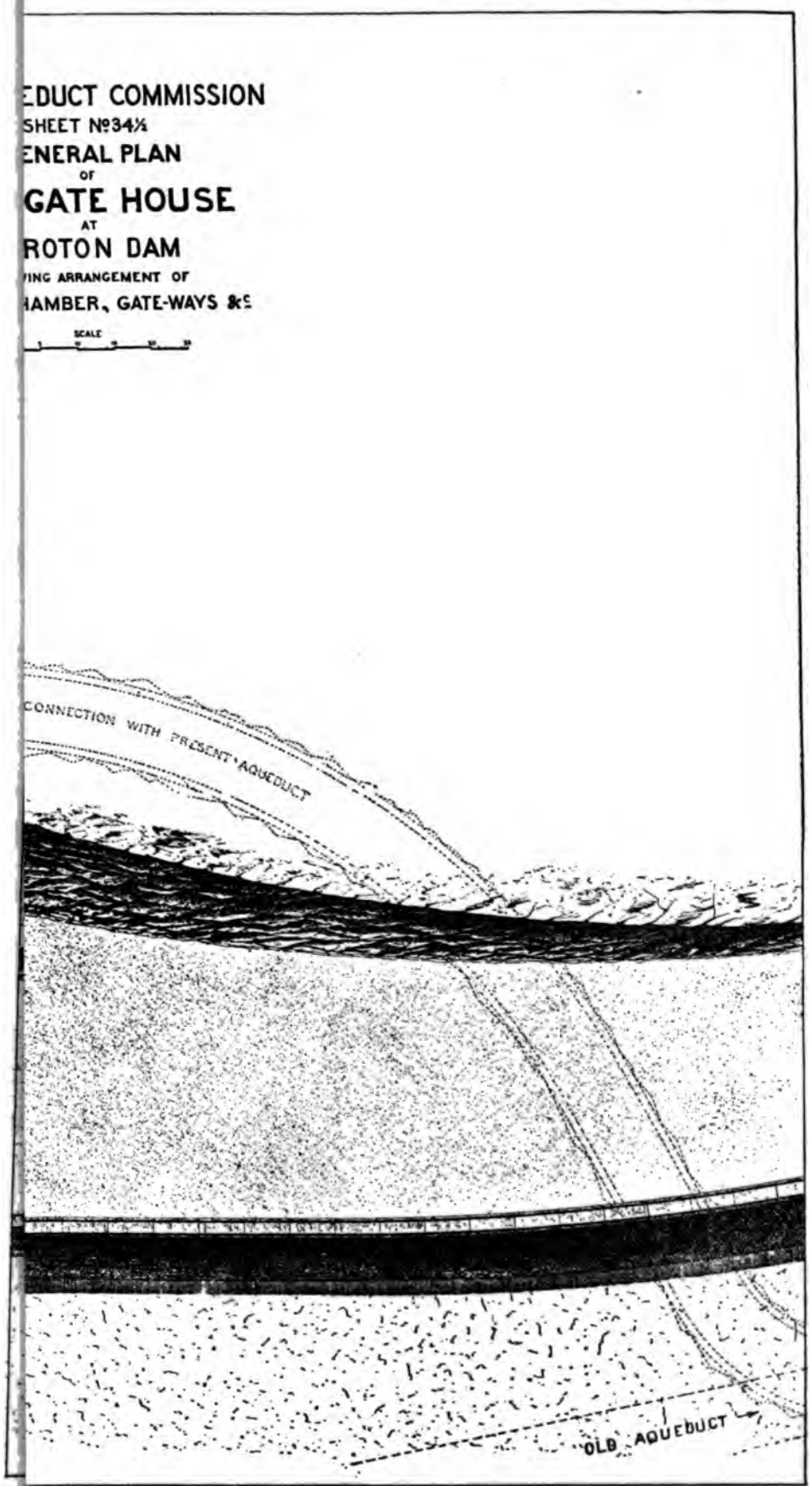

EDUCT COMMISSION
SHEET №34½
ENERAL PLAN
OF
GATE HOUSE
AT
ROTON DAM
ING ARRANGEMENT OF
AMBER, GATE-WAYS &c
SCALE
CONNECTION WITH PRESENT AQUEDUCT
OLD AQUEDUCT

PLATE 55.

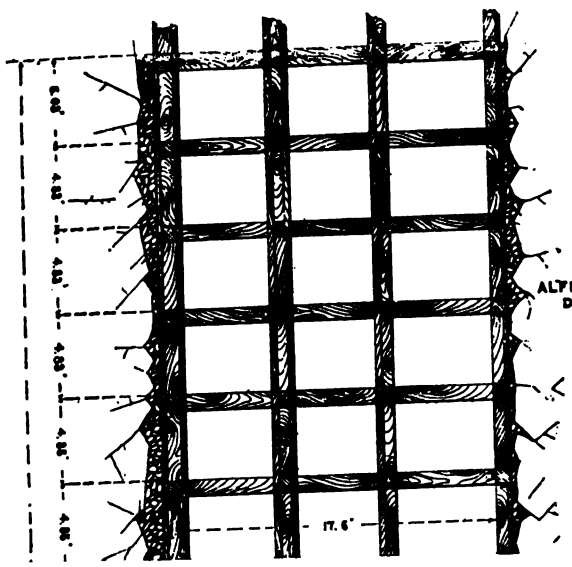
THE AQUEDUCT COMMISSION

TIMBERING

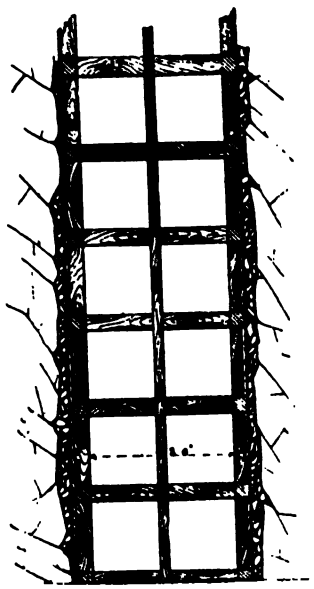
IN

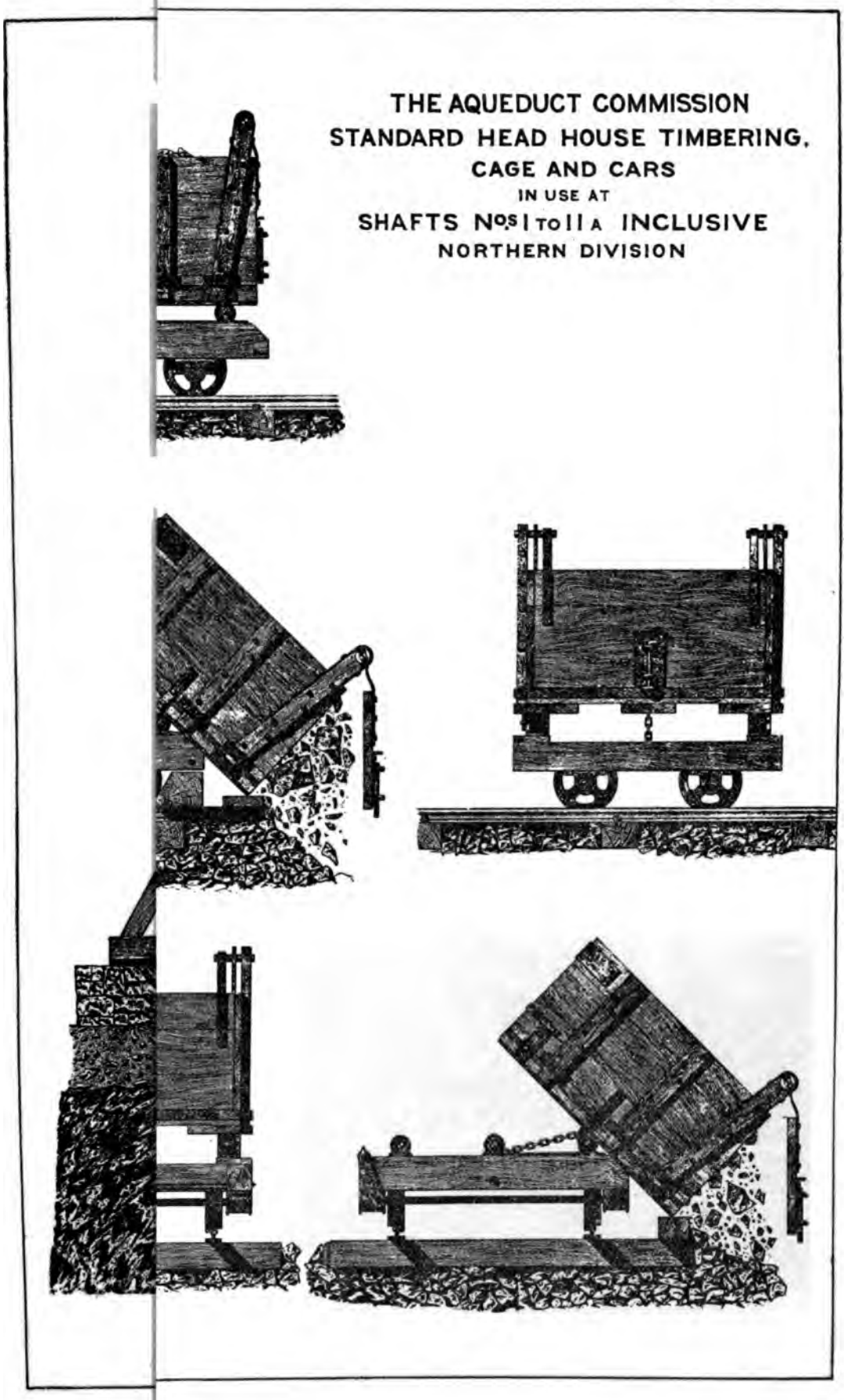
SHAFT Nº 13.

DIVISION Nº 3



ALFRED CRAVEN
DIVISION ENGINEER




THE AQUEDUCT COMMISSION
STANDARD HEAD HOUSE TIMBERING,
CAGE AND CARS
IN USE AT
SHAFTS Nos I TO II A INCLUSIVE
NORTHERN DIVISION

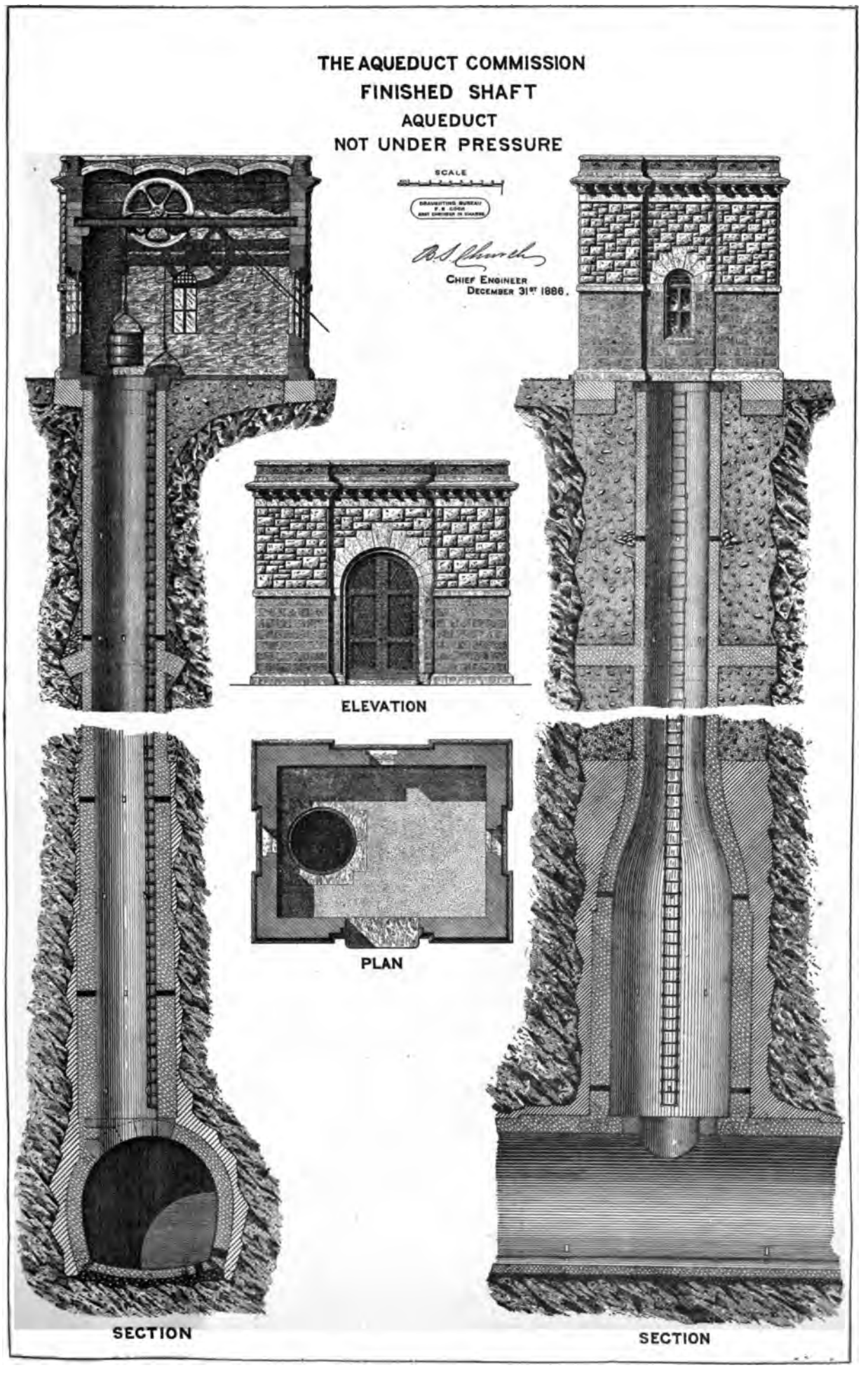
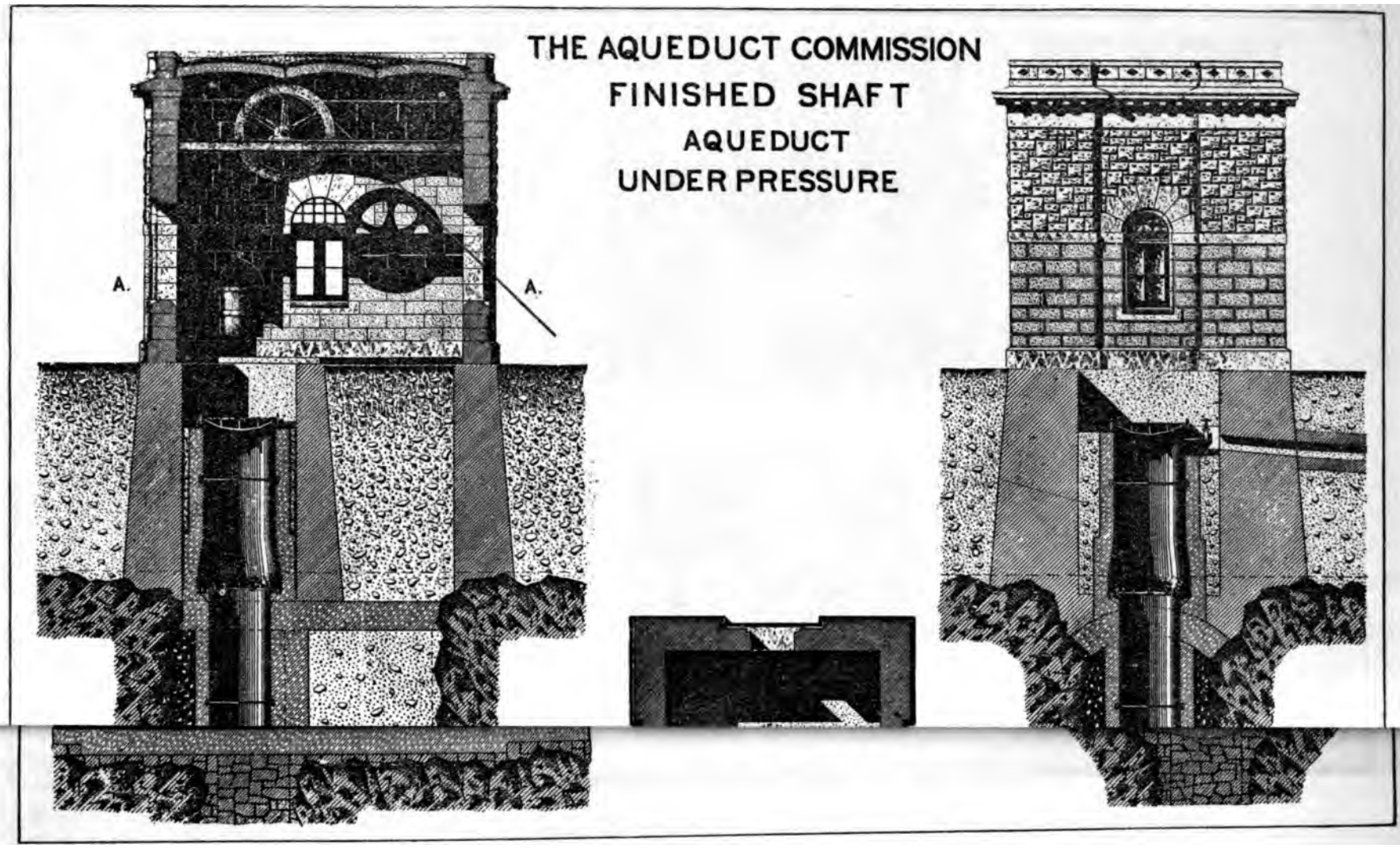

THE AQUEDUCT COMMISSION
FINISHED SHAFT
AQUEDUCT
NOT UNDER PRESSURE
SCALE
CHIEF ENGINEER
DECEMBER 31ST 1886.
ELEVATION
PLAN
SECTION
SECTION

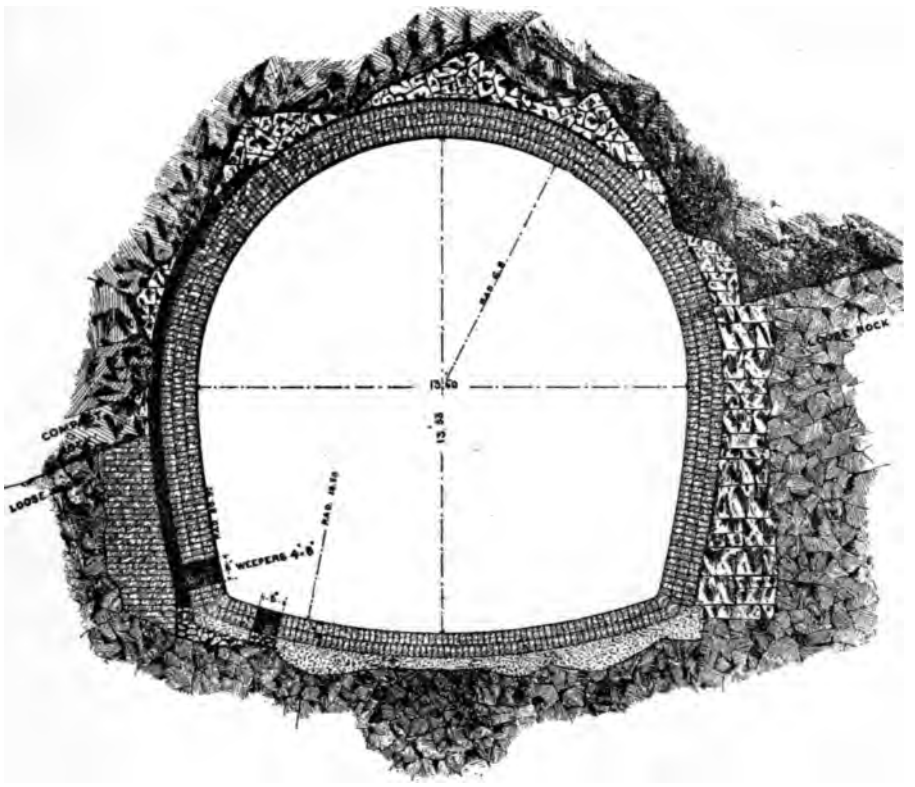
PLATE 58.

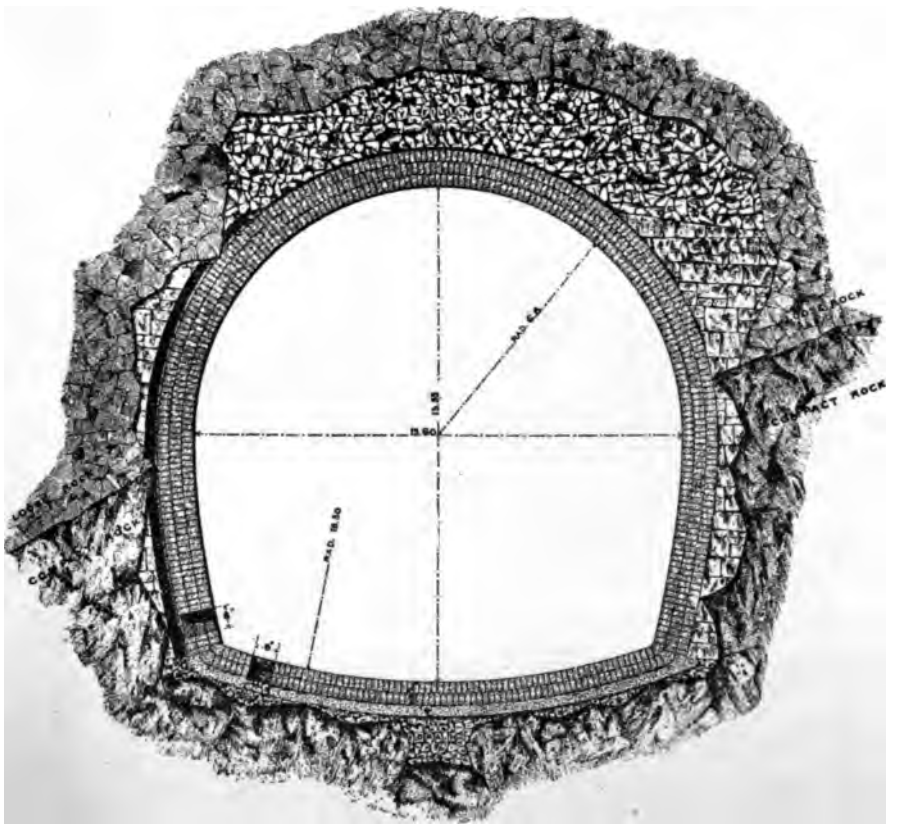

THE AQUEDUCT COMMISSION
FINISHED SHAFT
AQUEDUCT
UNDER PRESSURE
A.
A.

THE AQUEDUCT COMMISSION

AQUEDUCT IN COMPACT AND LOOSE ROCK

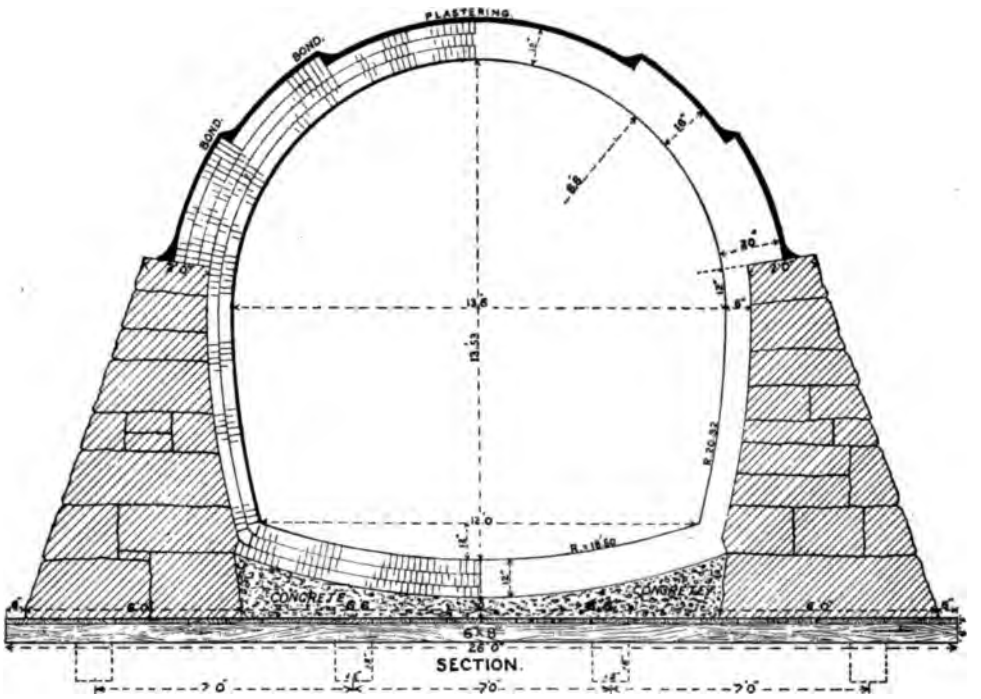
SCALE



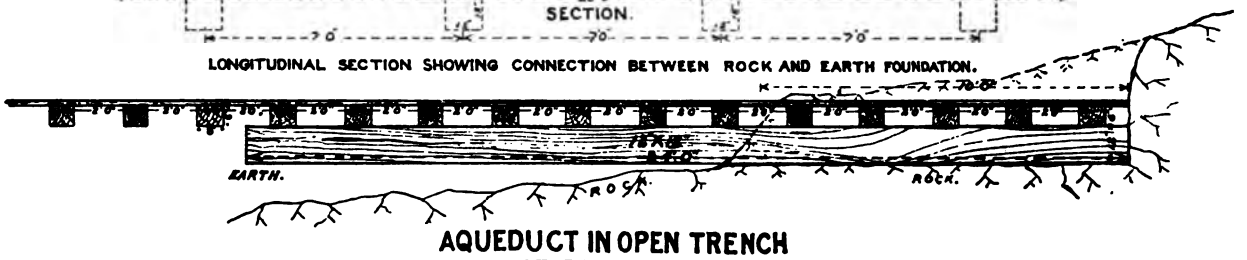


THE AQUEDUCT COMMISSION

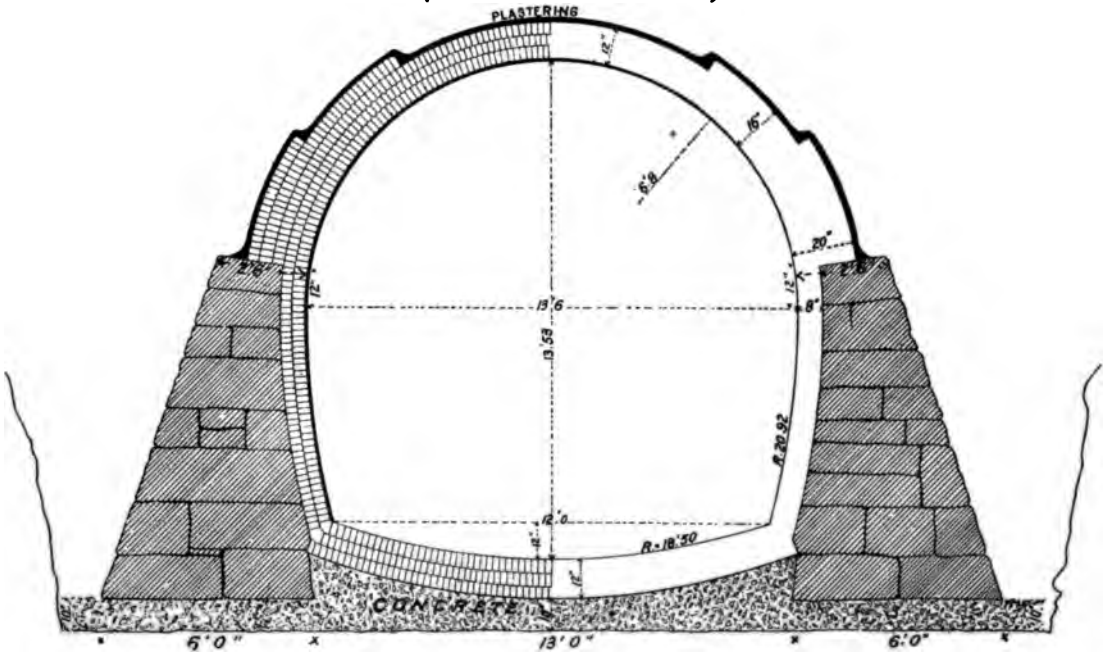
AQUEDUCT
NEAR SOUTH PORTAL AT
SOUTH YONKERS.
ABOUT STATION 1140+00.
SCALE



LONGITUDINAL SECTION SHOWING CONNECTION BETWEEN ROCK AND EARTH FOUNDATION.

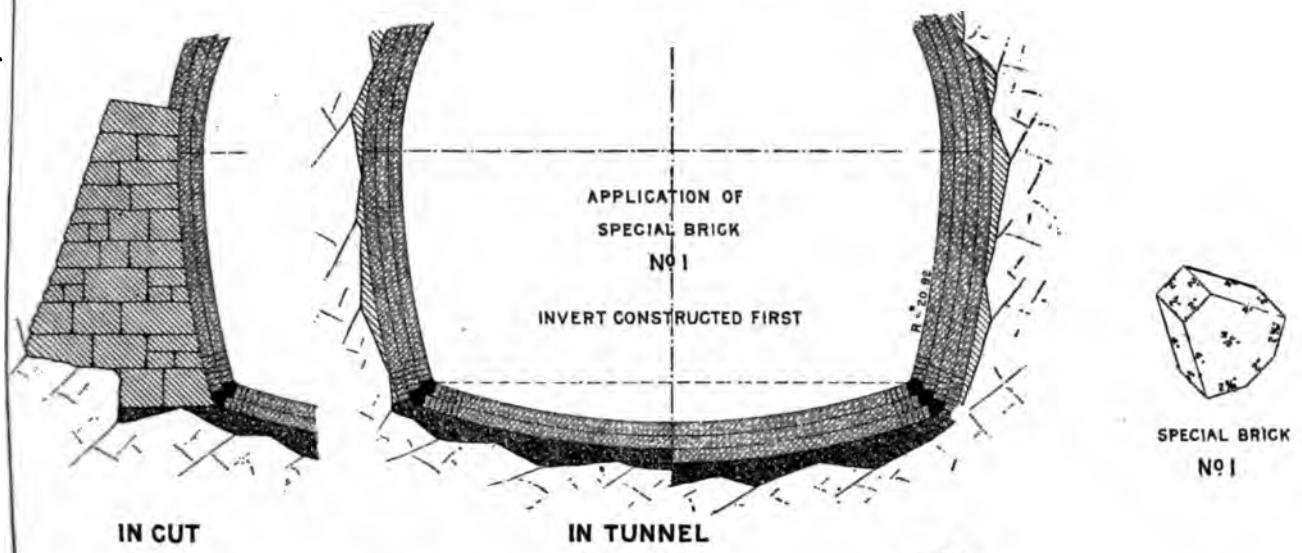


AQUEDUCT IN OPEN TRENCH AT POCANTICO
(STA. 485+ TO 489± IN EARTH)

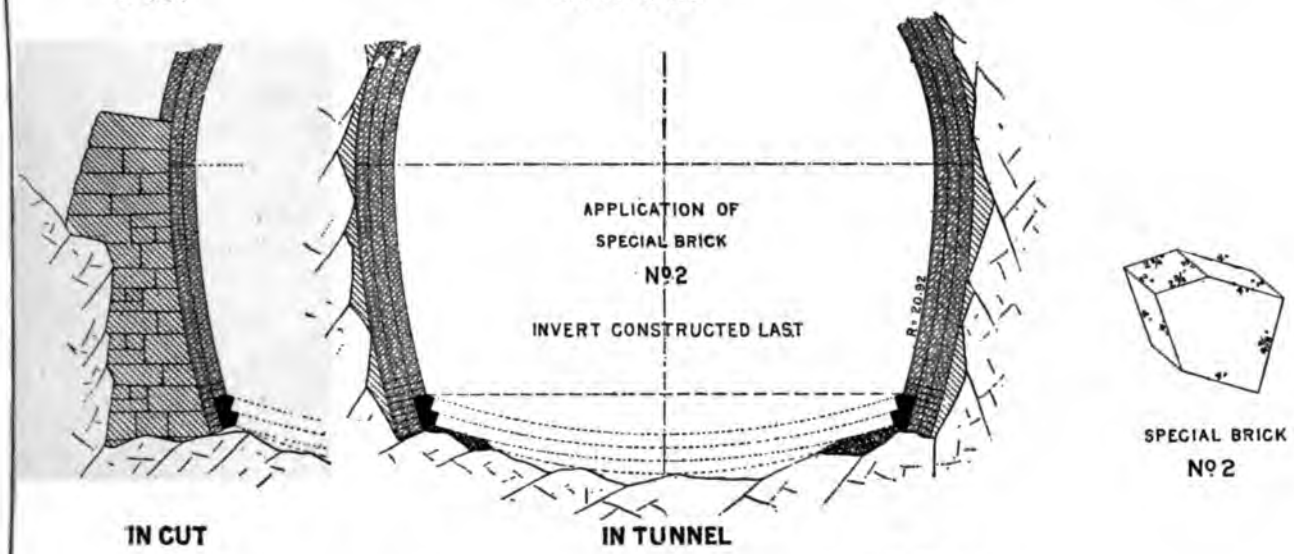


SECTION

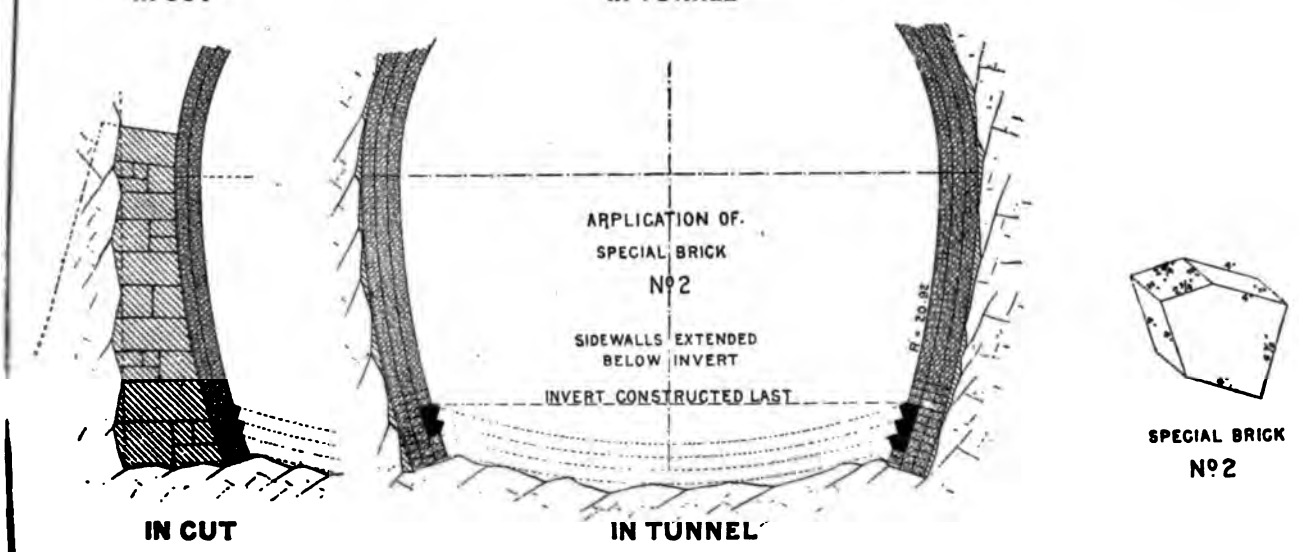
THE AQUEDUCT COMMISSION
SECTIONS SHOWING APPLICATION OF SPECIAL BRICKS



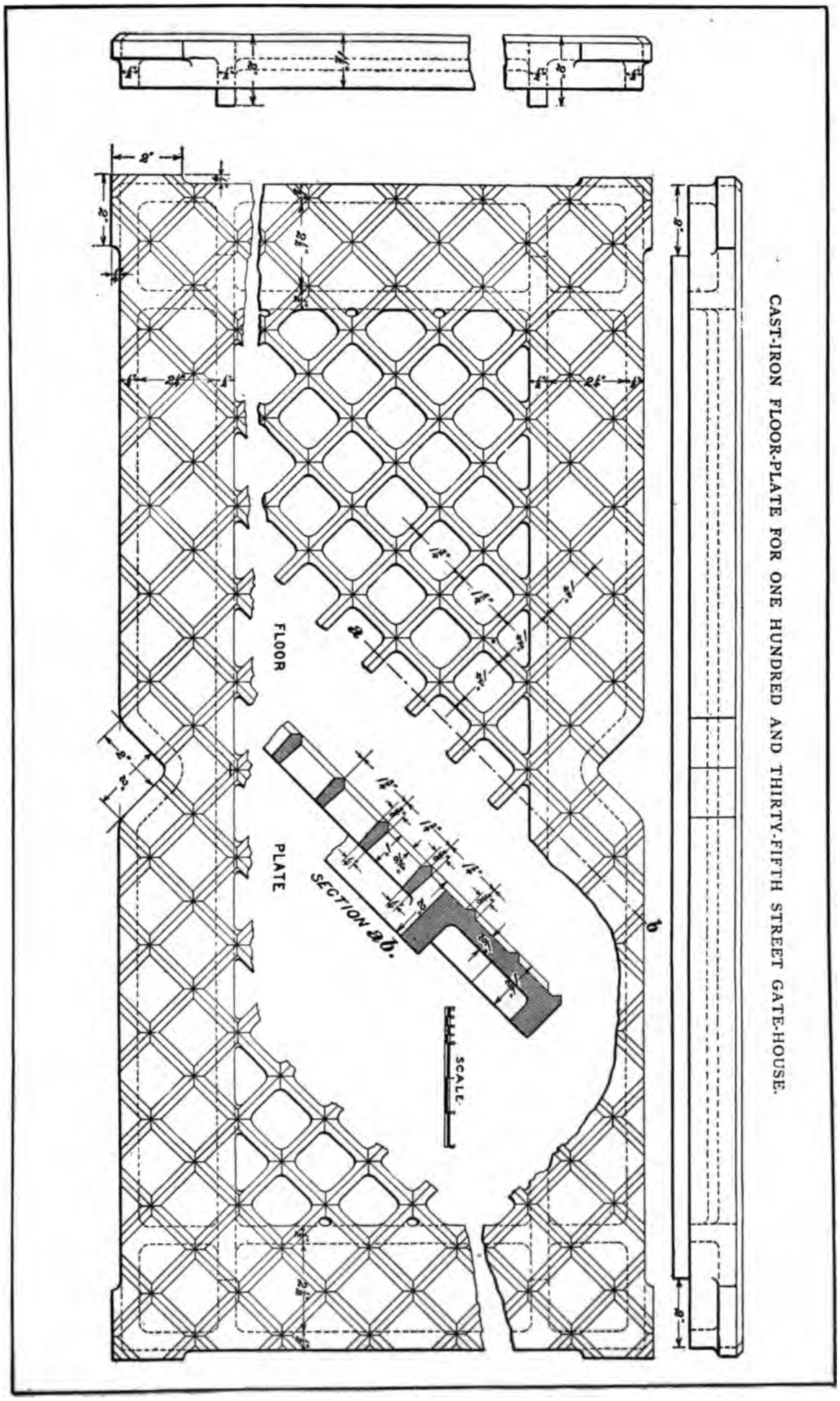
SPECIAL BRICK
Nº 1



SPECIAL BRICK
Nº 2



SPECIAL BRICK
Nº 2



CAST-IRON FLOOR-PLATE FOR ONE HUNDRED AND THIRTY-FIFTH STREET GATE-HOUSE.

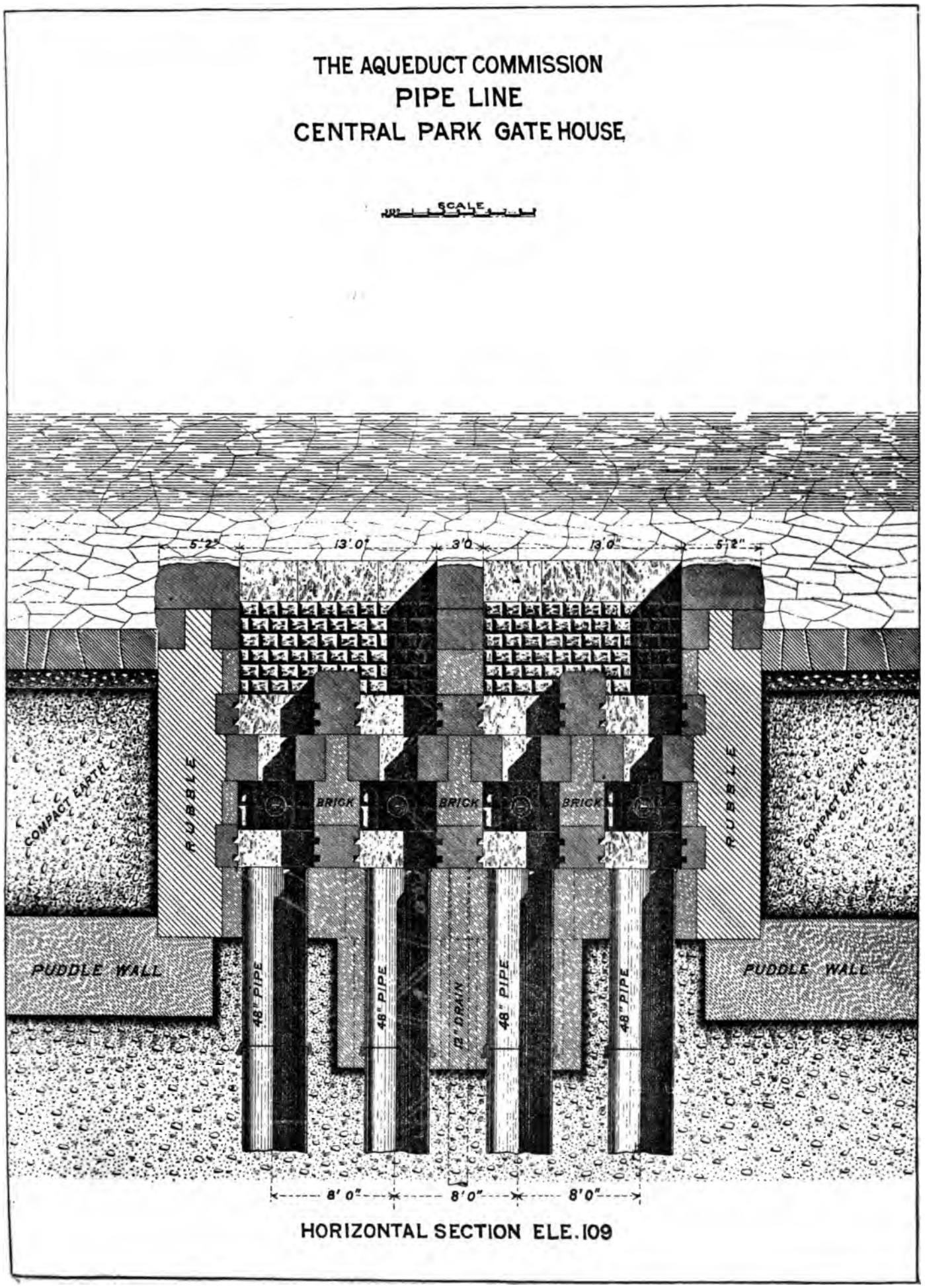
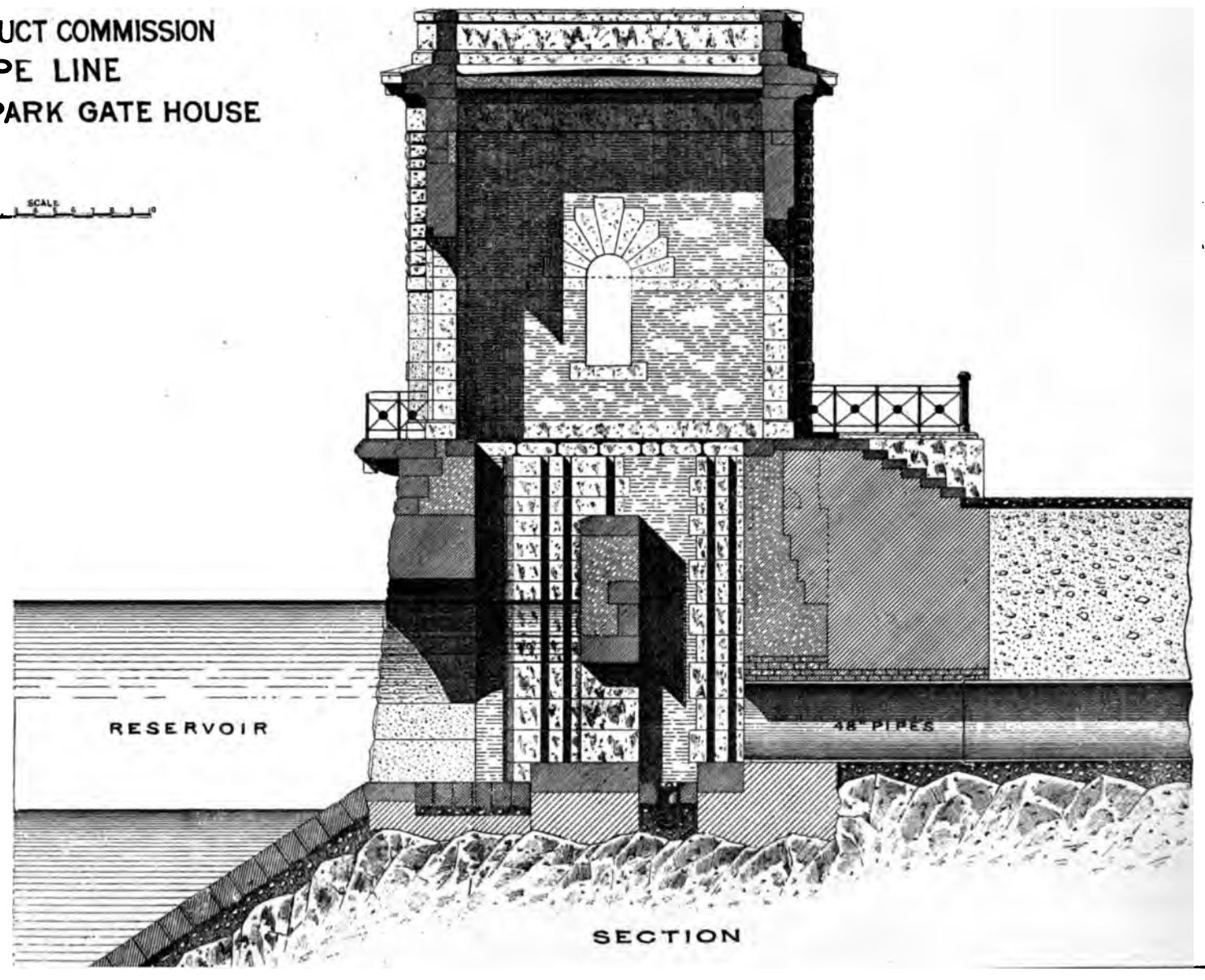

THE AQUEDUCT COMMISSION
PIPE LINE
CENTRAL PARK GATE HOUSE
SCALE
5'2"
13'0"
3'0
13'0"
5'2"
COMPACT EARTH
RUBBLE
BRICK
BRICK
BRICK
RUBBLE
COMPACT EARTH
PUDDLE WALL
PUDDLE WALL
48" PIPE
48" PIPE
12" DRAIN
48" PIPE
48" PIPE
8'0"
8'0"
8'0"
HORIZONTAL SECTION ELE. 109

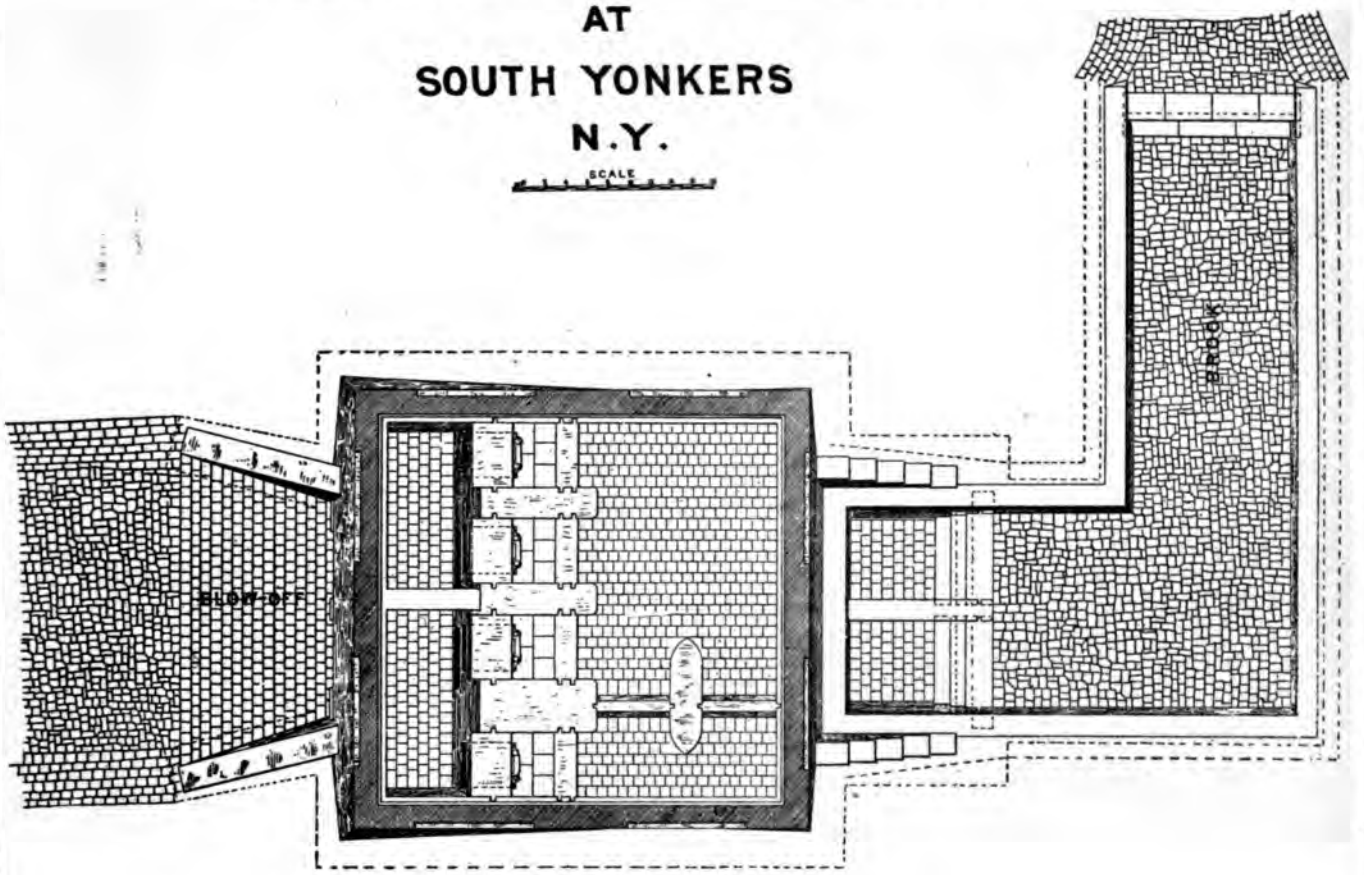
PLATE 76.

THE AQUEDUCT COMMISSION
PIPE LINE
CENTRAL PARK GATE HOUSE

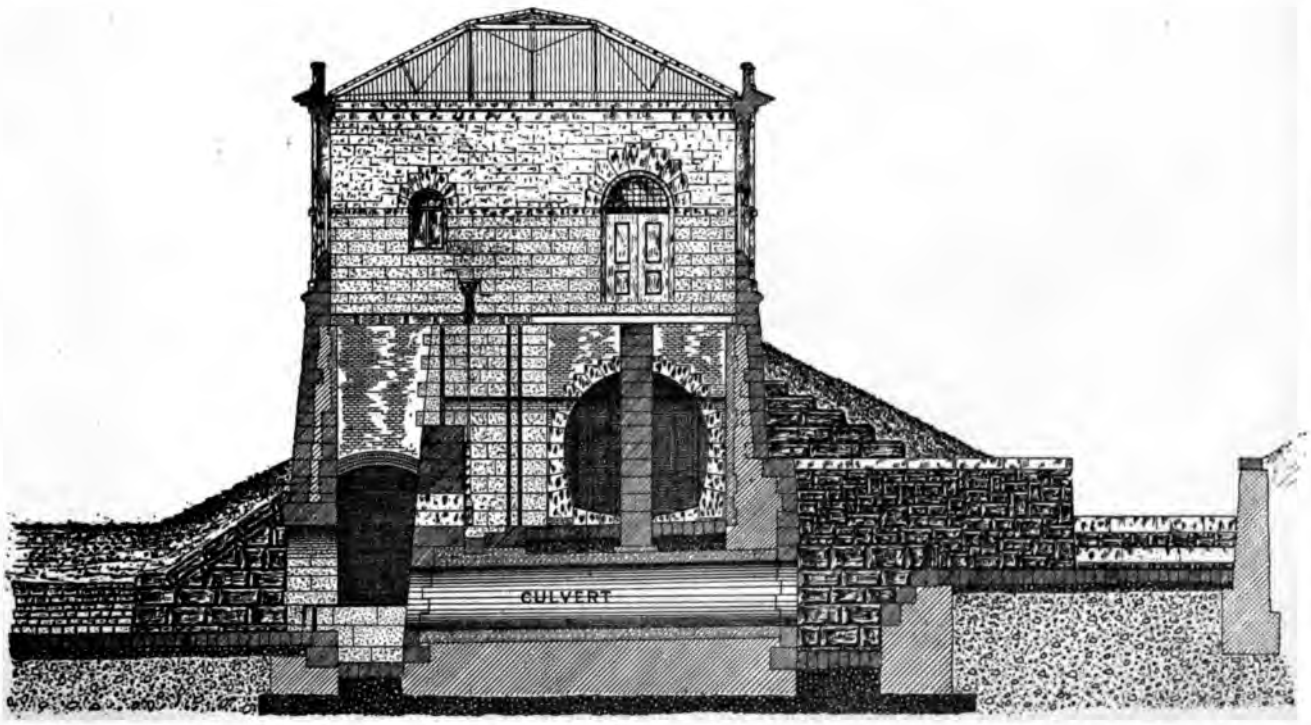


THE AQUEDUCT COMMISSION
BLOW-OFF AND WASTE WEIR
AT
SOUTH YONKERS
N.Y.

SCALE

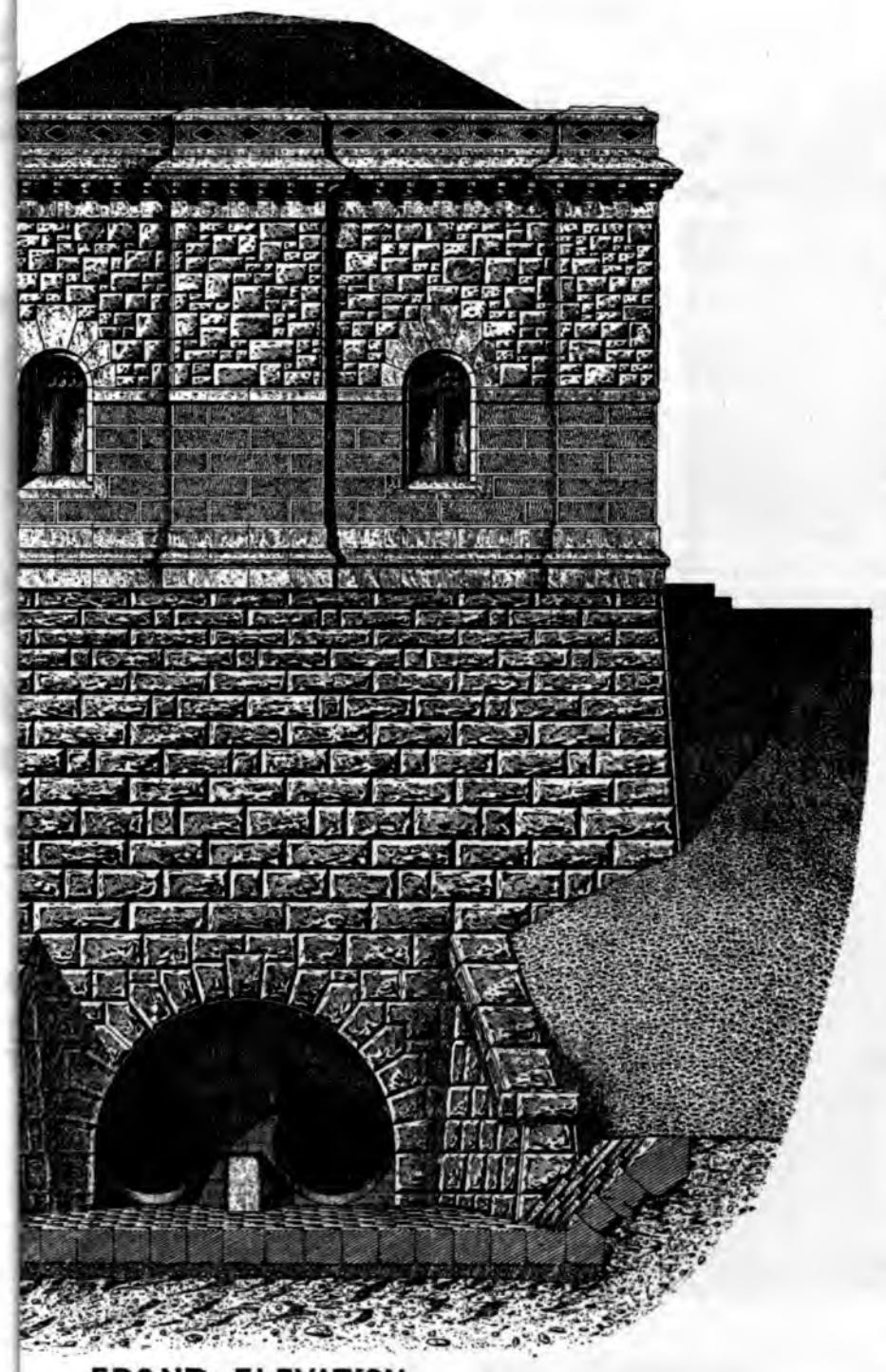


PLAN



SECTION

PLATE 78.



FRONT ELEVATION

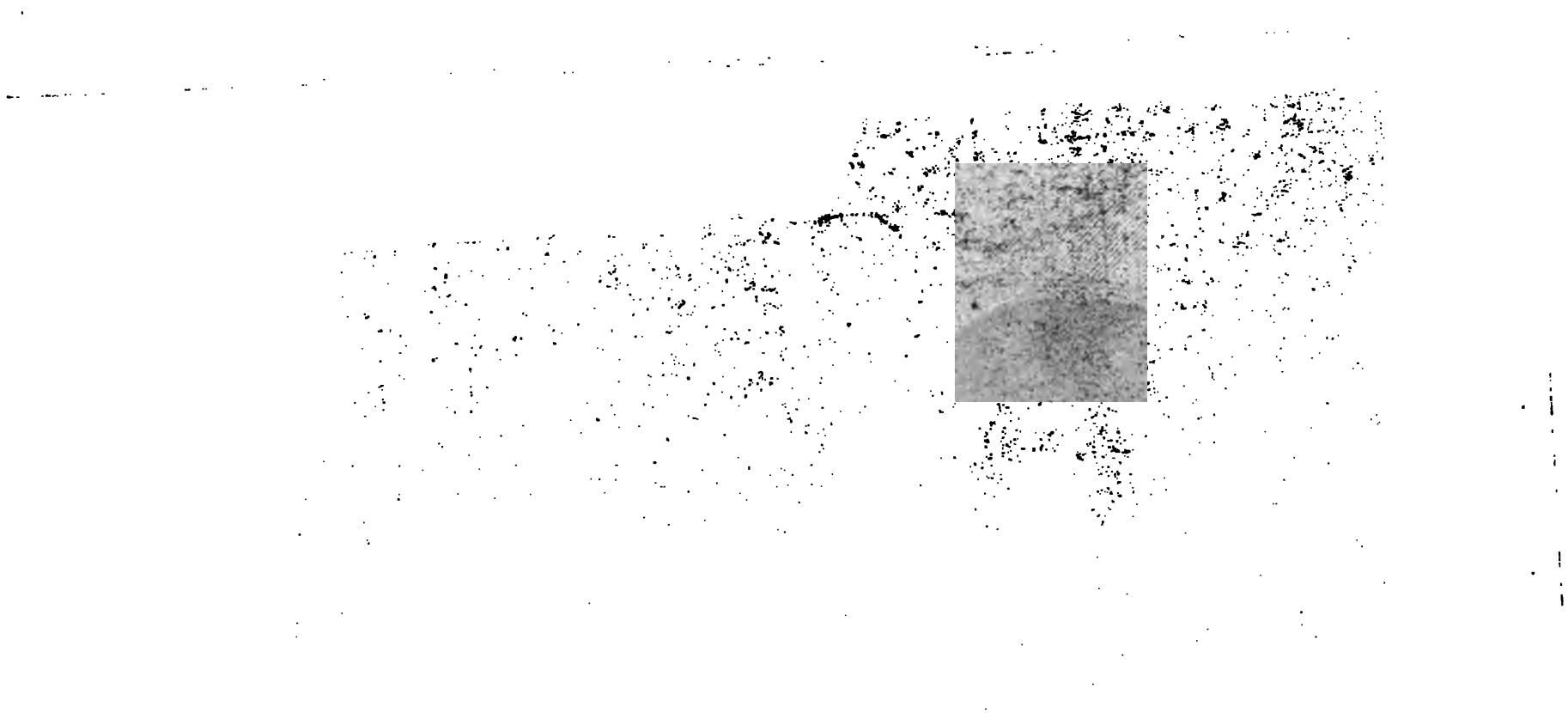
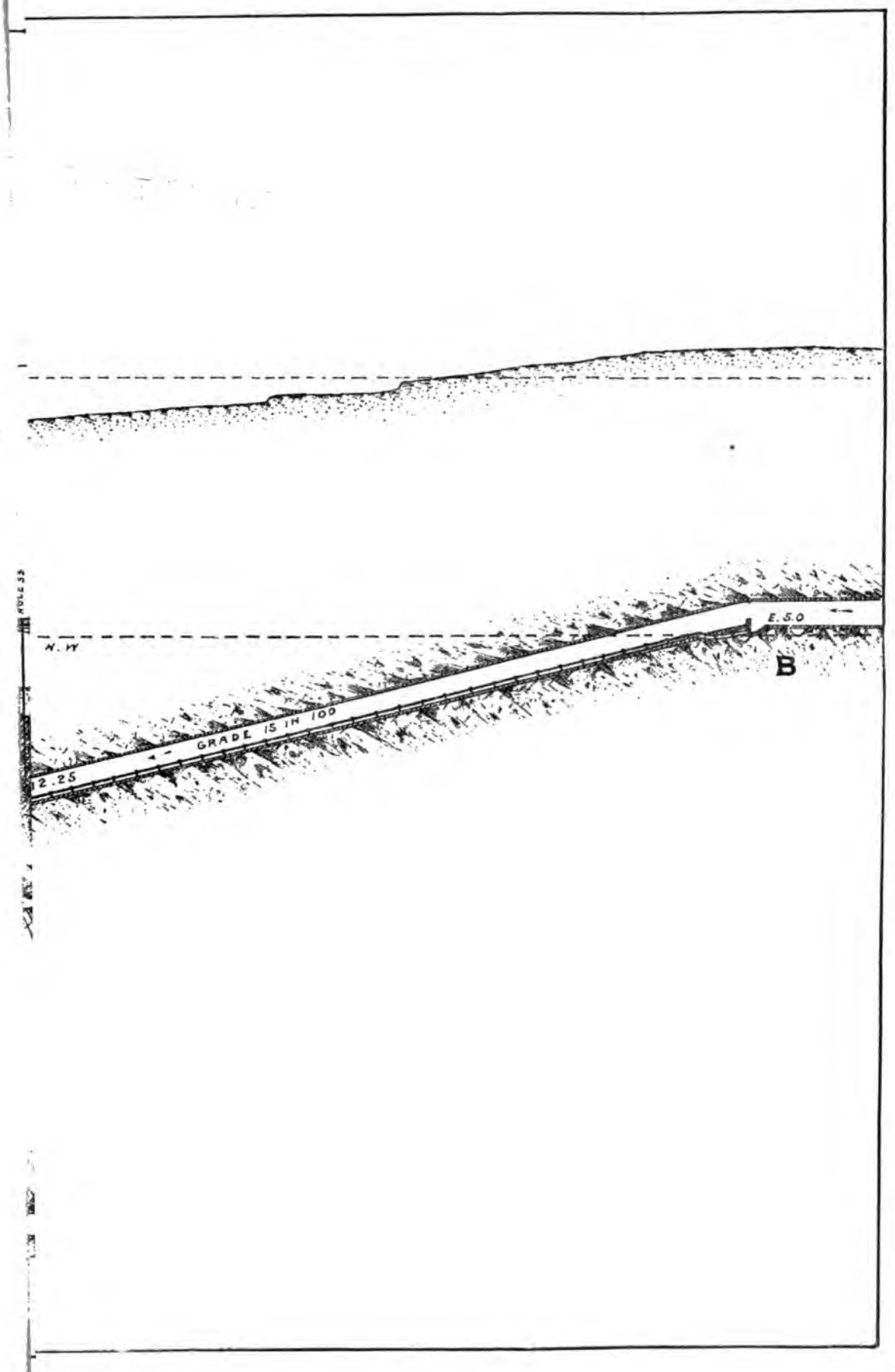


PLATE 80.



THE AQUEDUCT COMMISSIONERS

DETAIL DRAWING

SHAFT Nº 25

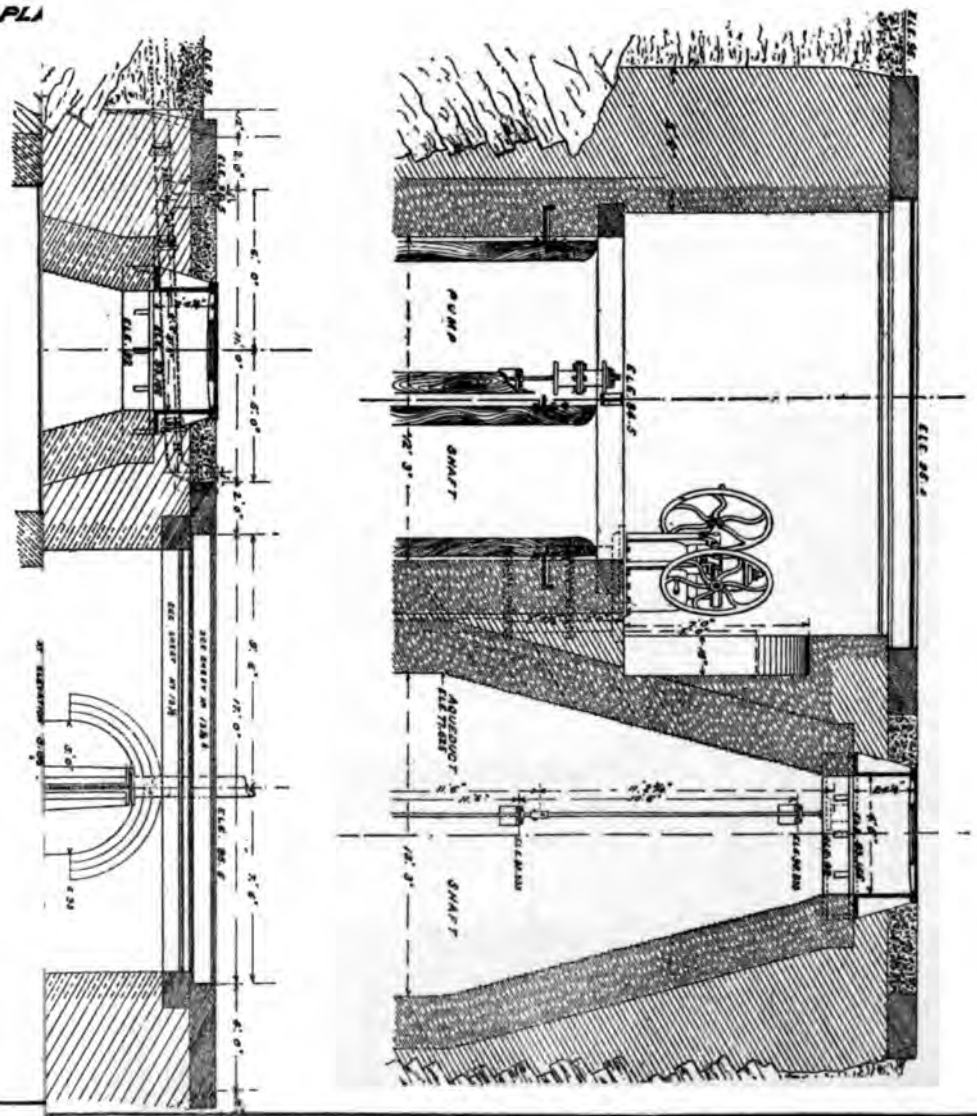
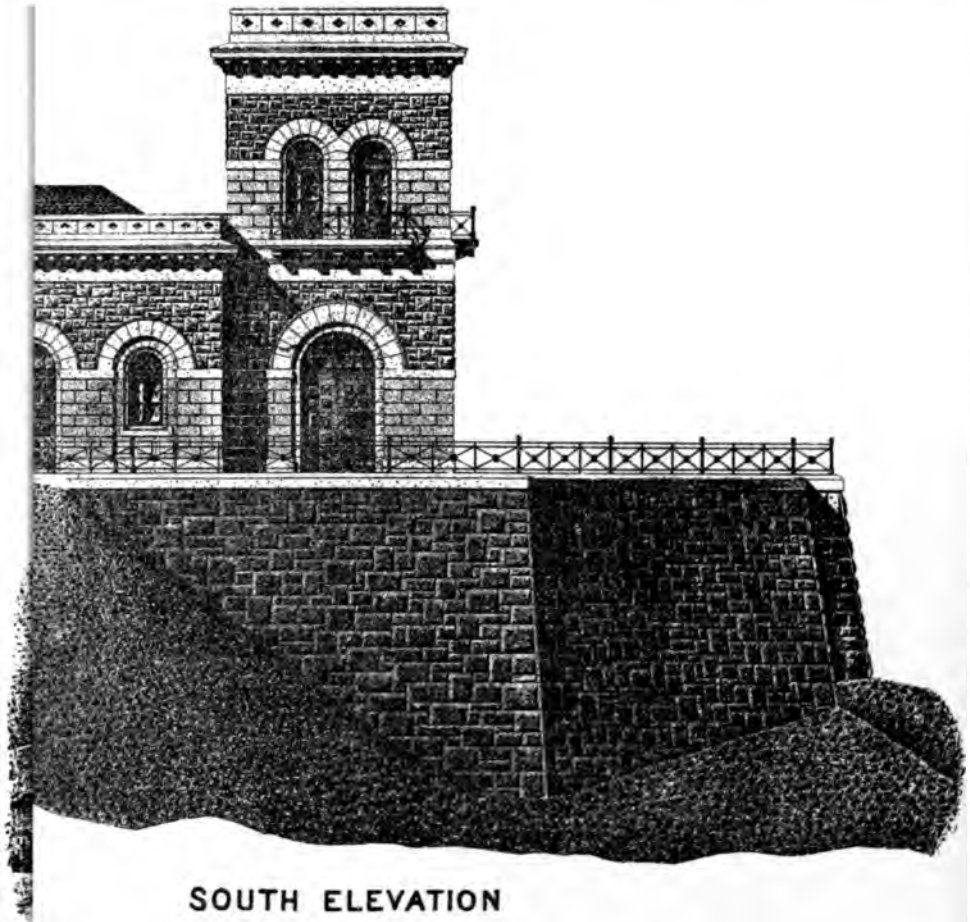


PLATE 83.



SOUTH ELEVATION

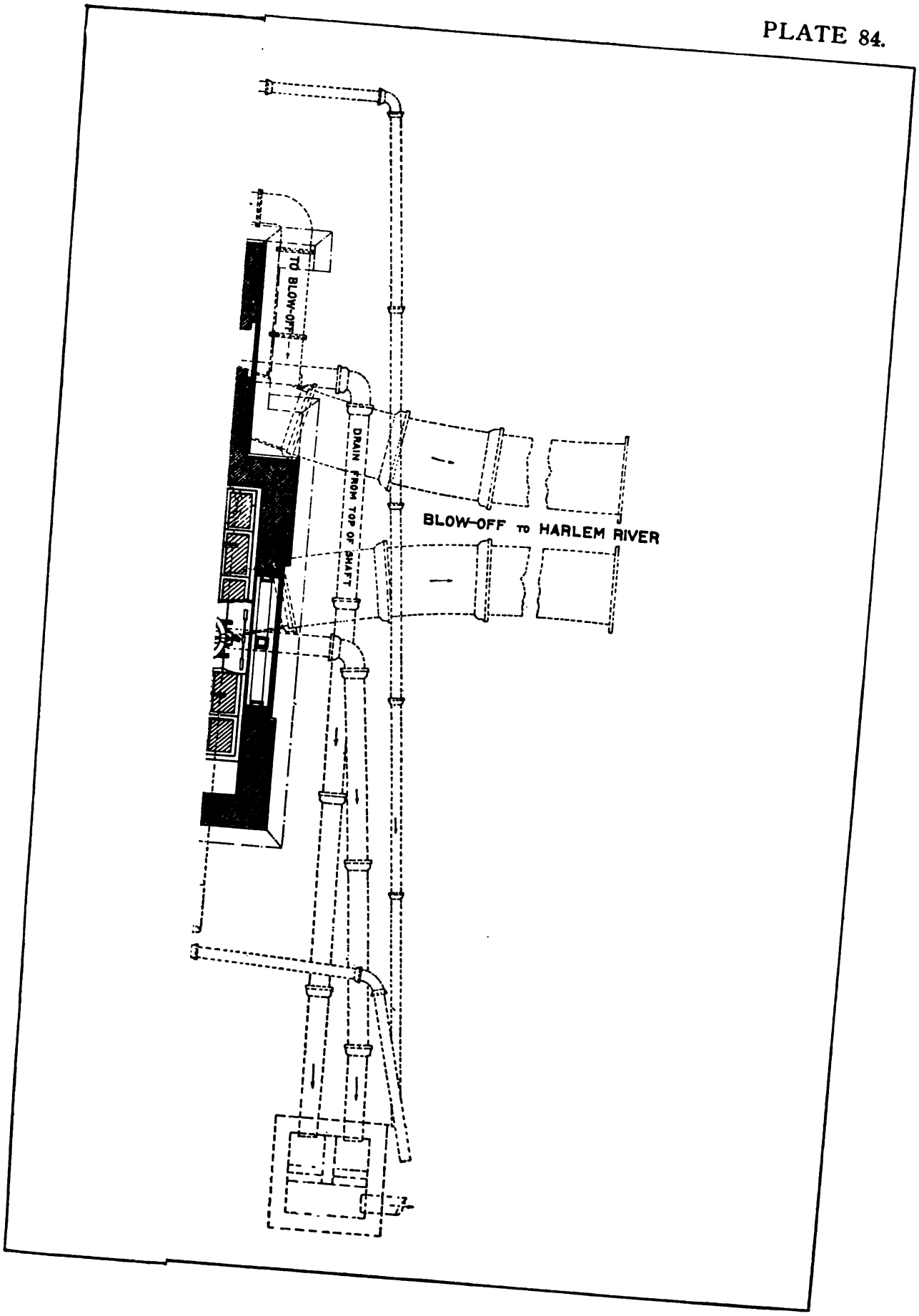
HE AQUEDUCT COMMISSION

HEAD-HOUSE AND RETAINING WALL,

BLOW-OFF AND DOCK

SHAFT Nº25

PLATE 84.



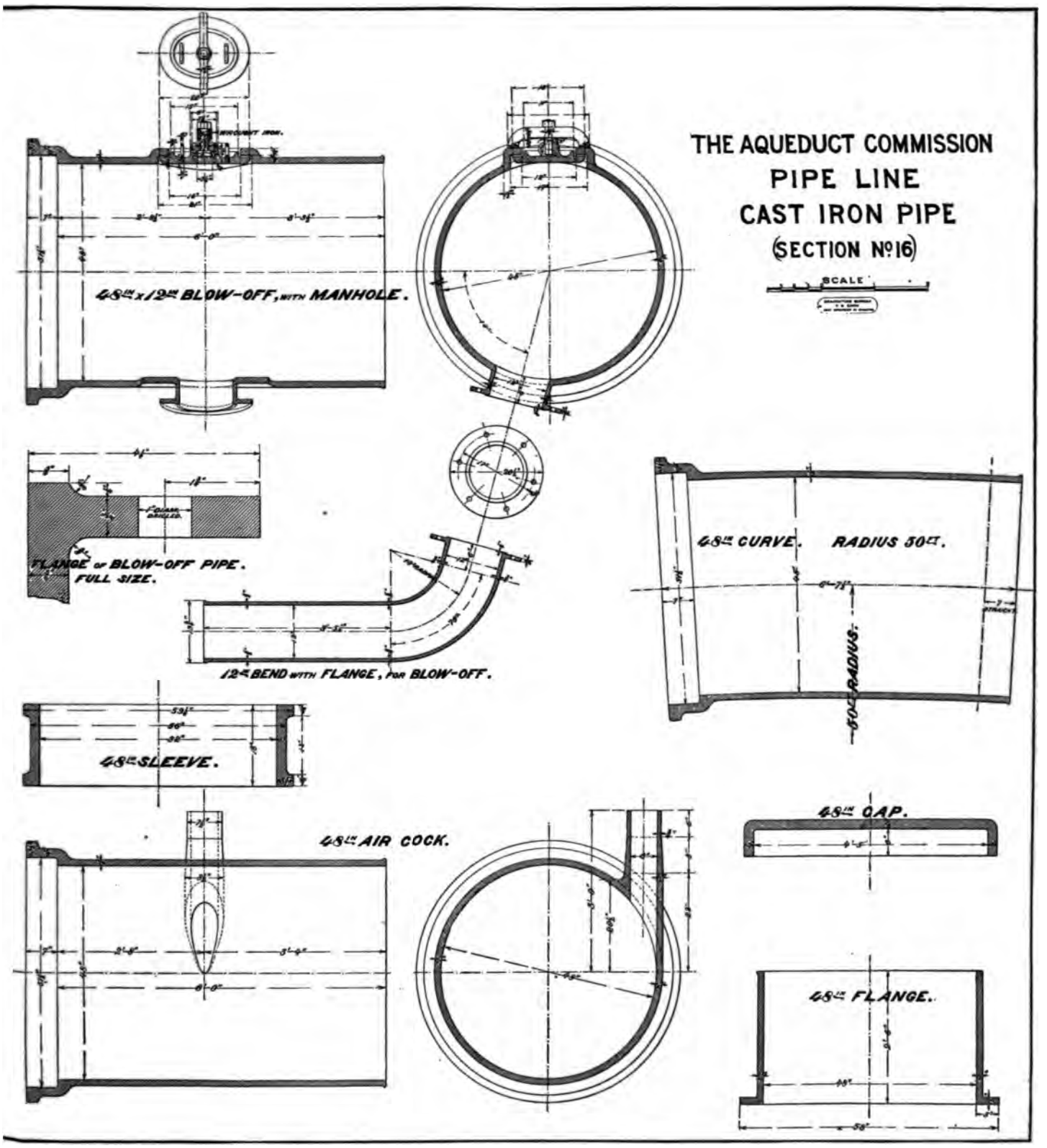
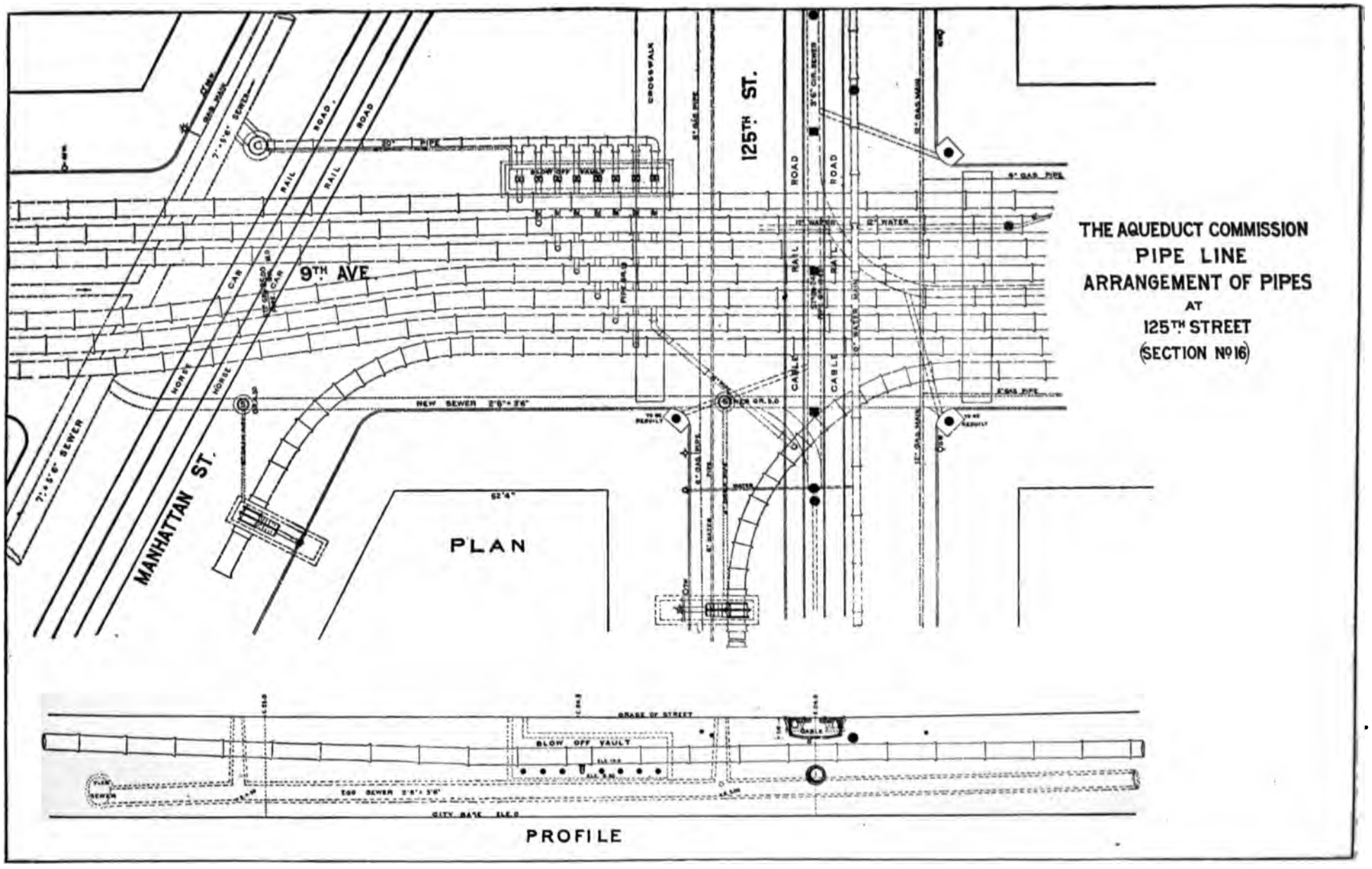
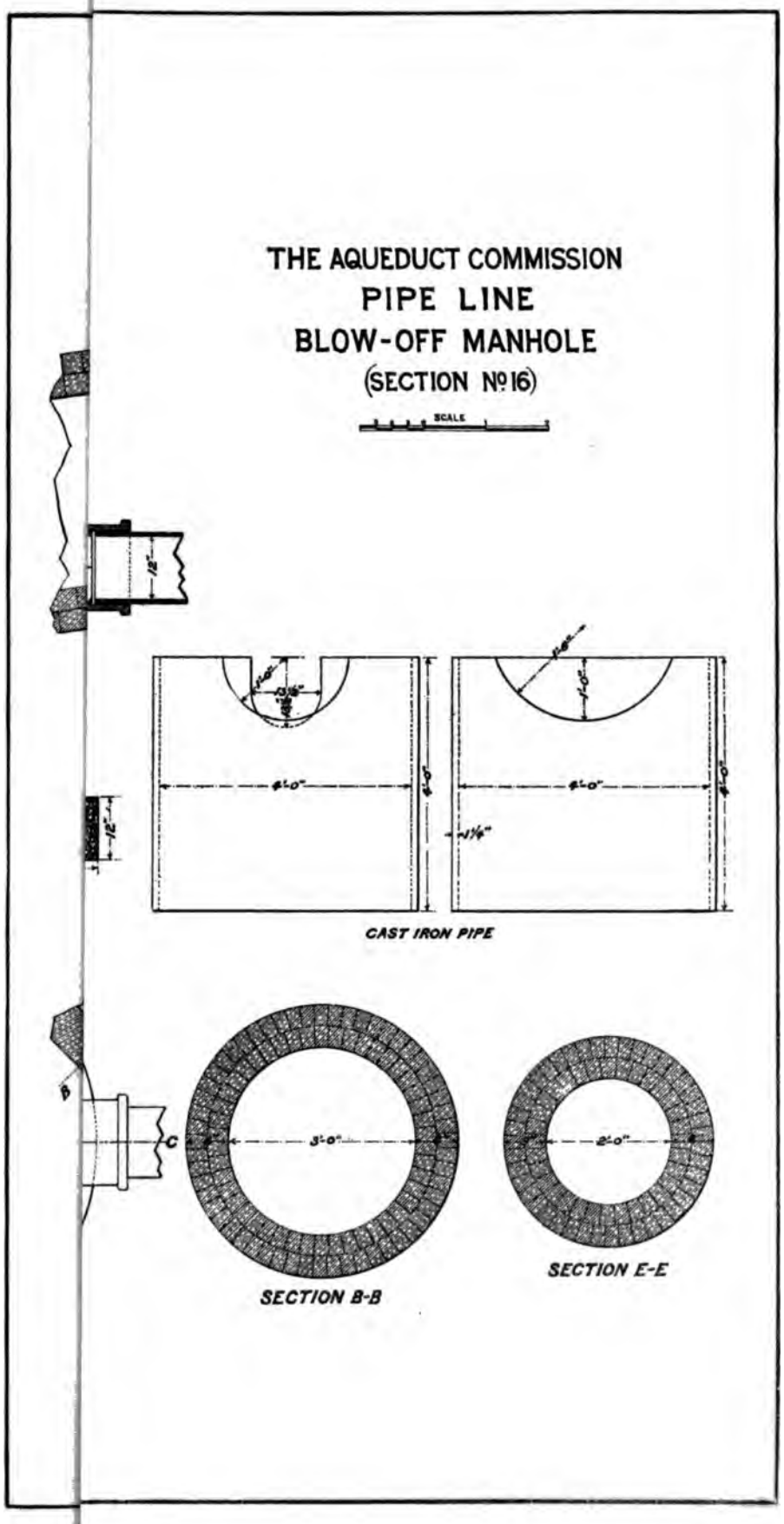

THE AQUEDUCT COMMISSION
PIPE LINE
CAST IRON PIPE
(SECTION No 16)
SCALE
48in x 12in BLOW-OFF, WITH MANHOLE.
FLANGE OF BLOW-OFF PIPE.
FULL SIZE.
12in BEND WITH FLANGE, FOR BLOW-OFF.
48in CURVE. RADIUS 50ft.
50ft RADIUS.
48in SLEEVE.
48in AIR COCK.
48in CAP.
48in FLANGE.

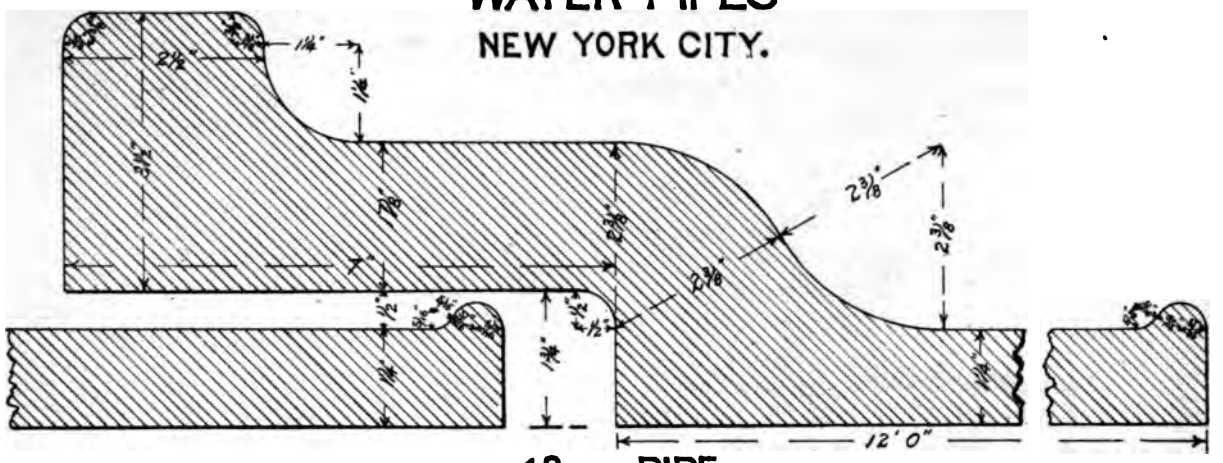
PLATE 87.


THE AQUEDUCT COMMISSION
PIPE LINE
ARRANGEMENT OF PIPES
AT
125TH STREET
(SECTION No 16)
PLAN
PROFILE
125TH ST.
9TH AVE.
MANHATTAN ST.
CROSSWALK
BLOW OFF VAULT
NEW SEWER 2'6"×3'6"
7'-5'6" SEWER
HORSE
CAR
RAIL
ROAD
CABLE
12" WATER
12" GAS MAIN
GRADE OF STREET
CITY BASE ELEV. 0

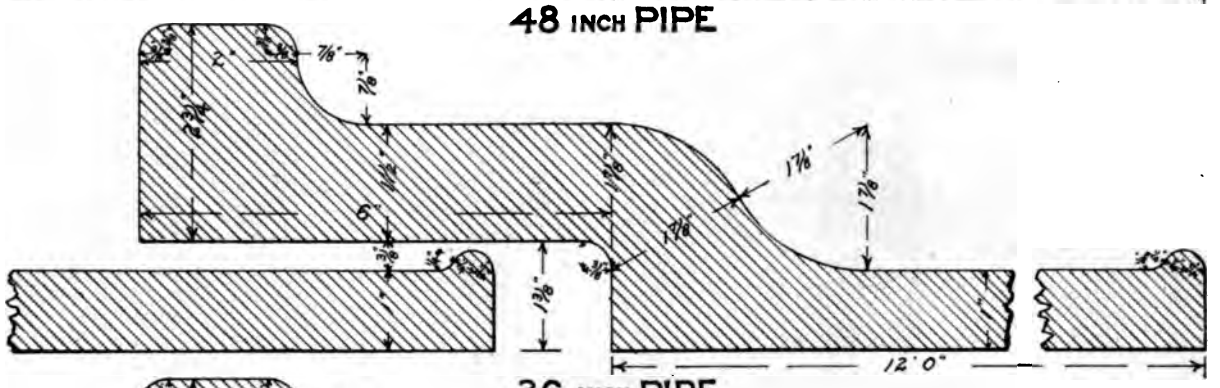

THE AQUEDUCT COMMISSION
PIPE LINE
BLOW-OFF MANHOLE
(SECTION No 16)
SCALE
CAST IRON PIPE
SECTION B-B
SECTION E-E

STANDARD SECTIONS OF WATER PIPES

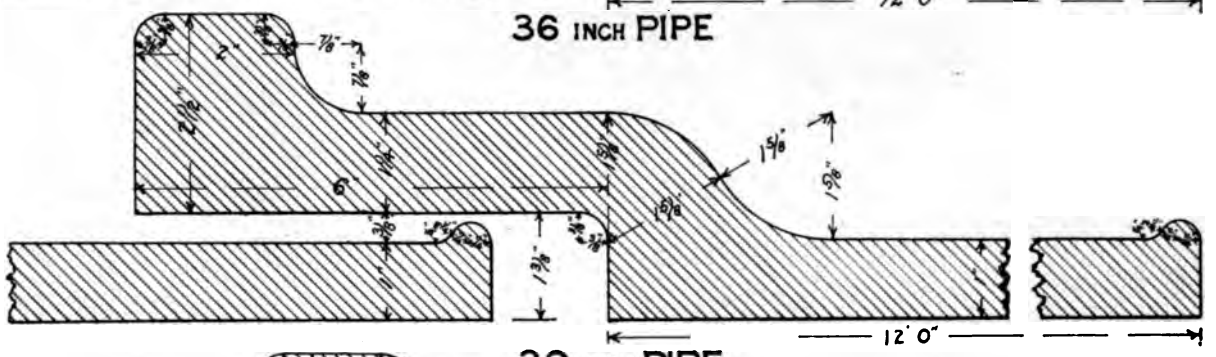
NEW YORK CITY.



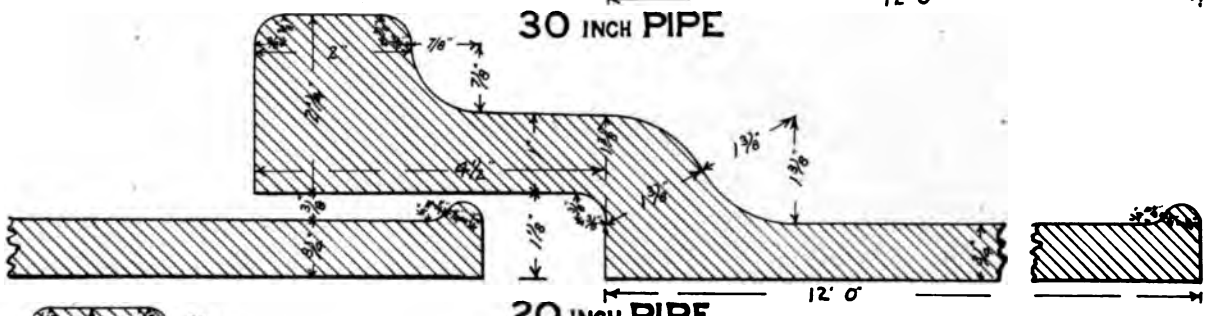
48 INCH PIPE



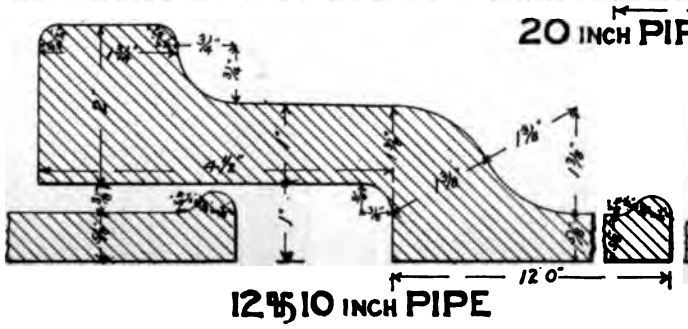
36 INCH PIPE



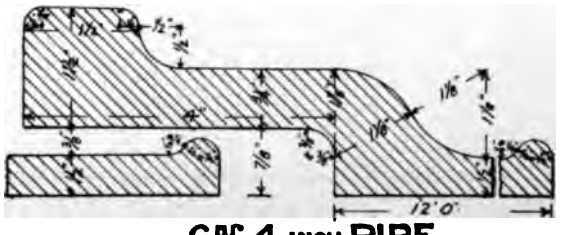
30 INCH PIPE



20 INCH PIPE



12 & 10 INCH PIPE

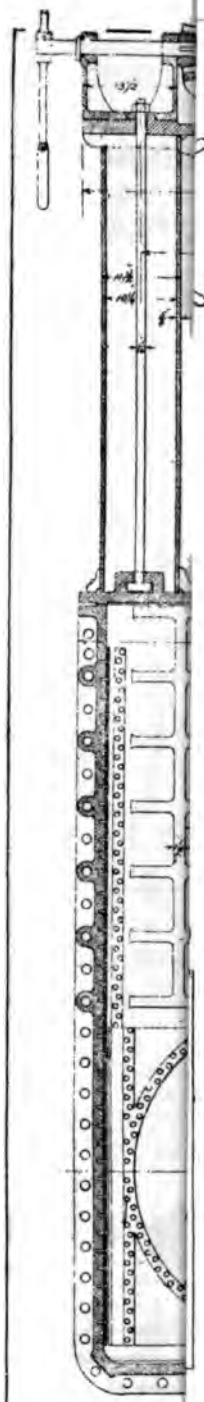


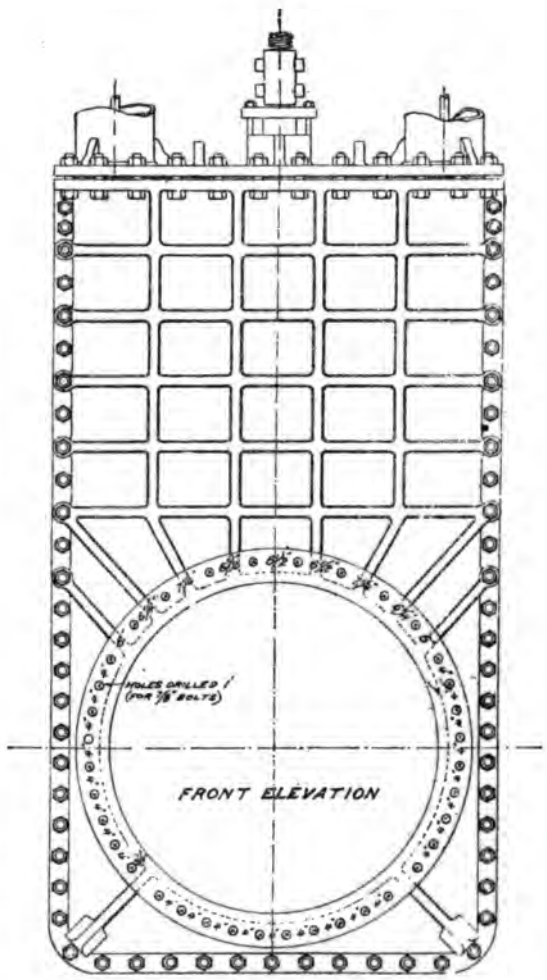
6 & 4 INCH PIPE

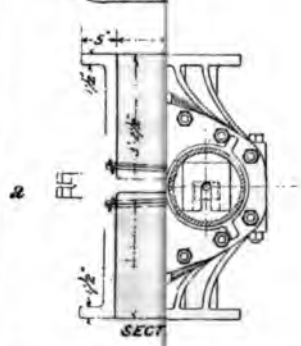
PLATE 90.

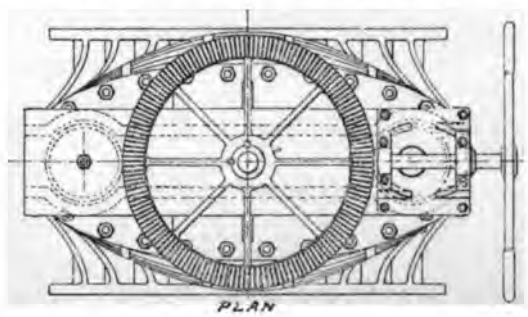
THE AQUEDUCT COMMISSIONERS

DETAILS OF STANDARD 48IN STOPCOCK VALVES USED ON AQUEDUCT



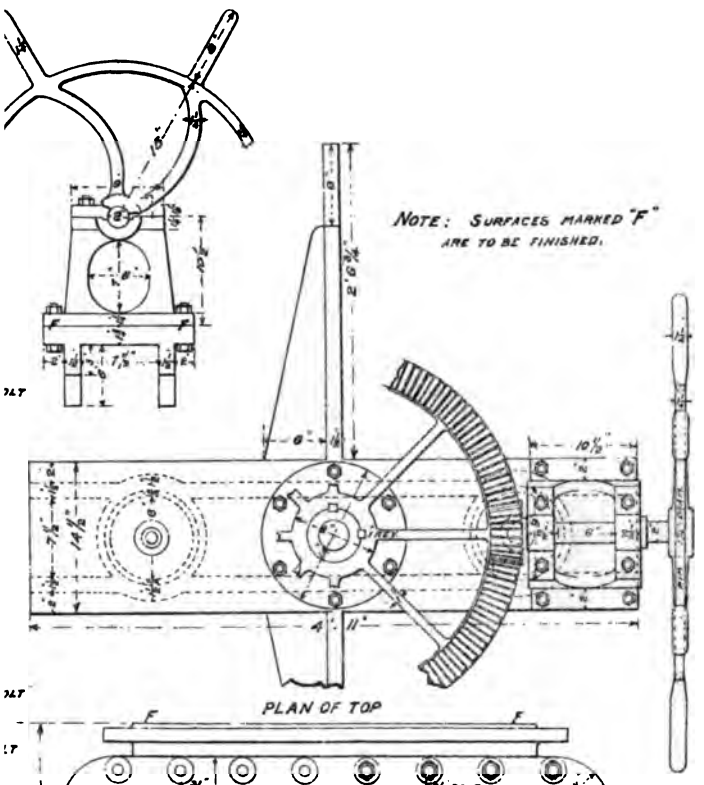


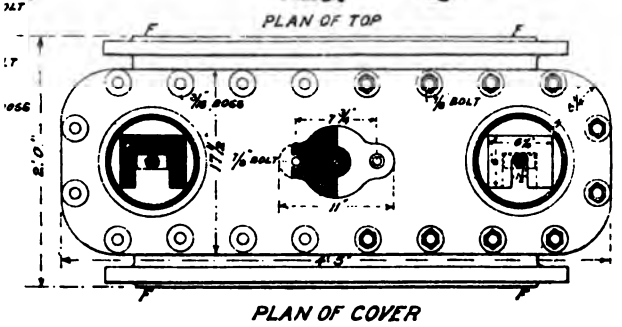




THE AQUEDUCT COMMISSIONERS

DETAILS OF STANDARD 36IN STOPCOCK VALVES USED ON AQUEDUCT





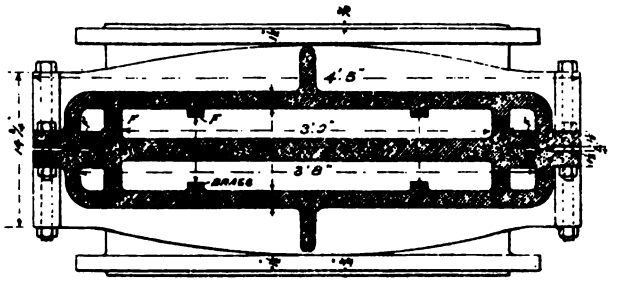


PLATE 93.

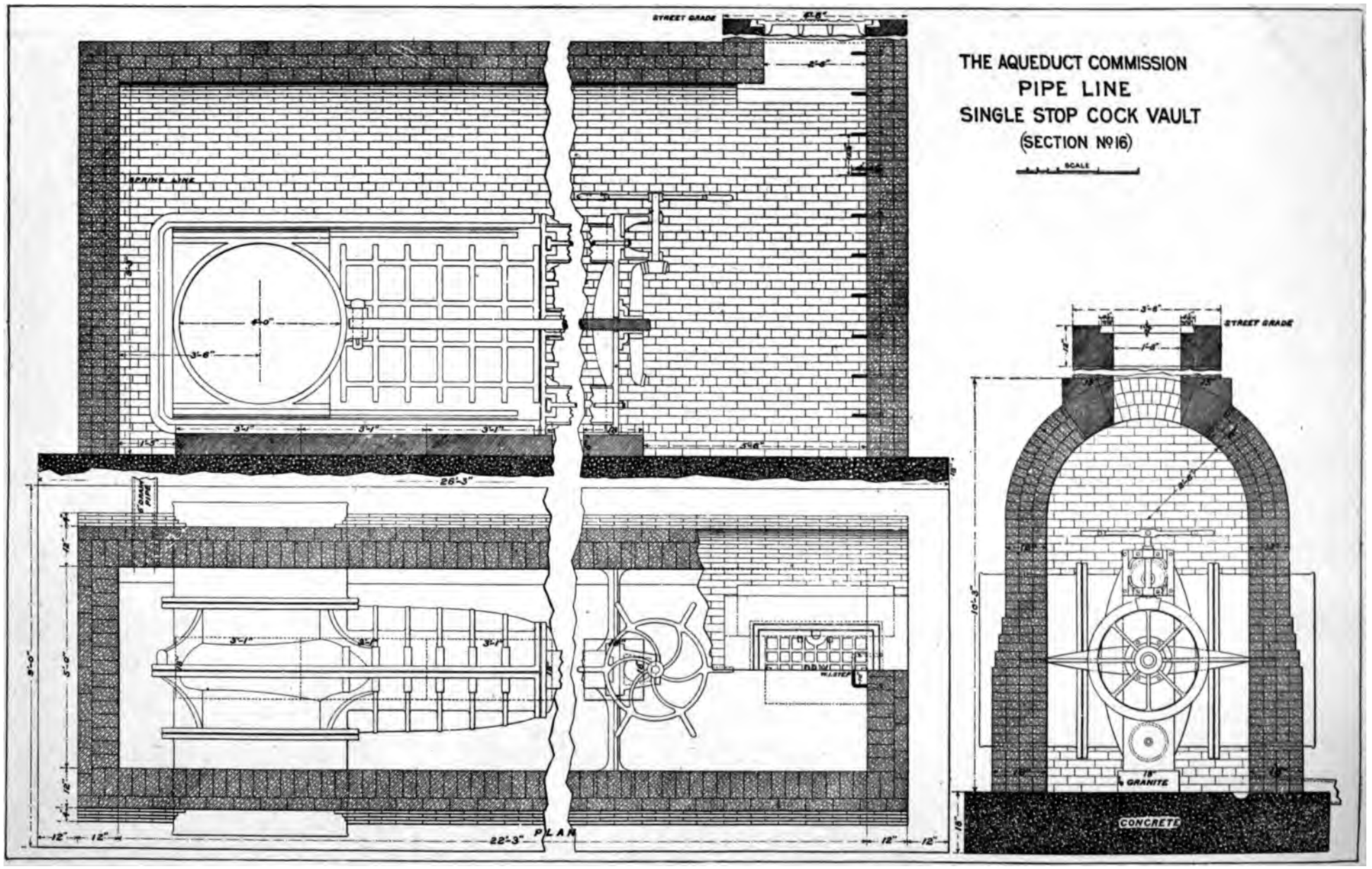

THE AQUEDUCT COMMISSION
PIPE LINE
SINGLE STOP COCK VAULT
(SECTION No 16)
SCALE
STREET GRADE
SPRING LINE
26'-3"
22'-3"
PLAN
STREET GRADE
18" GRANITE
CONCRETE

PLATE 94.

THE AQUEDUCT COMMISSIONERS

TWENTY-TWO 2'×5' SLUICE-GATES FOR 135TH ST. AND CENTRAL PARK GATE HOUSES

SECTIONS Nos 15 & 17.

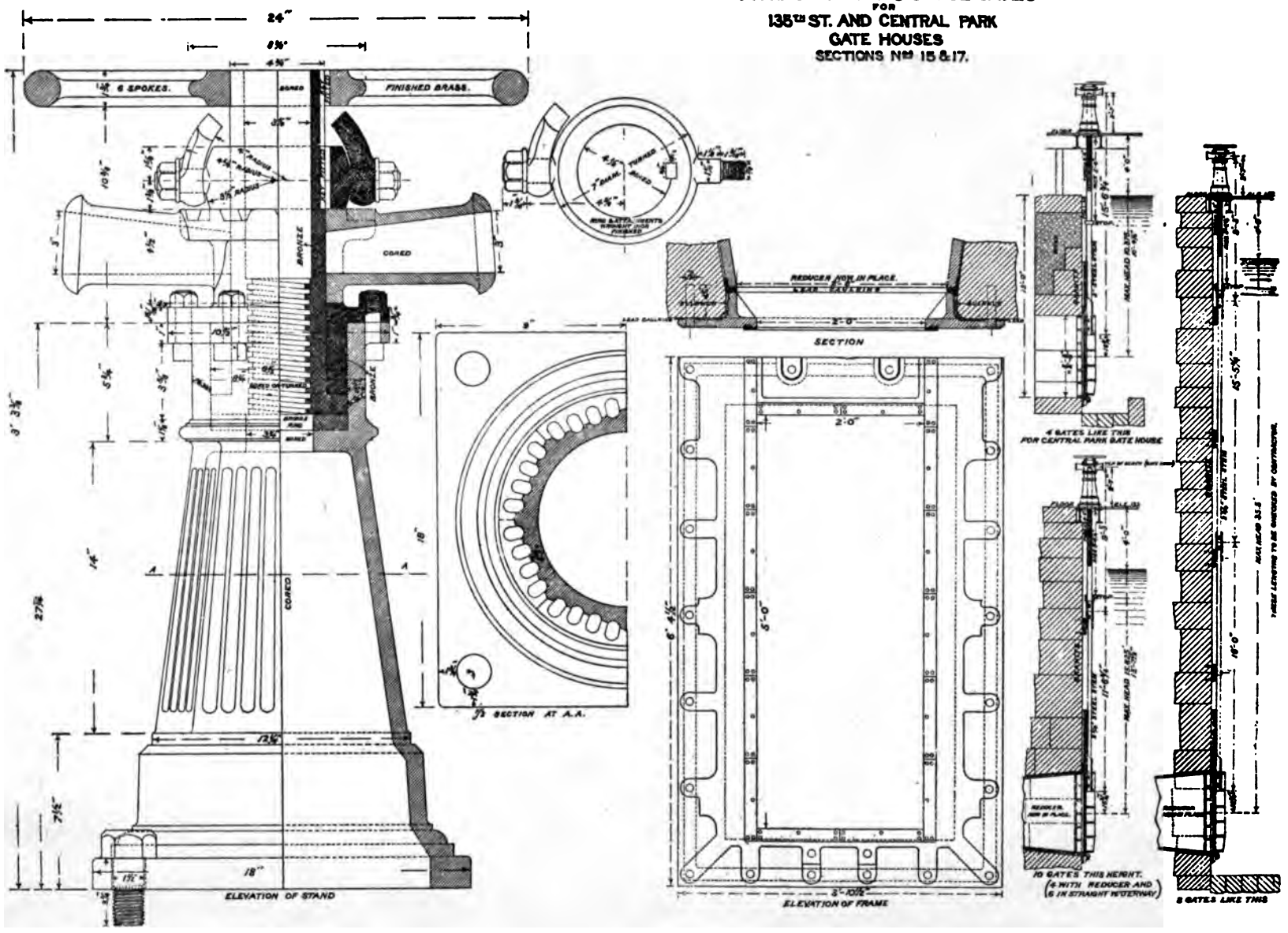


PLATE 95.

THE AQUEDUCT COMMISSIONERS

TWENTY-TWO 2'×5' SLUICE-GATES

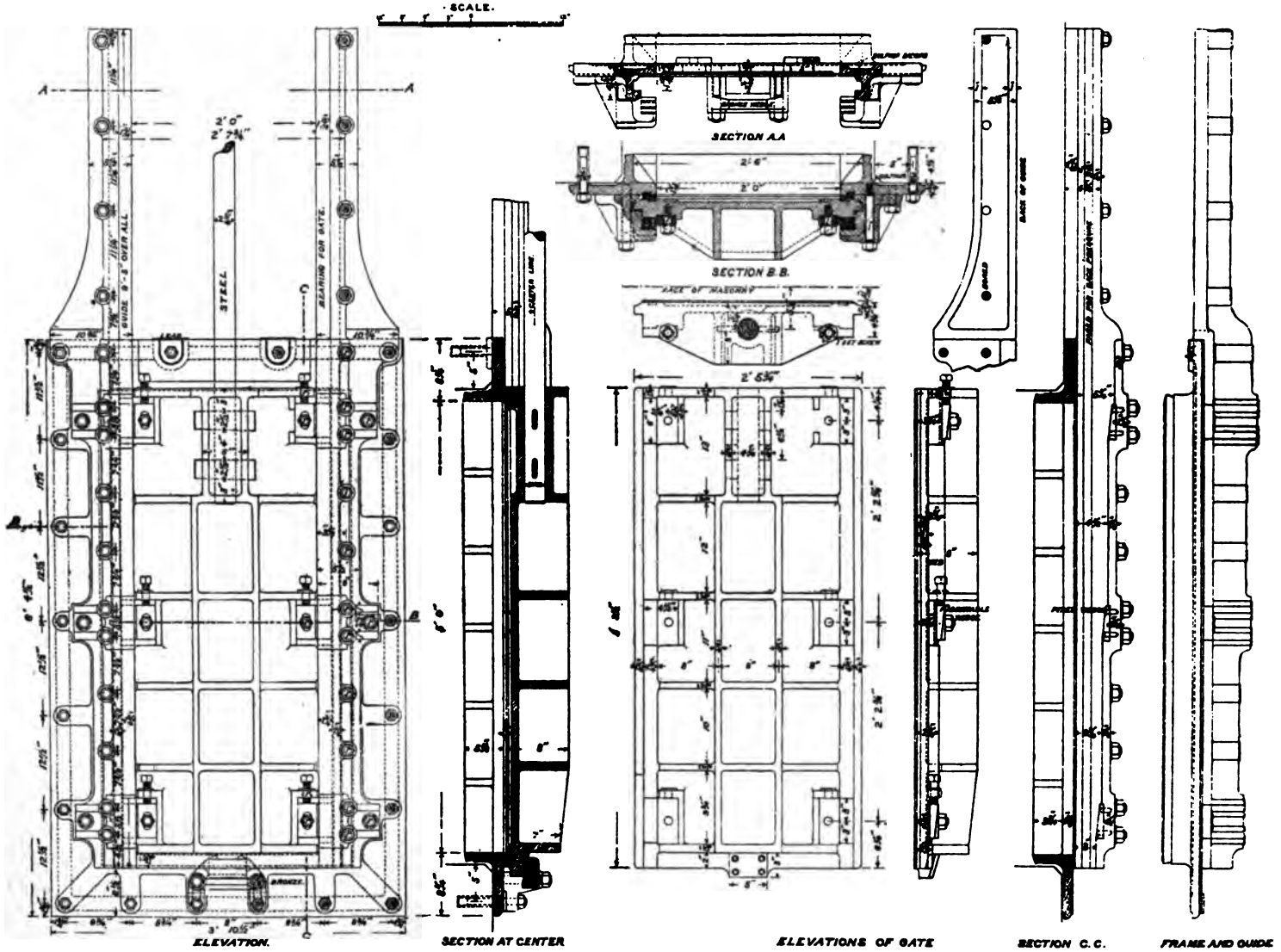
FOR

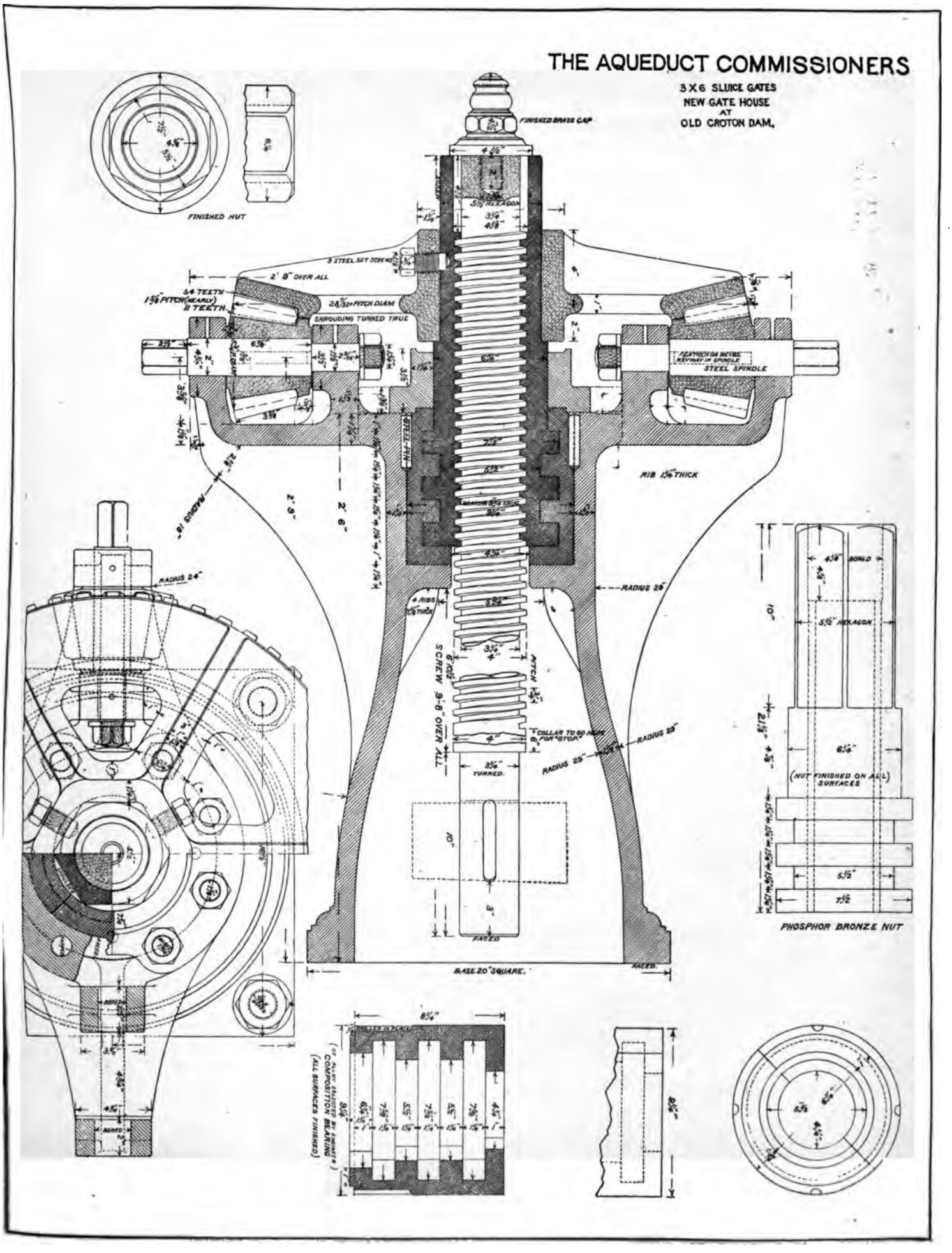
135TH ST. AND CENTRAL PARK

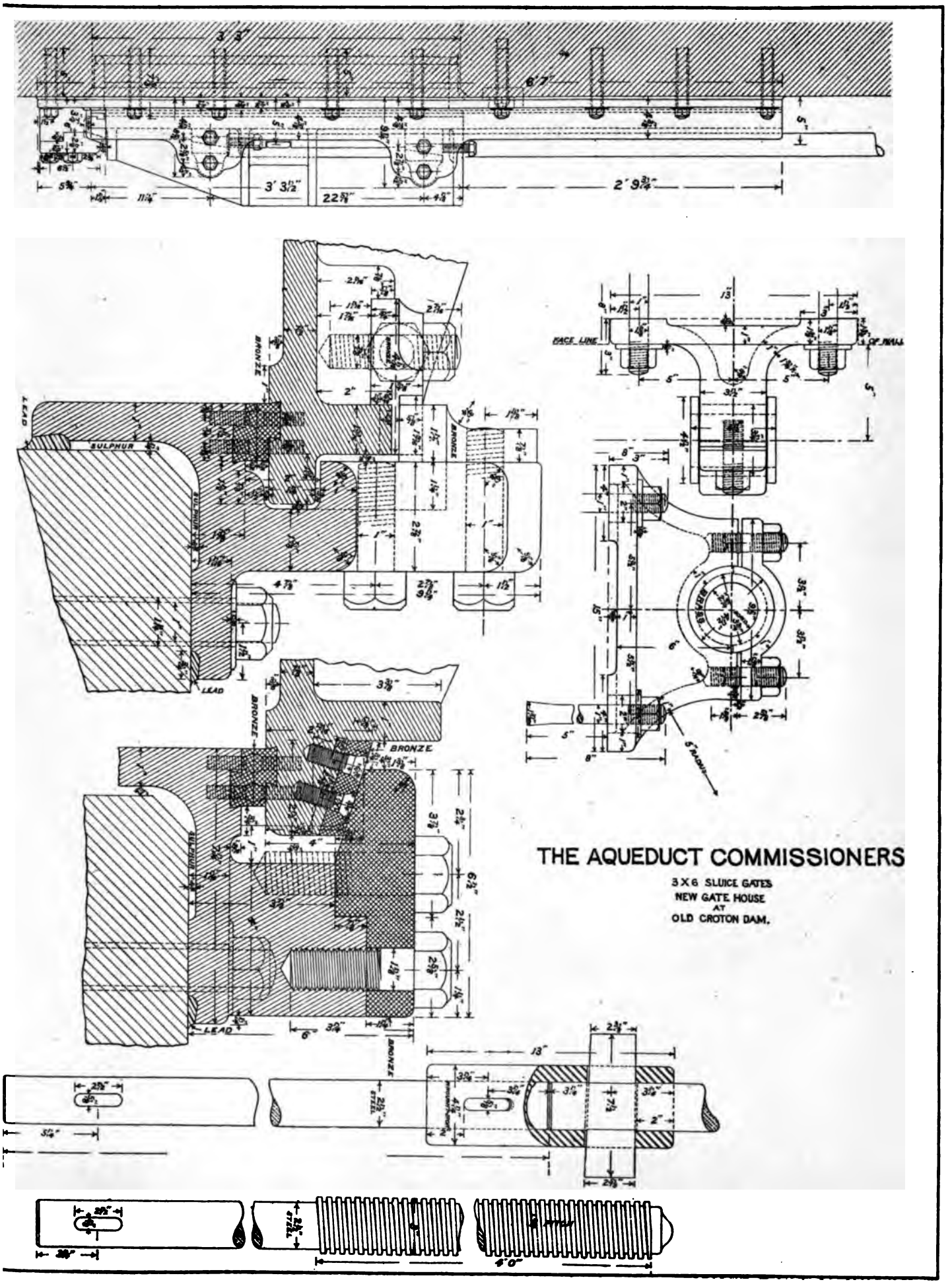
GATE HOUSES

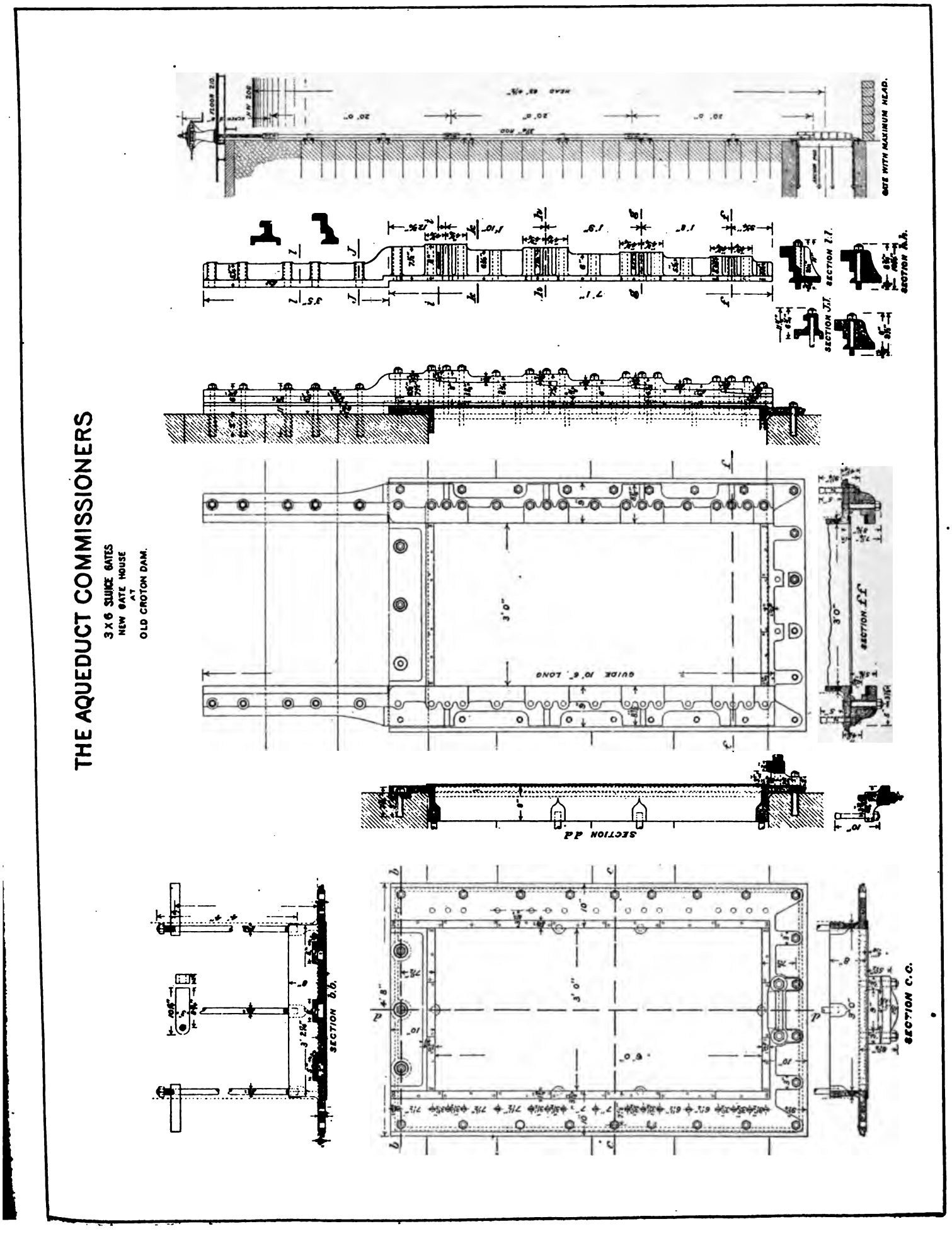
SECTIONS Nos 15 & 17.

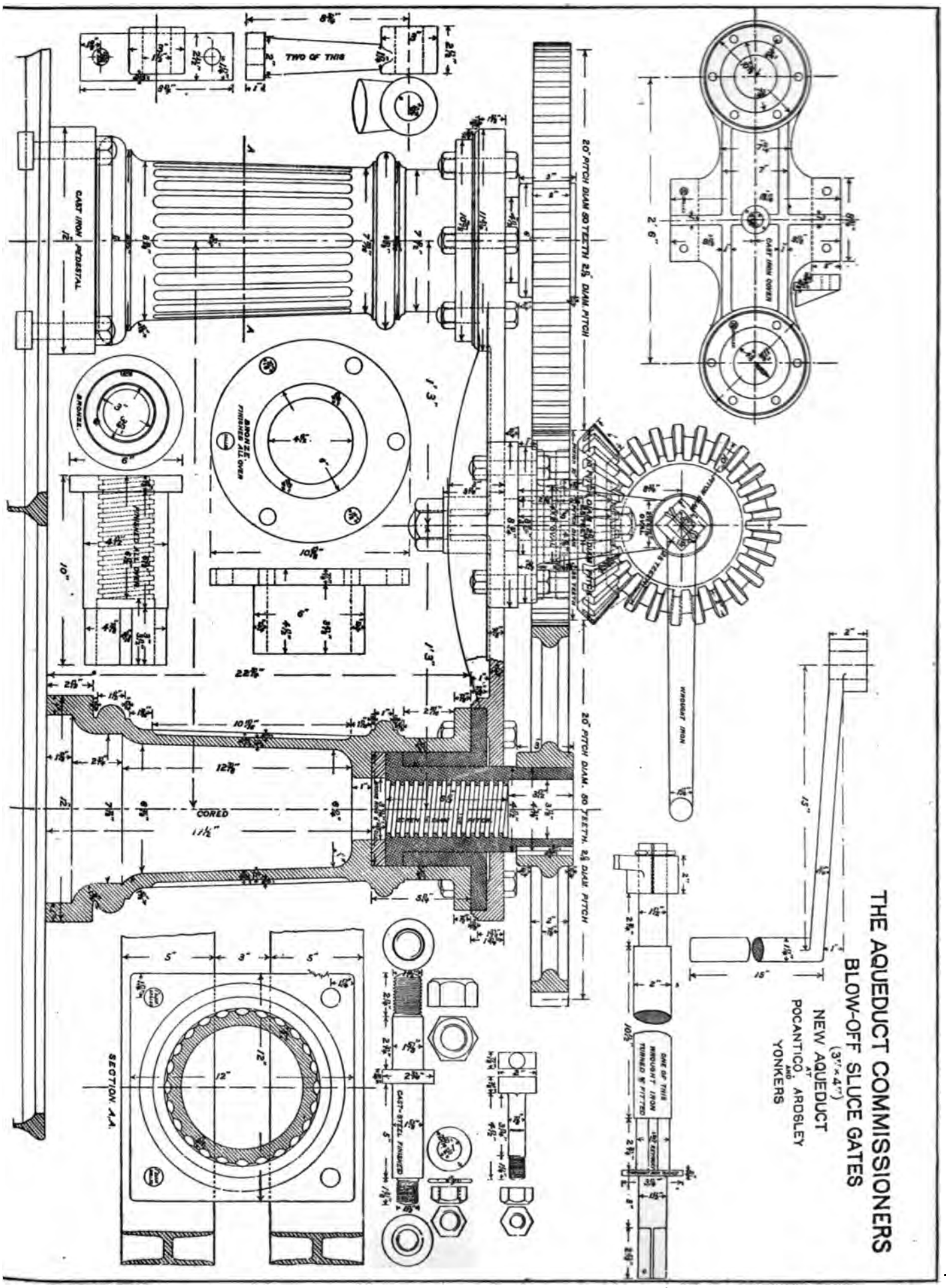
SCALE.




THE AQUEDUCT COMMISSIONERS
3 X 6 SLUICE GATES
NEW GATE HOUSE
AT
OLD CROTON DAM.
FINISHED NUT
FINISHED BRASS CAP
3 STEEL SET SCREWS
2' 8" OVER ALL
54 TEETH
1 5/8" PITCH (NEARLY)
11 TEETH
SHROUDING TURNED TRUE
STEEL SPINDLE
STEEL FAN
RIB 1 1/4" THICK
RADIUS 24"
RADIUS 28"
4 RIBS
SCREW 9'-8" OVER ALL
PITCH
COLLAR TO BE MADE FOR "STOP"
RADIUS 23"
TURNED.
FACED
BASE 20" SQUARE.
FACED.
PHOSPHOR BRONZE NUT
(NUT FINISHED ON ALL SURFACES)
5 1/2" HEXAGON
BORED
(OR "PLUG" SHOTTED BY LINOTYPE) COMPOSITION BEARING
(ALL SURFACES FINISHED)


THE AQUEDUCT COMMISSIONERS
3 X 6 SLUICE GATES
NEW GATE HOUSE
AT
OLD CROTON DAM.
SULPHUR
LEAD
BRONZE
FACE LINE
BRASS


THE AQUEDUCT COMMISSIONERS
3 X 6 SLUICE GATES
NEW GATE HOUSE
AT
OLD CROTON DAM.
GATE WITH MAXIMUM HEAD.
SECTION J.J.
SECTION I.I.
SECTION K.K.
SECTION F.F.
SECTION d.d.
SECTION b.b.
SECTION C.C.
GUIDE 10' 6" LONG
3' 0"


THE AQUEDUCT COMMISSIONERS
BLOW-OFF SLUCE GATES
(3'-0" × 4'-0")
NEW AQUEDUCT
AT
POCANTICO AND ARDSLEY
YONKERS
CAST IRON PEDESTAL
TWO OF THIS
20" PITCH DIAM. 80 TEETH 2½" DIAM. PITCH
20" PITCH DIAM. 80 TEETH. 2½" DIAM. PITCH
CAST IRON COVER
BRONZE
BRONZE FINISHED ALL OVER
WROUGHT IRON
CORED
SECTION A.A.
CAST-STEEL FINISHED
ONE OF THIS WROUGHT IRON TURNED & FITTED

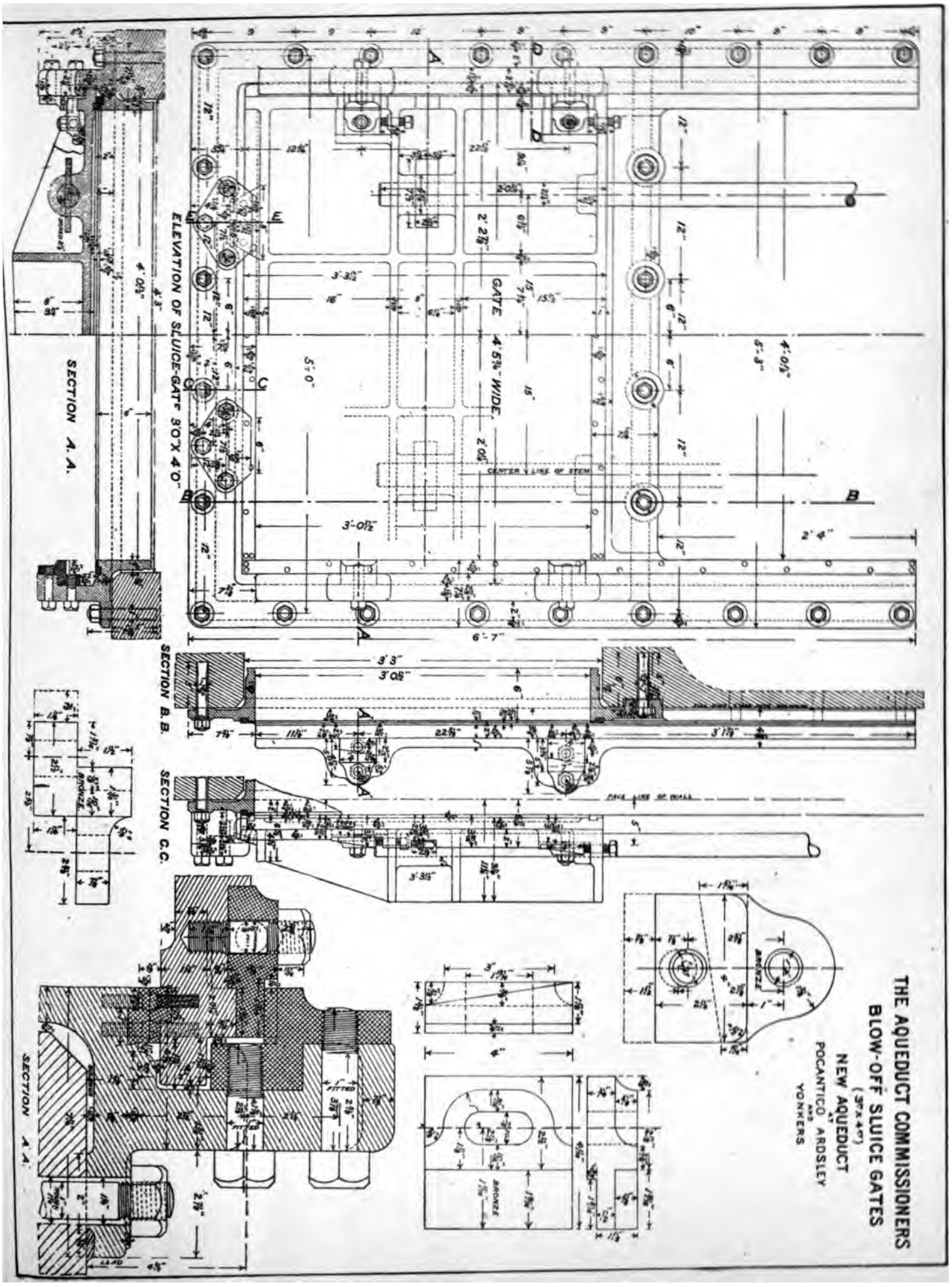
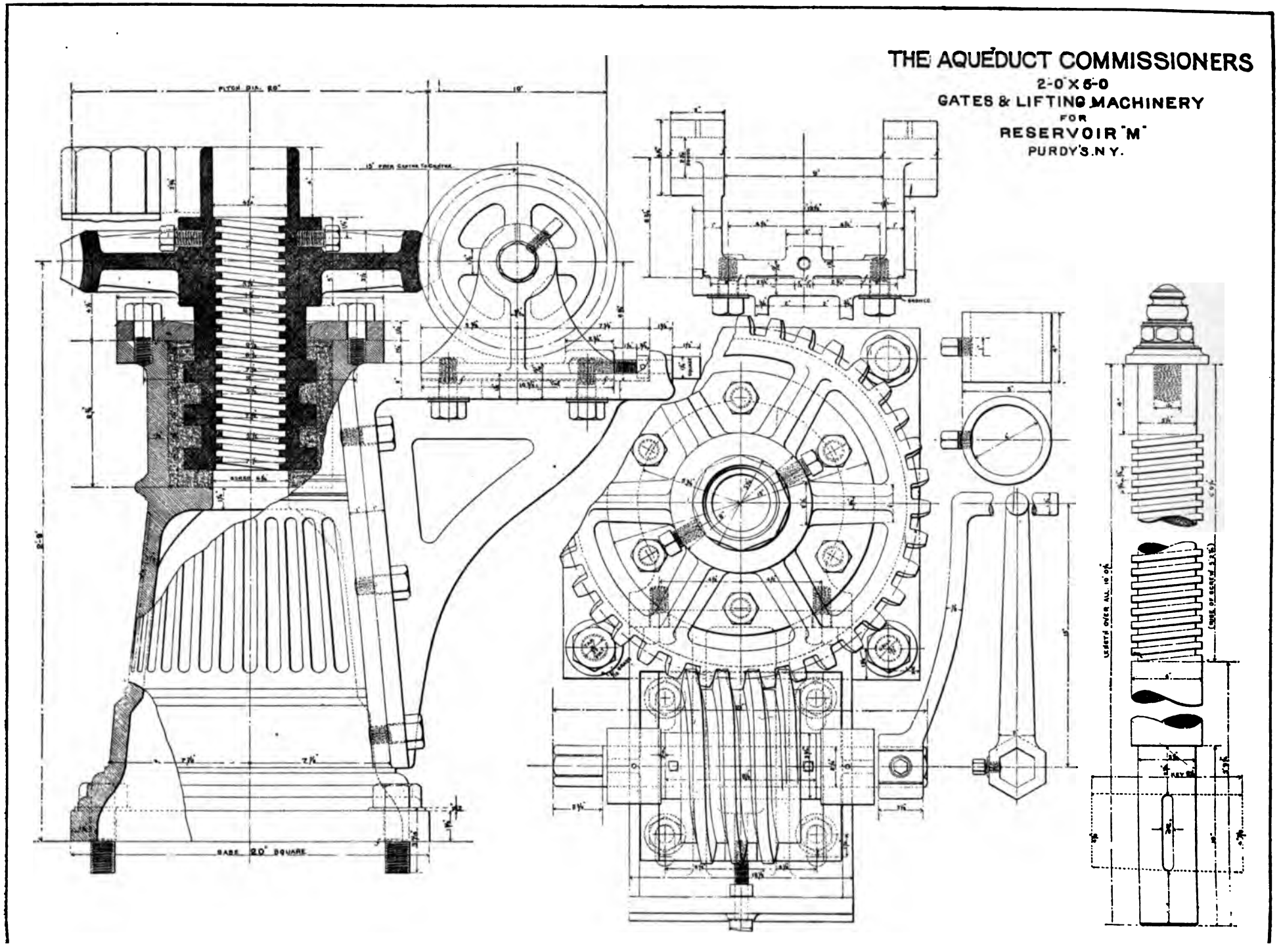
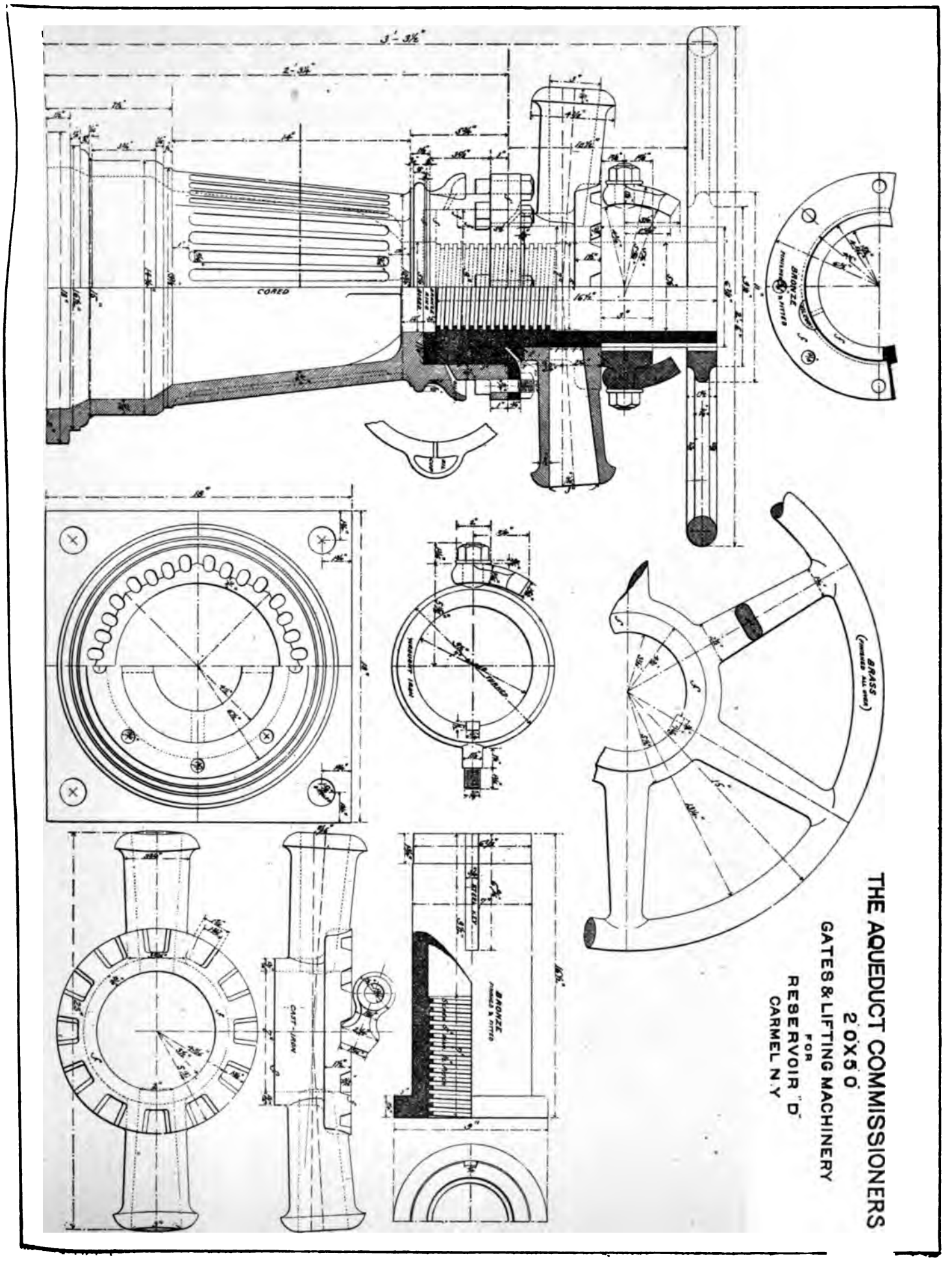
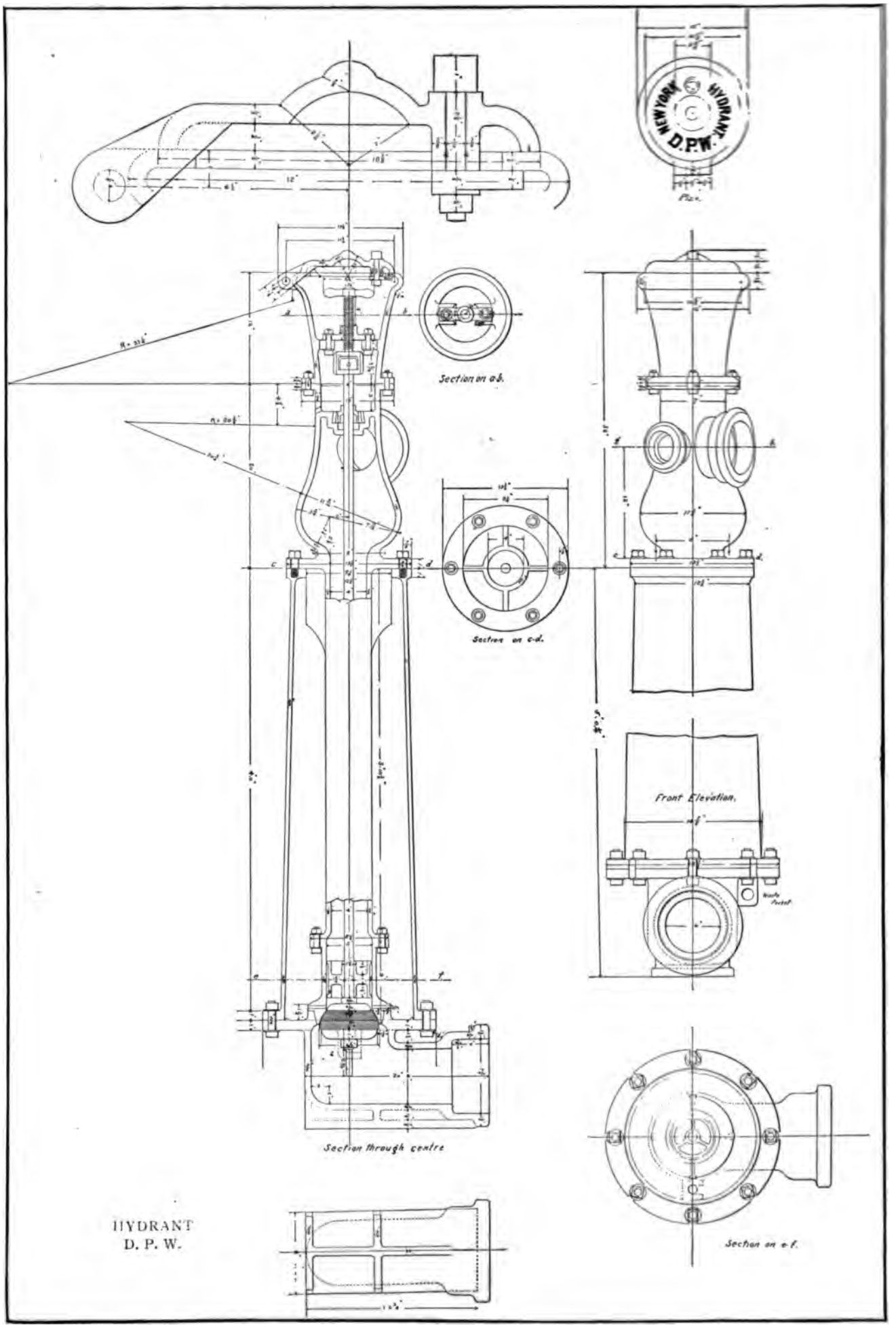

THE AQUEDUCT COMMISSIONERS
BLOW-OFF SLUICE GATES
(3'0"x4'0")
NEW AQUEDUCT
AT
POCANTICO ARDSLEY
AND
YONKERS
ELEVATION OF SLUICE-GATE 3'0"X 4'0"
GATE 4'5¾" WIDE
CENTER LINE OF STEM
SECTION A. A.
SECTION B. B.
SECTION C. C.
SECTION A. A.
BRONZE
CAST IRON
LEAD

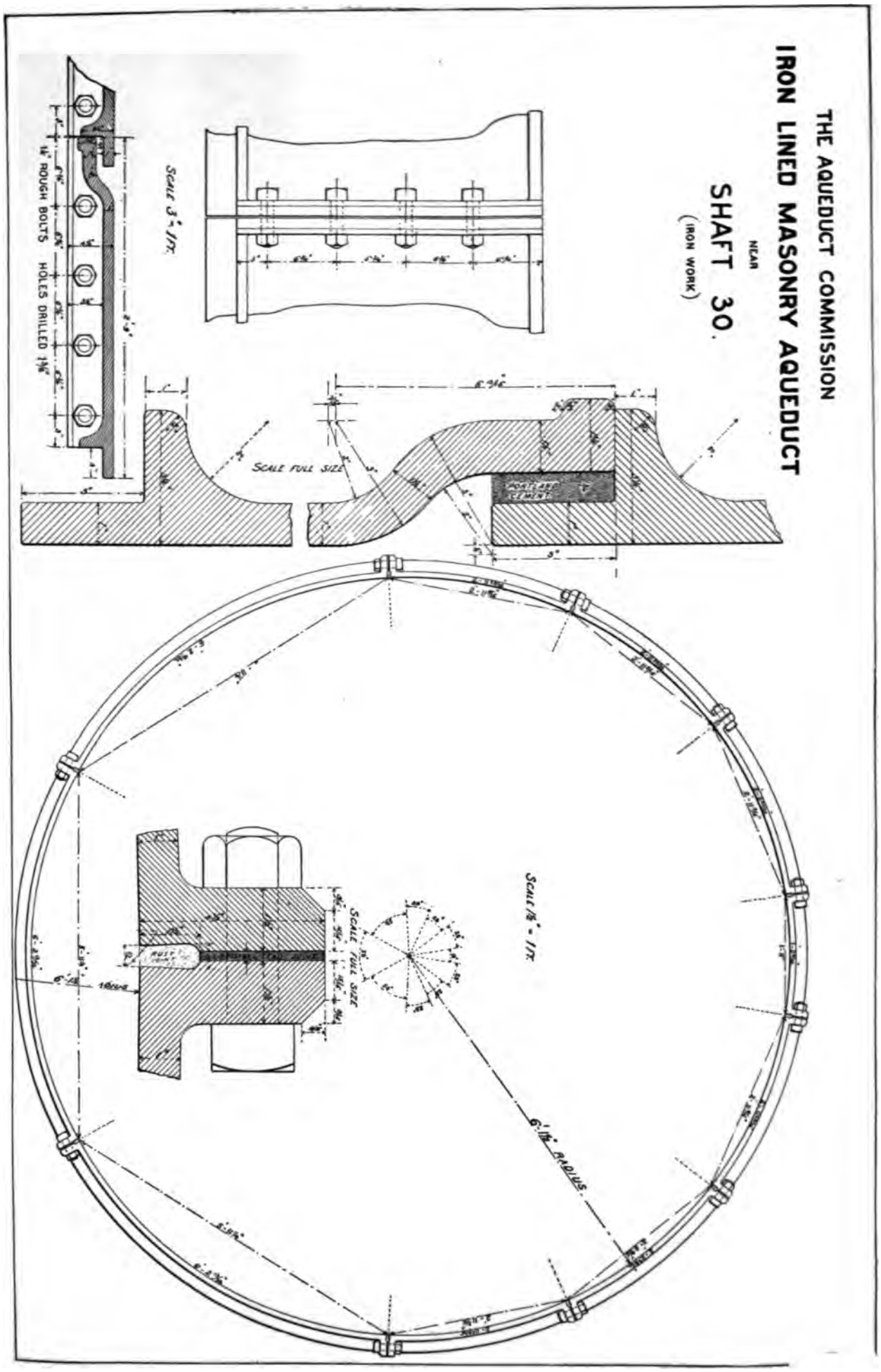
PLATE 101.

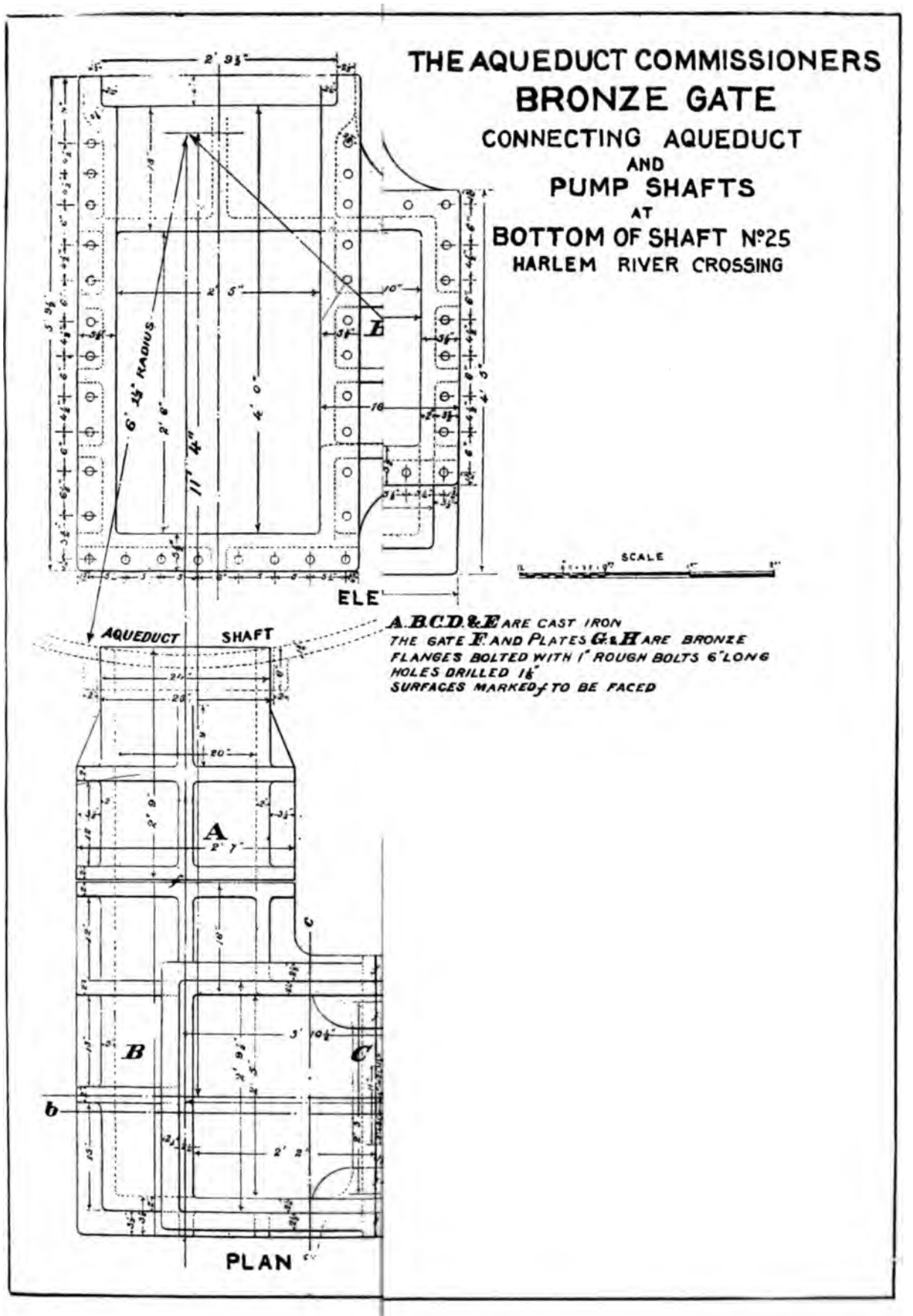

THE AQUEDUCT COMMISSIONERS
2'-0" X 6'-0"
GATES & LIFTING MACHINERY
FOR
RESERVOIR "M"
PURDY'S, N.Y.
BASE 20" SQUARE

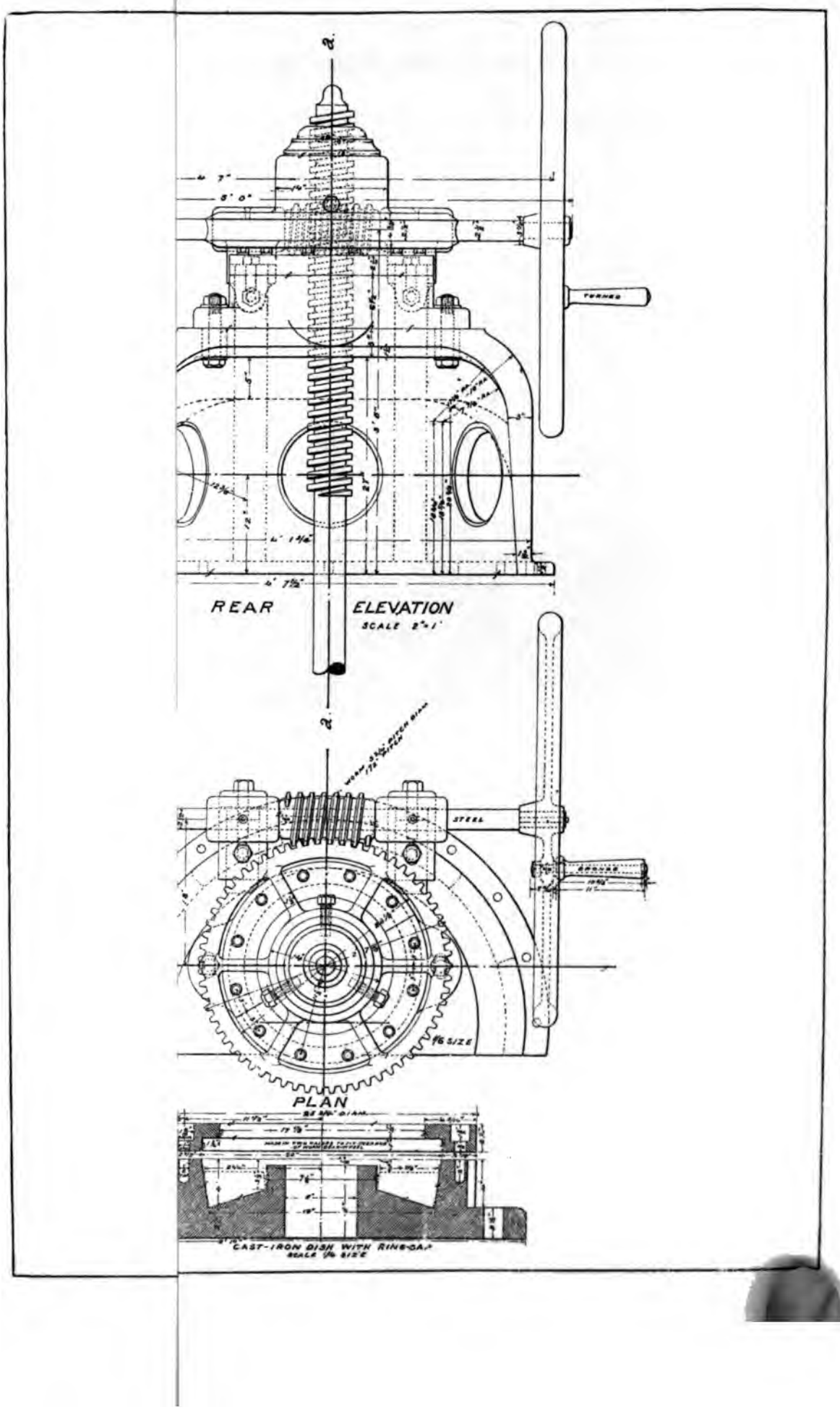

THE AQUEDUCT COMMISSIONERS
2'0"X5'0"
GATES & LIFTING MACHINERY
FOR
RESERVOIR "D"
CARMEL N.Y.
CORED
BRONZE
BRASS
CAST IRON
STEEL


NEW YORK HYDRANT
D.P.W.
Plan.
Section on a-b.
Section on c-d.
Front Elevation.
Section through centre
Section on e-f.

HYDRANT
D. P. W.


THE AQUEDUCT COMMISSION
IRON LINED MASONRY AQUEDUCT
NEAR
SHAFT 30.
(IRON WORK)
SCALE 3" = 1 FT.
SCALE FULL SIZE
SCALE 1/8" = 1 FT.
SCALE FULL SIZE
6'-1/8" RADIUS
1¼" ROUGH BOLTS HOLES DRILLED 1¼"


THE AQUEDUCT COMMISSIONERS
BRONZE GATE
CONNECTING AQUEDUCT
AND
PUMP SHAFTS
AT
BOTTOM OF SHAFT Nº25
HARLEM RIVER CROSSING
SCALE
ELE
AQUEDUCT
SHAFT
A.B.C.D.&E ARE CAST IRON
THE GATE F AND PLATES G.&H ARE BRONZE
FLANGES BOLTED WITH 1" ROUGH BOLTS 6" LONG
HOLES DRILLED 1⅛"
SURFACES MARKED f TO BE FACED
6' 1½" RADIUS
11' 4"
PLAN


REAR ELEVATION
SCALE 2"=1'
STEEL
PLAN
CAST-IRON DISH WITH RING-GAP

THE AQUEDUCT COMMISSIONERS

DETAILS OF BUCKET FOR SHAFT 25 SECTION 12

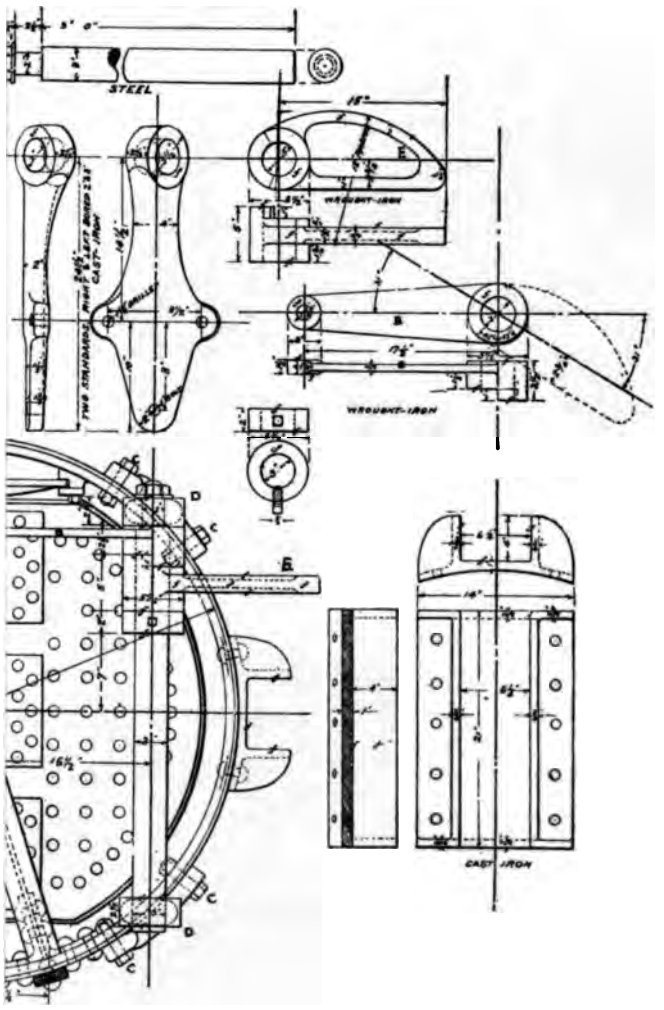
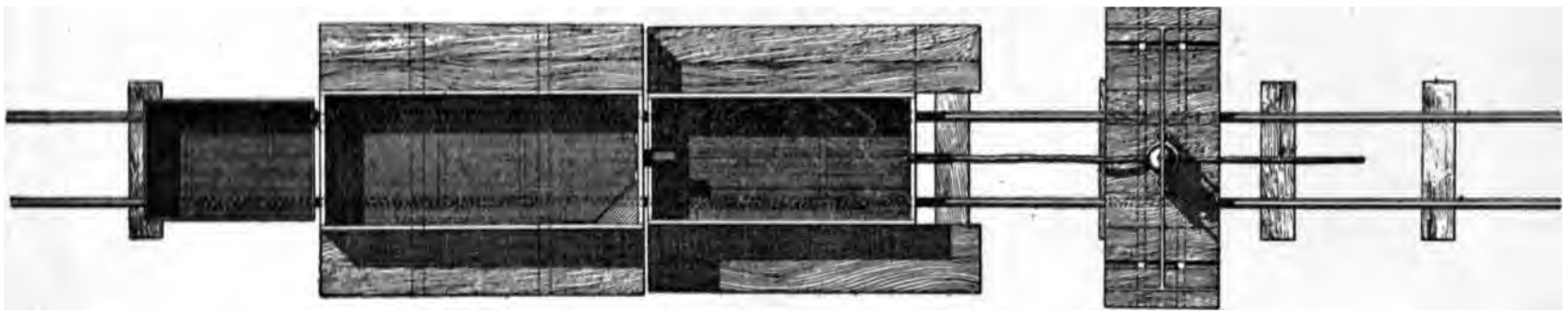


PLATE 108.

THE AQUEDUCT COMMISSIONERS

APPARATUS USED IN GROUTING DEFECTIVE MASONRY IN THE AQUEDUCT

SCALE



PLAN

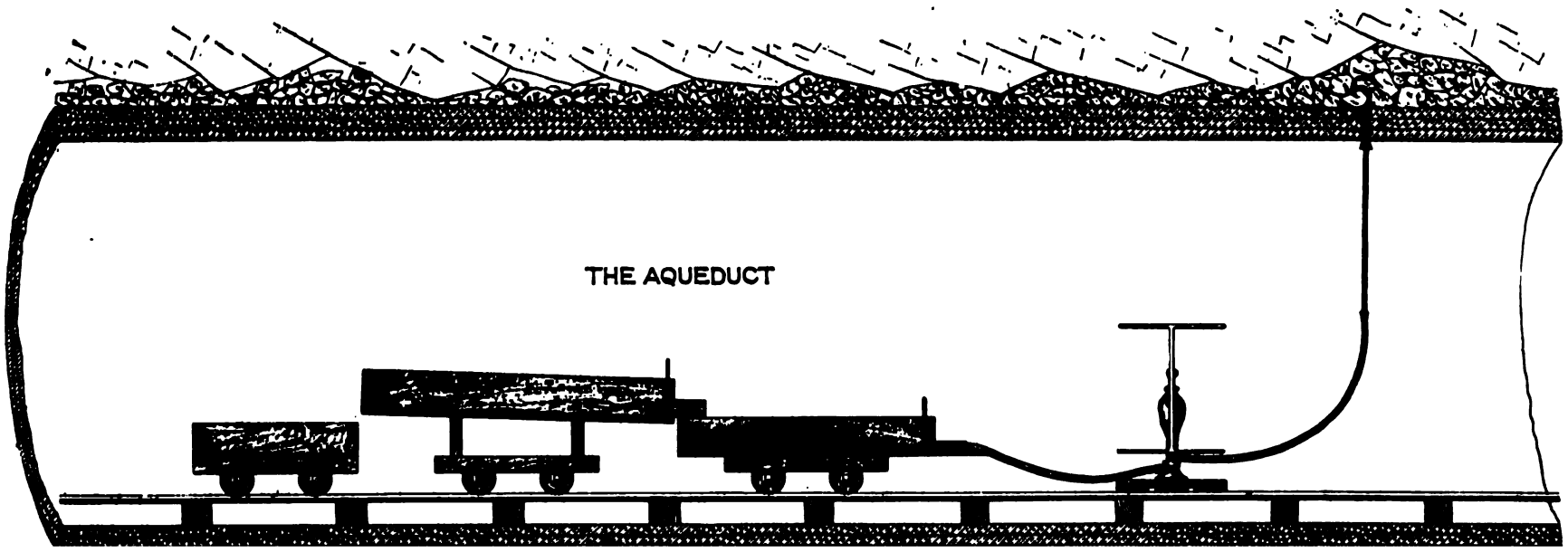
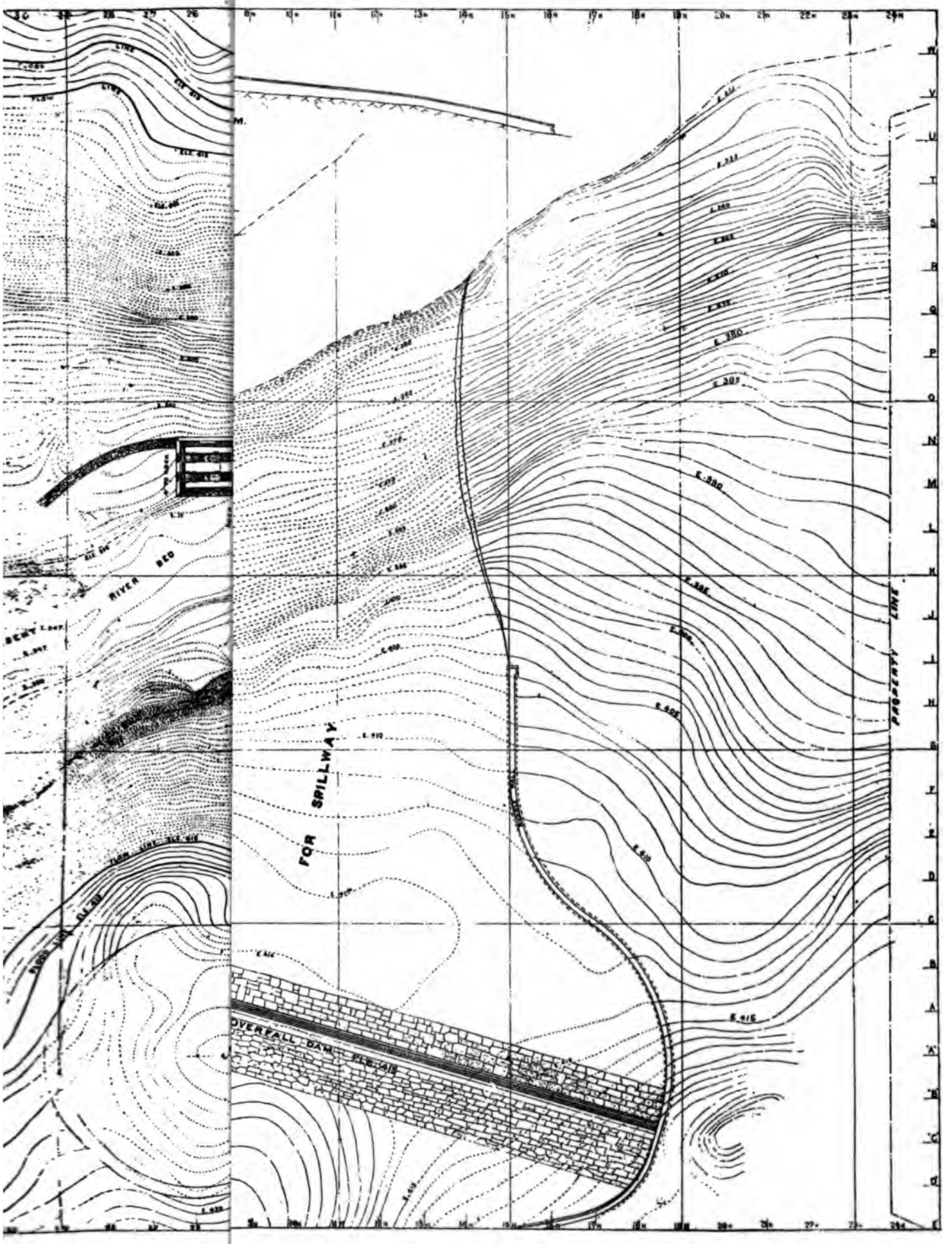
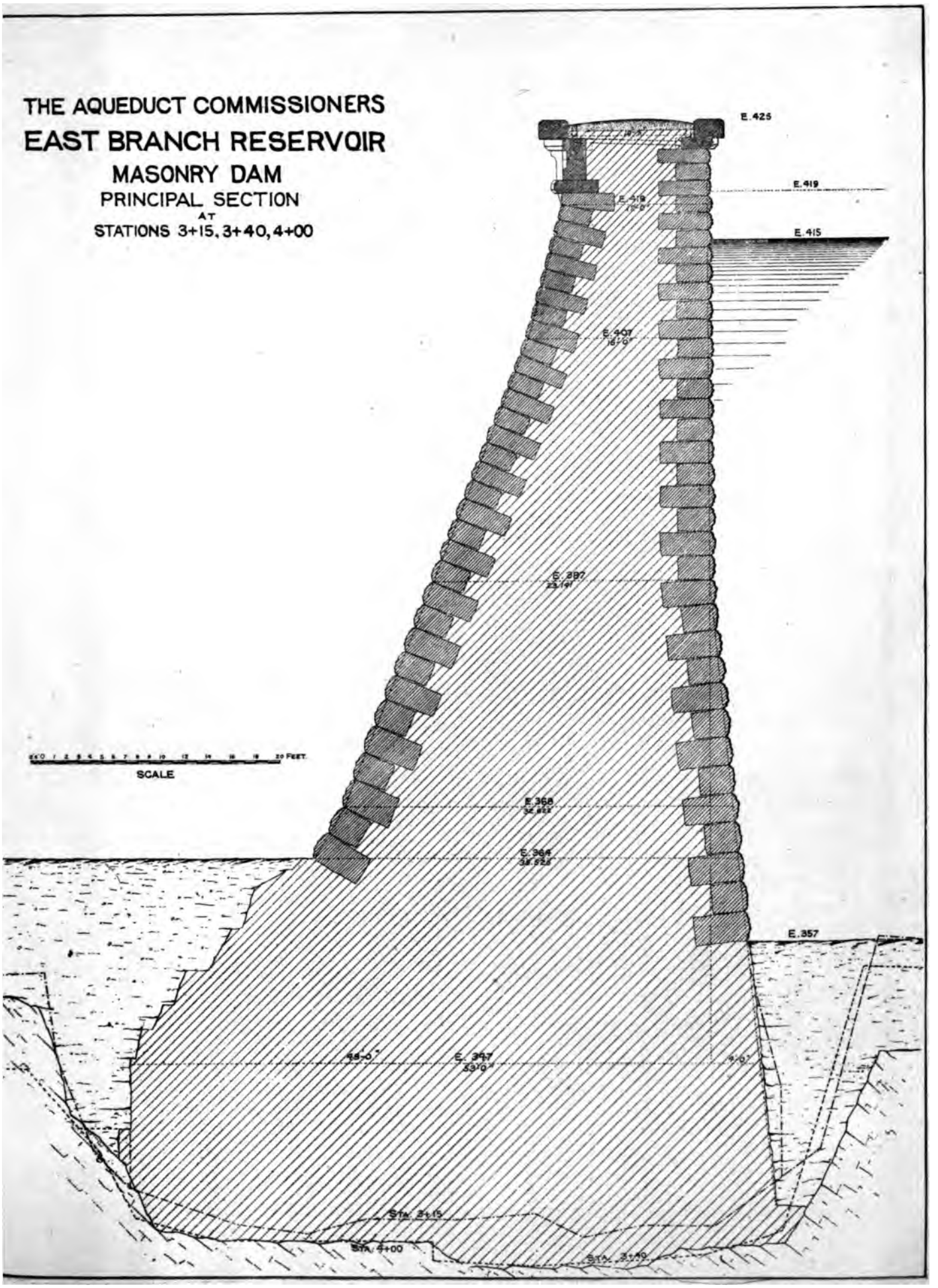


PLATE 112.




THE AQUEDUCT COMMISSIONERS
EAST BRANCH RESERVOIR
MASONRY DAM
PRINCIPAL SECTION
AT
STATIONS 3+15, 3+40, 4+00
E. 425
E. 419
E. 415
E. 407
E. 397
E. 368
E. 357
SCALE
Sta. 3+15
Sta. 4+00
Sta. 3+40

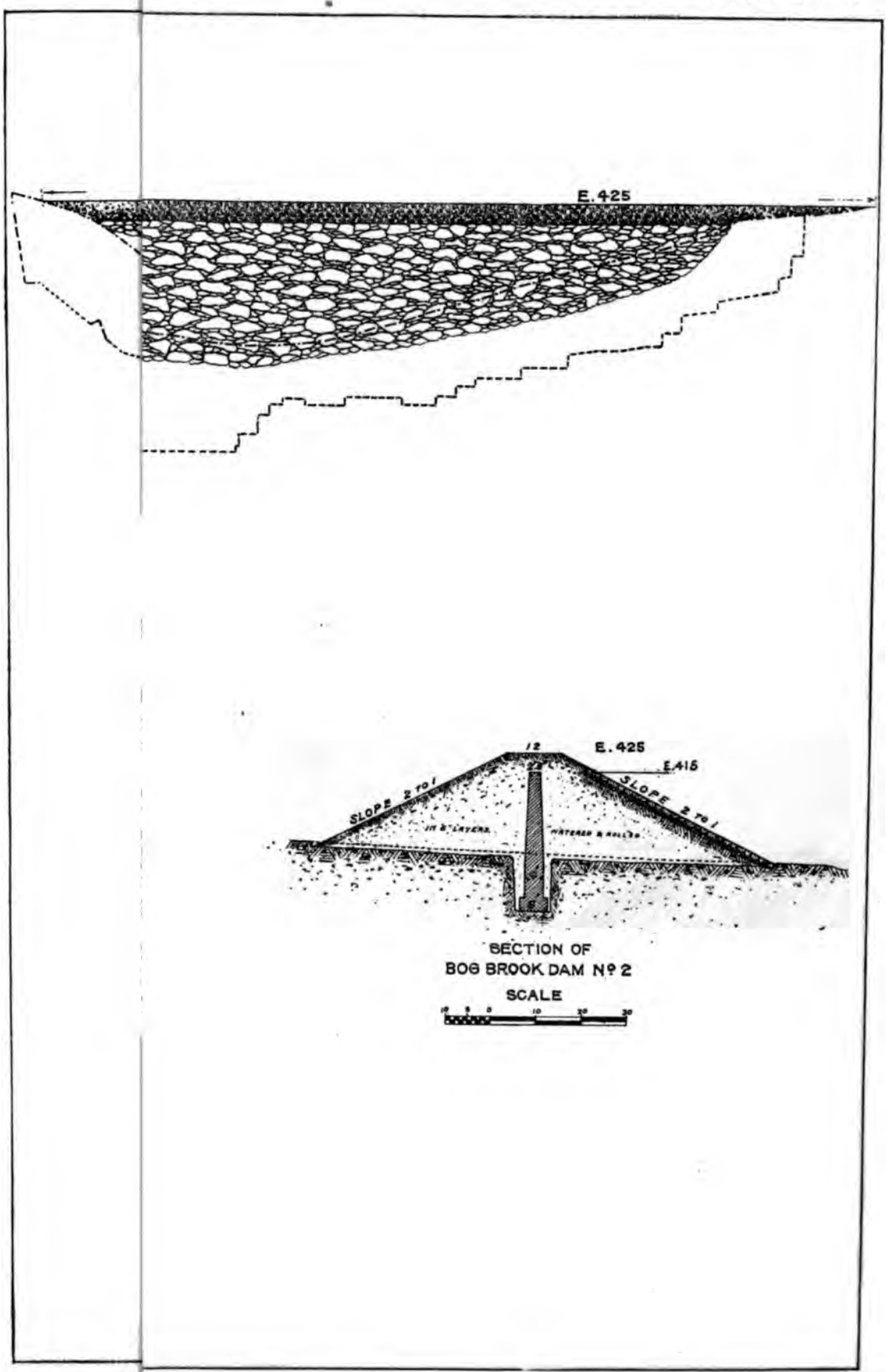
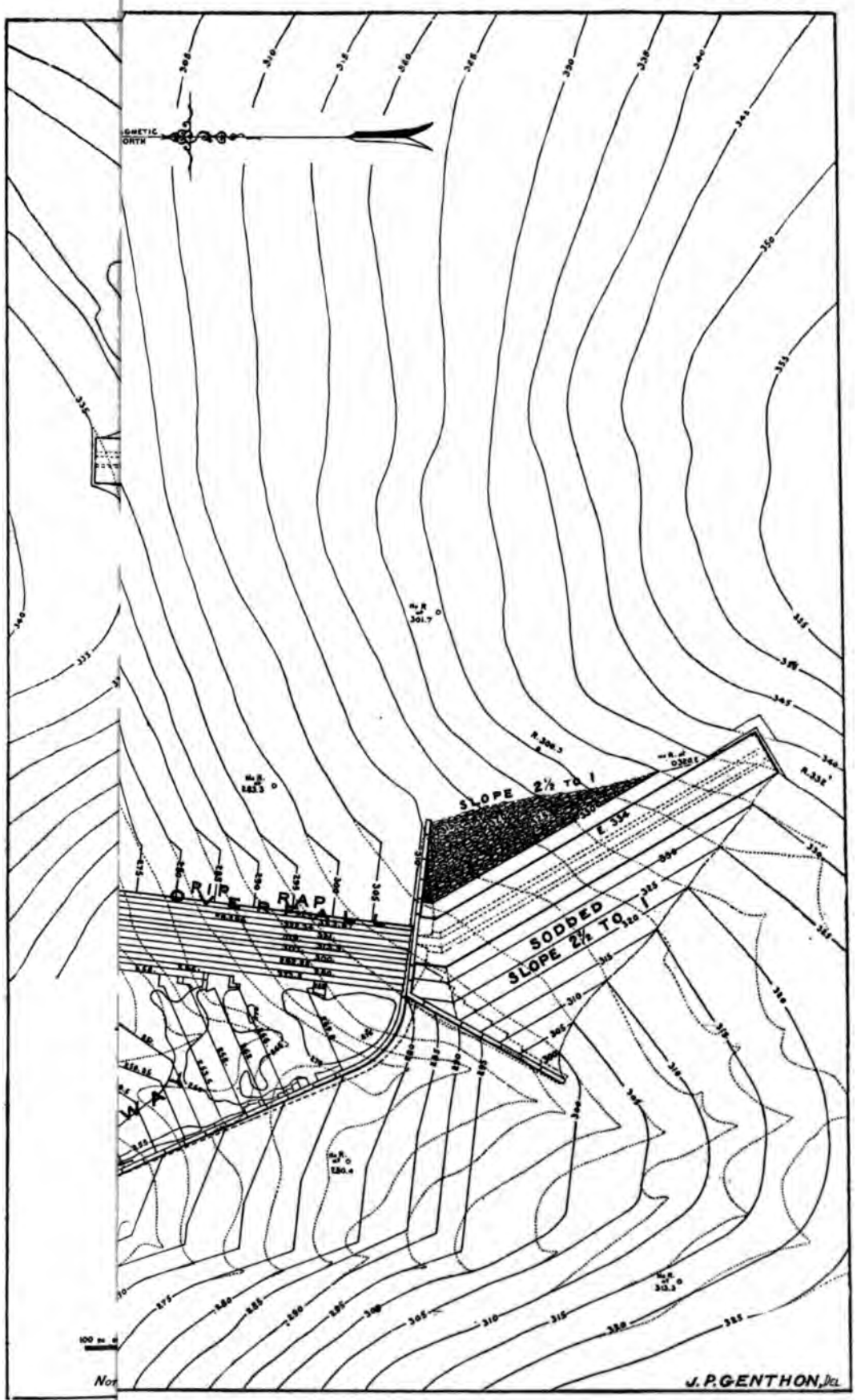

E.425
12
E.425
E.415
SLOPE 2 TO 1
SLOPE 2 TO 1
SECTION OF
BOG BROOK DAM Nº 2
SCALE

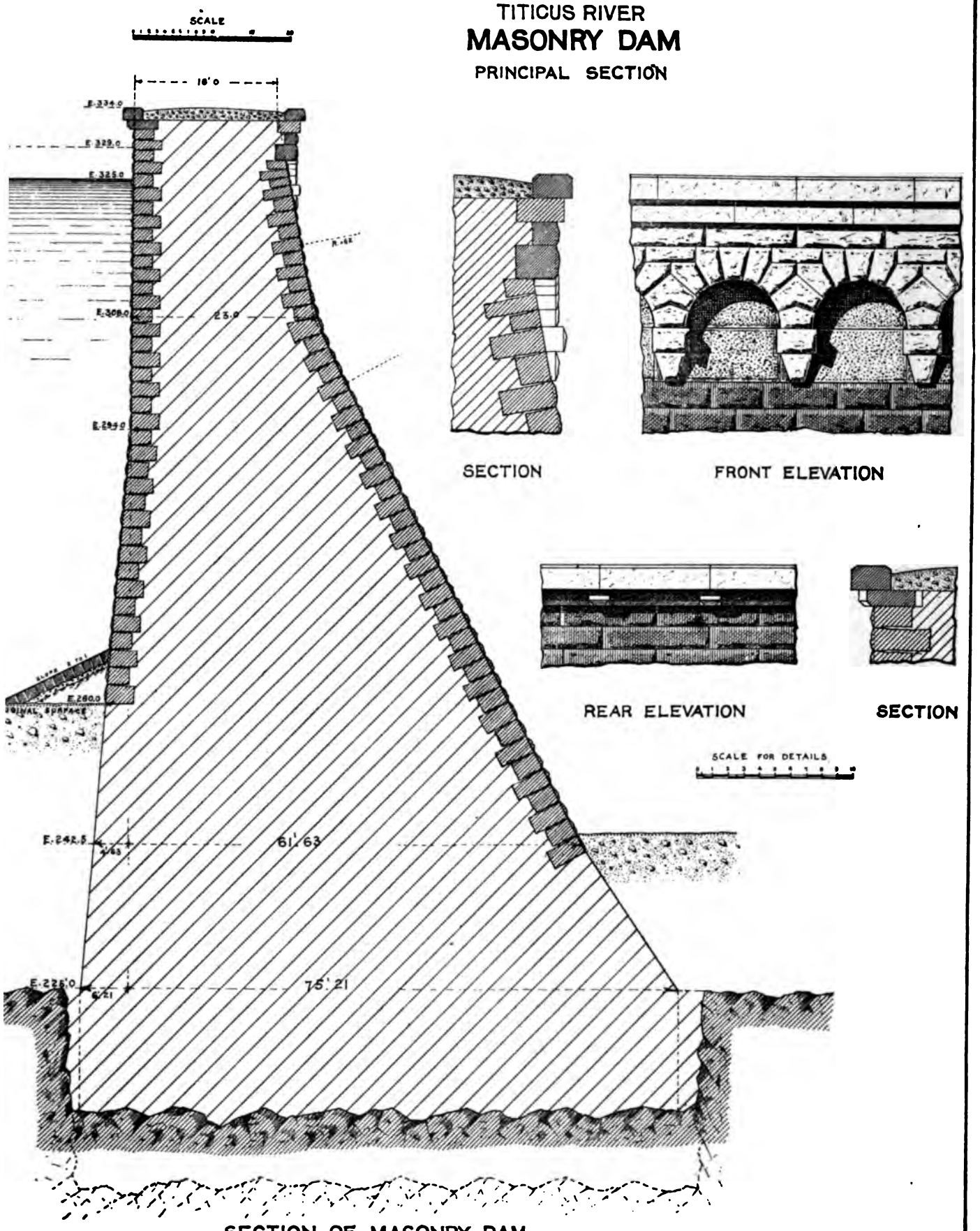
PLATE 117.



THE AQUEDUCT COMMISSIONERS
RESERVOIR M
ON
TITICUS RIVER

MASONRY DAM

PRINCIPAL SECTION



SECTION OF MASONRY DAM

PLATE 120.

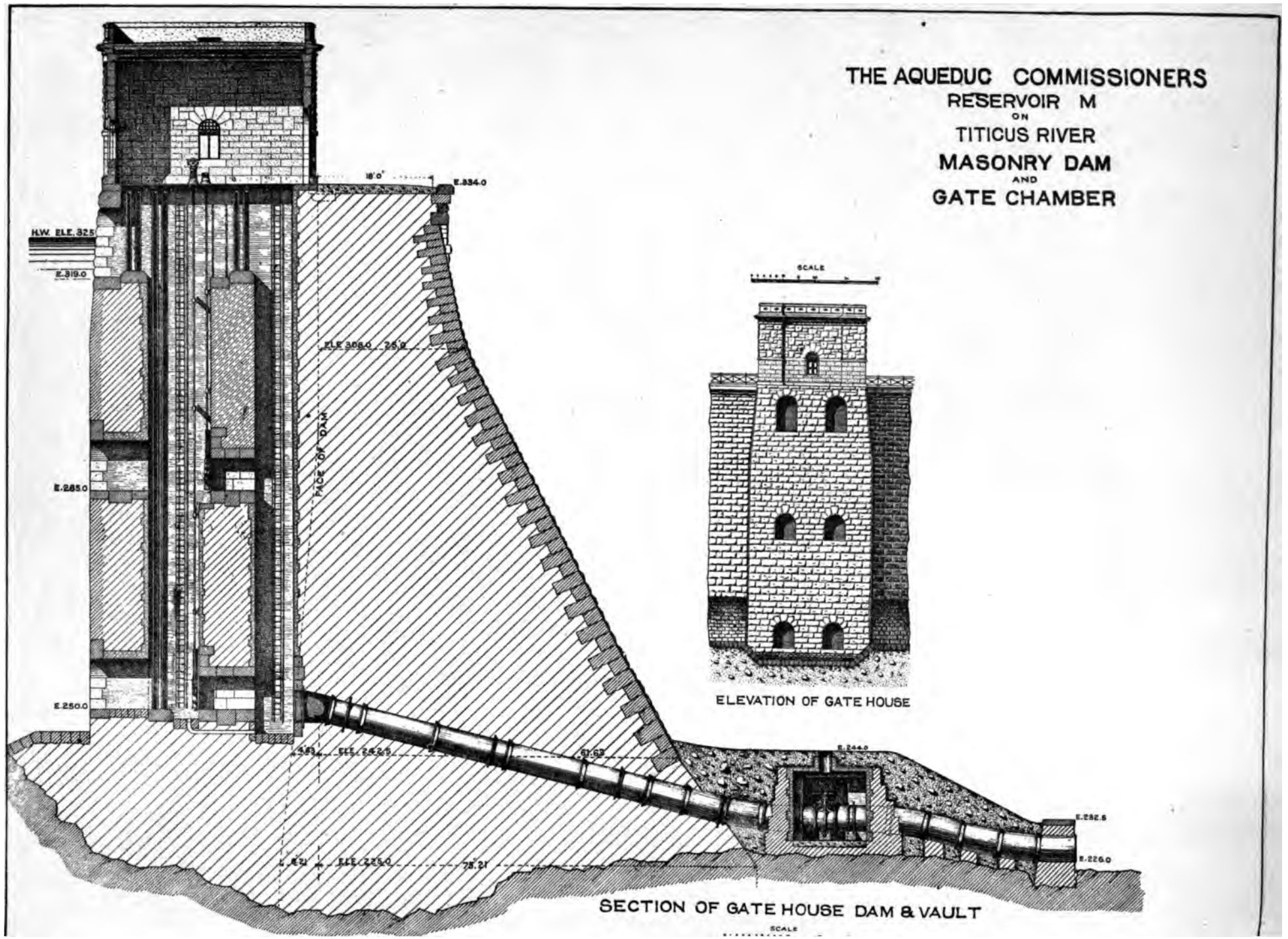
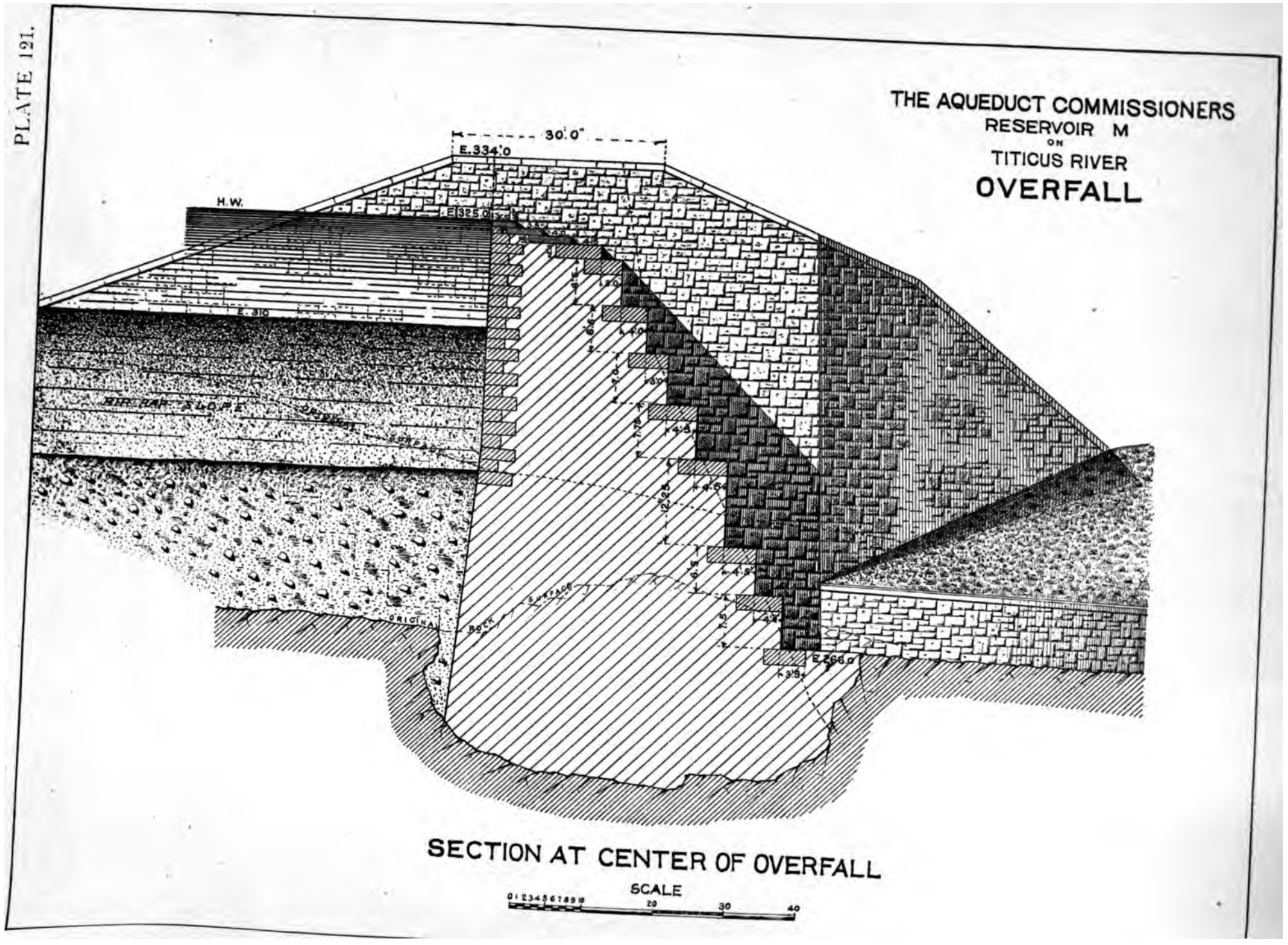

THE AQUEDUC COMMISSIONERS
RESERVOIR M
ON
TITICUS RIVER
MASONRY DAM
AND
GATE CHAMBER
SCALE
ELEVATION OF GATE HOUSE
SECTION OF GATE HOUSE DAM & VAULT
H.W. ELE. 325
E.319.0
E.285.0
E.250.0
E.334.0
18'0"
ELE 308.0
25'0"
FACE OF DAM
ELE. 242.5
ELE. 225.0
75.21
E.244.0
E.232.5
E.226.0
SCALE

PLATE 121.


THE AQUEDUCT COMMISSIONERS
RESERVOIR M
ON
TITICUS RIVER
OVERFALL
30.0"
E.334.0
H.W.
E.325.0
E.310
RIP RAP SLOPE
ORIGINAL
ROCK
SURFACE
E.266.0
SECTION AT CENTER OF OVERFALL
SCALE
0 1 2 3 4 5 6 7 8 9 10
20
30
40

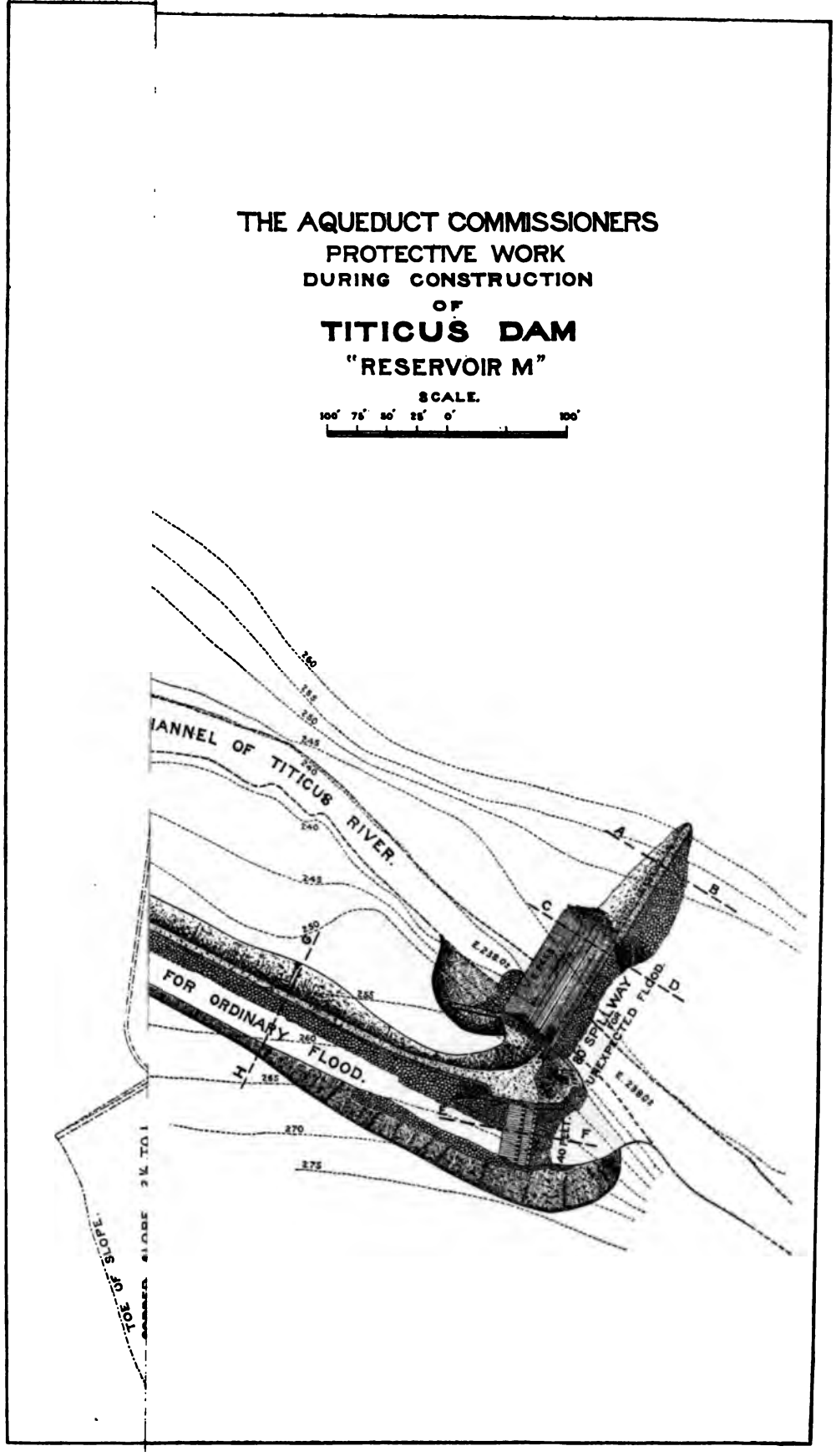
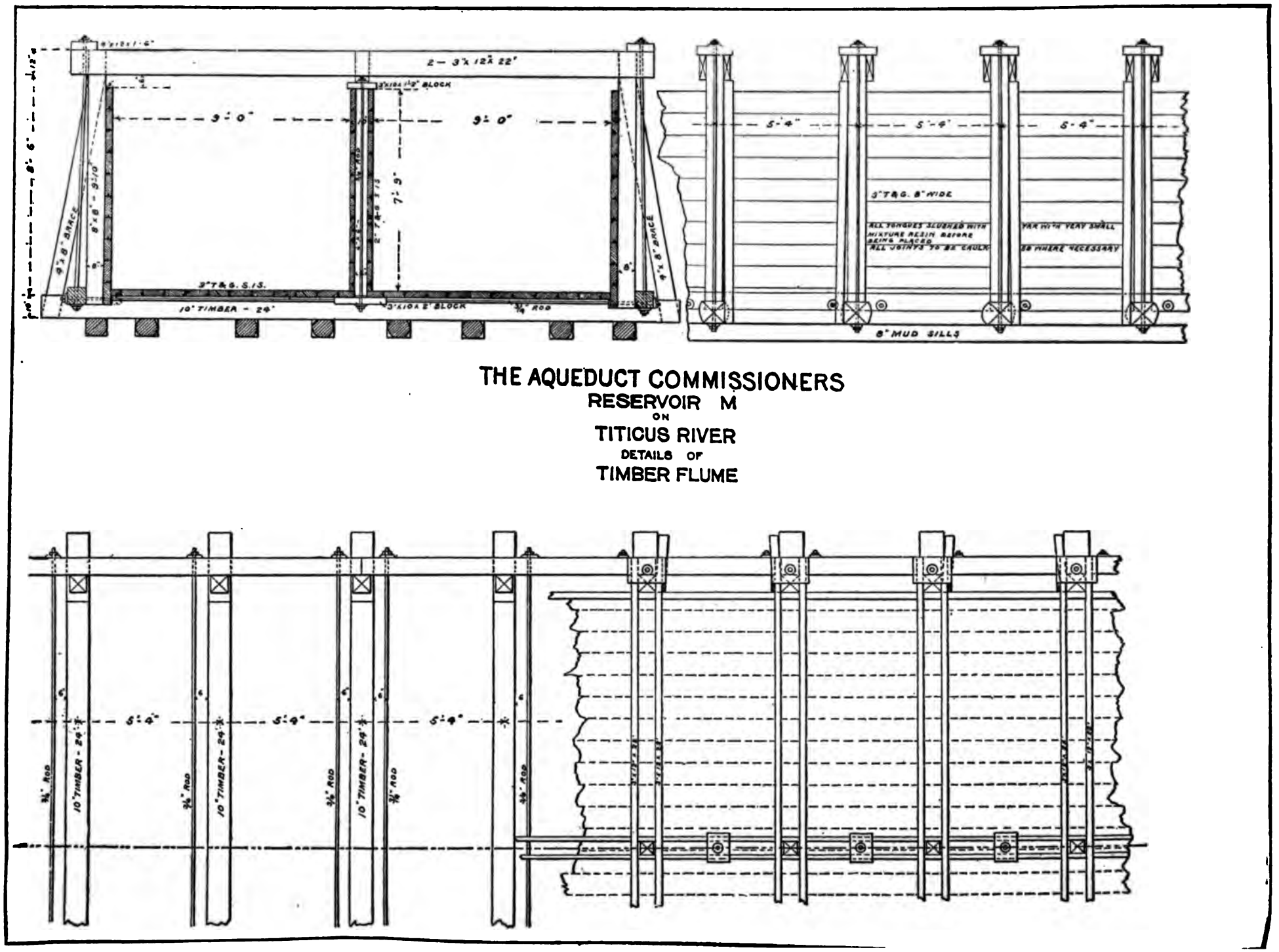

THE AQUEDUCT COMMISSIONERS
PROTECTIVE WORK
DURING CONSTRUCTION
OF
TITICUS DAM
"RESERVOIR M"
SCALE.
100' 75' 50' 25' 0' 100'
CHANNEL OF TITICUS RIVER.
FOR ORDINARY FLOOD.
80' SPILLWAY
FOR UNEXPECTED FLOOD.
TOE OF SLOPE.
A
B
C
D
E
F
G
H
250
255
260
265
270
275
280
285
290
295
300
305
310

PLATE 123.



THE AQUEDUCT COMMISSIONERS
RESERVOIR M
ON
TITICUS RIVER
DETAILS OF
TIMBER FLUME

PLATE 124.

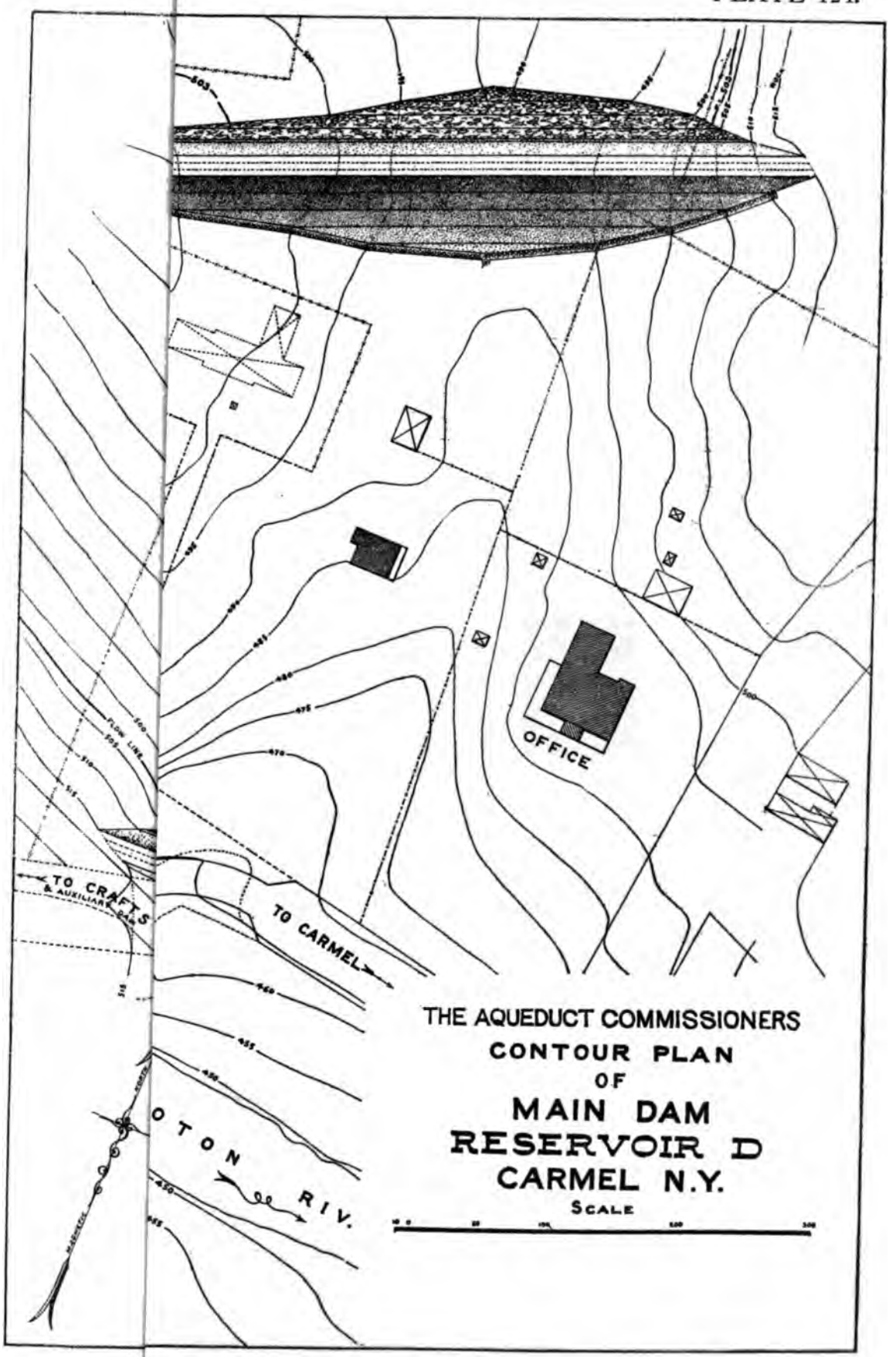
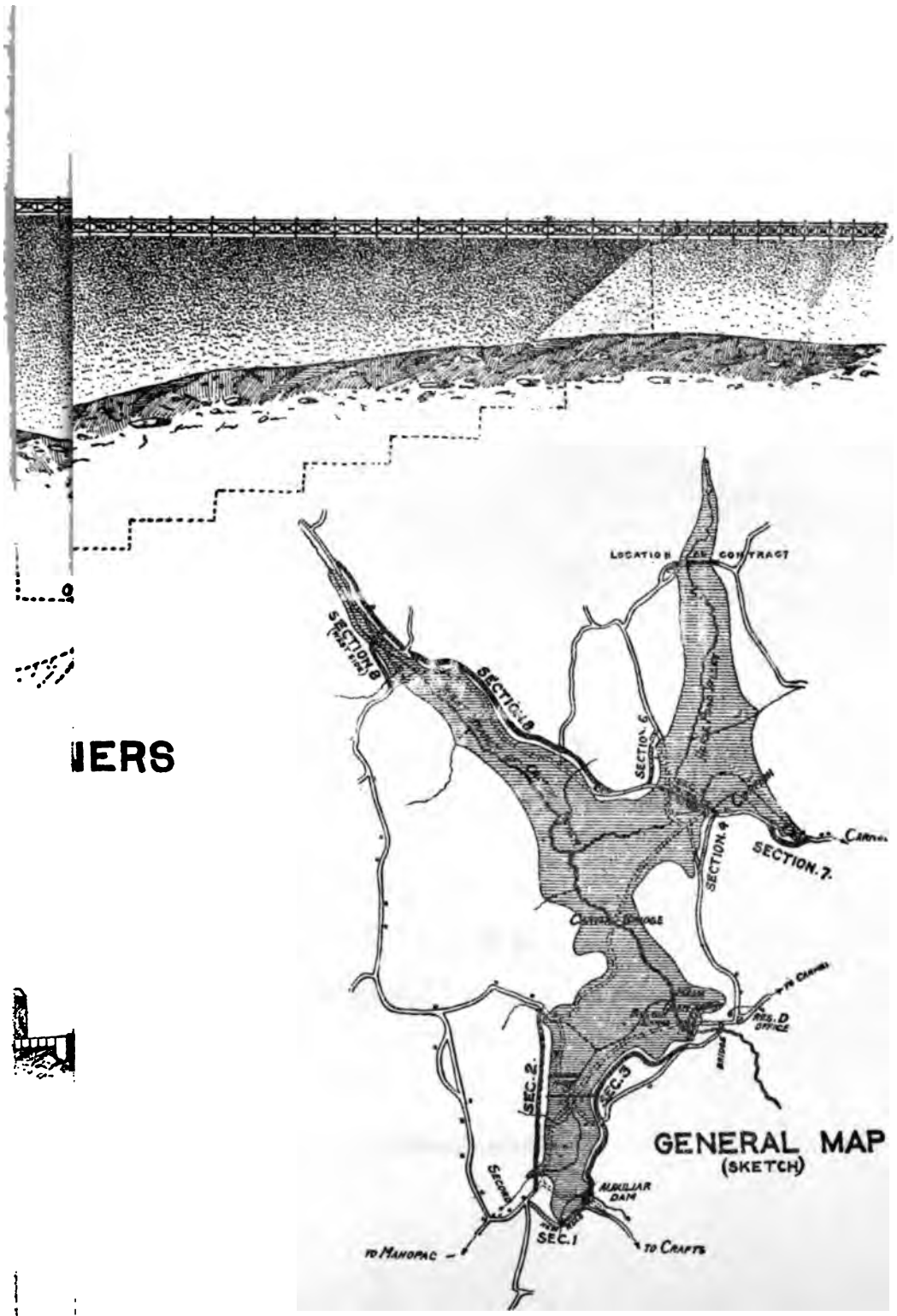

THE AQUEDUCT COMMISSIONERS
CONTOUR PLAN
OF
MAIN DAM
RESERVOIR D
CARMEL N.Y.
SCALE
OFFICE
TO CARMEL
TO CRAFTS
& AUXILIARY DAM
FLOW LINE
OTON RIV.

PLATE 125.



IERS

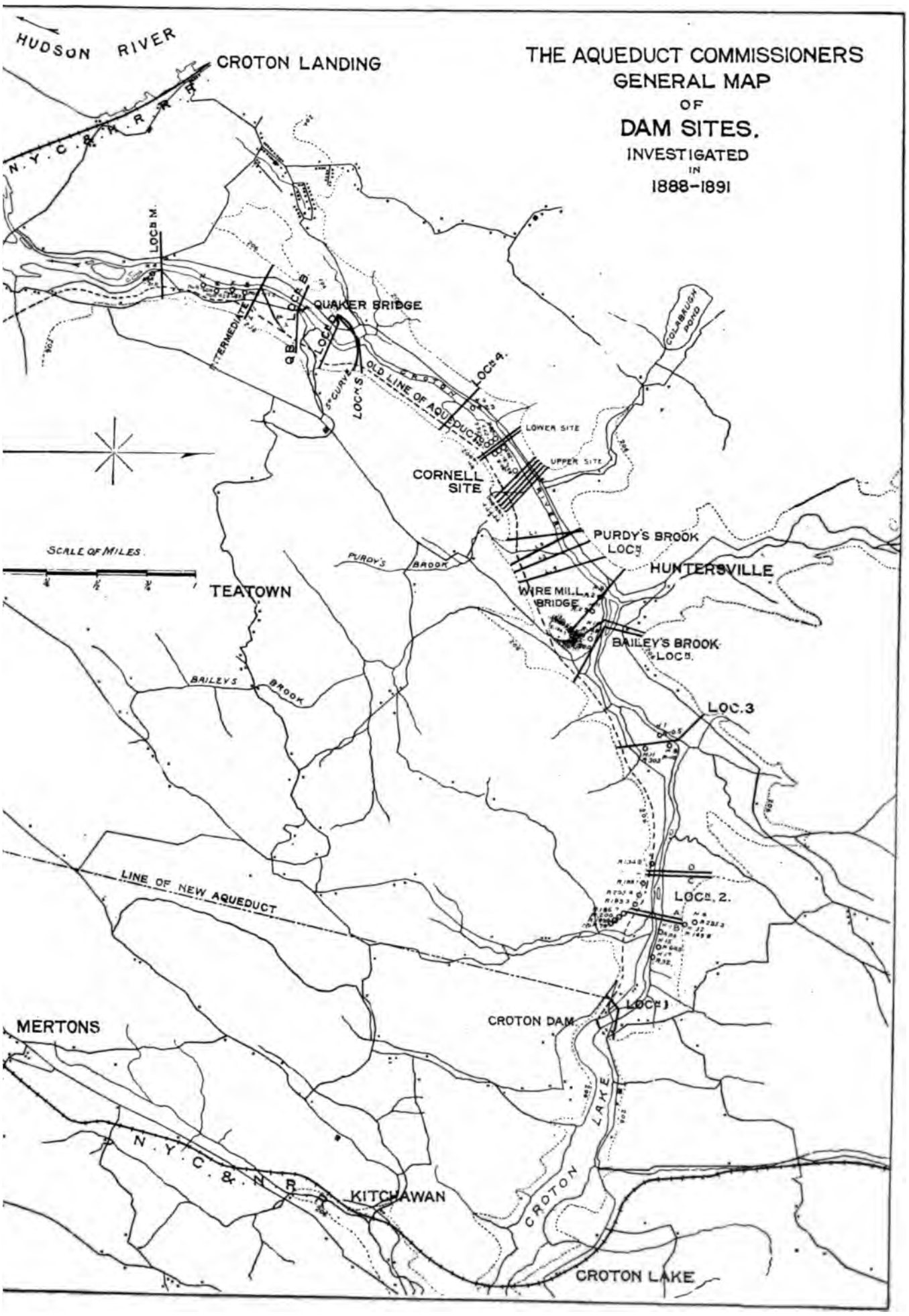
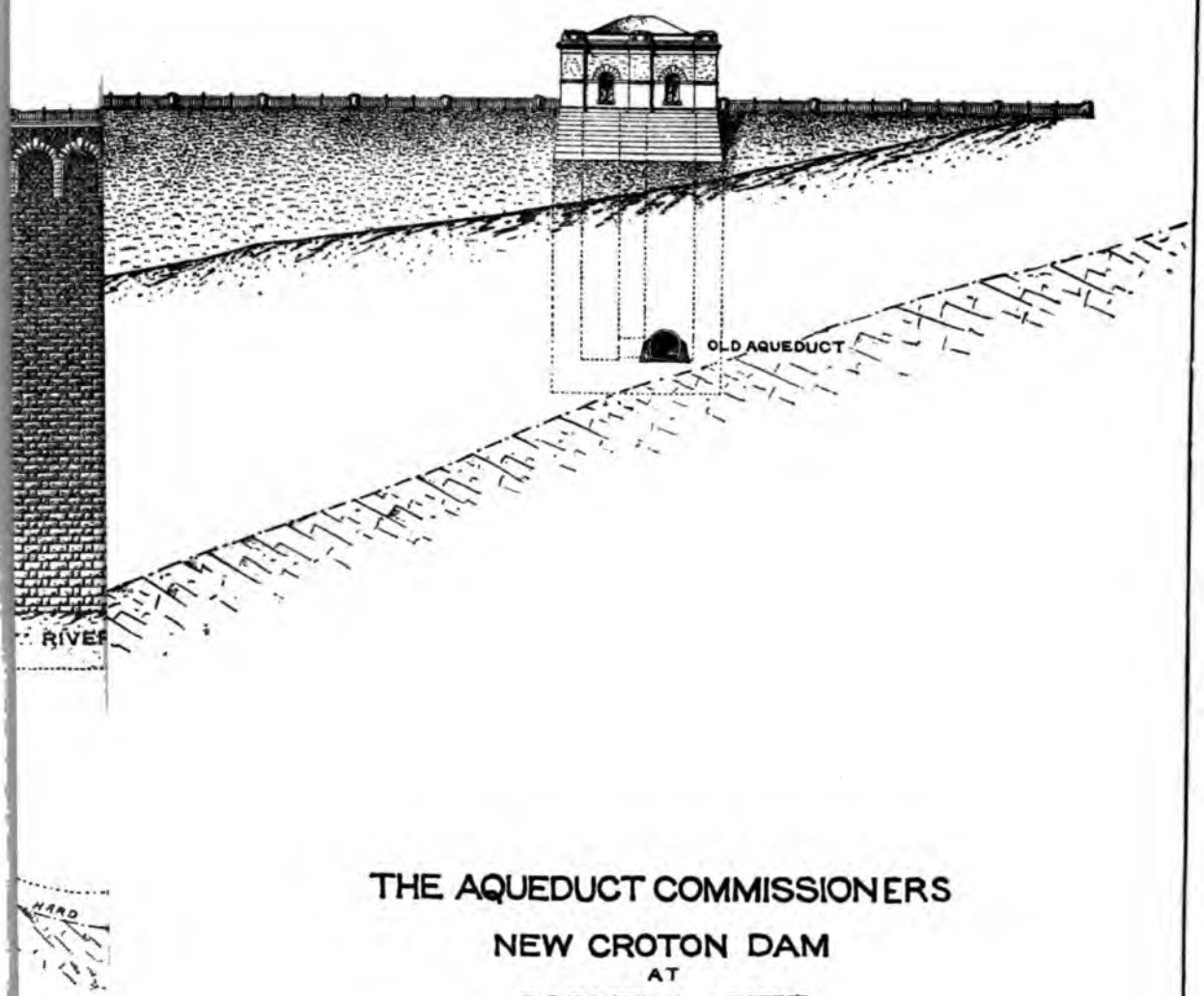

THE AQUEDUCT COMMISSIONERS
GENERAL MAP
OF
DAM SITES.
INVESTIGATED
IN
1888-1891
HUDSON RIVER
CROTON LANDING
N.Y.C.&H.R.R.R.
LOC.B M.
TERMEDIATE
QUAKER BRIDGE
LOC.B
LOC.9
S CURVE
LOC.S
OLD LINE OF AQUEDUCT
LOC.4
LOWER SITE
UPPER SITE
CORNELL SITE
COLABAUGH POND
PURDY'S BROOK LOC.
HUNTERSVILLE
WIRE MILL BRIDGE
BAILEY'S BROOK LOC.
LOC.3
LOC.2.
LOC.1
CROTON DAM
SCALE OF MILES
TEATOWN
PURDY'S BROOK
BAILEY'S BROOK
LINE OF NEW AQUEDUCT
MERTONS
N.Y.C.&N.R.R.
KITCHAWAN
CROTON LAKE
CROTON LAKE

PLATE 128.



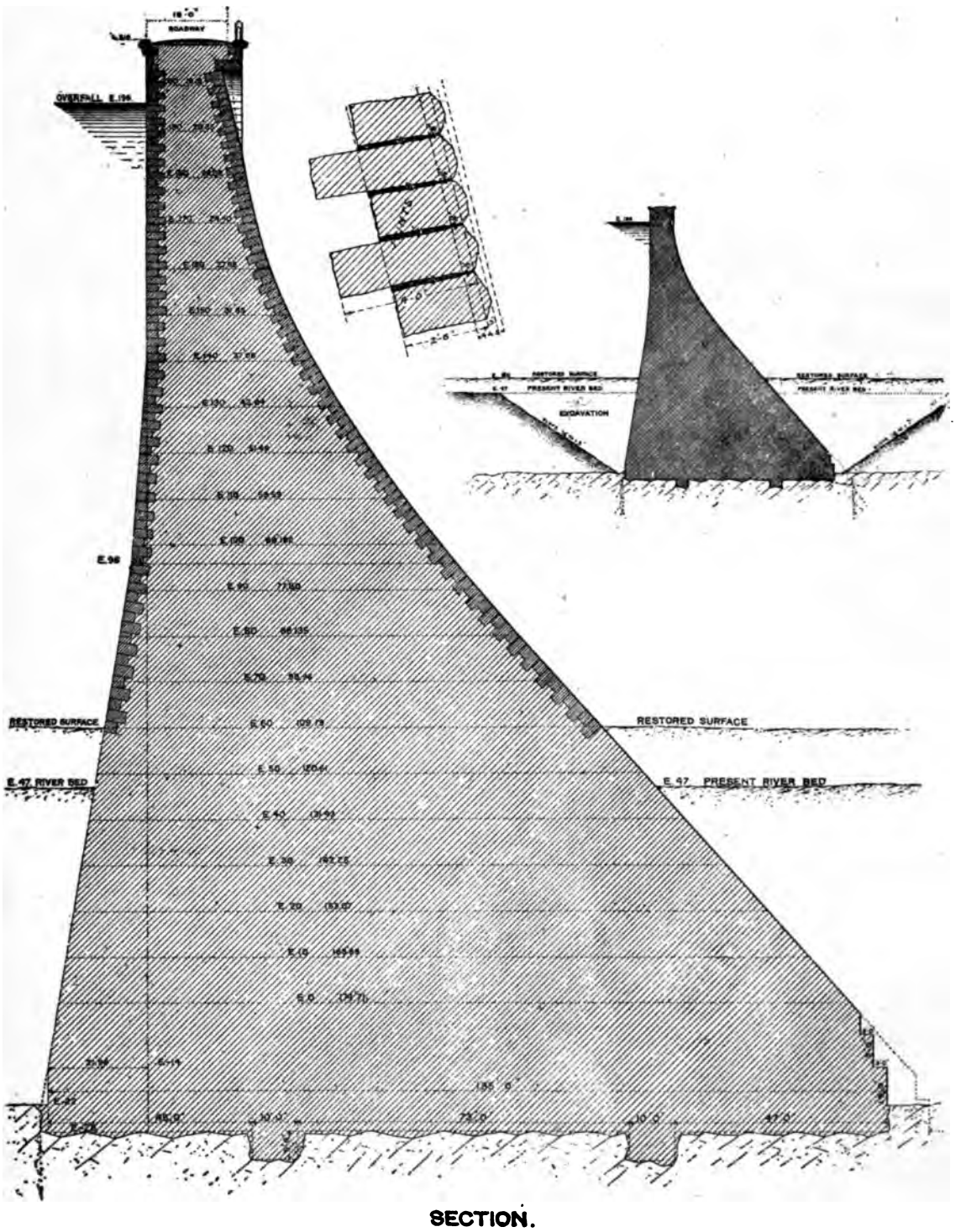
THE AQUEDUCT COMMISSIONERS

NEW CROTON DAM

AT

CORNELL SITE

THE AQUEDUCT COMMISSIONERS
NEW CROTON DAM

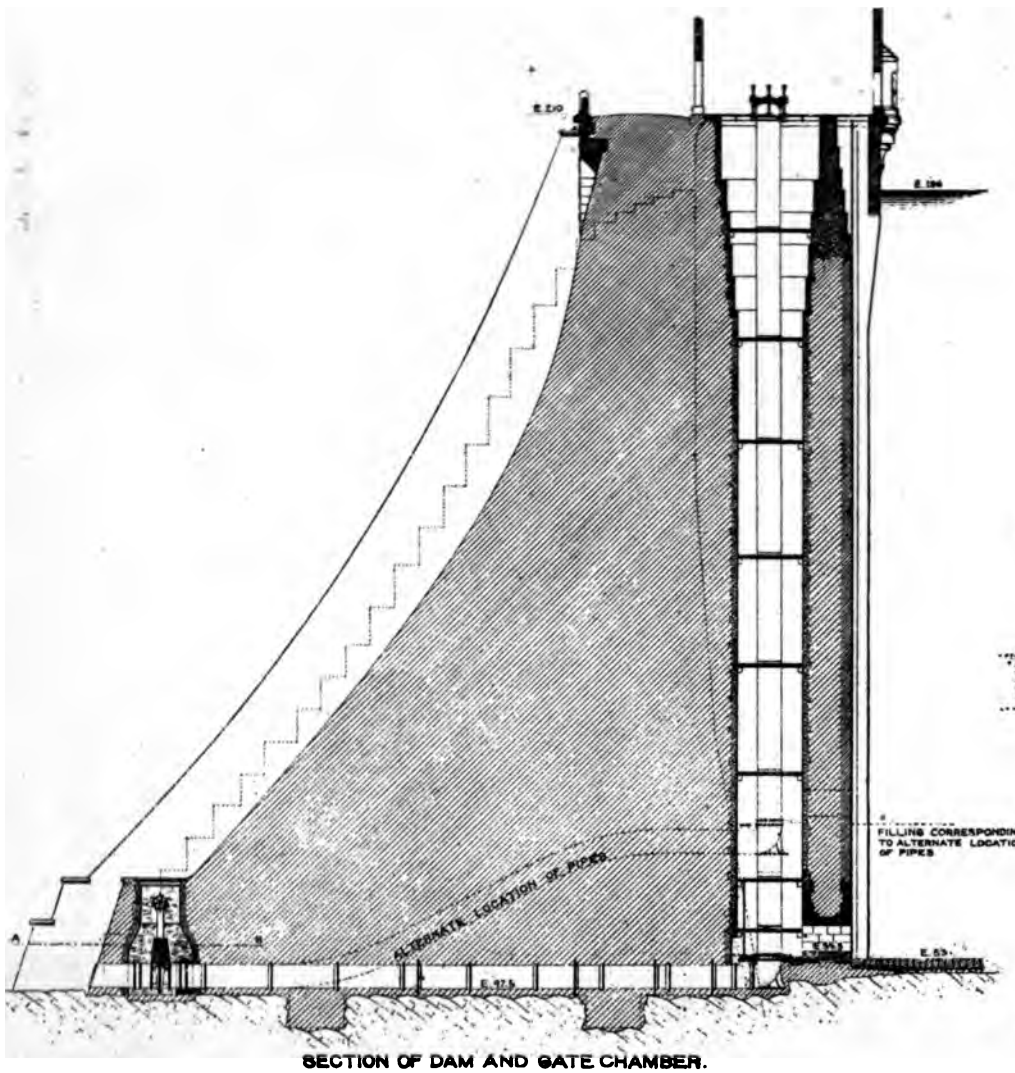


SECTION.

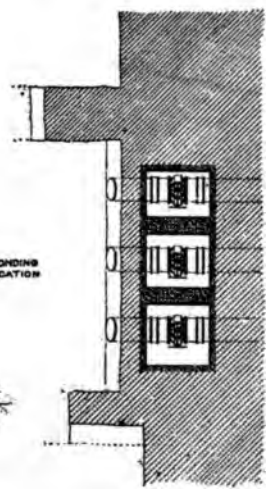
PLATE 180.

THE AQUEDUCT COMMISSIONERS

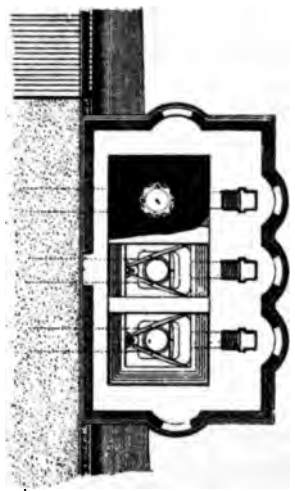
NEW CROTON DAM AT CORNELL SITE



SECTION OF DAM AND GATE CHAMBER.



SECTION A.B.



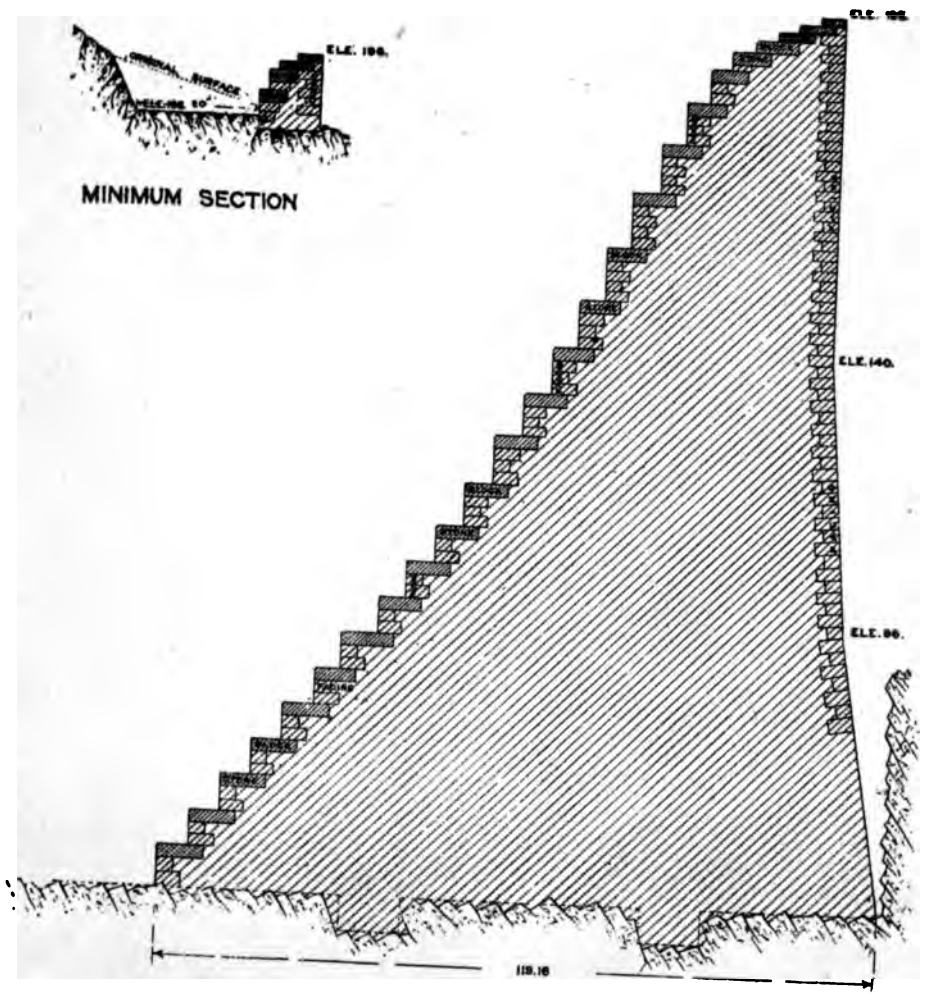
PLAN OF GATE HOUSE.

PLATE 131.

THE AQUEDUCT COMMISSIONERS
NEW CROTON DAM.
AT
CORNELL SITE

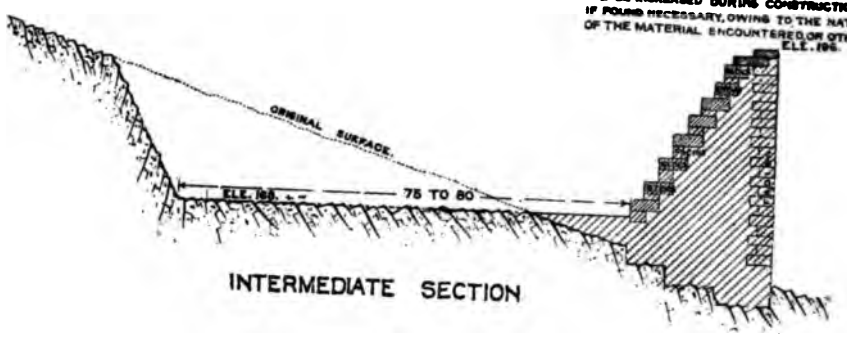
SCALE

MINIMUM SECTION

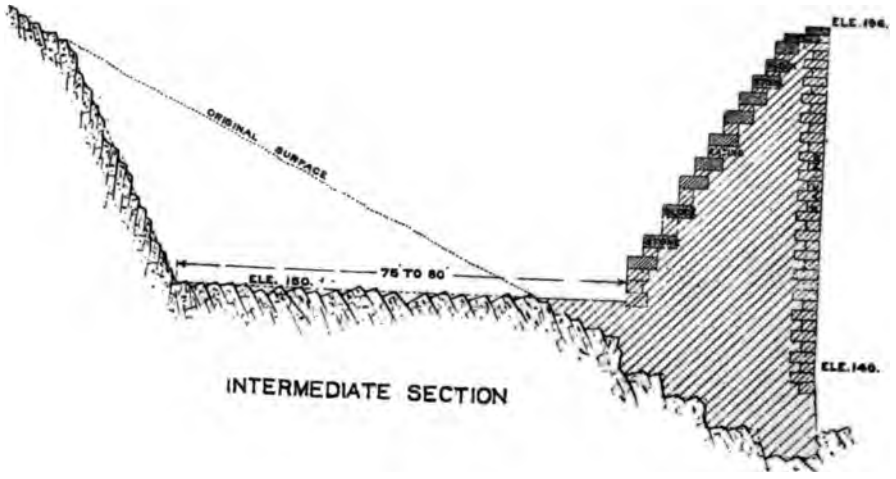


MAXIMUM SECTION OF OVERFALL

NOTE. THE WIDTHS OF THE SPILLWAY CHANNEL MAY BE INCREASED DURING CONSTRUCTION, IF FOUND NECESSARY, OWING TO THE NATURE OF THE MATERIAL ENCOUNTERED, OR OTHERWISE.



INTERMEDIATE SECTION



INTERMEDIATE SECTION

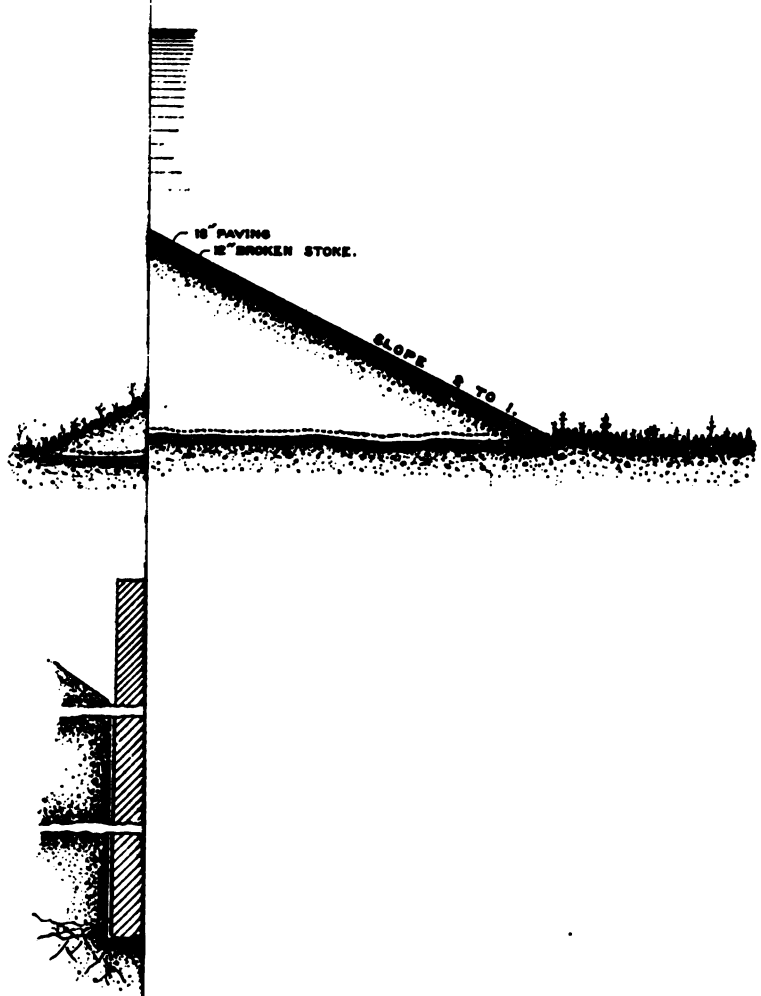
THE AQUEDUCT COMMISSIONERS

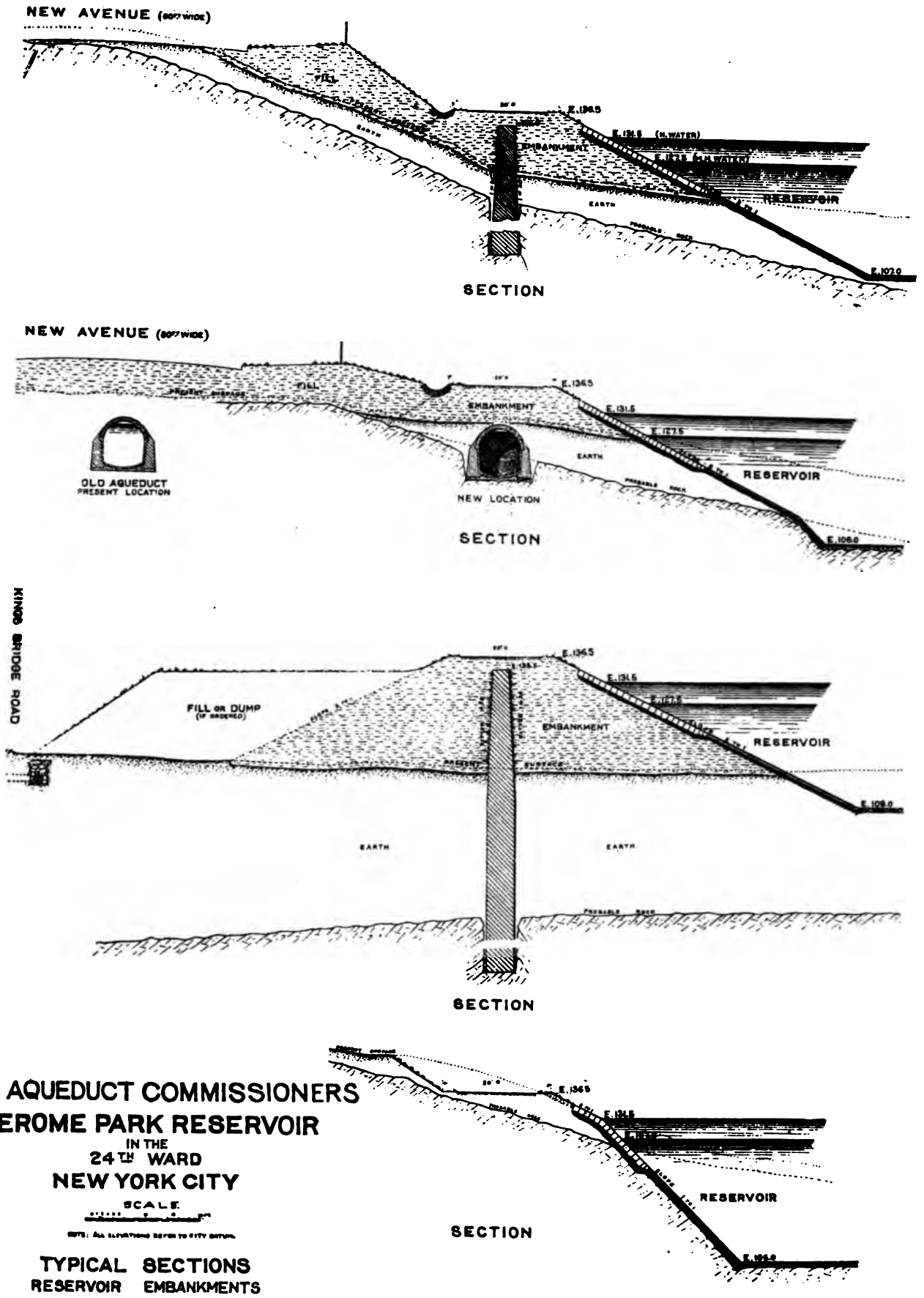
NEW CROTON DAM.

AT

CORNELL SITE

SCALE





THE AQUEDUCT COMMISSIONERS
JEROME PARK RESERVOIR
IN THE
24TH WARD
NEW YORK CITY

SCALE

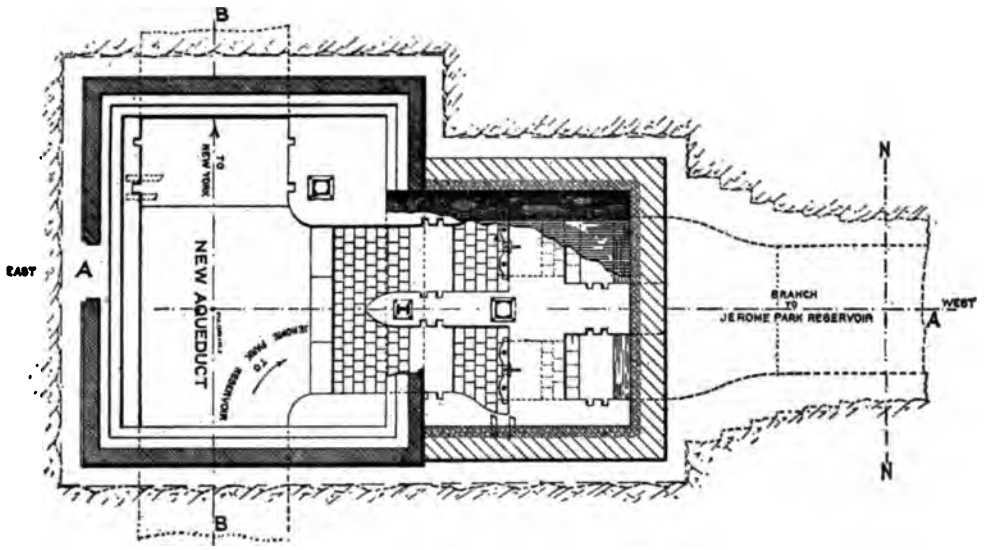
NOTE: ALL ELEVATIONS REFER TO CITY DATUM.

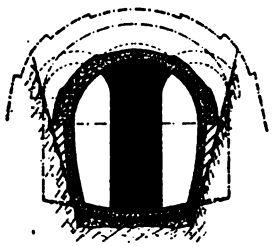
TYPICAL SECTIONS
RESERVOIR EMBANKMENTS

THE AQUEDUCT COMMISSIONERS
JEROME PARK RESERVOIR
IN THE
24TH WARD
NEW YORK CITY

SCALE.

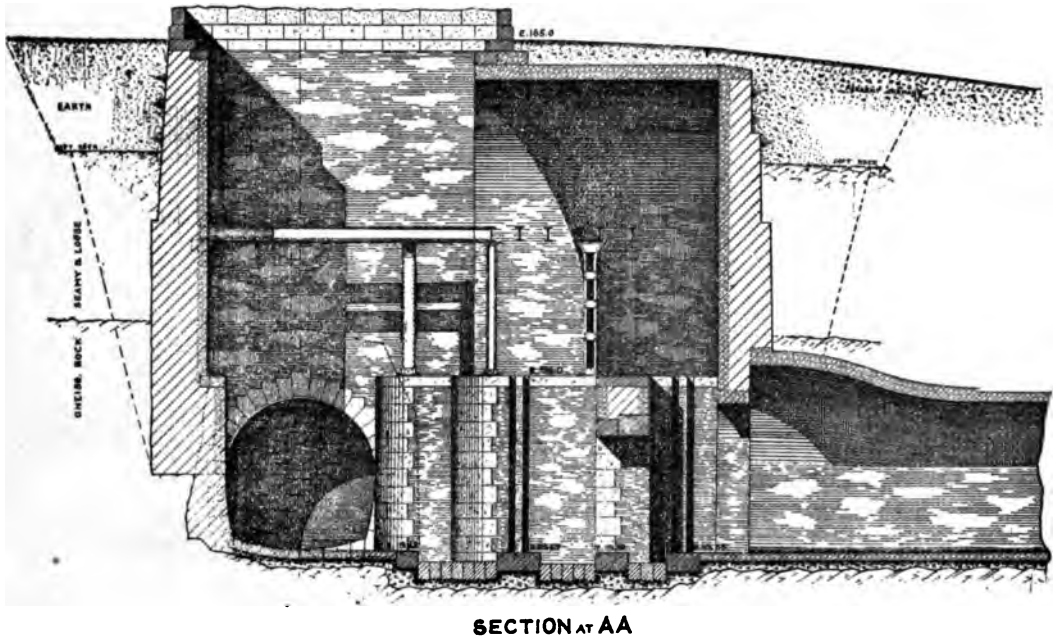
NOTE: ALL ELEVATIONS REFER TO CITY DATUM.



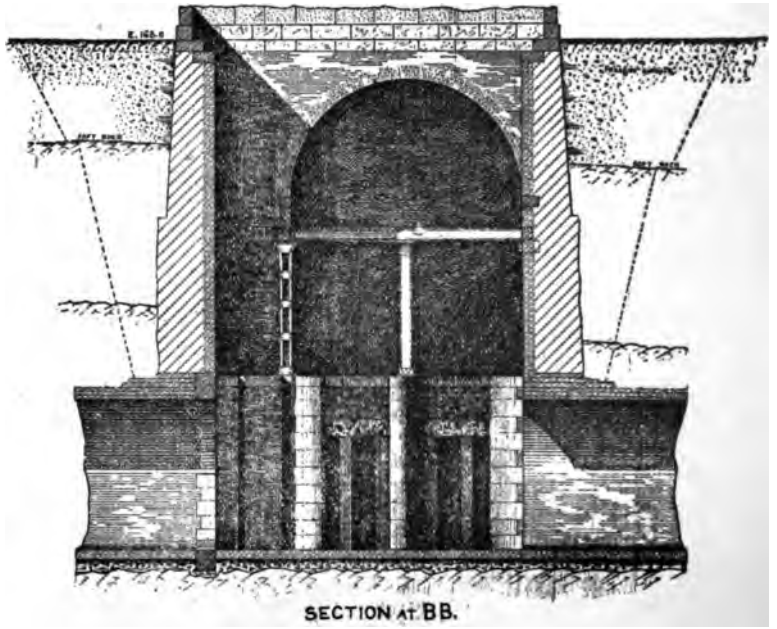


SECTION AT NN. (LOOKING EAST)

GATE HOUSE No. 1



SECTION AT AA

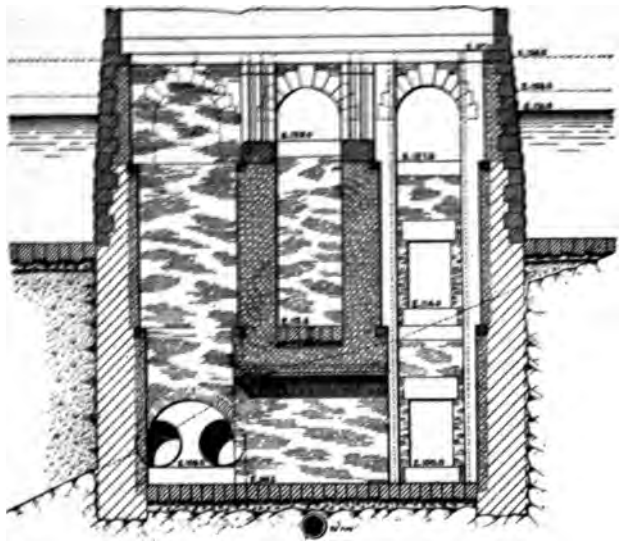


SECTION AT BB.

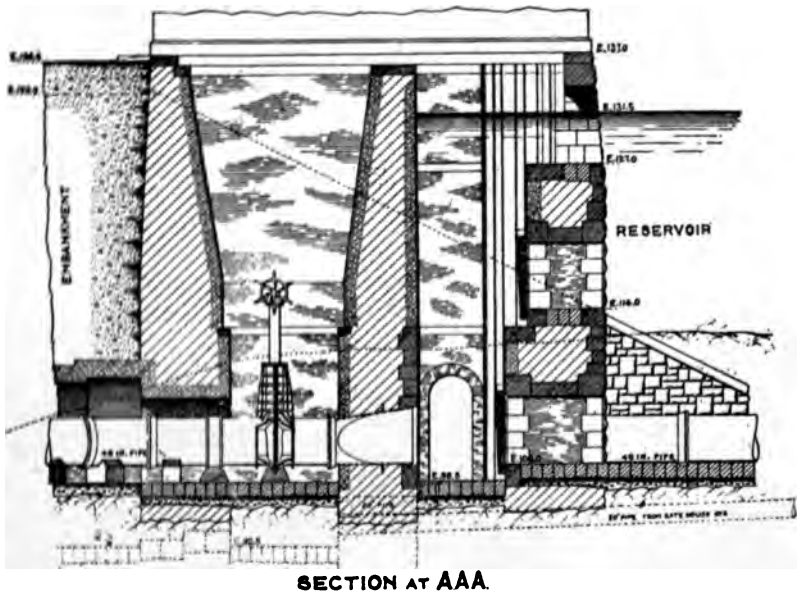
PLATE 186.

THE AQUEDUCT COMMISSIONERS
JEROME PARK RESERVOIR
IN THE
24TH WARD
NEW YORK CITY
SCALE

GATE HOUSE Nº2



SECTION AT C.C.



SECTION AT AAA.

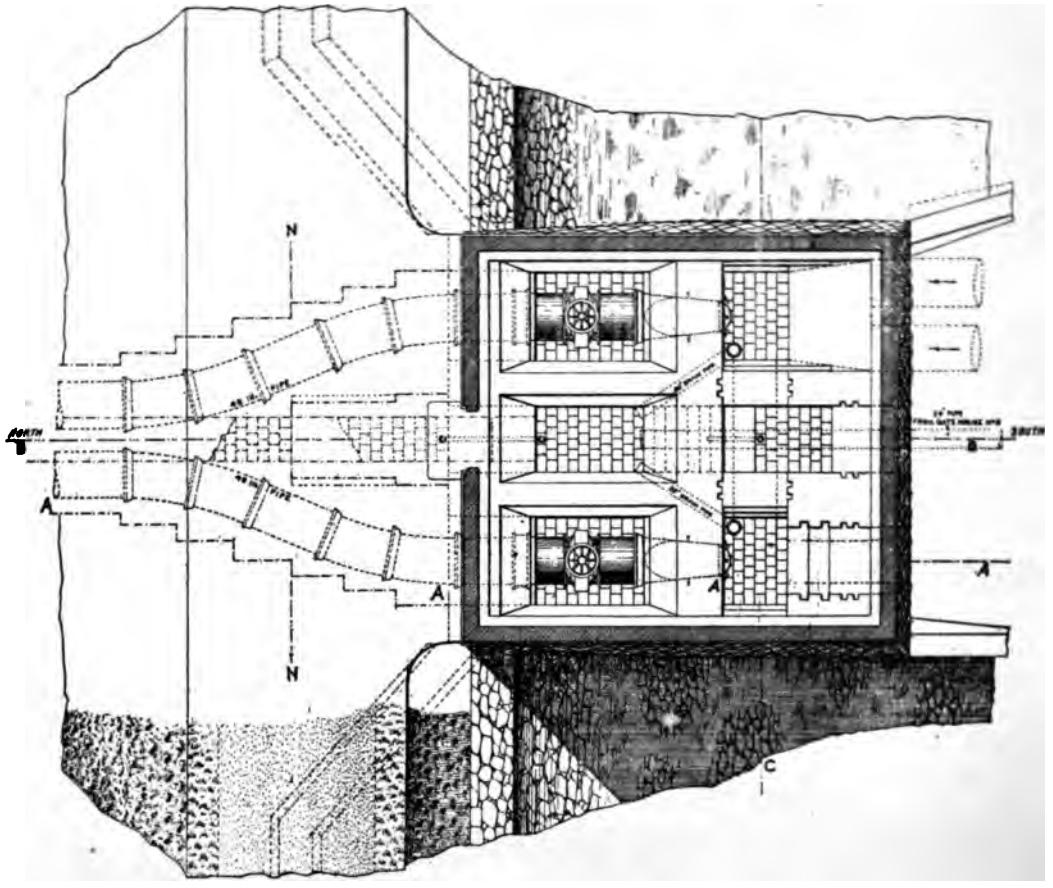


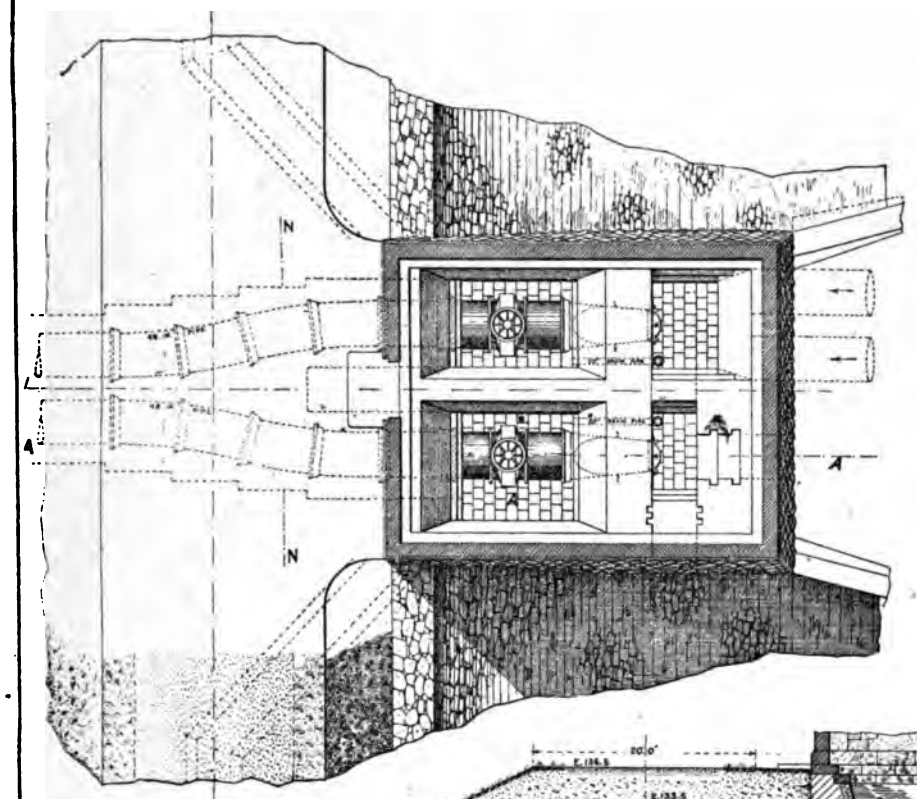
PLATE 137.

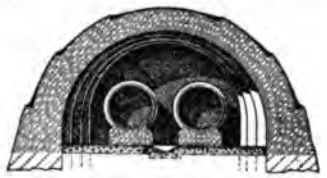
THE AQUEDUCT COMMISSIONERS
JEROME PARK RESERVOIR
IN THE
24TH WARD
NEW YORK CITY

SCALE

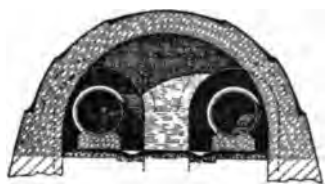
NOTE: ALL ELEVATIONS REFER TO CITY DATUM.

GATE HOUSES Nº3 & Nº4

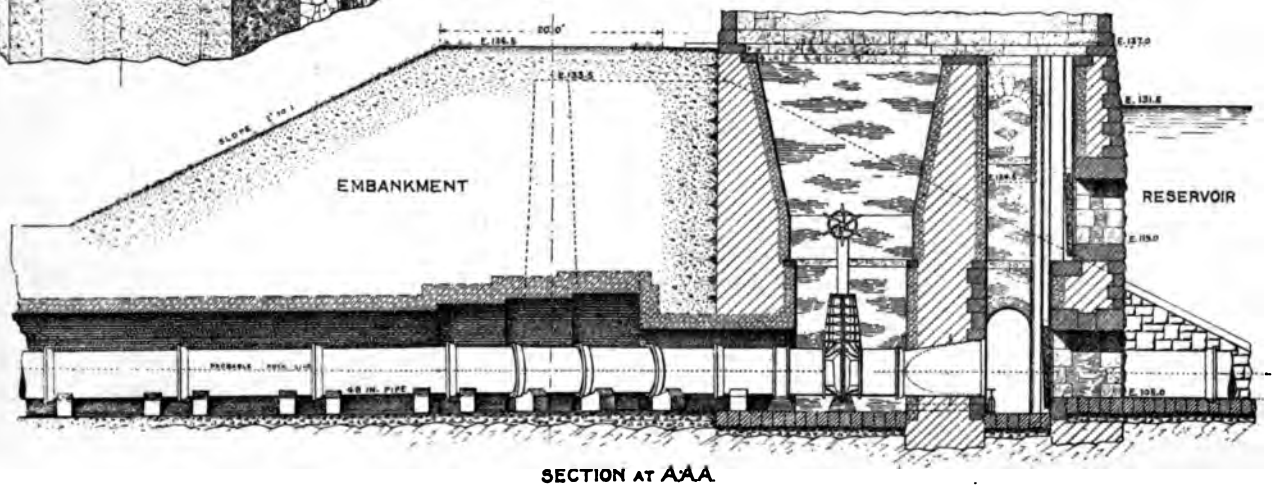




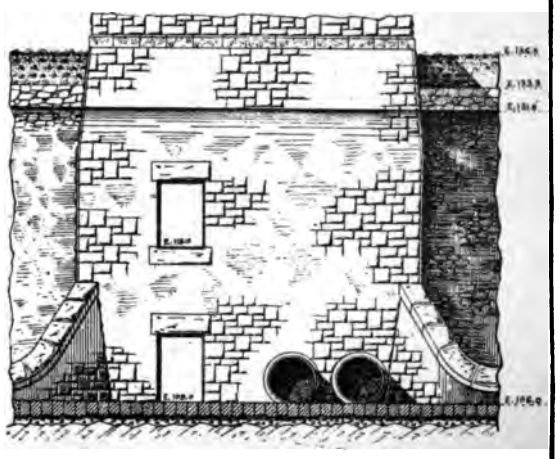
SECTION AT N.N.
(LOOKING WEST)



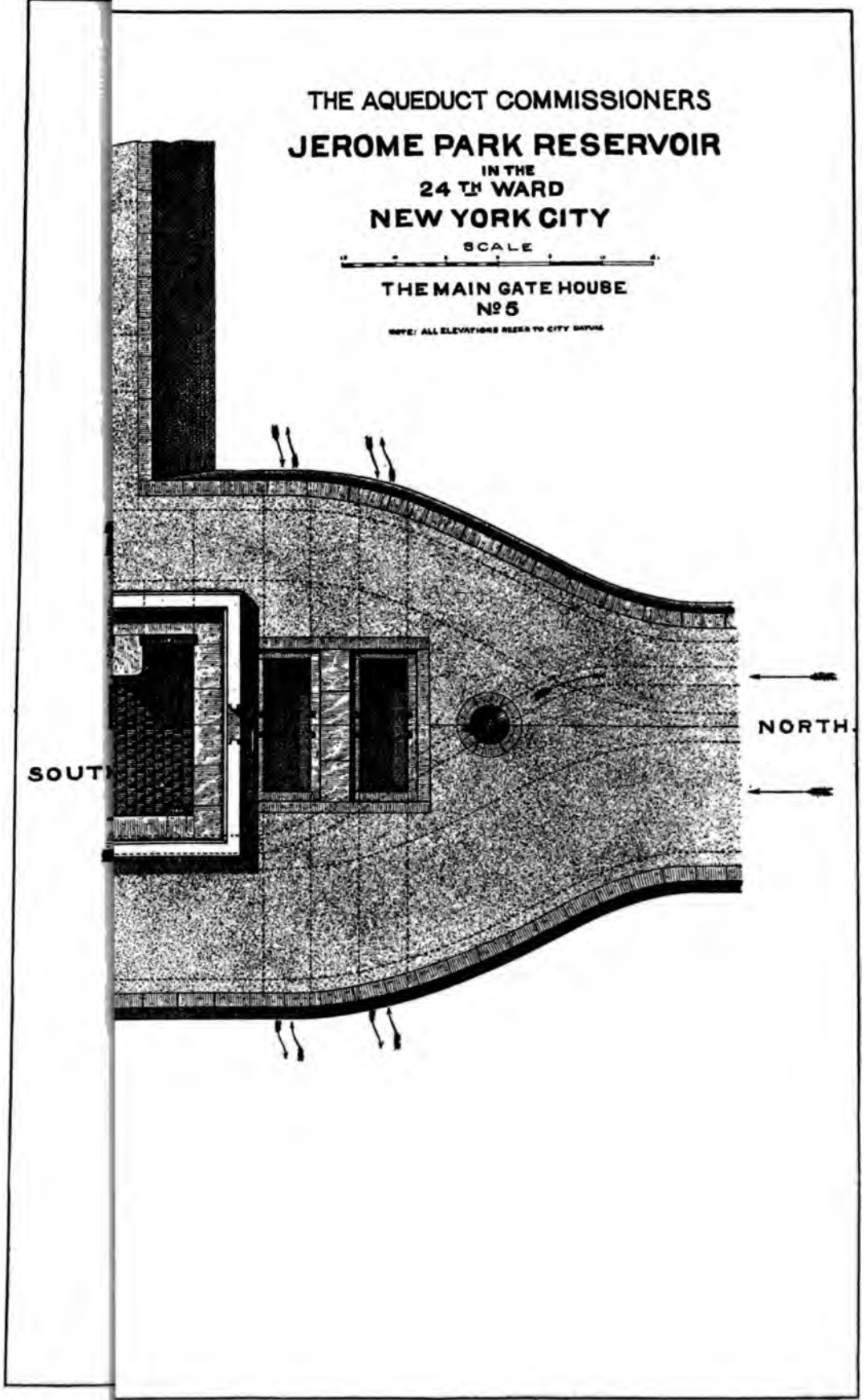
SECTION AT N.N.
(LOOKING EAST)

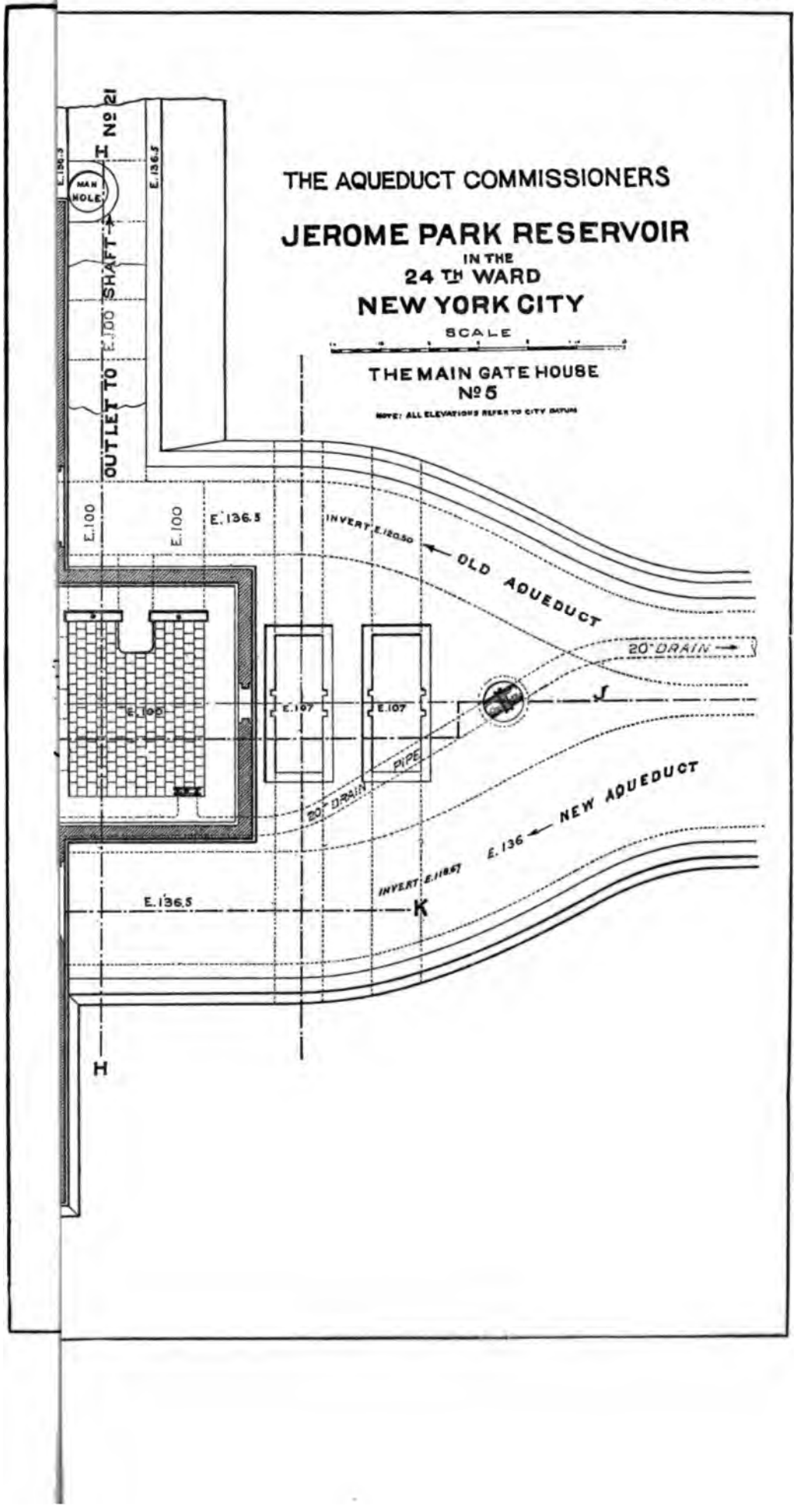


SECTION AT AAA



FRONT ELEVATION


THE AQUEDUCT COMMISSIONERS
JEROME PARK RESERVOIR
IN THE
24 TH WARD
NEW YORK CITY
SCALE
THE MAIN GATE HOUSE
№ 5
NORTH.


THE AQUEDUCT COMMISSIONERS
JEROME PARK RESERVOIR
IN THE
24TH WARD
NEW YORK CITY
SCALE
THE MAIN GATE HOUSE
Nº 5
NOTE: ALL ELEVATIONS REFER TO CITY DATUM
OUTLET TO SHAFT Nº 21
MAN HOLE
E.136.5
E.100
E.107
INVERT E.120.50
OLD AQUEDUCT
20" DRAIN
PIPE
NEW AQUEDUCT
E.136
INVERT E.118.67
H
J
K

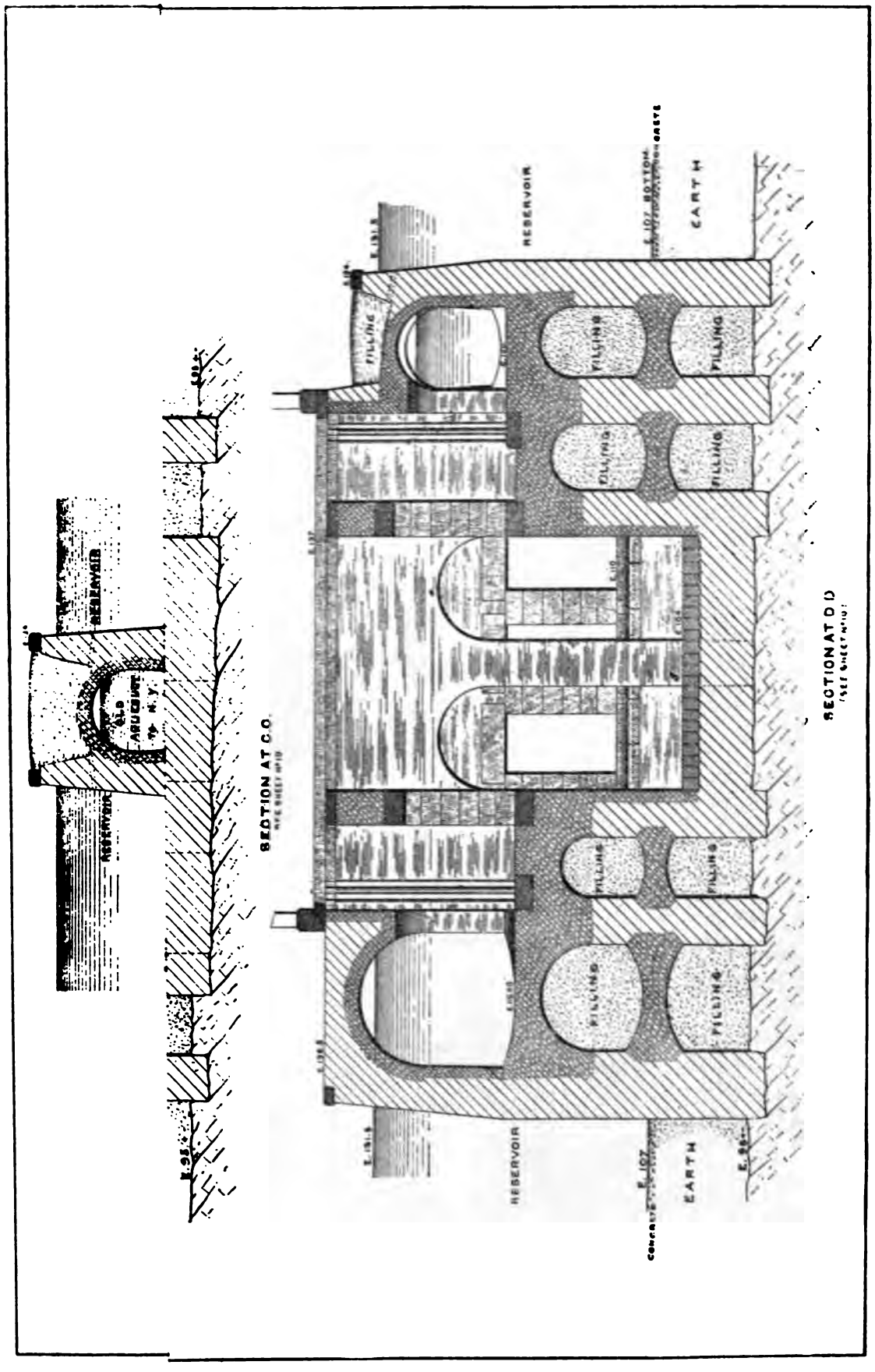
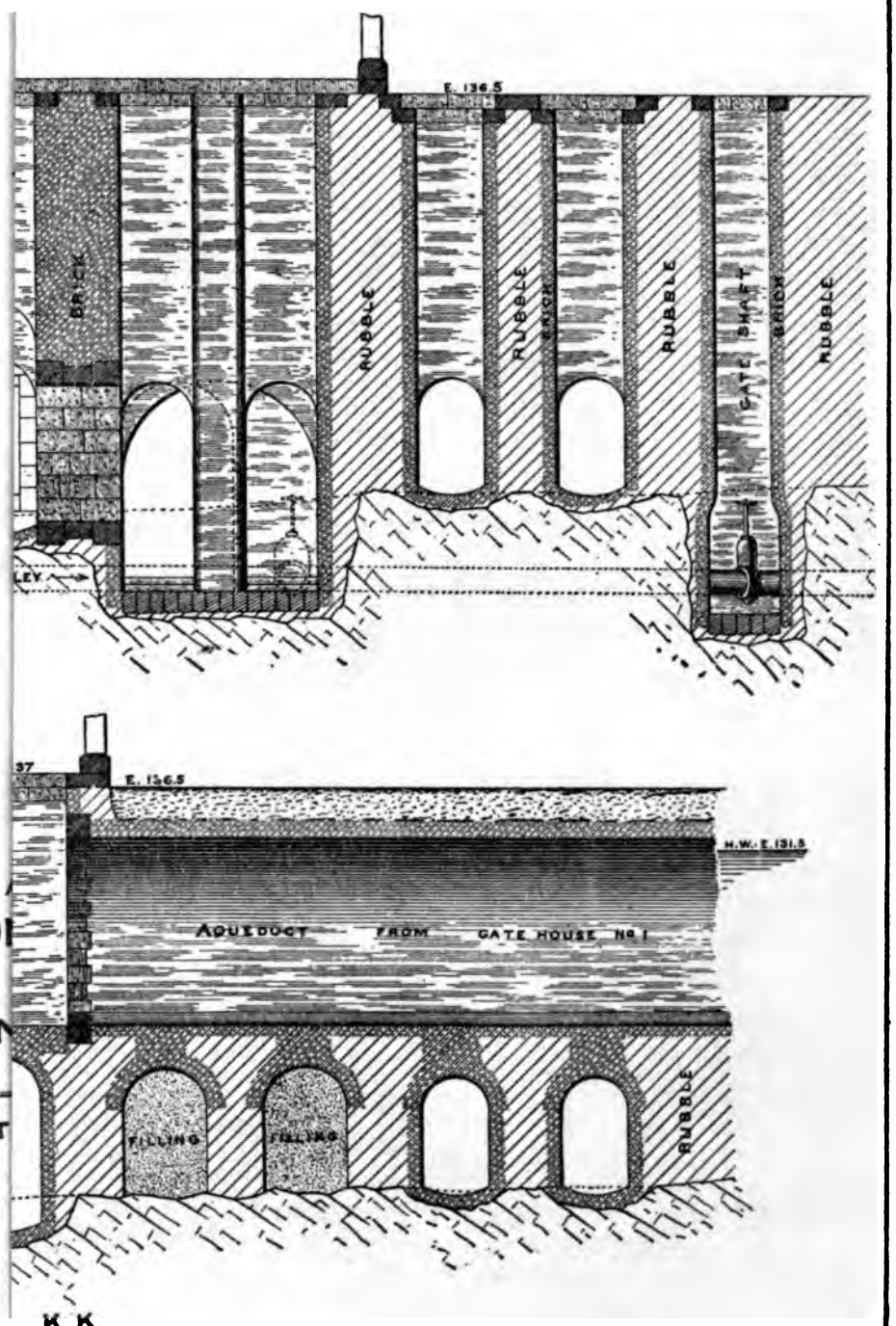
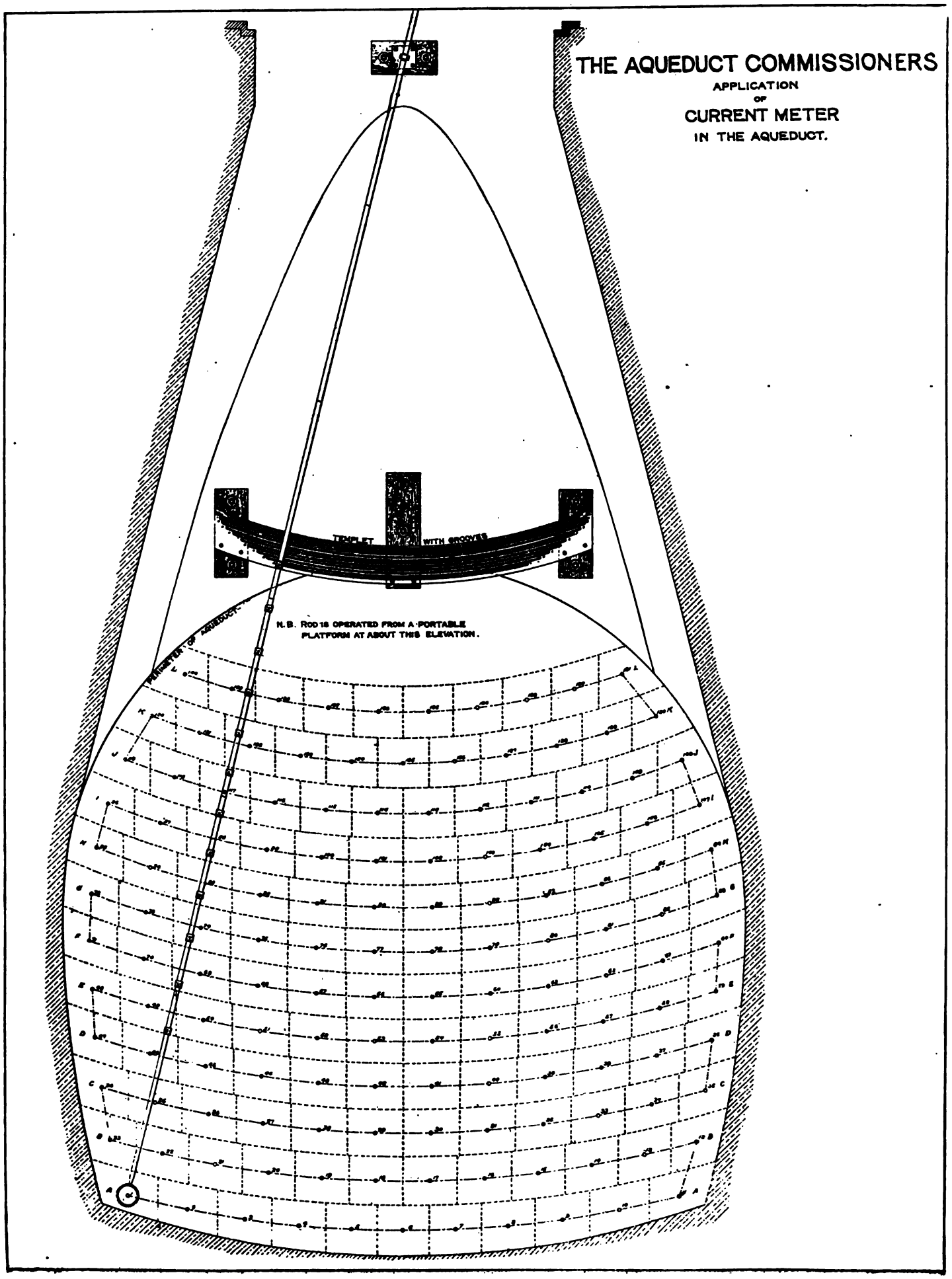

RESERVOIR
OLD AQUEDUCT
N. Y.
RESERVOIR
SECTION AT C.D.
RESERVOIR
EARTH
FILLING
FILLING
FILLING
FILLING
FILLING
FILLING
FILLING
FILLING
RESERVOIR
EARTH
SECTION AT D.D.

PLATE 142.



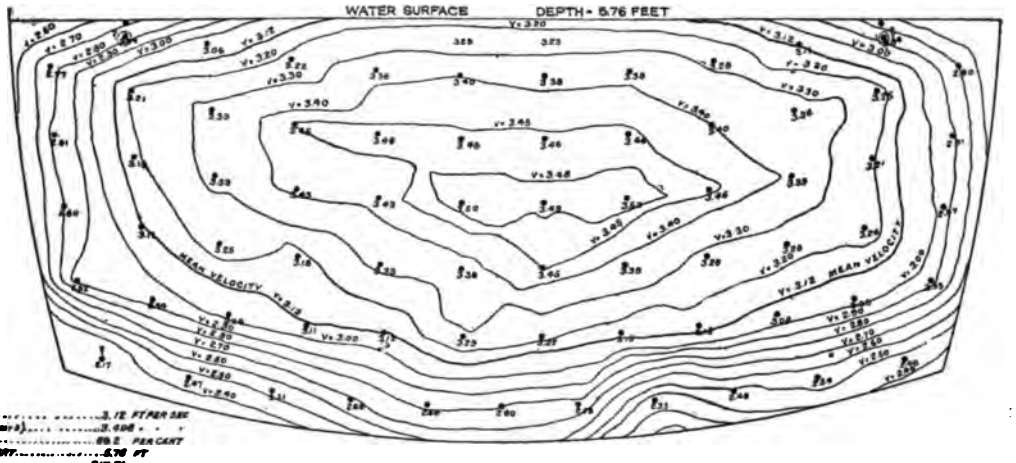
THE
JERO

K.K.

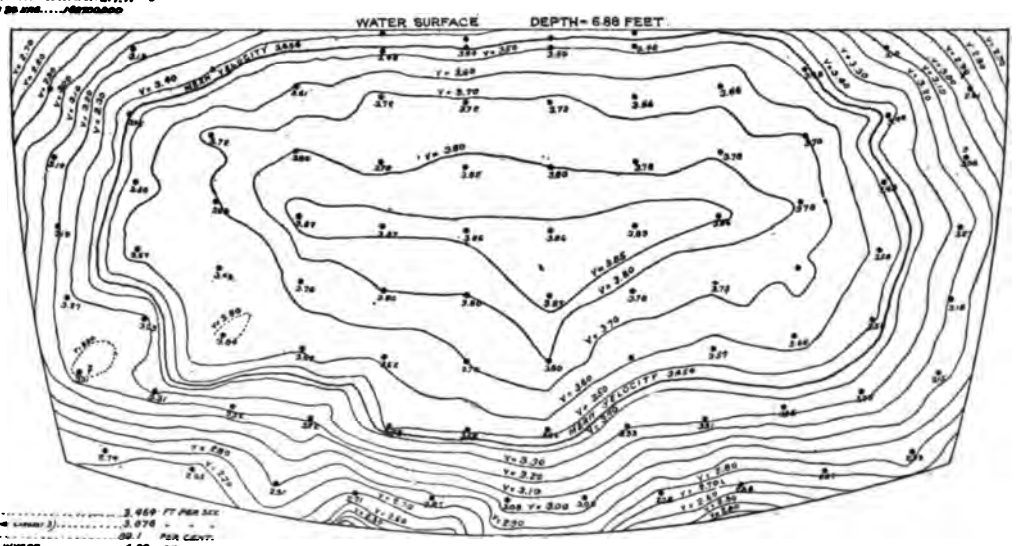

THE AQUEDUCT COMMISSIONERS
APPLICATION
OF
CURRENT METER
IN THE AQUEDUCT.
TRIPLET WITH GROOVES
N.B. ROD IS OPERATED FROM A PORTABLE
PLATFORM AT ABOUT THIS ELEVATION.
DIAMETER OF AQUEDUCT

THE AQUEDUCT COMMISSIONERS

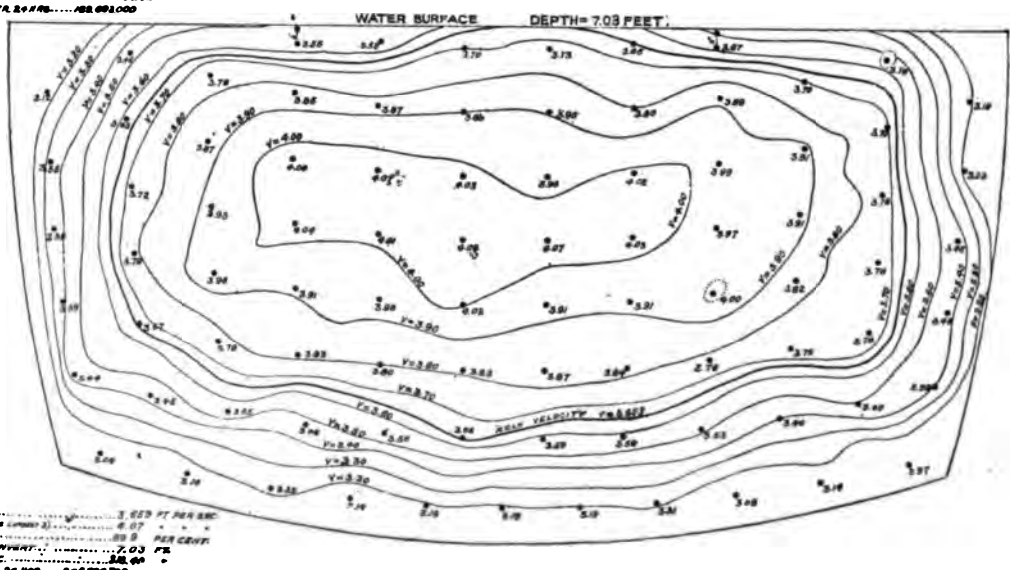
DIAGRAMS
SHOWING
DISTRIBUTION OF VELOCITIES
AND CURVES OF EQUAL VELOCITIES
IN
NEW CROTON AQUEDUCT
AT SPECIAL MANHOLE 18
STA. 1142+76



MEAN VELOCITY ..... 3.12 FT PER SEC
MAXIMUM ..... 3.696 " "
RATIO OF MEAN TO MAX ..... 84.2 PER CENT
DEPTH ABOVE CENTER OF INVERT ..... 5.76 FT
FLOW IN CUBIC FT PER SEC ..... 217.71 "
" " U.S. GALLONS PER 24 HRS. ..... [illegible]



MEAN VELOCITY ..... 3.459 FT PER SEC
MAXIMUM ..... 3.876 " "
RATIO OF MEAN TO MAX ..... 89.1 PER CENT
DEPTH ABOVE CENTER OF INVERT ..... 6.88 FT
FLOW IN CUBIC FT PER SEC. 292.62
U.S. GALLONS PER 24 HRS. 189,093,000



MEAN VELOCITY ..... 3.623 FT PER SEC.
MAXIMUM ..... 4.07 " "
RATIO OF MEAN TO MAX ..... 89.0 PER CENT
DEPTH ABOVE CENTER OF INVERT ..... 7.03 FT
FLOW IN CUBIC FT PER SEC. ..... 312.60 "
" " U.S. GALLONS PER 24 HRS. 202,786,700

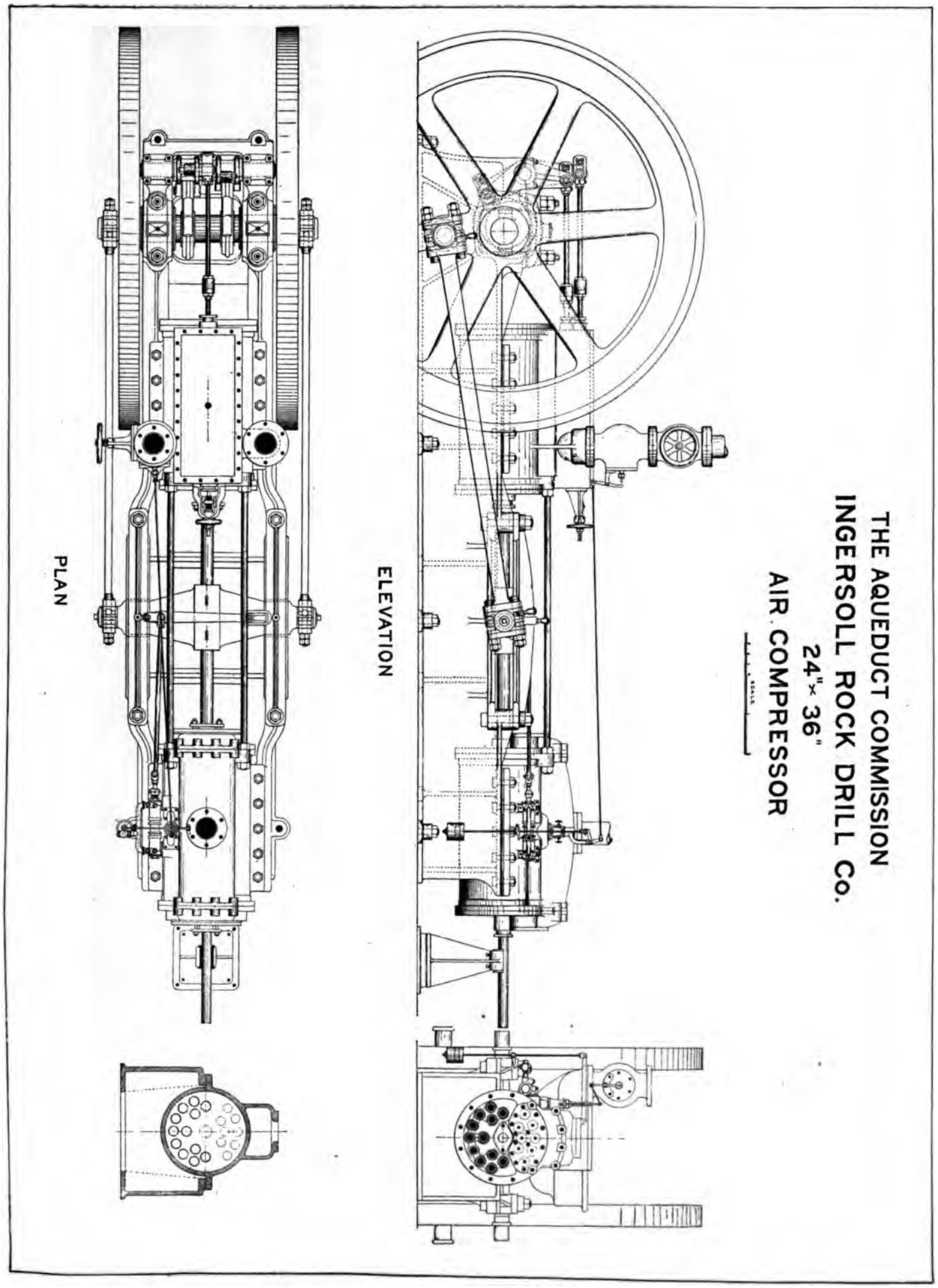
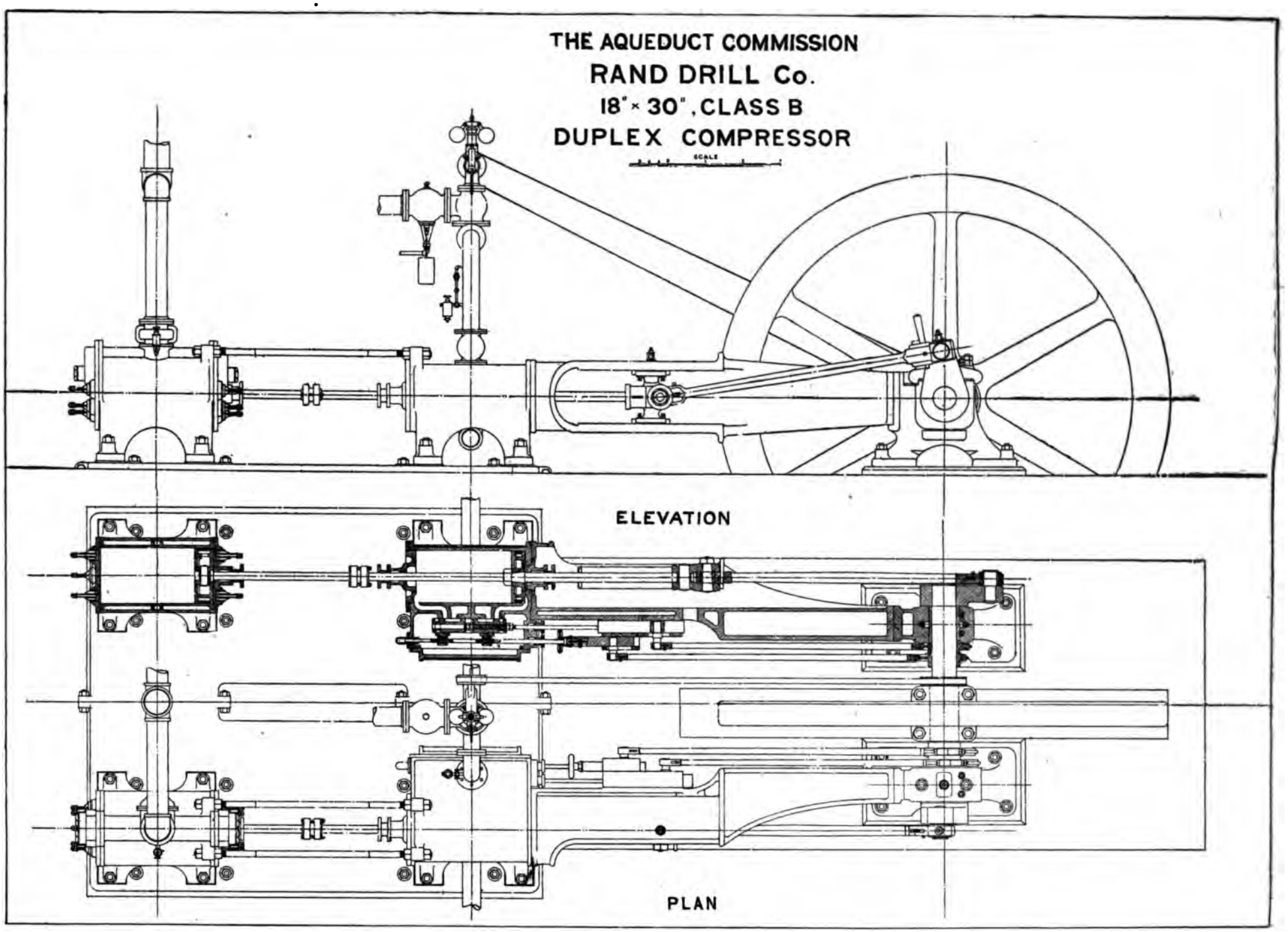

THE AQUEDUCT COMMISSION
INGERSOLL ROCK DRILL Co.
24" × 36"
AIR COMPRESSOR
ELEVATION
PLAN

PLATE 146.


THE AQUEDUCT COMMISSION
RAND DRILL Co.
18" × 30", CLASS B
DUPLEX COMPRESSOR
ELEVATION
PLAN


LONG ISLAND SOUND
Port Chester
Rye Lakes
Kensico
White Plains
River
MT VERNON
NEW AQUEDUCT SURVEYED IN 1879
CROTON AQUEDUCT

THE WATER-SUPPLY OF THE CITY OF NEW YORK.

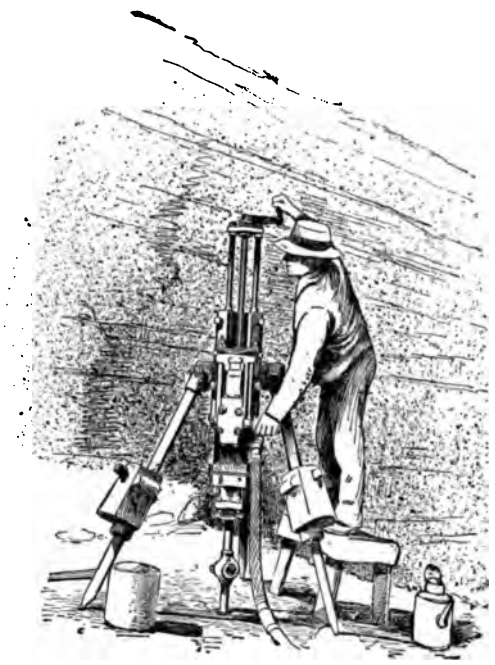
ADVERTISEMENTS.

242 Ingersoll Rock-Drills, 22 Ingersoll Air-Compressors

USED AT THE

NEW CROTON AQUEDUCT

TUNNEL WORK.



"**INGERSOLL DRILLS** were distributed along the line from the upper part of New York City to the Croton Lake. They were used exclusively on about one half of the line at first. As the engineers' tables of progress were made each month, the contractors saw that those sections using **Ingersoll Drills** were being driven faster than where other drills were used; hence, as the work progressed other makes of drills were rapidly replaced by "**Ingersoll**" machines, until at the completion of the work in 1887 the "Report of the Aqueduct Commissioners" showed the following condition of things:

(By actual count from Table 13.)

Number of Ingersoll drills used.....242

Number of drills of *all other* makes used.....103

(Including about twenty-three "Sergeants.")

Number of Ingersoll air-compressors used.....22

All other makes.....23

PROGRESS IN HEADINGS.

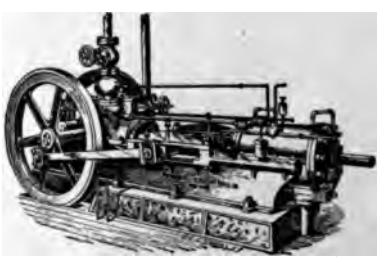
(By actual figures from Table 8.)

Average weekly progress in the best ten headings that used INGERSOLL DRILLS exclusively (omitting all idle weeks)....**38.73 feet**

Average weekly progress in the best ten headings that used other drills exclusively (omitting all idle weeks).....31.88 feet

Difference of 20 per cent. in favor of INGERSOLL DRILLS.

THE CHICAGO DRAINAGE CANAL.



ON THIS IMPORTANT WORK THERE WERE USED

129 INGERSOLL-SERGEANT ROCK-DRILLS.

7 INGERSOLL-SERGEANT AIR-COMPRESSORS.

34 INGERSOLL-SERGEANT CHANNELERS.

In the JEDDO TUNNEL recently completed, Ingersoll-Sergeant Machinery was used exclusively, making excellent records.

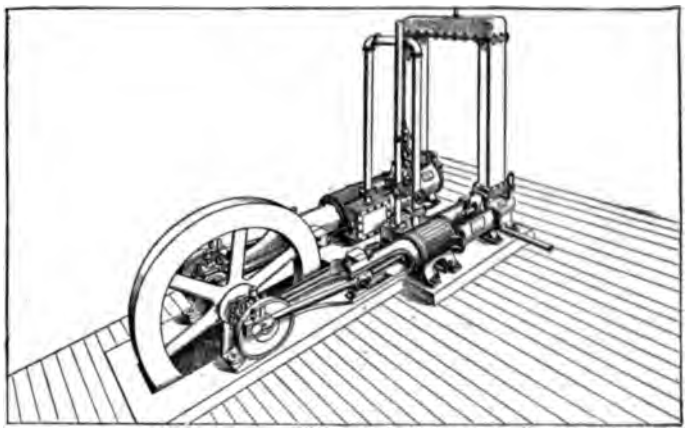
RAND DRILL CO.

ROCK-DRILLS,

AIR-COMPRESSORS.

AIR-COMPRESSORS

FOR MINES, TUNNELS, QUARRIES, AIR LIFT-PUMPS, RAILWAY AND MACHINE SHOPS, AND ALL USES TO WHICH COMPRESSED AIR IS ADAPTED.



COMPOUND STEAM AND COMPOUND AIR COMPRESSORS FOR RAILWAY SHOPS.

RAND DRILL CO.,

100 BROADWAY, NEW YORK.

BRANCH OFFICES:

Chicago, 1328 Monadnock Block.
Boston, 147 Pearl Street.
San Francisco, 141 First Street.
Denver, 427 17th Street.
Helena, Mont.
Butte, Mont., 221 S. Washington St.
Ishpeming, Mich.
Birmingham, Ala.
Sherbrooke, Que.
Montreal, 16 Victoria Square.
Halifax, N. S., Halifax Hotel.
Rat Portage, Ont.
Mexico City, Apartado 830.
Valparaiso, Chili.
Melbourne, Australia.
Sydney, Australia.
Johannesburg, South Africa.

CABLE ADDRESS, AGEBISHOP. A B C CODE, 4TH EDITION, AND RAND DRILL CO.'S CODE.

OTIS BROTHERS & CO.'S ELEVATOR WORKS.
MANUFACTORY AT YONKERS. NEW-YORK OFFICES AT 38 PARK ROW.

A LARGE NUMBER OF

OTIS HOISTS

WERE USED IN BUILDING THE AQUEDUCT.

THIS COMPANY HAS ALSO FURNISHED THE
SPECIAL HOISTING APPARATUS FOR THE

Glasgow Tunnel,
Otis Elevating Railway, Catskill Mountains,
North Hudson County Railway at Weehawken,
Eiffel Tower,
Prospect Mountain Incline Railway at Lake George.

OTIS BROTHERS & CO.,

38 PARK ROW, NEW YORK.

Improved Hoisting Machinery

OF EVERY DESCRIPTION

FOR MINES, TUNNEL WORK, CONTRACTORS AND GENERAL HOISTING PURPOSES.

Lidgerwood Improved Single-Cylinder Patent Friction-Drum Portable Hoisting-Engine

WITH BOILER AND FIXTURES COMPLETE ON BED PLATE.

SPECIALLY ADAPTED FOR

PILE-DRIVING, RAILROADS, CONTRACTORS, BRIDGE BUILDERS, DOCKS AND QUARRIES.

This engine is of entirely new design, is made from new patterns, and embodies the results of many years' experience. It is particularly simple in construction, and properly proportioned throughout [illegible]

300 Styles and Sizes . . . Over 12,000 in Use.

[illegible]

LIDGERWOOD MANUFACTURING CO.

WAREROOMS, 93 LIBERTY ST., NEW YORK.

PITTSBURGH. [illegible] CHICAGO. ST. LOUIS. [illegible]

SAN FRANCISCO. [illegible]

THE McNEAL
PIPE AND FOUNDRY COMPANY.

A. H. McNEAL, President.
I. SNOWDEN HAINES, Secretary and Treasurer.

CAST-IRON PIPES AND SPECIAL CASTINGS FOR WATER AND GAS.

Flanged Pipes and Pipes with Flexible Joints.

LARGE CYLINDERS, HEAVY CASTINGS, AND GENERAL FOUNDRY WORK.

OFFICE AND WORKS AT

BURLINGTON, NEW JERSEY.

Works: { Millville, N. J. / Florence, " / Camden, " }

R. D. WOOD & CO.,

400 CHESTNUT ST., PHILADELPHIA.

ENGINEERS— RON FOUNDERS · MACHINISTS.

CONSTRUCTORS OF GAS AND WATER WORKS,

BUILDERS OF

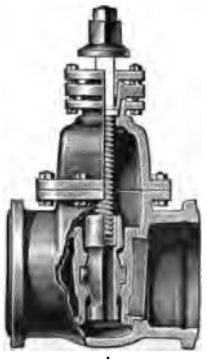
GAS APPARATUS, HYDRAULIC TOOLS, CRANES, TURBINES AND MACHINERY.

MANUFACTURERS OF ALL KINDS AND SIZES OF CAST IRON

PIPE

Flange Pipe and Special Castings, Rams and Cylinders.

Dunham Cutting-in Specials.



MATHEWS' SINGLE AND DOUBLE VALVE

FIRE HYDRANTS,

With or without Independent Nozzle Cut-offs.

EDDY VALVES. INDICATOR VALVE-POSTS.