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MANHATTAN *LIFE LINE*: ENGINEERING THE OLD CROTON AQUEDUCT, 1833-1842

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CHAPTER ONE

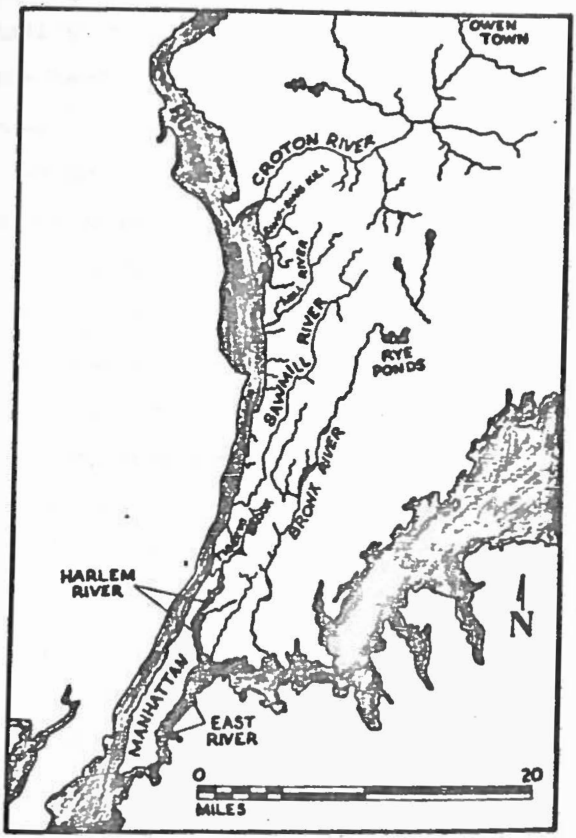
In the summer of 1836 Stephen Allen was anxious to finally get started. The Democrat, former Mayor of New York, now Chairman of the city's Board of Water Commissioners, wanted construction to begin on the Croton Aqueduct. He hoped that an army of Irish laborers would soon invade Westchester County and set up shanties near the stately manors along the Hudson River. Allen wanted to see shipments of brick, stone, timber and cement plying the Hudson, while the Irish wielded picks and shovels along the aqueduct's staked-out line. He wanted to see the Croton River cut by a tall stone dam, hills pierced by deep excavations or tunnels, and valleys, including the Headless Horseman's Sleepy Hollow, spanned by a masonry conduit that would carry much needed water to New York City. Unfortunately, Allen was not only anxious; he was disappointed, frustrated and angry that he had to wait still longer to see these things. He felt he had waited too long already.

In 1833 the State Legislature created Allen's Board of Water Commissioners for the purpose of discovering the best means of supplying New York with a copious supply of wholesome water. The Commissioners hired consulting civil engineers, undertook feasibility studies, and twice reported that in terms of both quantity and quality New Yorkers should turn to the Croton River for their water. This decision was a bold and controversial one, because the

Croton was far-removed from Manhattan. It sprang from about twenty lakes and ponds located some fifty miles north of the island. Three of the Croton's branches, the West, Middle and East, converged near Owen Town. From there the river ran southwestward through Westchester County, finally flowing into the Hudson at a point 25 miles from Manhattan's northernmost tip. Despite the Croton's remoteness, the Water Commissioners insisted upon drawing water from this river, and they expressed confidence that the city could successfully construct a 40-mile-long aqueduct running from the Croton to central Manhattan. (Plate I.)

From 1833 to mid-1835 the Croton Aqueduct was just an idea, an image contemplated by the Water Commissioners and their consultants. Then, after receiving the endorsement of the city's voters and the Common Council, the Water Commissioners took the first step to make the Croton Aqueduct a reality. On June 2, 1835 they hired Major David Bates Douglass as their Chief Engineer and instructed him to go ahead with the work. Douglass, a former professor of civil engineering at West Point, had served as the Commissioners' most influential consultant. He had studied the feasibility of such an aqueduct in 1833 and 1834. With surveying parties he had trod every foot of its proposed route, and he had prepared tentative designs and cost estimates for the aqueduct's structures. So in the summer of 1835, Stephen Allen and the other Commissioners, with Douglass in command of the engineering corps, looked forward to

PLATE I



Map -- Croton River to Manhattan.

a prompt execution of the project. But late in the summer of 1836, New York once again appeared to be a long way from having an adequate supply of water. The Croton Aqueduct was still an abstraction, an idea only partially formulated in the head of the Chief Engineer, who had proved himself overly cautious or incompetent. Major Douglass had not broken ground; he had let no contracts.

Stephen Allen was rightfully impatient and angry, not only because Douglass had failed to break ground, but because prior to 1836 New Yorkers had suffered for over half a century from an inadequate water supply. Since 1774 numerous engineers, dreamers, and opportunists had projected a plethora of Manhattan water supply systems. Most of them evaporated into nothingness, and even those few that were constructed did little to remedy the problem. Stephen Allen was a politician and a proud man. Characterized by his friends as strong-willed and decisive, and by others as stubborn, hard-headed and opinionated, Allen the public servant wanted the citizens of New York to benefit from a well-engineered water system, just as the citizens of Philadelphia already benefited from their Fairmount Water Works along the Schuylkill River. And Allen the politician wanted credit as the chief administrator of such a fine and important project. He did not want to become known as the progenitor of yet another failure.

* * * * *

When it came to providing its inhabitants with water, Manhattan Island was a geographic irony.[1] Although enticingly surrounded by three rivers -- the Hudson, the East and the Harlem -- its rivers were brackish. Because of the Atlantic's tides they contained a large amount of salt water which made them unfit for most domestic purposes. So from the very start, Manhattan's Dutch and English settlers drew water not from their rivers, but from natural springs, such as the one which supplied the "Tea Water Pump Garden," from ponds, such as a 50 acre pond called the "Collect," and from man-made wells or cisterns.[2] In the earliest years of settlement this simple and old technology of water-gathering sufficed, but by the mid-1700's serious problems began to arise which led one visitor, Peter Kalm, to assert in 1748 that, "There is no good water in the town itself."[3] Brackish water contaminated the wells on Manhattan's perimeter, and the seepage from privies, cess pools and graveyards, and the water washed down from fouled streets polluted interior wells. In short, the city's water supply deteriorated because a simple water-gathering technology conflicted with an equally primitive and inadequate technology of public sanitation.

Despite the seriousness of the problem, New Yorkers were dreadfully slow in making any significant changes in how they got their water. Instead of rapidly adopting a new technology, they made facile accommodations. Many simply grew accustomed to the foul taste of their water. Others resorted to deeper wells, to wells or springs located further from the population center, or to water purchased from street vendors who hopefully had a purer source of supply. At the least these accommodations were inconvenient, and at times the continued absence of a system delivering pure water in abundance proved a tremendous liability. The citizens of New York were more exposed to contamination and disease; the filthy urban environment was made more foul by inadequate cleaning; and citizens and structures alike were left with little protection from the ever-present danger of fire.

New Yorkers periodically suffered a great deal from such liabilities. In 1776 a fire destroyed one-fourth of the city's homes. Another fire in 1828 destroyed approximately $600,000 worth of property, and in 1835 yet another fire leveled twenty blocks and claimed 670 buildings. Disease, too, took its toll. In 1798 a yellow fever epidemic killed 2,000 citizens, and even in "ordinary" years the death toll ran high from yellow fever, typhoid fever and cholera.[4] In 1832, when Asiatic cholera descended upon New York in July, citizens hastily attempted to minimize its effect by cleaning up the city and improving health conditions. The efforts did not work. One-hundred thousand persons fled New York in August to avoid the pestilence, and yet by late October 3,500 residents had died.

While periodic catastrophes intensified the desire for a centralized water system, the quality of New York's existing water supply continued to decline. People were flooding into the city, and its population, clustered towards the southern end of Manhattan, increased at an overwhelming rate. In 1790, some 33,000 persons lived in New York. Over the next ten years that figure doubled to 66,000. By 1810, 96,000 inhabited the city, and between 1810 and 1830 the population jumped to 202,000. This population explosion had a direct and deleterious effect on the city's water. By 1830 New Yorkers deposited an estimated one-hundred tons of excrement per day into the same sand bank from which they drew their water.[5]

Against this background, it is no wonder that in 1836 Stephen Allen was anxious to break ground on the Croton Aqueduct. There was a dramatic and long-felt need for the water it would provide. And it is equally understandable why he was embarrassed over the aqueduct's slow start. Citizens voiced doubts that the Croton Aqueduct, like so many other plans to supply New York with good water, would ever be completed successfully.

There was strong precedent for such skepticism. In 1774 an English civil engineer, Christopher Colles, started to erect a water supply system for the city using wells, a Newcomen pumping engine, reservoirs, and bored-log mains.[6] Colles, interrupted by the Revolution, never operated the system. On July 2, 1798 Dr. Joseph Browne initiated another push for a new means of supplying the city with water.[7] Over the years, many persons had recommended that the city construct a centralized water works using the Collect as a source. Browne was appalled by this idea. In a "Memoir" addressed to New York's Common Council, Browne condemned the fifty acre pond between Pearl and Franklin streets on two counts.[8] First, the Collect was "infinitely too small" to meet the city's needs, and steam-driven pumps could empty it faster than natural springs could refill it. Secondly, Browne characterized the Collect as a "large stagnating, filthy pond," filled with "noxious" water which collected, among other things, the "filth from many of the streets" and the drainage from privies. Because it was a "general rule that the health of a city depends more on its water than all the rest of the eatables and drinkables put together," Browne urged the city to abandon the thought of using the Collect or any water available on Manhattan. Instead, the city should construct a $200,000 water system to supply its residents with 362,800 gallons per day from the Bronx River.[9] Browne suggested damming the Bronx and diverting its water into a 400-yard-long canal connecting with Morrisania Creek. Running for the most part in the creek's channel, the water would flow to the Harlem River, where a part of it, powering a 20-foot water wheel, would pump the rest of the water through cast iron pipes to a reservoir on Manhattan.

The Common Council reacted favorably to Browne's proposal and appointed a committee to study it more thoroughly. On December 17, 1798 the committee reported that the Bronx River "would afford a copious supply of pure and wholesome water" that "ought to be pursued by, and under the control of" the city government.[10] Next the Council sought the opinion of a technical expert, William Weston, a British civil engineer working on American canals.[11] In his report of March 16, 1799, Weston endorsed Dr. Browne's proposal, and with this additional support in hand the Common Council submitted a draft bill to the State Legislature requesting the requisite powers to construct a Bronx River water works. For a while it appeared that New York had found a solution to its water problem, but the appearance was an illusion -- thanks to the dubious political skills of Aaron Burr.

On March 30, 1799 the legislators in Albany passed a water bill championed by Burr, instead of the bill that the Common Council wanted.[12] Instead of granting the city the needed powers to harness the Bronx River, the Legislature granted them to a company which, coincidentally, Mr. Burr headed. The opportunist had successfully executed a brilliant, albeit devilish, scheme that even fooled Alexander Hamilton. Burr was not particularly interested in supplying New York with water, but he did want to start a bank in the city, a goal he had long been denied. Following his tightly-scripted plan to start a bank, Burr first convinced the Legislature that the expense of a water works should be assumed by private investors, not by New York City. Here Alexander Hamilton helped Burr by stressing to everyone the fiscal burdens a water works would place upon the city's residents. Next, when the legislators wrote "An Act for Supplying the City of New York with pure and wholesome water," Burr inserted a seemingly innocuous provision stating that the water company could use its surplus capital in any way not inconsistent with the laws of the state. Finally, under this act he and some select friends incorporated the Manhattan Company, which promptly gave up any idea it might have had about supplying New York with Bronx water. It abandoned the expensive Bronx project, thereby instantly creating a "surplus" of capital used to start a bank. While the new bank flourished, the Manhattan Company, to meet the minimum requirements of its charter, halfheartedly provided well water to a limited sector of the city.

Convinced that the Manhattan Company was never going to provide the city with enough water, in 1822 Mayor Stephen Allen and the Common Council revived the idea of a Bronx River water supply.[13] Allen chaired a special committee that visited the river and its principal source, the Rye Ponds. Encouraged by its visit, the committee recommended that the Council employ a civil engineer to conduct a thorough survey of the Bronx River watershed. Acting on this recommendation, the Council engaged Canvass White, an American engineer noted for his role in building the Erie Canal. White conducted instrumental surveys, measured the river's flow, and in January 1824 reported that for two million dollars the city could receive a minimum of 6.6 million gallons of water per day.[14]

White's report demonstrated the feasibility of a Bronx River aqueduct, but the Common Council was discouraged by its estimated cost and decided to leave the work to private enterprise. The New York Water Works Company, incorporated in 1825, started to tackle the Bronx project by employing Canvass White as its chief engineer. In 1826 White produced his second report on the Bronx which exhibited his "full conviction that a successful plan can be adopted" for introducing its water to Manhattan.[15] From his second survey White determined that he could deliver 9.1 million gallons per day at a reduced cost of $1,450,000. Unfortunately, White's work was cut short. His company's charter conflicted on the basic issue of water rights with a charter granted in 1823 to the Sharon Canal Company, a company with its own scheme for supplying New York with water. Unable to proceed because of this conflict, the Water Works Company never broke ground before surrendering its charter in 1827.[16]

And so it had gone. Since 1774, about every twenty years a seemingly serious bid had been made to supply New York with water. Meanwhile the Common Council's Committee on Fire and Water issued report after report on the need for such a supply, and numerous individuals petitioned the Council for the opportunity to demonstrate their proposed solutions to the problem. But all had been to no avail. The more outlandish proposals were ignored or quickly struck down. The others were buried by political machinations, legislative bungling, conflicting charters, high costs, the lack of requisite technical skills, or by endless debates over whether a water works should be publicly or privately funded.

Belatedly, the debates over private or public funding finally did come to an end. In reaction to the 1828 fire which destroyed $600,000 worth of property, city Alderman Samuel Stevens reported in 1829 that the private institutions chartered to supply the city with water had never satisfactorily fulfilled that goal. The Manhattan Company, for example, after operating for thirty years, distributed its well water through unreliable mains only to the lower third of the city, leaving the upper two-thirds devoid of any effective means of fighting fires. Stevens concluded that, "It has therefore become absolutely necessary for the corporation, in some manner, to give the upper part of the city, a supply of water for that purpose."[17] Spurred on by Stevens, the city finally acted on its own. It constructed a $42,000 fire-fighting system, composed of a 112-foot-deep well containing 175,000 gallons of water, a steam-driven pump, and an elevated reservoir containing an additional 233,000 gallons.

The fire-fighting reservoir served as a symbol of what the city could do when it finally quit relying on private enterprise to solve a public problem, and after its completion began a period of increased agitation for the construction of a centralized water system. At the end of 1830, Samuel Stevens again served as a catalyst. He wanted the Council to send a memorial to the State Legistature which set forth the failures of private enterprise and requested that the city itself be empowered to construct a water system.[18] Although Common Council voted this idea down on February 28, 1831, because a majority believed the State Legislature would not grant such a request, the vote signified no lack of determination or interest. On the same day as this vote, in fact, the Council grew more determined to solve the water problem because of a very disturbing report it received from the Lyceum of Natural History regarding the impurity of the city's water.

The quantitative side of the Lyceum's presentation had its effect. Chemist George Chilton reported that seven samples of water from the city contained from 4.05 to 10 grains of solid matter per pint, including such "ingredients" as muriates of soda and magnesia; sulfates of magnesia and lime; carbonates of lime and magnesia; and "extractive matter."[19] But perhaps the more narrative portions of the report carried the greatest impact:

> It has been observed . . . that the vicinity of grave yards communicates a ropy appearance to the water.

And:

> Into the sand bank, underlying the city, [from where we draw our water,] are daily deposited quantities of excrementious matter, which, were it not susceptible of demonstration, would appear almost incredible.

The "excrementious matter" amounted to one hundred tons per day and did not include urine, a substance which the Lyceum praised for its beneficial effect on the city's underground water sources:

> This liquid, when stale or putrid, has the remarkable property of precipitating the earthy salts from their solution, or in other words, it makes hard water soft. Although the fastidious may revolt from the use of water thus sweetened to our palate, it is perhaps fortunate that this mixture is daily taking place, for otherwise the water of this city would become, in a much shorter space of time than it actually does, utterly unfit for domestic purposes.

After describing the poor conditions of New York's water supply, the Lyceum felt it necessary to explain why New Yorkers tolerated such hard and foul water:

> We must impute to long use and the influence of habit the opinion that our water is sufficiently pure for domestic purposes. We have known our citizens, upon going into the country, [to] express a marked disrelish for pure spring water. The popular expression on such occasions is, "This water is like wind -- there is nothing substantial in it, nothing to bite upon . . . ." The coldness

> of our pump waters is another cause which conceals their impurities when swallowed. This may be tested by allowing it to stand until it has acquired the ordinary summer temperature; its various ingredients become then manifest, palpable.

In concluding, the Lyceum's report deplored any further toleration of poor water. Its writers unanimously opined "that no adequate supply of good or wholesome water can be obtained on this Island, for the wants of a large and rapidly increasing city like New York."[20]

This idea -- that no Manhattan water was fit to drink -- was by no means a new one. Dr. Browne had expressed it in 1798. But, like the concept of public funding, it was an idea whose time had finally come. On November 25, 1831 chemist Chilton quantified the difference between water taken from on and off Manhattan. The water he drew from a Manhattan Company pump yielded 125.80 grains of solid matter per gallon; a gallon of water from the Bronx River yielded less than 2 grains.[21] Armed with this data, in 1831 Samuel Stevens and the Committee on Fire and Water strongly, if unimaginatively, urged the city to finally launch a two-million-dollar Bronx River aqueduct. Displaying an activist's spirit, the committee urged that the Common Council:

> approach the subject as one of vast magnitude and importance to an already numerous and dense population, requiring our municipal authorities no longer to satisfy themselves with speeches, reports, and surveys, but actually to raise the means and strike the spade into the ground, as a commencement of this all important undertaking.[22]

Convinced of the need for action, Common Council submitted a draft bill to Albany, which, if passed, would authorize the city to initiate a Bronx River aqueduct. To make the draft bill more appealing to the Legislature, the Council called for the creation of a Board of Water Commissioners to administer the work -- the Board to be appointed by the Governor with Senate consent. Previously, the Council had itself intended to administer the construction of any water works. But that body was susceptible to disruptive political factions, and its individual members were susceptible to the whims of voters. It was believed that appointed Commissioners would provide the project with more constant and unified leadership.[23]

When the draft bill reached Albany it was defeated, presumably because of the Legislature's lack of faith in a critical aspect of the proposed plan. The Fire and Water Committee had suggested three means of carrying Bronx River water to the Harlem River: via an open canal, or, even better, through an enclosed brick conduit or through cast iron pipes. The real problem occurred once the water had been carried across the Harlem River on a bridge. Here it would have to be pumped up before it could be distributed throughout the populated regions of Manhattan. The city tentatively intended to accomplish this by damming the Harlem and using water wheels to lift the water into a reservoir 120 feet above tide. But after

Christopher Colles had abandoned his 1774 project that relied upon pumps, many New Yorkers had seemingly nurtured an aversion to machinery as an integral part of any water system that would operate day in and day out.[24] Machinery was costly to construct, prone to serious failure, and needed constant maintenance. Gravity, on the other hand, was both free and reliable. Many legislators in Albany, then, were holding out for a proposal whereby gravity would carry water across to Manhattan on a level high enough to obviate pumping machinery.

Actually, it was fortunate for the city that the Legislature voted down the Bronx River project. When Dr. Browne first suggested it in 1798 it was a bold plan which promised New York an adequate water supply for years to come. When Canvass White and the New York Water Works Company worked with the idea in the mid-1820's, it still seemed a bold and promising plan. But by 1831, even as the Committee on Fire and Water once again recommended the Bronx River watershed as a source of supply, others were beginning to declare that the river was not large enough. In a letter appended to the committee's report, Cyrus Swan, President of the New York and Sharon Canal Company, asserted that the Bronx was not capable of meeting both the present and future needs of the city. Instead of relying on that old standby, Swan said that New Yorkers should turn to the Croton River for their water.

Cyrus Swan was by no means the first to mention the Croton. In 1824, Canvass White wrote that "the Croton can be taken out at a sufficient elevation, and conducted along the bank of the Hudson River to the city."[25] White dismissed the Croton, though, because he "presumed that a sufficient supply can be had from the Bronx, much nearer, and of course at less expense." The same presumption held with the Fire and Water Committee in its 1831 report. Before recommending the Bronx, the committee made brief mention of the Croton:

> The advocates of bringing the water from the Croton, base their argument mainly on the abundance of the supply to be obtained from that river. This important advantage must be yielded to the advocates of this plan, over that of all the others; and were it not for the distance which the Croton River lies from the city, it certainly would be the most desirable source whence to procure the supply.[26]

City officials and consulting engineers had always dismissed the Croton River, saying it was unnecessarily large or too far removed from Manhattan. Now, however, when it was apparent that the city absolutely had to go away from Manhattan for water, and when critics started expressing the opinion that the Bronx River was too small to provide a long-range supply, the Common Council had to give the Croton River more serious consideration. And the Croton suddenly had one important advantage. Because it ran at a higher elevation than the Bronx, perhaps it could be delivered to the city without the use of any pumps.

If the legislative defeat of the Bronx River aqueduct in any way dampened the enthusiasm for a municipally funded water system, the Asiatic cholera epidemic in the summer of 1832 quickly aroused interest once more. Alderman Myndert Van Schaick, who was also Treasurer of the city's Board of Health, urged that something had to be done, and on November 10, 1832 the Committee on Fire and Water engaged Colonel DeWitt Clinton, Jr. to conduct yet another investigation of possible water sources. On December 22, without having run any instrumental surveys, Clinton submitted an engineer's report that was an excellent piece of propaganda.[27] He said that the city should build a water works immediately, using the Croton River, with a minimum flow of 20 million gallons per day, as a source:

> This supply may . . . be considered as inexhaustable, and it is not at all probable that the city will ever require more than it can provide.[28]

As a consulting engineer unaided by instrumental surveys, Clinton was not required to deal with all the specific engineering problems to be faced in delivering Croton water onto Manhattan. He did, however, outline a tentative plan for an aqueduct for this purpose. Clinton's aqueduct was an open canal with provisions for keeping dirt, debris, and vegetable matter out of the channel. It started at Pine's Bridge, at an estimated elevation of 183 feet above the level of the Hudson River.[29] It ran on a high bank alongside the Croton until entering the Hudson Valley, where it began running southward in the margin of that river. All the while it maintained a declivity or downward slope of 18 inches per mile. Eventually, in order to stay on its grade line, the aqueduct left the Hudson, cut inland, and ran to the Harlem River, where a bridge 138 feet high carried it across to Manhattan. Clinton's plan required no pumping machinery; the proposed aqueduct connected directly with reservoirs and a distribution system.

Clinton estimated that it would cost 2½ million dollars to implement his plan, but he stated that even if it cost 11 million dollars it would be worth it. This estimate was a shrewd bit of engineering diplomacy on Clinton's part, intended to minimize objections that might be raised to a Croton aqueduct on the basis of cost. In order to arrive at such a low estimate, Clinton, of course, had proposed an open aqueduct canal, the cheapest to build, even though Canvass White and the Fire and Water Committee were already on record as having stated that such a channel offered the least protection for the purity of the water under transport. But the consultant had done his job well. In less than a month and a half he projected a seemingly feasible and economical plan that encouraged the construction of a much needed water works.

Two days after receiving Clinton's report, the persistent, ever-resilient Fire and Water Committee proposed yet another bill to go to Albany requesting that long-sought authorization to build a water works. But Common Council wisely referred the bill back to committee, because it was so much like its predecessors which the Legislature had failed to pass. Before returning the bill in February 1833, the committee significantly revised it. Now the draft bill sought a more limited but practical goal. It requested that the Legislature provide for a Board of Water Commissioners authorized not to build a water system, but to examine various plans, conduct instrumental surveys, and estimate the costs of possible aqueduct routes to Manhattan, especially one from the Croton River.[30]

When this bill reached Albany it fortunately received the support of a Senator familiar with and sensitive to New York's water problems. Myndert Van Schaick, the former Alderman and Board of Health Treasurer, effectively campaigned on behalf of the bill which the Legislature passed on February 26, 1833.[31] Shortly thereafter Governor William Marcy appointed a Democratic Board of Water Commissioners, composed of Stephen Allen, Saul Alley, Benjamin Brown, Charles Busenburry, and William Fox. The Commissioners, appointed to a one year term, were directed to report their findings to New York's Common Council by the first of Nobember.

The new Water Commissioners selected Stephen Allen as their Chairman and got down to business. In need of for his gallant action in defense of the fort, and on January 1, 1815 Brevet Captain Douglass returned to West Point as an Assistant Professor in its new Department of Natural and Experimental Philosophy.

Douglass was the second man in the department. The first, Lieutenant Colonel Jared Mansfield, had just started his instruction the previous April. Together, Mansfield and Douglass lectured the cadets on a broad range of subjects, most of which, today, would fall under the rubric of "physics."[34] After lecturing for five years on such topics as dynamics, statics, and hydraulics, Captain Douglass served for the next three years as a Professor of Mathematics.[35] In 1823, after being promoted to Major, Douglass transferred to the Department of Engineering, a department just starting to offer "civil architecture and construction" along with its usual instruction in artillery practices, fortifications, and "Grand Tacticks."[36] Occasionally, Douglass left the Military Academy for forays into the field. In 1817 he made a reconnaissance of the defenses of Long Island Sound, and in 1819 he served as the astronomical surveyor for the commission establishing the United States border between Niagra and Detroit. The following year he accompanied General Cass on his exploration of the Lake Superior region. After joining the Department of Engineering in 1823, Douglass also served as a consultant on public works for the states of Pennsylvania and New York, and he surveyed the routes of the Upper Delaware Canal, the Sandy and Beaver Canal in Ohio, and the Morris Canal in New Jersey.

While Douglass served at West Point it was one of the few places in America which offered a formal engineering education. Most American engineers still learned their profession on the job; a "student" often started as an axeman or rodman with a surveying party and worked up from there. Lacking in European-styled polytechnical institutes, American engineers cut their teeth on the public works projects which proliferated after the completion of the Erie Canal. These projects served as "schools" of engineering, and the Erie Canal, running from Buffalo to Albany, had been the most impressive "school" of them all, graduating several of America's most prominent engineers in the first half of the 19th century.

Douglass, the Yale graduate and West Point professor, was cognizant of the fact that he was working somewhat outside of America's short tradition of civil engineering. The exciting, prestigious action was not in the classroom, but out in the field where engineers were solving actual problems and building bridges, canals, and the earliest railroads. To an extent Douglass got a piece of this action by doing consulting work, but that was not enough. So in 1831 he left the West Point faculty to become more directly involved in the work-a-day world of civil engineering. He abandoned lecture halls and French engineering texts to become Chief Engineer for the Morris Canal, whose route he had surveyed in the summer of 1828.

Douglass stayed with the Morris Canal for about a year and a half, during which time he improved it by substituting inclined planes for canal locks on long slopes. That job completed, he briefly returned to academe in 1832 as a Professor of Natural Philosophy at New York University. Douglass again found the role of full-time professor too restrictive, so in 1833 he resigned his chair of natural philosophy to accept a more compatible position. The university appointed Douglass a Professor of Civil Engineering, with the understanding that he would lecture on engineering only when and if he wanted. For Douglass, this was the perfect arrangement. He was still associated with academe, as he had been for virtually all his adult life, but he was also free to undertake any tantalizing engineering projects which came his way. In 1833, while surveying the route of the Brooklyn and Jamaica Railroad on Long Island, New York's Water Commissioners asked him to serve as a consultant. Douglass jumped at the chance, seeing it as an opportunity to get in on the ground floor of a major water-supply project that could elevate him to the top of his profession.

NOTES -- CHAPTER ONE

[1] This summary of the early history of New York's water problem is largely drawn from the following sources: Fayette B. Tower, Illustrations of the Croton Aqueduct (New York, 1843); Charles King, A Memoir of the Construction, Cost and Capacity of the Croton Aqueduct (New York, 1843); Edward Wegmann, The Water Supply of the City of New York (New York, 1896); Nelson Blake, Water for the Cities (Syracuse, 1956); and Charles H. Weidner, Water for a City (New Brunswick, 1974).

[2] For a more detailed description of early Manhattan water sources, see George Everett Hill and George E. Waring, Jr., Old Wells and Water-Courses of the Island of Manhattan (New York, 1897).

[3] The quote is taken from Weidner, p. 16.

[4] Weidner, pp. 17,18, 28.

[5] Lyceum of Natural History, "Report, Feb. 22, 1831," in In Common Council (New York, Feb. 28, 1831), p. 9.

[6] Tower, p. 57; King, p. 85.

[7] See Browne's "Memoir of the Utility and Means of Furnishing the City with Water from the River Bronx," in Proceedings of the Corporation of New York, on Supplying the City with Pure and Wholesome Water (New York, 1799).

[8] Browne, pp. 15-16.

[9] Ibid., pp. 22-24.

[10] King, p. 90.

[11] Tower, p. 58; King, p. 91; Weidner, p. 20.

[12] For a much more thorough account of Aaron Burr's Manhattan Company, see Blake, pp. 44-62. Also see Weidner, pp. 20-22; King, pp. 95-99; Tower, p. 58.

[13] King, pp. 100-101; Weidner, p. 24; Tower, pp. 58-61.

[14] See "Canvass White's Report, January 28th, 1824," in Fire and Water Committee, Report to the Board of Aldermen (New York, Dec. 28, 1831).

[15] See Canvass White, Report to the Directors of the New-York Water Works Company (New York, 1826).

[16] Tower, p. 61; King, p. 103.

[17] King, p. 105. Also see Wegmann, Water Supply of NY, pp. 16-17; Weidner, pp. 25-26.

[18] Weidner, pp. 26-27.

[19] For a discussion of the relationship between water purity and public health, see Blake, pp. 248-264.

[20] Lyceum of Natural History, pp. 8-10.

[21] King, p. 107.

[22] Fire and Water Committee, (Dec. 28, 1831), p. 1.

[23] Ibid., pp. 12-13.

[24] Weidner, p. 27.

[25] "Canvass White's Report," p. 20.

[26] Fire and Water Committee, (Dec. 28, 1831), p. 4.

[27] See "Report of Colonel DeWitt Clinton to Committee on Fire and Water, December 22, 1832," in Board of Aldermen Doc. No. 61, pp. 191-245.

[28] Quoted in Weidner, p. 29.

[29] Clinton's estimated elevation was approximately 40 feet too high.

[30] Blake, pp. 135-136; King, p. 115.

[31] Acts of the Legislature of the State and Ordinances and Resolutions of the Common Council . . . in Relation to the Subject of the Introduction, Supply, and Use of Croton Water (New York, 1861), pp. 3-4.

[32] This biographical sketch of Douglass is drawn from the following: "Major David Bates Douglass," Van Nostrand's Eclectic Engineering Magazine, January, 1872, pp. 1-6; G. W. Cullum, Biographical Register of the Officers and Graduates of the U. S. Military Academy (Boston, 1891) , I, pp. 35-36; Franklin B. Dexter, Biographical Sketches of the Graduates of Yale College (New Haven, 1912), pp. 550-553.

[33] The Laws of Yale College (New Haven, 1811), pp. 15-17.

[34] The Centennial History of the U. S. Military Academy (Washington: G.P.O., 1904), pp. 261-263.

Mansfield and Douglass used the following texts: Enfield's Institutes of Natural Philosophy; Parkinson's Mechanics, and Gregory's Treatise of Mechanics. They instructed the cadets in statics, hydrostatics, dynamics, hydrodynamics, heat engines, hydraulics, pneumatics, optics, electricity, magnetism, astronomy and machinery design.

[35] Ibid., p. 244.

Douglass used Hutton's Compendium as his main text and lectured on arithmetic, logarithms, algebra, geometry, trigonometry, land surveying, descriptive geometry and conics.

[36] Ibid., pp. 276-277. Also see "Studies and Class Books," in Regulations of the U. S. Military Academy at West Point (New York, 1823); and "Highlights of Department History," compiled for the Dept. of Military Art & Engineering, U.S.M.A., by N. E. Derhson, 1960, U.S.M.A. Archives.

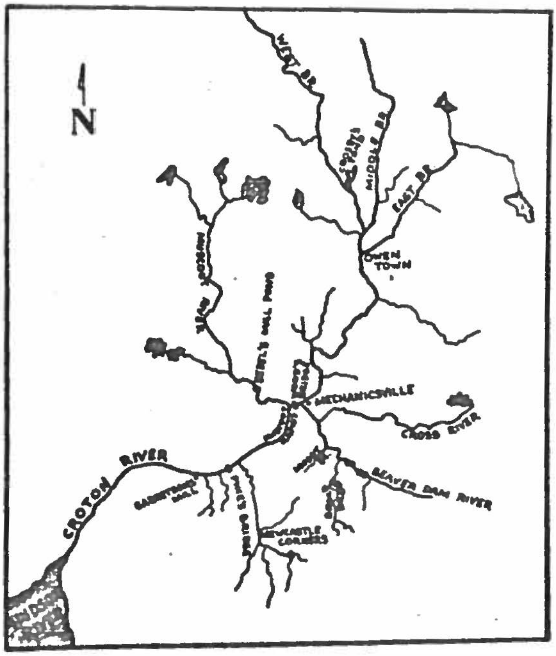
The texts used by the Department of Engineering in 1823 were Gay de Vernon's Treatise of the Science of War and Fortification; Hachette's Traité des Machines; and Sganzin's Programme d'un Cours de Construction.

CHAPTER TWO

From the very start of his service for the Water Commissioners, Major Douglass totally ignored many water-supply proposals that were being bantered about. He ignored the idea of damming the Hudson River to prohibit the entrance of salt water; he was oblivious to the die-hards who wanted to sink a number of very deep wells on Manhattan. Douglass concentrated on the question of whether it was feasible to deliver water from the Croton River into New York City. Traveling on foot and horseback, he spent the early part of June 1833 making a "general reconnaissance" of the Croton watershed and the Westchester land lying between the river and Manhattan. Then on June 20 he collected an eleven-man surveying party at the Croton's mouth. The party started its instrumental survey that same day and continued it until September 4. Between those two dates, Douglass and his men levelled over 200 miles and traversed more than 3,400 courses.[1]

After establishing the low water level of the Hudson River as their base or zero elevation, the men worked their way up the Croton, noting its elevation at certain key locations. At Wood's Bridge, near Mechanicsville, 12 miles from the Croton's mouth, the river's bed stood 170 feet above the Hudson. From Wood's Bridge Douglass led his men on surveys up the West, Middle, and East branches of the

PLATE II



Map -- Croton River Watershed.

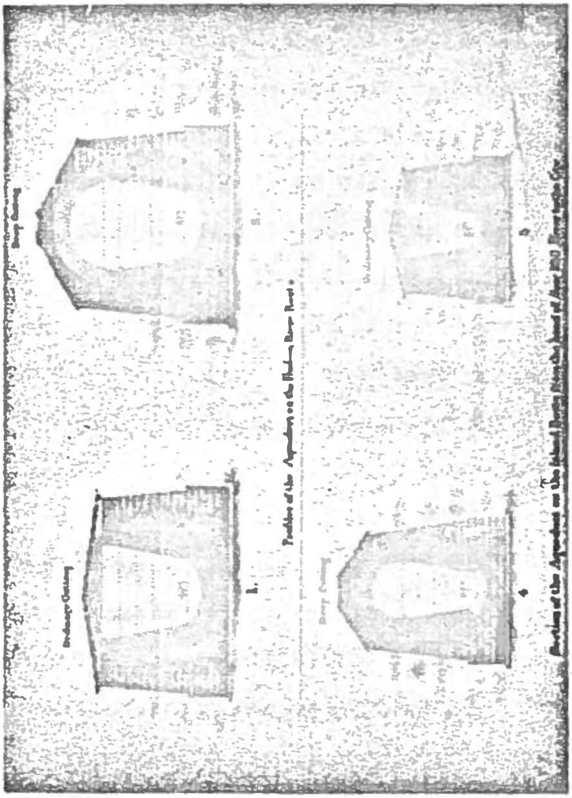
Croton. (Plate II.) They also went up to the outlet of Crosby's Pond and up the Muscoot to Bedel's Mill Pond. They levelled the Cross and Beaver Dam Rivers, as well as Broad Brook, Muddy Brook, and the Cisco River. Douglass believed he could take water for the aqueduct from any or all of these sources. After determining their elevations, the next step was to examine the ground south of the Croton "with a view of obtaining practical routes in the direction of the city."[2]

The land Douglass examined was "deeply undulating," marked by "irregular hills," and he hoped to find several convenient valley passages nestled between the slopes. The engineer quickly discovered, however, that all the various hills, taken together, "contained the rudiments of a great ridge" whose elevation was substantially higher than that of his potential water sources. Douglass dead-ended several times while seeking a passage through the ridge that would not require a prohibitive number of long tunnels or deep excavations. But finally Douglass found what he was looking for -- an aqueduct could follow the valleys of several small streams until it entered the larger Sawmill River valley, which ran southward towards Manhattan. Cutting the ridge to pass from one valley to the next would entail considerable work and expense, but no cut on the way to the Sawmill River presented insoluble problems.

Cutting the ridge south of the Croton seemed the shortest, most direct line to Manhattan, but Douglass anticipated that it was not the only line. Indeed, there was a more "obvious" route that Canvass White had briefly noted in 1824 and DeWitt Clinton, Jr. had suggested in 1832. Instead of turning south at its very start and confronting the ridge, an aqueduct could skirt it by staying in the Croton's valley and running southwestward until it entered the Hudson Valley. Then it could run towards Manhattan along the eastern bank of that river. After turning his attention to this idea, Douglass quickly concluded that the Hudson River route did not present "any difficulties involving the question of practicability."

With two possible routes leading from the Croton in hand, Douglass turned to surveying southern Westchester County, the northern portion of Manhattan, and part of the Bronx River watershed. When the surveying was concluded on September 4, he spent another three or four days gaging the flow rates of the streams and rivers he had examined. Then Douglass sat down to write his report for the Water Commissioners. In his report, dated November 1, the engineer restricted himself "to a <u>general outline</u> of the facts and principles concerned -- avoiding, as far as possible, all details not strictly necessary for the elucidation of the main question." The main question, of course, was whether an aqueduct from the Croton to Manhattan was feasible -- and Douglass answered with an unequivocal "Yes." To demonstrate this feasibility, he described how the city could lay a masonry conduit (Plate III) along either of the two

PLATE III

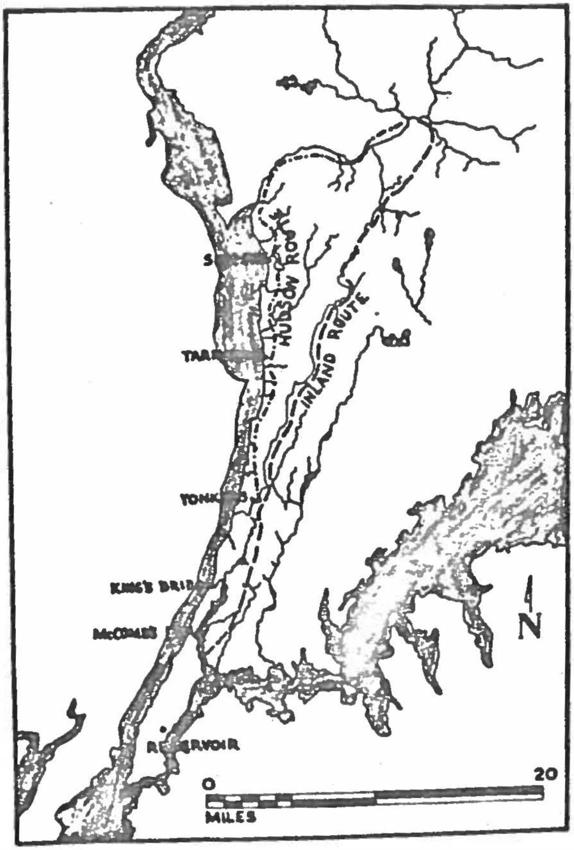


Cross-sections of Masonry Conduit Proposed by Douglass in 1833.

routes discovered by his surveying party (Plate IV).

Although an aqueduct which cut through the ridge, taking the "inland route," possessed the virtue of shortness, it lacked the virtue of simplicity.[3] Douglass' inland aqueduct required no dam across the Croton, because it did not draw its water directly from the river. Instead, in order to achieve a higher elevation at its start, the aqueduct commenced at a natural basin of solid rock located above the Croton at Mechanicsville. While the Croton's bed at this site had an elevation of 170 feet, the basin's elevation was 268 feet. To fill this "confluent reservoir," Douglass proposed to run iron pipes "of the largest size" out and up to the Croton's branches and feeders, intersecting them at points higher than 268 feet. Small dams on the feeders would prevent water from flowing naturally to the Croton's main channel. Douglass intended to collect the water in "fountain reservoirs," divert it into the pipes, and then conduct it to the elevated basin. From the confluent reservoir the free-flowing inland aqueduct began with a declivity or downward slope of one foot per mile. It cut the ridge south of the Croton by running successively within the Beaver Dam River, Muddy Brook, and Newcastle valleys. As it passed through a three-mile-long cut, at an average depth of 38 feet, the aqueduct left the Newcastle valley and entered the Sawmill River valley, where it began running with a drop of 6 feet per mile in order to better conform

PLATE IV



Map -- Routes of Croton Aqueduct Proposed by Douglass in 1833 Report.

to the valley's natural ground level. When it left the Sawmill and entered the valley of Tibbets Brook, Douglass graded the inland aqueduct with a drop of 2 feet per mile until it reached the bank of the Harlem River.

Douglass further complicated the inland aqueduct by suggesting that the city could build several water-storage reservoirs along its route. The changes in its declivity (going from one to 6 and then back to 2 feet of fall off per mile), also served to complicate matters. The masonry conduit's dimensions had to vary along different sections of the line, in order for those sections to have the same water-discharge capabilities. Water running at a greater fall off would travel with greater velocity, so Douglass sent it through a smaller conduit. Conversely, where he reduced the conduit's declivity he had to increase its cross-sectional area, to compensate for a loss of velocity.

When compared with the inland route, Douglass' alternative "Hudson River" route appeared a model of simplicity.[4] A 13-foot-tall dam on the Croton near Muscoot Hill backed up the water and created an 80 acre reservoir. Starting at an elevation of 175 feet, the aqueduct ran with a declivity of 15 inches per mile all the way to Manhattan. The aqueduct's line, until it passed considerably south of Tarrytown, was "wholly traced along the undulating hill-side of the Croton and Hudson" valleys. Where the high ground next to the Hudson began falling away, the aqueduct cut inland in order to find ground more hospitable to its established grade. The Hudson-routed aqueduct, like the inland aqueduct, eventually found its way to the Harlem River via the Sawmill River and Tibbets Brook valleys.

From the Harlem River into Manhattan, Douglass proposed only one line. Regardless of how it got to the Harlem, his prospective aqueduct crossed the river on a masonry bridge, a bridge with nine semi-circular arches which stretched 1188 feet across the Harlem's valley, and which rose some 126 feet above the river. Although Douglass had never built such an impressive bridge, he shrugged off its difficulties. In his report to the Water Commissioners he exhibited an optimism common among early American engineers:

> Our structure adapted to these dimensions would of course be a work of considerable labor and expense, but by no means of paramount difficulty in either of these respects. Many bridges of much greater magnitude, both in length and height, have been erected in other countries for the same object, from which we are enabled to derive certain data for all our calculations.

Douglass proceeded to mention six large aqueduct bridges in Europe, including the incompleted Maintenon aqueduct bridge in France, which had 666 arches and a length of 3¼ miles. He concluded that:

> With such examples of enterprise and skill before us, many of them undertaken for objects far less important than that of supplying the city of New-York with water, we may certainly look upon the design of the Harlem aqueduct without fear.[5]

From the Harlem River, Douglass ran the aqueduct first to a receiving reservoir bounded by Ninth and Tenth Avenues and by 133rd and 137th Streets. He then passed it through two equalizing reservoirs and terminated it at a distributing reservoir near 38th Street and Fifth Avenue. The distributing reservoir would provide a head to the city's future water mains of 117 feet above tide, or 15 feet more head than that provided Philadelphia by its Fairmount Water Works. The multiple reservoirs were both to store water, for use when the Croton might run low, and to assure a steady maintenance of the distributing reservoir's head. If the distributing reservoir were depleted, water from the nearest equalizing reservoir would automatically flow into it to relieve the deficiency. That reservoir would in turn be supplied by the one above it, and so on, until equilibrium was restored to the system.

Douglass' inland aqueduct ran a little over 43 miles long; the Hudson aqueduct nearly 47 miles long. After making "every calculation . . . on the side of stability and permanency," he estimated that the Hudson aqueduct would cost 4.7 million dollars and provide a daily running supply of up to 33 million gallons of water. (According to Douglass, there would be no difficulty in supplying this amount, because the Croton's <u>minimum</u> flow was 44 million gallons per day.) The estimated cost of the inland route varied, depending on how many iron pipes the city might choose to lay between the Croton's feeders and the confluent reservoir by Mechanicsville. For an estimated 4.5 million dollars, Douglass expected the inland aqueduct to deliver a minimum of 15.8 million gallons per day to Manhattan. For an additional 1.3 million dollars he thought he could boost its minimum to 26 million gallons.[6] Regardless of the selected minimum, the inland aqueduct could deliver a maximum of 30 million gallons daily. (Douglass was probably referring to Imperial gallons, each one equal to 1.2 U.S. gallons.)

Douglass did not choose between the two routes; he told the Commissioners that such a preference would have to be made on the basis of future examinations. And Douglass did not really argue the merits of a Croton aqueduct over those of a Bronx River aqueduct. He simply stated some figures and let it go at that. According to research undertaken by the Water Commissioners, London distributed 27 gallons of water per day to each of its citizens, while Philadelphia distributed 24 gallons and Edinburgh about 15. On an average, then, water works in large cities distributed about 22 gallons of water per day per person.[7] Given that New York's population would be 300,000 by the time the city could complete an aqueduct, it would have to deliver at least 6.6 million gallons per day just to meet the city's immediate needs. After gaging the Bronx, Douglass concluded that New York could "safely" depend on it for only 5.75

million gallons per day.[8] That, for him, closed the book on any Bronx River aqueduct, and for New York City as a whole it laid to rest a frustrating 35-year-long debate over the merits of such a project.

After receiving Douglass' report favoring the Croton, on November 12, 1833 the Water Commissioners presented a concurring report to the Common Council, and shortly thereafter they also reported to the State Legislature. Early in 1834, when the Council asked Albany for the authority to raise 2.5 million dollars to begin a water works, Senator Myndert Van Schaick again stepped to the fore to guide a water-works bill through the Legislature. On May 2, 1834 the Legislature passed an act directing the re-appointed Water Commissioners:

> to examine and consider all matters relative to supplying the city of New-York with a sufficient quantity of pure and wholesome water; [and] to adopt such a plan as in their opinion will be most advantageous.[9]

Under the provisions of this act the Water Commissioners were to re-examine their previous work, but they were to go beyond making just another survey or study. They were to adopt a plan that would first go to New York's Common Council. If approved there, it would go to the next general election. If the city's voters endorsed the plan, then the city could issue 2.5 million dollars worth of Water Stock, and the Water Commissioners could begin the work.

In their pursuit of an acceptable plan, the Commissioners asked Major Douglass to "re-examine his surveys, levels, and calculations." They hoped that he could find a way of building a Croton aqueduct which would entail "less labor and expense."[10] Initially the Commissioners, like Douglass, had made no choice between the inland and Hudson routes, but by now they preferred the Hudson route "both as to the practicability and expense of its construction."[11] Consequently, they instructed Douglass to try to shorten and improve that line. As a check upon his work, the Board also enlisted the services of John Martineau, a veteran canal builder, and George Cartwright, a Westchester engineer familiar with the Croton environs. As these men set out independently to do their work, the task which confronted each man was perhaps best summarized by another engineer:

> It was a field for the exercise of the talent and research of the engineer: in resorting to a distant stream for a supply, any plan which he might propose for conveying the water, would encounter obstacles requiring skill and ingenuity to overcome. He would find it necessary to build up the valleys, pierce through the hills, and span the waters of the arms of the sea which embrace the city and make it an island. Structures would be required, which in their design, would find no parallel among the public works of this country.[12]

On October 21 Major Douglass took to the field with an eight-man party. The men started their work at the Croton and endured uncomfortably cold weather before concluding on Manhattan on December 13. For the next month and a half, Douglass evaluated the field data and applied hydraulic, structural and economic criteria to try to discriminate between all the various means of carrying a Croton aqueduct along the Hudson River to Manhattan. Then, on the first of February, 1835, he submitted his second report to the Water Commissioners.[13]

The Hudson-routed aqueduct which Douglass reported in 1835 differed considerably from its predecessor. In his 1833 report he located a dam just above Muscoot Rapids, 11 miles from the Croton's mouth where the river was "compressed into a narrow channel" and "bounded on either side by bold shores." The Croton's bed at this site stood 163 feet above tide, so a dam only 13 feet tall would raise the Croton to 175 feet, an elevation which would allow the aqueduct to run with a desirable declivity of 15 inches per mile all the way into the city.[14] But after examining the Croton a second time, the engineer chose not to use the Muscoot Rapids site. He moved the dam 5½ miles downstream to just below Garretson's Mill.

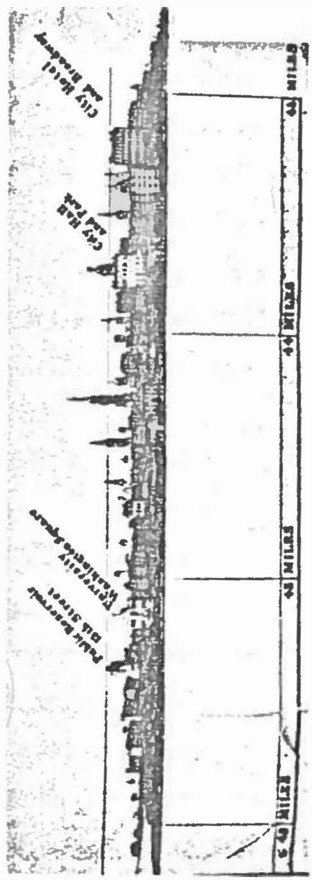
The downstream site was naturally suited for a dam; the Croton contracted and ran between a stone bluff and a steep hill. By moving the dam here, and shortening the aqueduct's run by 5½ miles, Douglass anticipated a savings of $92,000.[15] But in order to gain a savings of this magnitude, he had to sacrifice elevation — a commodity very valuable in its own right. Between Muscoot Rapids and

Garretson's Mill the Croton descended about 38 feet. Near the mill its bed stood only 122½ feet above tide. To fully regain this lost elevation, Douglass would have had to specify the construction of a dam some 45 feet tall at Garretson's Mill, and he did not want to do that for two reasons. First, he thought a 45-foot dam would be exceedingly expensive and difficult to construct. Secondly, such a tall dam would flood too much property on its upstream side and greatly increase the costs of a fountain reservoir. So instead of a 45-foot dam, Douglass opted for a dam 33 feet tall, and he settled for a reduced elevation of 155½ feet for the aqueduct's start. Since he sacrificed elevation, he also had to sacrifice declivity. The aqueduct starting at Garretson's Mill ran downward at a rate of 12, not 15, inches per mile.

After relocating the dam, Douglass had to adjust the aqueduct's line in Westchester to accommodate its new grade. From the dam down to below Tarrytown these adjustments were minor. The aqueduct still traversed the same range of slopes, but in general it ran a little further down in the Croton and Hudson valleys. Only near Greensburg did the engineer note the first significant change in the line. In his 1833 report the aqueduct left the Hudson at Greensburg and passed through a deep cut to begin running in the Sawmill River valley. But because of the reduction of the aqueduct's grade, Douglass now thought it would be too expensive to make this deep inland cut, so he carried the line further south along the Hudson and routed it into the Sawmill's valley at Yonkers. From the Sawmill the aqueduct passed along the valley of Tibbets Brook and crossed Bathgate's Meadow to reach the Harlem River. By the time it reached the Harlem, the new line virtually coincided with the 1833 line, and Douglass once again recommended a high bridge to carry the aqueduct over to Manhattan. Once on the island, instead of sending the aqueduct through four reservoirs, he sent it to a single, less expensive distributing reservoir tentatively located on Murray Hill (between Fifth and Sixth Avenues and 38th and 42nd Streets). The water in the reservoir would stand 114 feet 10 inches above tide, making the reservoir "competant to deliver the water, without any extraneous aid, upon the roof of every building in the city."[16] (Plate V.)

After delineating the aqueduct's route, Douglass described some of its physical characteristics, paying particular attention to its water-carrying channel. The channel had to be permanent, yet, as the Water Commissioners emphasized, it had to be as economical as possible. It also had to protect the purity of the Croton's water, which contained only 4.16 grains of solid matter per gallon.[17] Working with these criteria, Douglass narrowed

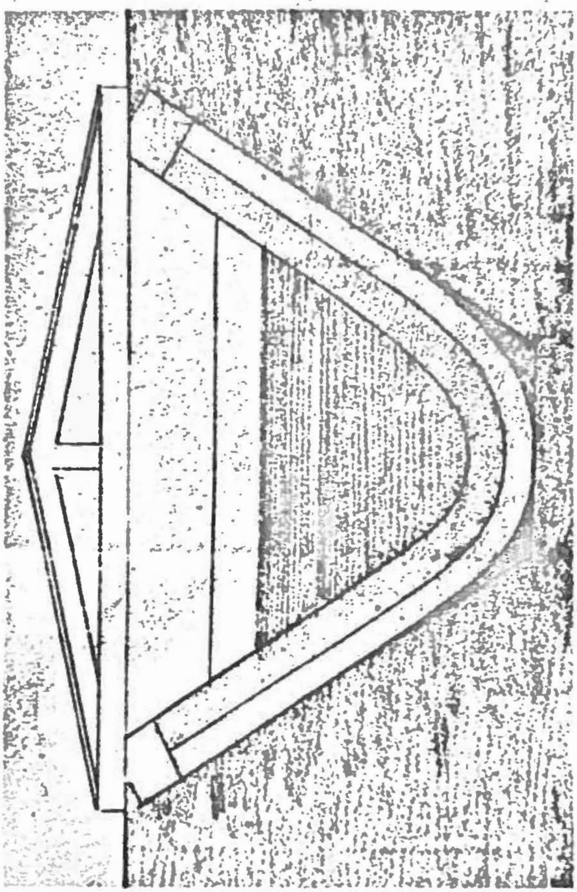
PLATE V



Level of Standing Water in Reservoir Proposed by Douglass in 1835 Report.

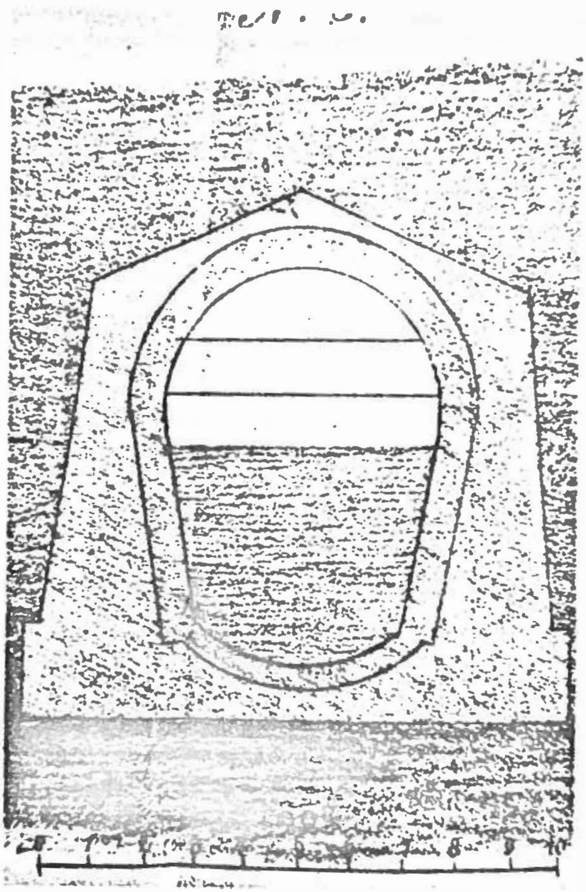
down his options. He dismissed the idea of a canal-like channel because it jeopardized the purity of the water under transport and offered no protection at all from frost. He abandoned the thought of constructing the aqueduct as an iron pipeline, because he feared the initial expense of iron pipes and at the same time doubted their durability.[18] Next he turned to the idea of a channel lined with masonry and covered with a wooden roof. (Plate VI.) This conduit was structurally sound; its inclined sides of brick and stone safely rested on earthen banks. And the shape of the conduit, with its slanting sides and rounded bottom, lent itself well to "self-cleaning." The water traveling down the conduit would scour the bottom and keep it free of sediment. This design's greatest asset, however, was its relatively low estimated cost of $43,620 per mile. Although it offered only minimal protection from frost, and although the wooden roof lacked permanence, Douglass felt that for the sake of economy the Water Commissioners could adopt this mode of construction on as many as 28 miles of the line. Still, there was a better way to construct the channel -- by making it a totally enclosed masonry conduit. (Plate VII.) Except for its high initial cost, estimated at $62,000 per mile, Douglass believed the enclosed channel of brick and stone "was preferable to every other."[19]

PLATE VI



Masonry Conduit Covered with Wooden Roof; Proposed by Douglass in 1835 Report.

PLATE VII



Totally Enclosed Masonry Conduit Proposed by Douglass, 1835.

In choosing a "horse-shoe" cross-section for the enclosed conduit, Douglass struck a compromise between hydraulic principles and the realities of construction. He knew that a cylindrical conduit would be the most efficient for carrying water. The water passing through any channel is slowed by friction as it passes against the walls, or the channel's "wetted perimeter." The cylindrical conduit is the most efficient, because for any given cross-sectional area it maintains a smaller "wetted perimeter" than any other geometric shape. Yet despite their knowledge and acceptance of this principle, engineers rarely constructed power or transportation canals or other hydraulic works in strict accordance with it. Instead, they generally adopted a cross-section which resembled a circle, but was less expensive, easier to construct, and, in some instances, more stable when put in the ground:

> The circle presents the best surface, and is therefore the most suitable for the conveyance of water, and the nearer we come to . . . a circle in the formation of the cross-section, the least resistence will the water meet with in its flow.[20]

Douglass' "horse-shoe" indeed mimicked a circle. The bottom was in fact part of a circle, an inverted arch. Then, in imitation of a circle which rises up and outward from its lowest point, Douglass planned for flat side walls which sloped outward as they rose from each end of the inverted arch. Over the bottom and sides, which would carry most of the water, the engineer proposed a semi-circular top arch. Compared with a circular cross-section, the "horse-shoe" was slightly less efficient, but its flat side walls were simpler to construct, the overall shape was easier for men to move and work in, and it provided, Douglass felt, "the greatest degree of stength and stability, with the smallest amount of material."[21]

Taken as a whole, Douglass' second report was much more thorough than his first, but it was certainly not complete or definitive. The engineer did not describe any of the aqueduct's structures -- its dam, reservoir, conduit, bridges, culverts, or embankments -- in detail sufficient to guide any future contractors in their work. And when Douglass' report was taken together with Martineau's, or with Cartwright's brief report, the proposed aqueduct became even less distinct. The engineers differed on point after point. While Douglass suggested a 33-foot dam at Garretson's Mill, Cartwright leaned towards a 40-foot dam at the mill, and Martineau, determined to shorten the aqueduct as much as possible, opted for a 150-foot dam just a mile upstream of the Croton's mouth.[22] Douglass proposed a "horse-shoe" conduit, while Martineau, following hydraulic principle to the letter, proposed a cylindrical conduit, and Cartwright an open canal. Douglass' aqueduct would deliver 30 million gallons of water per day. Martineau's would deliver 40, and Cartwright's only 20. Douglass would cross deep valleys with aqueduct bridges, while

Martineau preferred to throw massive embankments across low areas. Douglass retained his idea of a high masonry bridge to maintain the aqueduct's grade across the Harlem River; Martineau recommended that the river be crossed on a low structure carrying an "inverted syphon" of wrought iron pipes.[23] The Douglass aqueduct ran 41 miles and would cost an estimated 4.8 million dollars, if the enclosed conduit were used exclusively. Martineau's ran 36 miles at a cost of 4 million dollars. But despite all these differences, the engineers agreed on the essential point: New York could successfully build a Croton aqueduct which ran to Manhattan in the margin of the Hudson River.

The Water Commissioners, when they digested the engineers' reports, seemingly were nonplussed by the variant plans. Perhaps they were even pleased that their resourceful consultants presented them with such an assortment of means to accomplish the same end. At any rate, on February 16, 1835 the Commissioners reported to Common Council their own plan for a Croton aqueduct which would cost an estimated 4.25 million dollars. The Commissioners proposed:

> that a dam of sufficient elevation be erected near the mouth of the Croton River, and from thence the water to be conducted in a close/d/ stone aqueduct to Harlem River. The river to be crossed by inverted syphons of wrought iron pipes of 8 feet in diameter, formed in the manner that steam boilers are. From the south side of the river, a line of stone aqueduct will again commence, and proceed across Manhattan Valley to the distributing reservoir at Murray's Hill.[24]

The Commissioners' "plan" was none too specific, but it certainly succeeded in presenting the Croton aqueduct as a simple and straight-forward exercise in civil engineering. Common Council approved the plan, and in the next general election, held April 14-16, New York City's voters supported it by a three-to-one margin. With that final endorsement in hand, early in May the Common Council instructed the Water Commissioners to get on with the work. The Commissioners immediately began searching for a Chief Engineer for the Croton Aqueduct, and on June 2 they unanimously chose to employ Major Douglass at an annual salary of $5,000. The Commissioners and Douglass entered the aqueduct's implementation phase with the highest expectations. The Water Commissioners expected their seasoned engineer to carry the work to a prompt completion, and Douglass expected the Croton project to shoot him to the top of his profession.

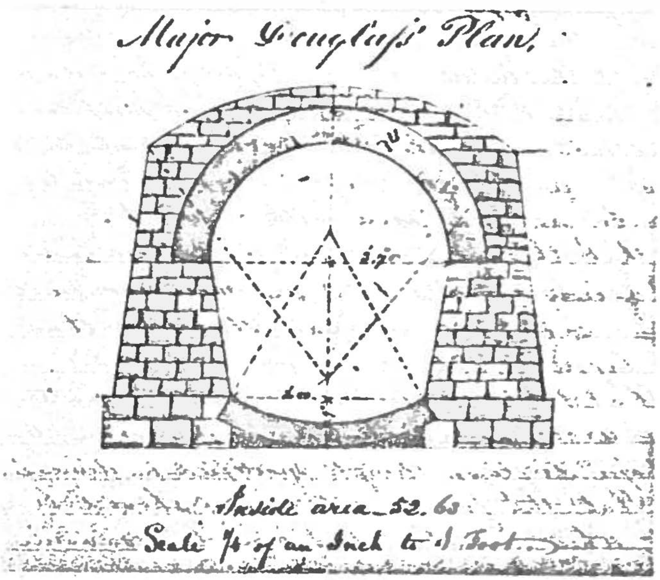
By the time the Commissioners hired Douglass as Chief Engineer, they had fleshed out the skeletal aqueduct plan written up in February. They decided that the Croton Dam should be 40 feet tall and located a short ways downstream of Garretson's Mill.[25] They also wanted a receiving reservoir north of the single distributing reservoir that Douglass specified in his 1835 report. After informing their new Chief Engineer of these decisions, the Commissioners instructed him "to select a proper Corps of assistants at as early a day as possible." Douglass accordingly requested an engineering corps of 17 men, composed of 5 assistant engineers, 5 rodmen, and 7 chain-men and laborers.[26] With about a third of these positions already filled, the new Chief Engineer and his party hurriedly took to the field on June 6 and headed up to the Croton.[27]

The first order of business was to identify the land the aqueduct would occupy, so Douglass' corps staked out the boundaries of the fountain reservoir to be formed behind Croton Dam. The Commissioners hired George Cart-wright to assist in this work by surveying the reservoir and preparing its land maps.[28] After staking the fountain reservoir, Douglass moved back to Manhattan to stake out the reservoirs there. Then he and his men returned to Westchester to run the aqueduct's line from the dam down to the Harlem River, a line predicated on a 40-foot dam and a declivity of a little over 13 inches per mile. Cartwright presented the Commissioners with his land maps of the fountain reservoir in November, while Douglass still worked the line. Finally, by January 8 the corps had staked the line all the way to the Harlem, and Doug-lass abandoned field work for the rest of the winter.

Set up in a New York office, Douglass retained eight members of his corps to conduct the office work needed in advance of the next summer's field operations. Their foremost task was to prepare a set of maps showing the Commissioners exactly what land they needed to purchase, and who presently owned it. The engineering corps also started to develop a general schema for embankments, tunnels and excavations, and more particularized plans for larger structures such as Croton Dam and the high bridge over the Harlem. Because the Water Commissioners now wanted a larger aqueduct, Douglass worked on the cross-section for a new conduit capable of delivering 45 to 50 million Imperial gallons daily.[29] (Plate VIII.)

In February Douglass temporarily put these tasks aside to deal with an inquiry from the Mayor regarding "the practicability and expense of raising water from the North [Hudson] or East River by steam power, and delivering it into the contemplated reservoir on Murray's Hill."[30] As soon as Douglass could finish the reservoir, the Mayor wanted to store local river water in it for fire-fighting purposes. This practice would of course be temporary, lasting only until the Chief Engineer completed the entire aqueduct, and Croton water filled the reservoir. Douglass sympathized with the Mayor's request. In December, when he was still staking the line for the long overdue aqueduct, New York had suffered the worst fire in its history, which ravaged 20 blocks in the commercial district and

PLATE VIII



Douglass' Last Conduit Plan.

put thousands out of work. But although sympathetic to the request, the Chief Engineer discouraged it. First, he could not complete the Murray Hill reservoir much in advance of the rest of the line, and secondly, it would be a mistake to run corrosive salt water through any cast iron pipes later to be used for distributing the Croton's water.

The office work proceeded slowly during the winter, and when the season drew to a close the engineering corps had not finished the land maps or any final drawings or specifications for the aqueduct. The Commissioners were dismayed by such a "lack of energy in the operations of their Engineer department," but actually they were growing accustomed to this kind of disappointment.[31] Their high expectations had faded. Long before the winter ever closed, the Commissioners, and particularly Stephen Allen, were at odds with the Chief Engineer.

The friction between Allen and Douglass resulted from a variety of factors. A politician and an engineer were not above having a personal squabble, and to an extent their falling out reflected the fact that two strong-willed, proud individuals were seeking prestige and credit for executing the same project. Allen felt that Douglass, with two feasibility studies behind him, should have proceeded more quickly with the work in 1835. Douglass, on the other hand, considered the two earlier reports as mere preliminaries, every point of which he had to carefully review.

The real conflict, however, resided in their opposing views of the proper working relationship between the engineering corps and the Board. Douglass believed that his corps should be virtually autonomous, and that he should decide all technical matters regarding the aqueduct. Allen, on his part, felt that if Douglass exercised such authority, then the Commissioners would be "deprived . . . of nearly all the powers given them by the act under which they were appointed."[32]

This basic conflict must have arisen almost simultaneously with Douglass' appointment. In his last feasibility study, he had opted for a 33-foot dam just below Garretson's Mill; the Commissioners instructed him to construct a dam 40 feet tall and a little further downstream. The Water Commissioners, not Douglass, brought in George Cartwright to prepare land maps of the fountain reservoir. Douglass continued to plan for a high bridge across the Harlem; the Commissioners publicly endorsed Martineau's idea of an inverted syphon. Douglass protested each time the Commissioners intervened in the affairs of his engineering corps, and with each protest Stephen Allen grew more weary of the Chief Engineer's recalcitrance. It was a situation that could only grow worse over time, as the two men played a serious game of constantly testing the mettle and resolve of the other.

Stephen Allen had hoped to let some contracts on the aqueduct in 1835. Since the Chief Engineer had failed to complete the land maps over the winter, he began to fear that no contracts would be let even in 1836. Knowing how anxious Allen was to put the line under contract, Douglass tried to manipulate that anxiety. He tried to get Allen to recognize that only a strong and well-manned engineering corps could quickly dispatch the work. On March 12, 1836 the Chief Engineer proposed to engage a corps of 60 to 70 men for the summer, including Major Thomas B. Brown, who was to be hired as his principal assistant engineer at an annual salary of $3,500.[33] This proposal was extravagant, even for a project of the aqueduct's size and importance. The Water Commissioners immediately denied it, and Allen no doubt hoped that the denial would prompt the Chief Engineer to resign -- but he did not. On March 15 Douglass proposed a smaller, more modest corps. The Commissioners delayed their approval until April 9 -- and still Douglass did not resign. So on April 11 a dogged Chief Engineer took to the field with a corps which numbered, in different months, from about 13 to 21.

Allen, needless to say, was distraught to see Douglass return to Westchester County only to begin his fourth survey of the aqueduct's line. Allen called him on the need for such repetition, and Douglass answered that he was still seeking to shorten and improve the aqueduct. He also said, according to Allen, that "It would be a great advantage to the work, if every one of the engineers employed, did instrumentally make a level and survey of the line."[34] The Commissioners' Chairman took this to mean that another survey would be good training for Douglass' engineers, and even though he knew that many engineers still learned their profession on the job, Allen felt it imprudent of Douglass to be running training exercises at this time. Stephen Allen wanted nothing to do with neophyte engineers; he wanted land maps, specifications, contracts, and then construction.

Allen finally received some of the land maps on June 11, and on June 17 Douglass provided the remainder. But as far as Allen was concerned, this was a case of getting too little too late. If the recalcitrant Chief Engineer would not resign, then the Commissioners simply had to establish proper grounds for firing him. They quickly set this up. On June 23 they passed a resolution requiring Douglass to furnish them with:

> plans and specifications of the Croton Aqueduct, the several tunnels along the line of the aqueduct, the embankments on said line, culverts, the Croton Dam, the Aqueduct Bridge over Sing Sing Kill and across Harlem River, with proper descriptions of materials to be used, the manner in which they would be worked together, and all necessary information to enable the commissioners to place a part or whole of the work under contract with as little delay as possible.[35]

Major Douglass acknowledged receipt of the resolution on July 26, but he sent no plans or specifications. On September 13, instead of sending plans, he again requested that Major Brown be hired as his principal assistant. If Douglass stalled in a final attempt to impress the Commissioners with the need for a stronger, larger engineering corps, the ploy failed miserably and played right into their hands. The Commissioners did not believe Douglass was short-handed; they believed he had proved himself an incompetant Chief Engineer:

> The conclusion was irresistible, and it was unanimous with the commissioners, that Mr. Douglass doubted his own ability to perform the duty required of him in preparing the necessary specifications . . . of the work.[36]

Long before September 1836, Stephen Allen had reached another conclusion: that the Board had hired the wrong type of civil engineer. They had hired "a mere theorist in engineering."[37] In 1840, in a published letter Allen more fully expressed this conviction:

> I have always admitted, that Mr. Douglass was a ripe scholar, a good mathematician, and in theory, well acquainted with the science of engineering . . . . But my opinion, nevertheless, was and still is, that he does not possess that practical knowledge which I deemed necessary to carry on a work of so much importance to the City . . . , and holding these opinions, I should have been traitor to the trust reposed in me, if I had not urged upon the commissioners, the necessity of a change in the office of the Chief Engineer.[38]

Douglass, the Yale graduate, the professor at the Military Academy and at New York University, was a man steeped in engineering literature, and a man practically devoid of any first-hand experience in construction. Aside from his work on the Morris Canal, Douglass had never built anything. He was an excellent surveyor, and he often served well as a consultant. But a consultant offered opinions and structures on paper. A Chief Engineer had to go beyond the paper, beyond initial conceptions, and carry them through to finished bridges, culverts, embankments, reservoirs and dams. Because Douglass failed to meet the more exacting demands placed upon a Chief Engineer, the Commissioners fired him on October 11, after already hiring his successor. Following his dismissal, for the next 12 years before he died in 1848, Douglass wandered in and out of several academic positions. Ultimately he became known not as a great engineer, but as a capable designer of cemetaries.

In 1840, when Stephen Allen's Board of Water Commissioners were themselves removed from the Croton project, in favor of a Whig Board appointed by a Whig governor, Major Douglass attempted to regain the Chief Engineership. In defense of his failure to put the Croton Aqueduct promptly under contract, he recited all of the times when the first Commissioners had refused to provide him with a strong engineering corps.[39] This defense, although it garnered some support for Douglass, was really a poor one, because the man who succeeded him had already destroyed the alibi four years earlier in a six-month flurry of engineering activity. In September of 1836, Douglass had had a corps of 21 men: 5 assistant engineers, 2 draftsmen, 2 levellers, 7 rodmen and 5 axemen.[40] When his successor took over on October 20 he did not augment the staff. On the contrary, when winter arrived and field work ceased, he laid off two-thirds of the men. Yet by the beginning of spring, 1837, the successor, "an energetic and practicable Engineer,"[41] had prepared the structural plans and specifications needed to put the Croton Aqueduct under contract. The successor was John Bloomfield Jervis, Civil Engineer.

NOTES -- CHAPTER TWO

[1] Douglass' work in 1833 for the Water Commissioners is described in his "Engineer's Report," included in "Report of the Commissioners Under an Act of the Legislature of this State, Passed February 26, 1833, Relative to Supplying the City of New-York with Pure and Wholesome Water," Board of Aldermen Document No. 36 (New York, Nov., 1833), pp. 381-408.

[2] Ibid., pp. 381-382.

[3] Ibid., pp. 386-397.

[4] Ibid., pp. 397-401.

[5] Ibid., p. 394.

[6] Ibid., pp. 397, 401.

[7] Ibid., pp. 365-366.

[8] Ibid., pp. 403, 407.

[9] The full text of the May 2, 1834 act is found in Acts of the Legislature, pp. 5-11.

[10] "Report of the Commissioners Under an Act of the Legislature of this State, Passed May 2, 1834, Relative to Supplying the City of New-York with Pure and Wholesome Water," Board of Aldermen Document No. 44 (New York, Feb., 1835), p. 325.

[11] Stephen Allen, "New York Water Works No. 1," MS, Stephen Allen Papers, New York Historical Society.

[12] Tower, p. 69.

[13] See "Report of Mr. D. B. Douglass," Doc. No. 44, pp. 403-433.

[14] In Doc. No. 36, Douglass called for a 13-foot dam; in Doc. No. 44 he refers to the dam as being 14 feet tall.

[15] Doc. No. 44, pp. 404-407.

[16] Ibid., pp. 414-415.

[17] "Mr. Chilton's Report," Doc. No. 36, pp. 409-410.

[18] Doc. No. 44, note, pp. 421-422. Also see Doc. No. 36, pp. 402-404.

[19] Doc. No. 44, pp. 424-429.

[20] Ibid., p. 358. The quote is from Albert Stein, a civil engineer who apparently volunteered technical assistante to the Commissioners.

[21] Ibid., p. 427. For a discussion of the horse-shoe cross-section, see Edward Wegmann, Conveyance and Distribution of Water for Water Supply (New York, 1918), p. 242.

[22] Doc. No. 44, pp. 360-361, 483-486.

[23] Ibid., p. 496.

[24] Ibid., p. 366.

[25] Allen, "New York Water Works No. 1."

[26] Allen, "New York Water Works No. 1." Also Board of Aldermen Document No. 12 (New York, Aug. 1, 1836), p. 63.

[27] For Douglass' version of his efforts as Chief Engineer, see his letter in the New York Times & Star, Oct. 30, 1840. Also found in New York Courier and Enquirer, Oct. 28, 1840.

[28] Doc. No. 12, p. 63.

[30] Board of Aldermen Document No. 89 (New York, Feb. 15, 1836), p. 467.

[31] Board of Assistant Aldermen Document No. 24 (New York, January 9, 1837), p. 103.

[32] Allen, "New York Water Works No. 1."

[33] Douglass, Times & Star, Oct. 30, 1840.

[34] Allen, "New York Water Works No. 1."

[35] John Travis, ed., "Memoirs of Stephen Allen," p. 159. Typescript located in New York Historical Society and in Manuscript Division, New York Public Library.

[36] Stephen Allen, letter, New York Morning Courier and Enquirer, Nov. 12, 1840.

[37] Allen, "New York Water Works No. 1."

[38] Allen, Morning Courier and Enquirer, Nov. 12, 1840.

[39] Douglass, Times & Star, Oct. 30, 1840.

[40] "Schedule of Pay," Sept., 1836, Jervis Papers.

[41] Allen, Morning Courier and Enquirer, Nov. 12, 1840.

CHAPTER THREE

In September, 1836 Stephen Allen and Saul Alley visited John Jervis in Albany, where he was working on the enlargement of the Erie Canal. They told Jervis that they were definitely going to oust Major Douglass, and they asked him to assume the role of Chief Engineer for the Croton Aqueduct. Jervis, a man with a strong sense of professional ethics, later wrote that he was "quite surprised at receiving the proposition," which he accepted because he saw "no impropriety in accepting a position that appeared professionally desirable and [had been] offered without the least effort or knowledge" on his part.[1] Yet Jervis should not have been too surprised by the Water Commissioners' offer, because for over nine months he had known that Douglass had only a tenuous hold on his Chief Engineership.

The first inkling of Douglass' fall from grace came to John Jervis from Stephen Allen himself. Towards the end of 1835, Allen asked Jervis for copies of specifications and contracts he had written for canals in New York State. Allen said he wanted to study these documents; he wanted to see if they were in any way applicable to the Croton Aqueduct.[2] John Jervis recognized that Allen's communication was more than a simple request for information. He took it as a distinct sign that Douglass had performed his duties unsatisfactorily. There was no other reason for Allen to have consulted an outsider on the matters of specifications and contracts, which were clearly the responsibilities of the incumbent Chief Engineer.

Between January and March of 1836, Senator Myndert Van Schaick presented Jervis with a stronger signal of the trouble brewing between Douglass and the Commissioners. Van Schaick, the influential supporter of the legislation which created the Board of Water Commissioners, invited Jervis to New York to examine the plans for the aqueduct. He also expressed the desire that Jervis become professionally involved in the project, perhaps as Chief Engineer. It is not clear today, and it may not have been clear to Jervis, if Van Schaick contacted him strictly on his own initiative, or if in fact he spoke as a liason sanctioned by Stephen Allen.[3] In either case, men closely associated with the Croton Aqueduct had contacted Jervis twice, and both contacts pointed to serious problems within the engineering corps. His curiosity aroused, John Jervis investigated the situation, using a very convenient and reliable informant. His brother, F. B. Jervis, worked on the aqueduct. When Jervis sent Allen the requested documents on state canals, Allen had reciprocated the favor by placing F. B. Jervis in a position under Douglass.[4]

On January 27, 1836 F. B. Jervis wrote his brother that progress was being made, "though very slow[ly], in getting ready for contracts on the water works. When the plans are developed, I shall advise you in relation to their character." On February 16 he wrote that "We are going on quite slowly with our office work," and he added that "I have through the politeness of Maj. Douglass obtained a copy of the most important documents published in relation to the N. Y. Water Works, which I will send you by first opportunity." Then, on March 25, apparently in response to a specific query from John Jervis, F. B. Jervis wrote:

> I do not know that it would be practicable for me to give you an accurate view of the difficulties existing between Maj. Douglass and the Water Commissioners. I have formed the opinion that the Commissioners, and especially Mr. Allen, wish to so arrange the work so that the credit of its successful prosecution will fall exclusively to them . . . . The Board have been almost continually passing Resolutions for the last two or three weeks, the general tenour of which go to show in some form that the Board have little confidence in the Engineer. In my opinion, he should resign at once.[5]

So before Allen and Alley called on him in September, John Jervis was familiar with the history of the Croton project and with the progress, or lack of progress, in its planning. He also knew that a new Chief Engineer for the Croton Aqueduct was a virtual certainty. Yet there is no evidence that Jervis in any way conspired with Allen for Douglass' removal in order to further his own career. Stephen Allen may have schemed for Douglass' removal on both personal and professional grounds, but Jervis had no active part in this. If he exacerbated the falling out of Allen and Douglass in any way, it was only by his proximity and stature. Jervis was close at hand, and he was a better engineer than Douglass -- and Jervis could hardly be faulted for that.

John Jervis could have attributed his success as a civil engineer to numerous factors, including happy circumstance. He had a nimble, inquisitive mind. A small man, whatever he lacked in size he more than made up for in energy and perseverance. Judged by modern standards, he was perhaps a "workaholic." He lived for his profession, was totally dedicated to it, and his private life was subservient to his professional one. Engineering, to Jervis, was more than a bread-winning occupation. It was a serious, demanding way of life imbued with heavy responsibilities. And yet his entrance into the profession had been quite by accident.

Jervis was born in Huntington, Long Island on December 14, 1795, the son of Timothy and Phebe Jervis.[6] In 1798 his family moved to Rome, a small community in heavily-timbered upstate New York. Raised in Rome, John Jervis endured the hardships and trials of a pioneer. The young boy undoubtedly learned a great deal from his father. Timothy Jervis had been trained as a carpenter, but in Rome he farmedand operated a sawmill. While John Jervis worked beside his father to clear land, cut timber, and run logs through the family sawmill, he provided himself with a very practical knowledge of labor, materials and mechanics that would be of much use later in his life. Jervis himself never underestimated the value of the hard toil he had undertaken in Rome's rugged environment. Later, when he was in a position to hire young men aspiring to become civil engineers, he displayed a marked preference for aspirants raised in the country. He preferred the sons of farmers over the sons of "influential men in the city."[7]

Timothy and Phebe Jervis belonged to the Congregational Church in Rome, a church aligned with Calvinist theology. The parents were anxious for their children to receive a good education in the proper life of a Christian, so John Jervis, like his six brothers and sisters, read his Bible and New England primer and developed a life-long interest in man's relationship to his God. In Jervis' case, this interest went far beyond any intellectual or spiritual curiosity. He integrated his religion, his life and his work. Jervis trusted in God, but he believed that a "proper trust in God does not exclude the means God has provided for our use. It rather inculcates prudence and energy in conforming to . . . His Commands."[8] His religion freed him to act, to build, and to strive for success, but all the while John Jervis tried to act in a moral, sober, dedicated and responsible manner. When Jervis was 81 years old and wrote on the attributes of a good engineer, he made apparent the influence of his moral philosophy:

> A true engineer, first of all, considers his duties as a trust, and directs his whole energies to discharge the trust, with all the solemnity of a judge on the bench. He is so immersed in his profession, that he has no occasion to seek other sources of amusements, and is therefore always at his post.[9]

His common schooling ended at age 15, and John Jervis, as he grew to adulthood, looked forward to a life that was much like his father's. He toyed with learning Latin for a short while; he contemplated various careers. But at age 22 he was still home, still working the farm and sawmill. As it turned out, that was the perfect place for him to be at the time.

In 1817 Judge Benjamin Wright, a friend of the Jervis family, stopped by the house to ask Timothy Jervis for the use of a few of his men. Wright was embarking upon an exciting project -- the construction of the Erie Canal -- and as Chief Engineer he needed men to clear timber for a surveying party. John Jervis was luckily in attendance when Wright visited, and axe in hand he went off to join a surveying party on the Erie Canal. Eight years later, when he left the canal, he was one of the foremost graduates of the Erie's "school" of engineering.

Jervis' rise from axeman to engineer was meteoric.

In the summer of 1817 he cleared timber and cut stakes and pegs for the men routing the canal. In the summer of 1818 he served as a rodman. Later that year, having advanced to become one of the "men using the instruments," Jervis conducted levels. During the winter he served as a stone-weigher between Onandaga and Syracuse, and the following summer Benjamin Wright named him resident engineer of the 17-mile stretch of canal running from Canastota to Lime-stone Creek. In truth, John Jervis had not proven himself an engineer by 1819, but at least for the first time he attained the title. That was one fortunate aspect of the Erie project -- there were so few qualified civil engineers in America that a hard-working, inquisitive beginner, quick to learn, was also quick to be given greater responsibili-ties. These responsibilities in turn presented new prob-lems to solve, new knowledge to be acquired, and new opportunities for advancement. As long as a young, ambi-tious prospect did not falter, his upward mobility was almost unlimited.

By the time Jervis left the Erie Canal in 1825, he had indeed earned the title of "civil engineer." He had learned to survey, run levels, draw maps and profiles. He had learned how to manage construction and repair opera-tions and to provide cost estimates for work to be done. Jervis had constantly studied the work done by the men above him, so that whenever an opportunity came for advancement, he was always ready for it. He carefully studied the plans provided by the office of the Chief Engineer for locks, wooden aqueducts, waste weirs, and culverts. All the while he gained more experience and became more confident of his own abilities. Jervis began to initiate his own technical designs, and this was a critical step in his professional development:

> Holding strict ideas of discipline, I was very careful . . . to fully understand and strictly carry out all directions from my superiors . . . . They rarely made complaint of my operations but often gave me encouraging words, implying satisfaction with the direction I had exercised. As time went on, and I had become more familiar with the wants of such works, I gradually began to criticize the plans, being careful to keep my own counsel until I had fully matured my views in every particular.[10]

On the Erie Canal, Jervis learned most of his engineering in the field. It was a practical education, designed to improve his competence in solving real and immediate problems. But the young engineer did not slight the academic side of his profession. To supplement his field lessons, he started building a collection of technical literature that he continued to augment throughout his life. Jervis was not content with learning a new skill simply by imitating his peers or by relying on his own ingenuity. He began to read. He studied surveying and drawing, mathematics, mechanics, mill-wrighting, carpentry, architecture, hydraulics, and natural philosophy.[11] In 1830, in a letter to Professor James Renwick at Columbia College, he faulted those early American engineers, even the "most eminent" ones, who had not done the same:

> In the profession generally, there is doubtless a great deficiency in scientific knowledge. This in great measure may be attributed to the limited education of a large portion of those who were early admitted to subordinate stations in the parties of engineers, and who by their application becoming familiar with the ordinary duties and the plans of construction pursued on the work in which they were engaged, were considered engineers, without ever having made much inquiry into the reasons or principles of what they had been doing or its applicability to other situations.[12]

After serving for two years as a supervising engineer on an operating 50-mile stretch of the Erie, Jervis left the canal in March, 1825. In his own words, he was "an engineer seeking new fields of occupation," and he "looked to new enterprises."[13] Jervis wanted to further his own education and to elevate his status within the profession by becoming involved in a new and different project. In doing so he was following a common pattern for early civil engineers in this country. The best engineers sought out the most difficult and challenging work they could get, and after completing that work they quickly moved on to yet another project.

Benjamin Wright, who hired Jervis as an axeman in 1817, hired him as his principal assistant engineer on the Delaware and Hudson Canal in 1825. Although he was second in command of the Delaware and Hudson, Jervis organized its engineering department and superintended the work because Wright, busy working on several projects at once, was largely a Chief Engineer in absentia. Wright maintained final authority, but Jervis routed the canal and prepared its plans and specifications. When Wright resigned his position in 1827, the canal company appointed Jervis, for the first time in his career, as Chief Engineer.

In the spring of 1830 Jervis resigned his position on the Delaware and Hudson to become Chief Engineer for the Mohawk and Hudson Railway. In 1833 he returned to canal building as Chief Engineer for the Chenango Canal, which ran 98 miles from Utica to Binghamton, New York. While working on the Chenango he also served as a consultant on the proposed enlargement of the Erie Canal, and when New York State began the enlargement in 1836 Jervis served as Chief Engineer on the Erie's eastern division. Jervis, however, did not work long on the new Erie project. On September 27, 1836 he accepted the position of Chief Engineer for the Croton Aqueduct.[14] The Water Commissioners terminated Douglass on October 11, and Jervis took over nine days later. If Douglass had been too academic, lacking in experience and in the confidence necessary to erect the Croton Aqueduct, John Jervis suffered from none of these ills. He took command in a very literal sense, and within just a few days the project was his. In 1842, when describing the first flow of Croton water into Manhattan's distributing reservoir, one of Jervis' subordinate engineers wrote that "our Chief Engineer arranged his corps and made his movements with all the circumspection and tact of a Napoleon." Fayette B. Tower's remark aptly underscored Jervis' dominant role in building the aqueduct, and Tower intended no pejorative. He also described the Chief Engineer as "a man of so much worth" who had shown him "so much kindness."[15]

When Jervis assumed command of the aqueduct's engineering department, everyone felt a high level of anxiety. The Water Commissioners were anxious to begin construction immediately, but Jervis successfully checked their impatience and earned a needed delay until the following spring. Because winter was almost upon them, even if they contracted for work, virtually no construction could go forth until the return of favorable weather. And because Douglass had produced few if any final plans for the aqueduct's structures, no specifications detailing how the work was to be done, and no contract forms, the engineers simply could not prepare themselves for construction until after the winter. Actually, even if Douglass had left complete plans for the aqueduct, Jervis still would have pressed for delaying contracts and construction until the following spring. He would have insisted upon fully evaluating those plans before any contractors started work.

Because of their conflicts with Douglass, the Water Commissioners were also anxious to define the proper working relationship between themselves and their Chief Engineer. They sought "perfect harmony and confidence" between the two parties. After discussing the subject with Jervis, on November 19 the Board passed a resolution which delineated the Chief Engineer's many responsibilities, and which at the same time made it clear that he did not head an autonomous department.[16] Jervis was to recommend applicants for engineering positions, and he was to supervise all of his department's work -- but the Commissioners maintained final authority in all matters relating to the engineers. Jervis was responsible for preparing all maps, drawings, and working plans, and for selecting materials and establishing standards of workmanship -- but all of his plans were subject to review. After the plans were prepared and approved, Jervis was to write the contract forms and to assist the Board in the letting of contracts. Once contracts were let, it was "under the immediate inspection and control of the Chief Engineer" to see that they were faithfully performed -- but the Commissioners, not the engineers, served as final judge in any contractual disputes.

The resolution made several other points. It set the Chief Engineer's salary at $5,000 per year and recommended that he "enforce a reasonable and just discipline" within his department. It informed Jervis that all engineering drawings "must be plain and without ornamental painting," and that in most instances the engineers themselves would pay for needed surveying instruments. Jervis agreed with this last point, believing that "It is no doubt most proper that Engineers should furnish their own instruments. This arrangement is most compatible with the proper dignity and character of the profession."[17] Jervis, in fact, agreed with all the points in the resolution, but he noted that the Commissioners had made an important omission:

> In deciding on the plans that may be proposed by the Chief Engineer, while the Commissioners should have the right to make such modifications as to them appear necessary and proper, it should be considered in the right of the engineer to decline a superintendence if in his opinion, the mode determined on by the Commissioners is unsafe, or such as would in his opinion, be hazardous to his reputation as an engineer.[18]

Jervis recognized the politics of the situation; the Board of Water Commissioners had the final decision on all important matters relating to the design and construction of the Croton Aqueduct. Yet Jervis was the engineer, and he naturally wanted the Board to approve his plans with a minimum of debate or interference. So to strengthen his own position, Jervis held out a trump card. If the Board interfered with the engineering of the aqueduct in a significant way, he would disclaim responsibility for the Board's decisions and perhaps even resign his position - a move which would greatly embarrass the Commissioners who had already gone through one Chief Engineer.

If the Water Commissioners were anxious upon Jervis' arrival, so were the subordinate engineers he inherited from Douglass. Their Chief had been fired, and their own positions were certainly suspect. They knew a potential conflict existed with the new Chief Engineer, who might chose to fill their positions with hand-picked men. But Jervis avoided this conflict. As the work progressed and he required more engineers, Jervis did employ several men who had worked for him before. In the spring of 1837 he brought Peter Hastie to the project as a resident engineer, and he hired Edward Tracy as an assistant engineer. Both men had worked under Jervis on the Chenango Canal. Late in 1837 Horatio Allen joined Jervis as his principal assistant; previously he had served with Jervis on the Delaware and Hudson Canal. Jervis also hired his younger brother, William, as a resident engineer, and James Renwick, Jr., the son of a professional acquaintance, as an assistant engineer.[19] But even though he brought in a number of his own men, Jervis tried to avoid "wounding the feelings or disappointing the expectations" of the men hired by Douglass.[20] He conducted no purge, and several of Douglass' men, particularly Edmund French and Henry T. Anthony, served well under Jervis for the duration of the project.

Jervis quickly relieved his subordinates of any feelings of job insecurity, but at the same time he let them know in no uncertain terms that a new man was in charge who had strong opinions about how a professional engineer should conduct his business. On November 10 he wrote H. T. Anthony that:

> The work on which we are engaged is a highly important one, and demands steady devotion of purpose in all its important agents; and I confidently expect your cordial cooperation in every measure designed to give energetic supervision and efficiency to its business concerns.

Jervis then went on to note that Anthony's engineering party started work too late in the mornings:

> The days are short, and to make much progress in field work it is indispensable to have an improvement of their early hours. This remark is made, not that I have the least doubt of your industry and application -- but because I have observed the parties commence at a later hour in the morning than has been usual in the operations I have heretofore conducted.

On the same day Jervis wrote Anthony, he also wrote Edmund French. He asked French to compile an inventory of the drafting and surveying equipment in his Sing-Sing office (see Appendices I and II), and he instructed French to:

> Have Pitcher, bowls, glasses, candlesticks, etc. properly cleaned and set up and the instruments and table so arranged as to admit of being kept in order. Remove from the office articles that do not belong to it and which only promote confusion. Allow no one to derange the order of the office, or to remove papers of any kind without direction. Allow no smoking and no play of

> any kind in the office. In all respects let it be strictly a place of business.[21]

Several months later, Jervis wrote a general circular to his resident engineers, which included both Anthony and French. By this time there was no need to chide them for late starts or to imply that their offices were unkempt. He spoke of the Croton Aqueduct in terms of professional success and ambition:

> In the work you have undertaken, great vigilance, discrimination and firmness in the prosecution of its several duties, are indispensable to its successful accomplishment . . . . It may be viewed, not only as involving great responsibility, but as highly exciting to professional ambition, and without the strong motive of ambition, no important member of the Department can be expected to be eminently useful in its accomplishment.[22]

While Jervis infused his assistants with an energy and dedication to match his own, he also collected the information he needed to design the aqueduct. Beginning on October 20 and working into early November, he first assayed the 33 miles of line located in Westchester County by Major Douglass. Jervis walked the line, accompanied at times by both assistant engineers and Water Commissioners. At the head of the aqueduct he approved of the most recent plan for a 40-foot dam on the Croton. He thought that its proposed location "at the Bluff rock" below Garretson's Mill was "probably a good one," although the dam might advantageously be moved "a short distance further down the river."[23] As Jervis examined the center line staked from the dam to Yonkers, he noted the positions of the numbered station markers placed every 50 feet. He thought that between stations 76 and 90 "the line may be improved," and that between 172 and 205 "it may be improved by laying 5 to 10 feet north."[24] On the basis of this impressionistic examination, conducted without the aid of instruments, Jervis came to believe that the Douglass line, although imperfect, was in the main well-placed. Still, he might have significantly altered the aqueduct's route in a few locations, if the Water Commissioners, hoping to expedite matters, had not urged him to follow the Douglass line closely. They already had the land maps of that line and were proceeding to obtain the needed right-of-way by appraisement.[25]

After examining the line, Jervis returned to his New York City office with a good appreciation of the technical problems posed by the environment. The problems were numerous and complex. He saw that in Westchester some 16 tunnels were required, ranging from 160 to over 1200 feet in length; that 25 streams crossed the line at a depth of from 12 to 70 feet below the aqueduct's grade; and that over 100 culverts were needed to carry streams and the wash of the countryside away from the conduit. Yet despite the complexity of the problems, Jervis evinced no doubts about his ability to solve them. With the assistance of his engineers, he unhesitatingly continued to gather the diverse data that he needed.

On instructions from the Chief Engineer, Edmund French prepared a map and profile of the line from the Croton to Tarrytown.[26] The profile showed Jervis the relationship between the aqueduct's grade line and natural ground levels. Jervis could see just where embankments or bridges were needed to cross valleys, and just how tall the structures had to be. He could see each rise in the ground that required a tunnel or excavation. French also prepared transverse sections showing the steepness of the hills that the line ran alongside of. Using these sections, the Chief Engineer could devise a system of protection walls to guard the aqueduct against erosion and slides. Finally, French provided Jervis with geological data. He sank shafts every 220 yards along the route and recorded the types of soil and rock which he encountered before reaching grade.

Jervis instructed H. T. Anthony to check the aqueduct's line from Tarrytown to the Harlem River and to reset any stakes vandalized by Westchester residents unhappy with New York City's intrusion into their domain.[27] While Anthony and French were busy with their tasks, T. J. Carmichael, an architectural draftsman, traveled the line between the dam and Tarrytown in search of local stone quarries. Most of the stone near the line was gneiss, a metamorphic rock whose mineral constituents -- combinations of feldspar, hornblende, mica and quartz -- were arranged in layers. Because of its stratification and the structural instability of some of its minerals, most of this gneiss was "not likely to be very durable when saturated with water and still less so when exposed to freezing and thawing."[28] Some of the gneiss, however, was less stratified and composed principally of feldspar. This gneiss, called "bastard granite," was a more durable stone, suitable even for bridge construction and other heavy work. The best stone in the region was true granite, but it was available from only a few isolated quarries. Fortunately, the largest granite quarry was located on the northern side of the Croton, only two miles from the site of the dam. Carmichael provided Jervis with descriptions of all the quarries and sent him a large number of stone specimens. He also reported on coves along the Hudson where contractors might be able to get clean sand for mortar.

While his subordinates gathered information in the field, in November and early December Jervis prepared for design work by compiling his own data on local labor and materials costs.[29] How much would contractors have to pay for a bushel of quick lime or hydraulic lime? For a bushel of sand? For 1000 hard bricks? How much would it cost to hammer dress a cubic yard of stone for an arch? What was the going rate for a bricklayer and tender? While he gathered all this data and began piecing it together to form the Croton Aqueduct, in the Chief Engineer's mind two large concerns dominated all the small details. First, he was very much aware of the fact that he was not building just another railway or canal. These things could occasionally break down. Canals could breech and railways could stop running, but such aggravations, in the end, were usually not all that serious. The aqueduct, however, was another matter entirely. It was literally to become a life line for the city of New York, and the life line had to be durable, permanent, and constant. Jervis was very much aware of the Roman aqueducts, aware of the fact that many of them had functioned for centuries. He felt that the Croton Aqueduct, too, had to be built not just for now, but for ages to come.

The second dominant concern was the fact that Jervis, as he said himself, had no pattern to follow:

> The enterprise of the Croton Aqueduct was an improvement for which there was no specific experience in this country or hardly any in modern times. It was hydraulic, and in this respect resembled canals; but it had no parallel in canals. In short, it presented at that time many features that had no specific guide from experience in this country.[30]

The very newness of this large work, and the fact that it was to be the longest modern aqueduct in the world, running across an especially difficult terrain in a harsh climate, demanded that Jervis be innovative in his design. But Jervis was never entirely comfortable in the innovator's role. Although he was very ambitious and fully realized that any new, daring structures that he built would enhance his reputation, he also realized that innovation was a risk. While a success would signal progress to his career and his profession, he had to weigh that success against the possibility of a time-consuming and expensive failure. Jervis was not daring, and he was not a trial-and-error engineer. When designing an innovative structure he steadfastly sought support from theories based on "well established and thoroughly analyzed facts," and from engineering precedents which at least in part appeared applicable to his task at hand.[31] So when the Chief Engineer, a conservative innovator, began in late December, 1836 to design the multi-million dollar Croton Aqueduct, he "did not hesitate to avail . . . [himself] of any hint of information that . . . [he] could obtain from any source that promised to be useful for the work." "Originality," he later wrote, was "regarded as subservient to success."[32] Jervis drew upon his background of almost twenty years in engineering. He drew upon the unfinished work of his predecessor. And he scoured the literature for help. He borrowed civil engineering practices from here and there, filtered them through his own philosophy of design, calculated their costs, and arrived at a plan which was his personal amalgam of theory, practice, and economy.

NOTES -- CHAPTER THREE

[1] Neal FitzSimons, ed., The Reminiscences of John B. Jervis (Syracuse, 1971), pp. 119-120.

As FitzSimons notes in his "Preface," p. ix: "This book is based on a series of autobiographical sketches, entitled 'Facts and Circumstances in the Life of John B. Jervis, by himself,' probably begun after the author's fiftieth year and continued past his eightieth year." Jervis' work in manuscript form is maintained by the Jervis (Public) Library; Rome, New York.

[2] Allen, Courier and Enquirer, Nov. 12, 1840.

[3] Van Schaick later claimed to have had Allen's sanction, but Allen denied it. See published letters from both men in New York Evening Post, April 29, May 3, 13, 19, 22, 24, and 27, 1845.

[4] Allen, Courier and Enquirer, Nov. 12, 1840.

[5] All three letters are in the Jervis Papers.

[6] This biographical sketch of Jervis' early life and engineering career was condensed from Reminiscences of JBJ, pp. 29-119. For another account of his career, taken largely from the same source, see Elting Morison, From Know-How to Nowhere (New York, 1974), pp. 40-71.

[7] Jervis to S. B. Roberts, March 9, 1838, Jervis Papers.

[8] Reminiscences of JBJ, p. 21.

[9] Jervis, "Memoir of American Engineering," p. 53, MS dated March 1, 1876, Jervis Library. Published as "A Memoir of American Engineering," Transactions of the ASCE, 6 (1878).

[10] Reminiscences of JBJ, p. 47.

[11] Jervis' personal library still exists as a special collection within the Jervis Library.

[12] Jervis to Renwick, April 6, 1830, Jervis Papers.

[13] Reminiscences of JBJ, p. 64.

[14] Jervis to Allen, Sept. 27, 1836, Jervis Letter Book.

[15] Tower to Helen M. Phelps, July 8, 1842; Tower to John Wolcott Phelps, Sept. 2, 1842; John Wolcott Phelps Papers, Manuscript Division, New York Public Library.

[16] "Resolutions of the Board of Water Commissioners," Nov. 19, 1836, Jervis Papers. Also see Jervis to Water Commissioners, Oct. 5, 1836, Jervis Letter Book; and Stephen Allen to Jervis, Nov. 4, 1836, Jervis Papers.

[17] Jervis to Resident Engineers, April 1, 1837, Jervis Papers.

[18] Jervis, "Remarks in relation to preamble and Resolutions for the regulation of the Engineer Department," Nov., 1837, Jervis Papers. Although dated 1837, it seems very likely that these "Remarks" were actually written in 1836.

[19] See Hastie to Jervis, Nov. 20, Dec. 6 and 22, 1836, Jervis Papers; Jervis to Hastie, December 13, 1836, Jervis Letter Book; William Jervis to John Jervis, January 17, 1837, Jervis Papers; and _Reminiscences of JBJ_, p. 126.
The engineers on the Croton project fell into a five-level hierarchy:

Title	Salary
Chief Engineer	$5,000/year
Principal Assistant	$3,500/year
Resident	$1,500/year
1st Assistant	$75-100/month
2nd Assistant	$50/month

The 1st and 2nd Assistants were not fully-trained, competent engineers. They were working "students" learning the profession, and their low salaries reflected that fact.

[20] Jervis, "Memo for Commissioners Meeting," Nov. 12, 1836, Jervis Papers.

[21] Both letters are in the Jervis Papers.

[22] Circular dated May 30, 1837, Jervis Papers.

[23] See the entries for October, 1836, in Jervis Memoranda Book, Jervis Library.

[24] Jervis Memoranda Book, p. 8; _Reminiscences of JBJ_, p. 121.

[25] See Allen, "New York Water Works No. 3," and Blake, pp. 148-150.

[26] Jervis to French, Nov. 10, 1836, and French to Jervis, Dec. 28, 1836, Jervis Papers.

[27] Jervis to Anthony, Nov. 10, 1836, Jervis Papers.

[28] Carmichael to Jervis, Dec. 21, 1836, Jervis Papers.

[29] Jervis, "Report to the Board of Water Commissioners," Dec. 23, 1836, and "Estimate for brick and stone masonry," n. d., Jervis Papers.

[30] _Reminiscences of JBJ,_ pp. 121, 153.

[31] "Memoir of American Engineering," MS, p. 58.

[32] _Reminiscences of JBJ_, p. 122.

CHAPTER FOUR

In the winter of 1836-37, John Jervis did not have the luxury of time. He did not have time to turn ideas over and over at his leisure, or time to design the Croton Aqueduct all at once. He had to let contracts the following spring, but he could not possibly ready the entire line by then. So although Jervis envisioned the aqueduct as a system whose parts had to function harmoniously, he designed it piece-meal, starting with the structures along the 8½-mile stretch of the line from the dam to just below Sing-Sing. He decided to put that part of the aqueduct under contract first, and then worry about the rest.

Jervis took each engineering design through a step-by-step process. First he imagined a structure; he formulated a mental template of its physical characteristics. In many instances his practical experience and his familiarity with engineering problems stood him in good stead, and an image came easily to mind. Another image, of a more difficult and complex structure, came only with more coaxing. But in either case, as rapidly as possible Jervis translated his mental template into a pencilled drawing showing a structure's size and shape. Working from the drawing, the Chief Engineer, or one of his assistants, computed volumes -- the quantity, usually the cubic yardage, of each different material in the structure -- and from the volumes Jervis computed cost. Assuming that he was satisfied with the structural merits and the estimated cost of a given design, he next reported it to the Board of Water Commissioners. If the Board approved his plan, then Jervis prepared it for a contractor's use. While his draftsmen and assistant engineers inked sets of final working drawings, the Chief wrote a specification detailing how the work was to be done.

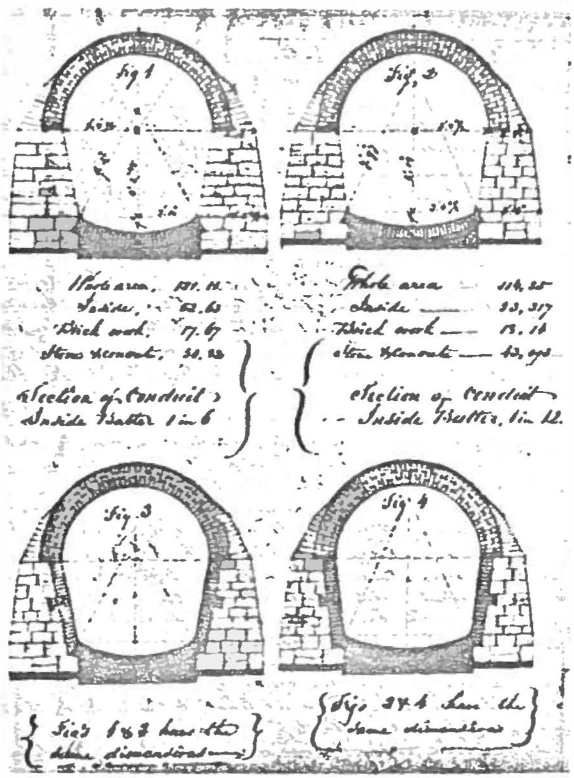
Jervis worked first on the general cross-section of the aqueduct's masonry conduit. He briefly considered the feasibility of a "double aqueduct" whose side-by-side channels shared a common inside wall.[1] Jervis liked the concept of twin conduits because it lessened the threat of any long interruption in the delivery of water to New York. If one channel breeched or failed, or if it had to be shut down for inspection, minor repairs or cleaning, the other side could maintain service. But he dismissed a double aqueduct on the basis of economics. Its promise of greater constancy did not compensate for the fact that it would cost much more than a single conduit, such as the last one proposed by Major Douglass. (Plate VIII.)

Douglass had been on the right track with his "horseshoe" conduit, but Jervis saw room for considerable improvement. In particulat, he felt that the structure's exterior poorly matched the physical demands to be placed upon it, because Douglass had squandered material on the conduit's top and skimped on the bottom. The aqueduct was to be free-flowing and gravity-fed. Water would not flow under pressure or fill the entire conduit. An air space would always exist between the water and the roofing arch. Consequently, this arch did not require a great thickness to resist internal pressures; it was simply a roof which would be covered with three or four feet of earth to protect the conduit from frost.[2] Nevertheless, Douglass intended to carry courses of stone up and over the brick top arch. Figured at 20 cents per cubic foot, Jervis estimated that this reinforcement would cost $12,000 per mile, or approximately $500,000 over the aqueduct's entire run. Since Jervis believed this expensive reinforcement was superfluous, he omitted it. Yet at the same time he added material where Douglass had skimped. Douglass' last design showed no foundation running all the way across the bottom of the conduit, the part that would have to bear up under a load of water weighing 62.5 pounds per cubic foot. Jervis felt that the aqueduct was most likely to fail at the juncture of the bottom and the side walls, so he added a concrete foundation, 3 inches thick under the sides, and 6 inches thick under the inverted arch, "to give greater, and what I deem necessary security to this part of the structure."[3]

If Jervis had not been engineering such a long aqueduct, he might have stopped after making the above two changes in the conduit. He continued to modify the structure because "in view of the great amount [of masonry] required, a small difference in the facility of construction should not be disregarded."[4] These modifications are shown in Plate IX, a drawing which accompanied Jervis' first design report submitted to the Water Commissioners on December 23, 1836. Figures 1 and 3 represent the Douglass conduit, minus the stone courses going over the top, and plus the concrete foundation. The two figures are identical in their dimensions and shape, but show different modes of constructing the side walls, which could be faced with stone or hard brick. Figures 2 and 4 represent the conduit design which Jervis preferred.

As shown, Jervis retained the horse-shoe shape; the bottom formed by an inverted arch of brick;[5] the sloped, flat sides; and the brick top arch. But he altered some important dimensions. Notably, he increased the chord line of the inverted arch from 6 feet to 6 feet 9 inches, and he reduced the vertical rise of the sides while changing their inside batter or slope from 1 in 6 to 1 in 12. These changes opened up the conduit's interior, further reduced the masonry in the structure, and made the conduit, because its sides were closer to vertical, slightly easier to build. In economic terms, Jervis estimated that the plans on the left would cost $94,350 per mile, while his preferred plan

PLATE IX



Plan for Masonry Conduit Preferred by Jervis, 1836.

would run $93,900 per mile.[6]

Jervis was concerned with more than just the geometry and cost of the conduit; he had to assure himself that it would deliver the desired amount of water to New York. In order to gain this assurance, he turned to water-discharge formulae developed by contributors to the study of hydraulics, men such as Bossut, Dubuat, Prony, Eytelwein, Langsdorf and Robison. Jervis had John Robison's 4-volume A System of Mechanical Philosophy, and he often consulted this wide-ranging work because he considered Robison "a writer on Mechanical Philosophy of high authority and great practical usefulness."[7] In order to study the other authors' works on hydraulics, such as Eytelwein's Handbuch des Mechanik fester Korper und Hydraulic (1801), the Chief Engineer resorted to summaries or translations published in English, because he had never been schooled in German or French.[8] One such summary, Charles S. Storrow's Treatise on Water-Works for Conveying and Distributing Supplies of Water, was published in Boston in 1835, just in time for consultation on the Croton project. Storrow's book contained several water-discharge formulae, some of which were also available to Jervis in Olinthus Gregory's Mathematics for Practical Men (London, 1825), in Thomas Tredgold's Tracts on Hydraulics (London, 1826), and in the 1832 edition of the Edinburgh Encyclopaedia.[9] Using formulae developed by Robison, Prony, Etylwein and Langsdorf, Jervis calculated that water in his preferred conduit, when running at capacity, would flow with a velocity of 1.725 feet per second, meaning that New York could expect a maximum delivery of 60 million U.S. gallons per day.[10]

When the Water Commissioners reviewed Jervis' first design report, they were pleased with his ability to pare the conduit's cost without sacrificing its structural integrity. They were not so pleased, however, with one of the materials he chose to use throughout the structure. Because the "constant and successful operation" of the conduit depended on a durable and impervious bond between its parts, Jervis had recommended that all cement, grout and concrete be made with hydraulic lime. This material cost almost twice as much as the more common quick lime, but Jervis believed the aqueduct called for its greater convenience and especially its durability. Unlike mortar made with quick lime, hydraulic mortar set quickly in a variety of environments: dry, damp, or even underwater. And once it set, hydraulic mortar was much less likely to be leached or washed out by water.

American civil engineers had been using hydraulic lime for almost 20 years, ever since Canvass White began using it when he served as principal assistant engineer on the Erie Canal.[11] Yet because of its cost, engineers had tended to use it sparingly. They generally used hydraulic mortar only in the face of a structure, where it was constantly exposed to water. Behind the face, or in the backing, they resorted to less expensive quick lime, or to quick lime mixed with a small percentage of hydraulic lime. Jervis had often followed this very practice when building canals, but in the case of the conduit, he thought that any resort to quick lime was an exercise in false economy. The Chief Engineer was unwilling to gamble on a cheaper material that might cause a disasterous breech, if it failed to harden properly. Jervis leaned towards "the opinion of some engineers, that in very heavy walls in damp places, pure quick lime will never obtain a good set." To substantiate this opinion, he cited the case of a 30-year-old canal lock which had been constructed with quick lime. When workers had taken the lock down, "the mortar in the backing was found to have made no set of consequence." So although it meant an additional expense of approximately one-quarter of a million dollars, Jervis strongly recommended the exclusive use of hydraulic lime:

> The most of my time for near[ly] twenty years, has been employed on hydraulic works, where it has been considered important to lay all masonry exposed to contact with water, as requiring particular permanence, in hydraulic cement. In reviewing those works, not one of them appears to me, to have required in so eminent a degree, the use of an entire hydraulic cement, as the work under consideration.[12]

Because of this recommendation, Jervis' first design report once again raised the question of the balance of power between the Water Commissioners and the Chief Engineer.

Douglass had intended to use quick lime in the backing of the conduit, and some of the Commissioners, including two who were builders, also believed that quick lime would suffice. Jervis, in several discussions with the Commissioners, continued to argue to no avail that the additional expense was necessary to secure impervious, durable masonry. Since the technical merits of hydraulic lime did not sway the Commissioners, Jervis changed his tack. He played his trump card, the one he reserved only for a time when the Board significantly interfered with his work. In effect, he threatened to embarrass the Commissioners. If they decided to use quick lime, he would place his technical expertise and professional reputation in opposition to their decision. The new tack worked:

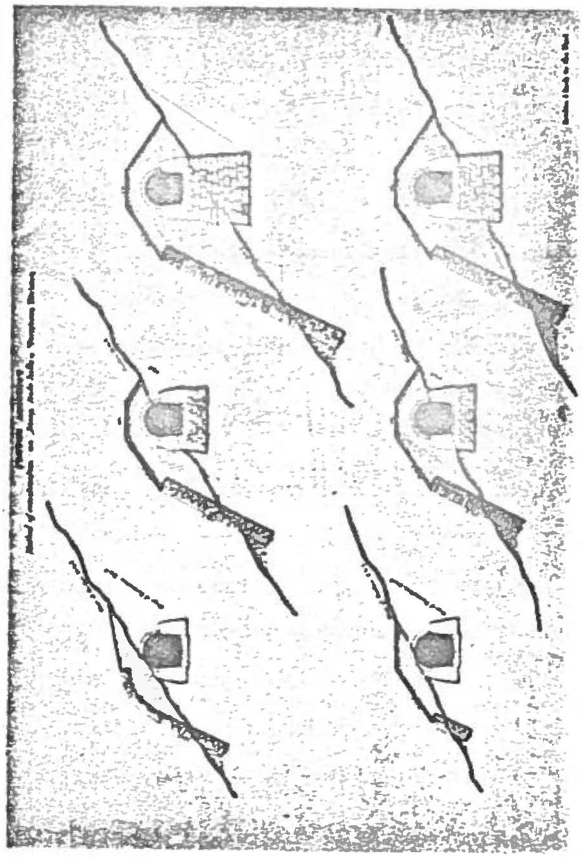
> After exhausting what I had to say, and seeing no prospect of the board agreeing to my views, I said to them that I could not consent to the use of quick lime in any part of the masonry. It was no doubt a cheaper material but did not appear to me as affording the best security for the work, and if the board insisted on its use, they must assume the responsibility of the measure. This closed the discussion, and the board immediately adopted the specifications in full.[13]

In a sense, both Jervis and the Water Commissioners benefited from this early confrontation over the use of quick lime. Instead of creating friction, it delineated their respective and valid interests. Unlike Boss Tweed's cronies, who 25 or 30 years later would buy patronage and fill their own coffers with money syphoned from public projects, the Water Commissioners truly held their positions as a public trust. They actively sought to protect the public's interest by checking the aqueduct's cost; they wanted the best aqueduct they could get for the least amount of money. Unfortunately, even by December 1836 the Commissioners feared that their 1835 estimate of 4½ million dollars for the work had been absurdly low.[14] They could see that Jervis was estimating materials costs at much higher rates than Douglass ever had, and they could see that land costs were going to run much higher than expected, because of the growing opposition of Westchester landowners to the aqueduct.[15] Westchester residents resented the city's intrusion into their domain and protested that it was unconstitutional for New York City to take their lands by appraisement. Conseqently, the city would be paying high prices for land, hoping at the same time to buy peace with its northern neighbors. As the Commissioners saw the probable cost of the aqueduct escalate, they became more determined to check its cost wherever possible.[16] Their frugal stance on quick lime, then, served to impress upon Jervis the need for cost-cutting measures. At the same time, Jervis impressed the Commissioners with his professional pride and integrity, and he earned from them a deference which they had never paid his predecessor.

On December 27, 1836, just four days after submitting his conduit plan, Jervis presented a second design report to the Commissioners which explained how he intended to carry the conduit along hillsides and across low areas.[17] Where the aqueduct ran along the slopes adjoining the Croton and Hudson Rivers, Jervis proposed the type of construction shown in Plate X. This plan incorporated three means of protecting the conduit from erosion and slides. First, the Chief Engineer seated the structure securely in the hillside, effecting "a lodgement that may not be disturbed." Where the aqueduct's grade line ran sufficiently below ground level, this was no problem. Jervis simply buried the conduit in the hill, as shown in the two views of the left. Where the grade line placed the conduit above ground level, he had to take more stringent precautions. In these locations he placed the conduit on a heavy foundation wall made of stone which he sunk far enough into the hill to achieve a firm footing.

To further protect the conduit's stance, Jervis planned to erect a supportive embankment on its downhill side. A stone protection wall, "well settled in the hill at its foot," rested on earthen fill as it leaned into the conduit. Jervis chose this mixed construction, instead of an embankment made entirely of earth, because the stone facing offered much greater protection from erosion. Also, because the stone protection wall could stand at a steep angle, it allowed for a narrower embankment. An earthen embankment, of necessity graded at a gentler slope, would have extended

PLATE X



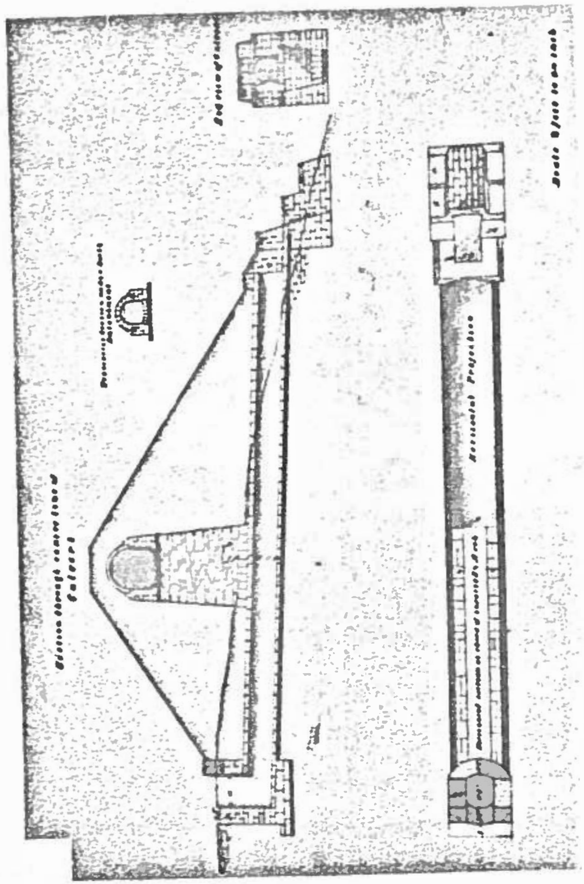
General Plan for Constructing the Aqueduct on Hillsides.

much further down the hill.

As a third means of protecting the conduit on side slopes, Jervis guarded against heavy rains and the water that might course down a hill and undercut the masonry. Where he buried the conduit in a hillside, he proposed simply to carry the water over its top in a paved channel. Where the conduit protruded from a hill, the problem was more critical and called for the construction of strategically placed "drop-well" culverts to collect water and channel it under the aqueduct. This type of culvert, made of well-hammered masonry laid in hydraulic cement, is shown in Plate XI.

After dealing with the structural problems posed by side slopes, Jervis dealt with the question of "passing ravines, or grounds that fall below the grade line of the Aqueduct."[18] The Chief Engineer anticipated that four aqueduct bridges would be required along the entire route to pass the conduit over particularly wide or deep valleys. These four bridges would be needed over the "kill" or brook in Sing-Sing, over Mill River in Sleepy Hollow near Tarrytown, over the Harlem River, and, once on the island, over Manhattan Valley. Of the four, only Sing-Sing Kill merited prompt attention, because it alone fell within the first 8½ miles of the line. Still, because an aqueduct bridge posed special problems, Jervis deferred discussion of his plan for Sing-Sing until he could prepare a special report

PLATE XI



Design of Drop-Well Culvert.

dealing exclusively with the bridge there. For the time being he concerned himself with the development of a general embankment plan to be implemented at numerous valleys.

In his 1835 consultant's report, Major Douglass proposed a way of carrying the conduit across shallow valleys. He suggested supporting it on a mound of rubble stone dumped into the valleys as fill:

> In embankments . . . it is proposed to construct the work . . . by forming as a foundation, immediately under the base of the conduit . . . , a mound of solid stone . . . , this material being found in sufficient abundance everywhere on the line, and forming in this way, as the writer has occasion to experience in similar situations, a cheap and very safe foundation. The residue of the embankment after the conduit is built, is then to be formed to the necessary height and width, with good gravel or loam, on the slopes of which, in situations requiring enclosure, live hedges, of a proper kind, may be profitably and tastefully cultivated.[19]

John Jervis, like Douglass, had an admirable respect for nature. He delighted in the rigors of field work and reveled in "wild surroundings" that would someday yield a new canal or aqueduct. Nevertheless, when it came to designing embankments, Jervis thought more highly of stone protection walls than he did of tastefully cultivated hedges "of a proper kind." As in the case of the conduit's design, Jervis thought that his predecessor's embankment plan needed considerable improvement.[20]

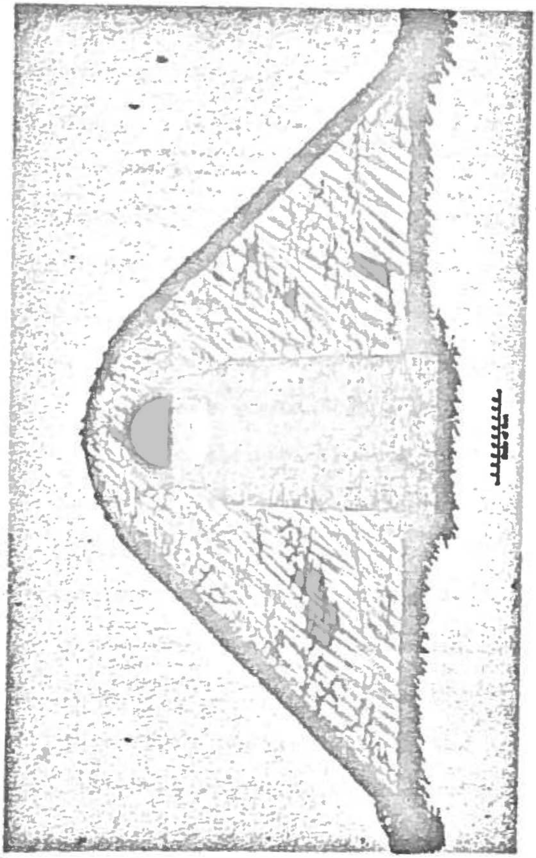
Besides rejecting live hedges, John Jervis rejected the idea of building the conduit on a mound of stone simply dumped into place. The mound might slide or settle unevenly, creating cracks in the masonry. In lieu of Douglass' approach, Jervis conceived on an embankment design very similar to his plan for supporting the aqueduct on hillsides. (See Plate XII.) Jervis placed the conduit on a trapezoidal wall composed:

> of large stones laid in a rough but compact manner, the interstices between the stone[s], and to level up the courses, to be filled with fine broken stone, so as to give firmness and stability to the work.[21]

While this foundation wall, laid without mortar, was more expensive than the mound of rubble stone proposed by Douglass, it appeared to offer much more security for the conduit, and at the same time it was less expensive than another plan which Jervis had considered. Over the aqueduct's entire run, the Chief Engineer believed that a foundation wall laid dry would cost some half-million dollars less than a wall "built of solid hydraulic masonry."[22] Since his foundation wall contained no mortar, it did require a heavy earthen embankment on both sides to assure that it "kept in place." If the height of the embankment demanded it, the earth, in turn, was to be kept in place by a stone protection wall.

The aqueduct which ran along hillsides needed protection from heavy rains, and so did the aqueduct which crossed a valley on an embankment. Even in those valleys which were

PLATE XII

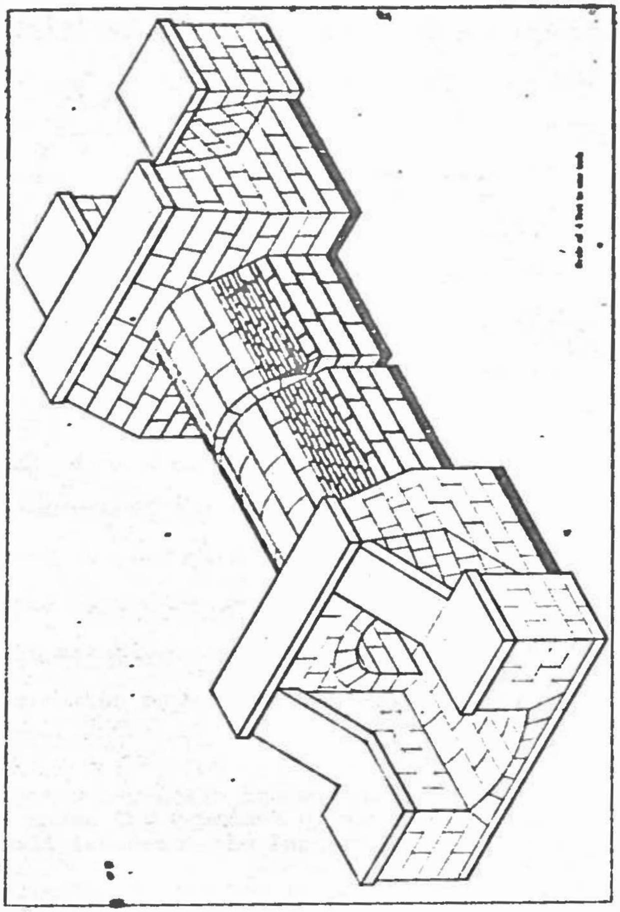


FOUNDATION WALL, flanked by earth embankments and stone protection walls. This mode of construction was adopted along a total of six miles of the aqueduct's run.

normally dry, Jervis believed that culverts were needed to carry potential flood waters under and away from the line. In his second design report, the Chief Engineer proposed a system of standardized culverts. These culverts ranged from 2 to 12 feet wide. They had inverted arches on the bottom, vertical side walls, and arched tops.[23] (See Plate XIII.) Once his engineering department had completed plans for the standard culverts, Jervis could choose one of a proper size for a given valley, and conveniently plug the structure into the line.

No standard culvert would suffice at Sing-Sing. The kill, or brook, that ran through the village was small, but over the centuries it had carved a substantial valley for itself. When Major Douglass first proposed the Hudson River route, he recognized Sing-Sing Kill as one of the major obstacles on the way to Manhattan. Consequently, when he ran the line through Sing-Sing he took particular care to seek out the easiest passage across the valley. Still, he left Jervis with the problem of carrying the aqueduct across a depression 536 feet wide which bottomed out at a depth of slightly over 70 feet below grade. And Jervis faced more than natural obstacles at Sing-Sing; he faced man-made ones as well. As it crossed the valley the aqueduct's line intersected two village roads which the Chief Engineer had no authority to move. Conseqently, he had to design a crossing that would accommodate them. The line ran

PLATE XIII



Isometric view of typical masonry culvert. Well over 100 of these structures were required along the line.

almost perpendicularly to the first road and passed it shortly after entering the valley. This road posed no significant problems; Jervis spanned it with a relatively small viaduct arch. The second road, however, was situated in a "peculiar manner," as Jervis called it.[24] The road crossed Sing-Sing Kill on a wooden bridge as it ran to a small water-powered mill. The aqueduct's line intersected this road at a sharp angle right over the deepest part of the valley -- and right over the road's wooden bridge. Jervis' structure, then, had to span an already existing bridge. It also had to contend with yet another man-made obstacle — Mr. Sing's house, located between the two roads. The line passed right behind the residence and cut it off from the owner's garden. On May 25, 1836, the State Legislature had passed an act which anticipated this sort of unfortunate situation. The act protected the rights of property owners such as Mr. Sing. It required New York City to:

> erect and sustain convenient passes across or under the aqueduct whenever said aqueduct shall intersect the land in said county of Westchester, belonging to an individual, or individuals, for the farming and other purposes of the land thus intersected.[25]

It is not known if gardening constituted a form of farming, or if it more properly fitted the category of an "other purpose." Regardless, in crossing Sing-Sing Kill the Chief Engineer had to make sure that Mr. Sing retained his free and easy passage between house and garden.

After considering the diverse problems posed by this valley, on February 8, 1837 Jervis presented the Water Commissioners with a "Report of Sing-Sing Kill Aqueduct Bridge." Although he referred to the entire 536-foot-long structure as a bridge, for the greatest part of its length a solid stone wall, laid in cement, supported the conduit. Where this wall intersected the first road, Jervis called for a low arch spanning 20 feet, the arch to be built slightly askew since the road and the wall did not quite meet at right angles. After passing the first road, the wall continued for some 120 feet, its facade broken only by a small arch for Mr. Sing, before it encounted the second road and its wooden bridge. To pass these obstacles, Jervis specified an impressive aqueduct bridge with a single elliptical arch which spanned 80 feet; the underside of the arch stood nearly 70 feet above the stream's bed. At the termination of the bridge, Jervis again commenced the solid wall and carried it approximately 190 feet to complete the crossing.

Jervis exhibited considerable ambivilance towards this design. If the aqueduct's line had not passed so near Mr. Sing's house, he probably would have thrown a wide embankment across most of the valley, instead of the narrow, solid wall. And in particular, if the line had not crossed the second road in such a "peculiar manner," he would have shunned the aqueduct bridge, with its high, wide arch, in favor of one or two large culverts placed under the embankment to straddle Sing-Sing Kill. The challenge of building the bridge excited the Chief Engineer, who fully realized that well-executed bridges were status symbols among civil engineers. They were baubles to delight one's peers. Yet he would have avoided this bridge, if he could have, for two reasons: cost and stability. Its large masonry arch was expensive because it required extremely good stone that had to be cut and fitted precisely. But an even greater liability, the one paramount in Jervis' mind, was the susceptibility of the large arch to structural deterioration, if any of the water under transport should leak into the masonry and then freeze. He feared that in New York's climate, "leakage amounting to only a sweating of the arch stone in the bridge masonry would tend to disintegrate even the most durable stone."[26]

Jervis informed the Water Commissioners that many aqueduct bridges had exhibited this tendency, beginning with ancient Roman structures which had been built in a climate much milder than New York's:

> It may be observed that even in Rome, that portions of their aqueducts, which are elevated on bridges of masonry, have often required extensive repairs . . . , and those portions of the Roman aqueducts, which have stood, undisturbed, the test of time, are placed underground, and therefore, not exposed to material atmospheric changes.

English aqueduct bridges, too, had suffered:

> In the stone aqueducts for the English canals they formerly adopted the plan of lining the inside with well puddled earth. This earth was found to heave by frost, and this produced the same derangement in the masonry as had been experienced when the masonry only was depended upon. It was not infrequently the case that a portion of the masonry in a few years required to be supported by strong bars of iron, or taken down and rebuilt.

As for aqueduct bridges in the United States, Jervis found them "quite too leaky, to promise the durability required in the Croton Aqueduct." The Little Falls Aqueduct on the Erie Canal, for example, had been in service only 12 years before exhibiting "decided marks of injury from frost."[27]

Forewarned of the danger of leakage and frost, the Chief Engineer sought means of protecting the masonry in the Sing-Sing Kill Aqueduct Bridge. The first step, of course, was to try to make the conduit water-tight. Jervis searched the literature and discovered that Thomas Telford, "an eminent English engineer," had placed a cast iron floor in an aqueduct bridge on the Ellesmere Canal, and thirty years later "the aqueduct was tight, and in all respects appeared in good condition." Following Telford's lead, engineers on the Glasgow and Union Canal had lined three aqueduct bridges with cast iron on the bottom and sides, and these structures, too, escaped injury from frost. Citing these precedents, Jervis wrote the Commissioners:

> After much reflection I have come to the conclusion, that the aqueduct over heavy arches, after being made of the best hydraulic masonry, should be lined with cast iron, made impervious to water.[28]

The Chief Engineer's lining, made of plates five-eigths of an inch thick, went between layers of brick on the sides and bottom of the conduit.[29] These plates offered the best known protection against leakage, but what if they failed? Jervis felt he had to build for such a contingency, so he provided a means for any leakage to drain out of the structure before it could do any harm. If the conduit leaked, the water that ran down the arch barrel would be carried outside the structure by small copper pipes. On top of this measure, the Chief Engineer took one other very significant step to protect and preserve the large arch above Sing-Sing Kill. He reduced its superincumbent mass, believing that the less load the arch supported, the longer it would last. In the case of the Sing-Sing Kill Bridge, its deck -- the masonry conduit, lined with cast iron, filled with water, and topped with earth -- would place a heavy load on the arch, an inescapable load that Jervis could not reduce. He could, however, reduce the dead-load imposed by that part of the bridge which supported the deck and carried its load down to the arch. In most masonry bridges of the period, builders used an earth or rubble fill to support the deck.[30] Jervis chose not to follow this practice. Instead of totally filling the space bounded by the arch barrel, the exterior spandrel walls and the deck, he supported the deck on a series of interior spandrel walls, tied together with cross-walls. By leaving large spaces between the walls, and by leaving hollow spaces in the walls themselves, he significantly reduced the dead-load on the arch.[31]

At Sing-Sing, man-made obstacles posed serious problems for the Chief Engineer. Fortunately, when he turned to designing Croton Dam such obstacles were dispensed with. The Water Commissioners purchased all properties, including small mills, that would be flooded by the reservoir, and they received permission from the State Legislature to move a road and a bridge that were in the way. Jervis, then, did not have to warp the dam's design to protect any existing structures. But he did have to contend with formidable natural obstacles.

Jervis had no time to survey the entire Croton River in search of the best site for a dam; he had to make do with the stretch of river just below Garretson's Mill that Douglass and the Water Commissioners had selected. Douglass had tentatively marked an exact spot for the dam with a wooden stake. Although he was not bound to build precisely on the spot his predecessor had selected, Jervis was restricted to locating the dam somewhere along this short stretch, where the Croton contracted to a width on only 120 feet. Here water ran at a depth of 4 to 10 feet, and a stone bluff bordered the southern bank of the river. From the base of this bluff, a gneiss shelf ran under the river for a short distance before giving way to a gravelly bed. On the Croton's northern bank, a sand table, rising three feet above the river, ran 80 feet before intersecting a sandy hill that rose at a 45-degree angle.

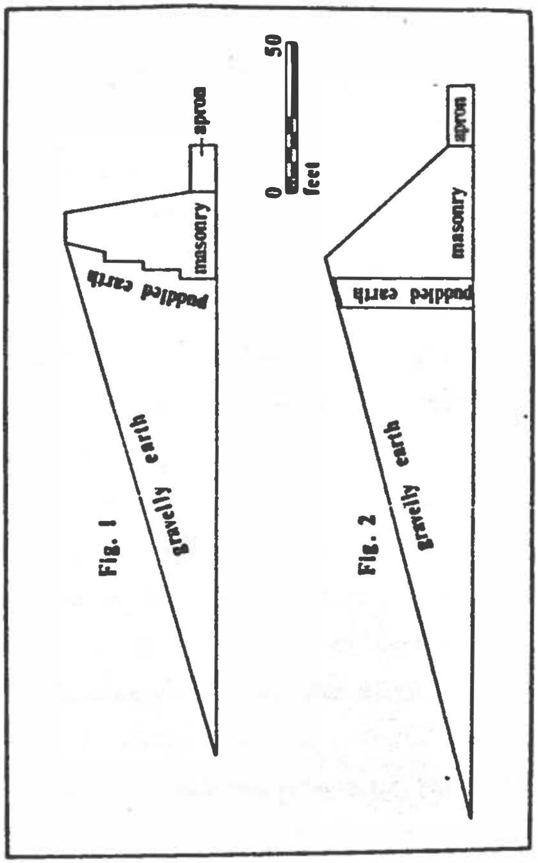
The Chief Engineer did not object to the idea of building a tall dam in this environment, because it would create a doubly useful reservoir. Besides storing some 600 million gallons that could be drawn from in dry seasons, the reservoir would purify the stilled water before it entered the aqueduct, by allowing its impurities to settle out. These benefits, Jervis thought, were "a sufficient inducement to encounter the difficulty and expense of a high dam." Still, as he considered the problems of building a connecting structure between the stone bluff and the sandy hill, he worried. It was one thing to build a dam across the Croton; it was another matter entirely to build a dam that would last and last. As usual, the Chief Engineer's main concern was durability:

> In the case under consideration, it is inadmissable to contemplate even extensive repairs, and much less a renewal that would consume some months, and consequently suspend the supply of water from the aqueduct during that time.32

Because of the dam's height and the demand for permanence, Jervis dismissed the idea of timber construction; the over-flow weir had to be of masonry. Masonry dams, however, were by no means immune to failure. A tall masonry dam required an exceptionally good foundation, preferably bed-rock, to support the masonry when it received the impact of falling water. Here was the engineer's greatest problem: neither he nor Douglass had been able to find a line of solid rock going clear across the valley. Under directions from Jervis, in November and early December Edmund French had tried once again to find such a line by boring into the river's bed. But French had met with no success before severe weather halted his efforts, and he could not resume the work until the next summer brought both warm weather and low water. But Jervis, under pressure to put the head of the line under contract, could not wait for another examination. He had to design Croton Dam working with information already on hand, and that information told him that only the extreme southern side of the Croton Valley lent itself to a masonry structure. Jervis decided to run the masonry dam's southern abutment right into the stone bluff, and if necessary he would cut the bluff down to provide room for the weir. Since he would not risk carrying the masonry beyond the gneiss shelf and onto gravel, he had to close the remainder of the valley with a massive earthen dam (or embankment), 15 feet taller than the over-flow weir. The sloped embankment, constructed over wooden piers and backed by a heavy stone wall, would be secure as long as water never passed over it. Jervis studied the extent of previous floods along the Croton, and he convinced himself that this would never happen. The masonry weir would discharge any flood waters fast enough to prevent them from rising over the top of the embankment.[33]

Jervis first reported his plan for Croton Dam to the Water Commissioners on February 13, 1837. He described a masonry dam whose main wall, in profile, took the dimensions and shape shown in Plate XIV, Figure 1.[34] The Chief Engineer intended to lay this wall so that when viewed from the top, it would appear as a segment of a circle. The wall curved eight feet into the reservoir while spanning between two abutments 100 feet apart, measured on the curve's chord line. Jervis recommended that a 10-foot-thick wall of impervious, puddled earth (a compacted mixture of clay, loam, and gravel) be worked into place against the dam's upstream face to protect its masonry from the deleterious effects of constant contact with water. The offsets, or steps, on this side of the dam were a convenient means of reducing the thickness of the main wall as it rose, and they also served "to check the water that will seek a passage between the masonry and the [puddled] earth." To further protect the upstream face, Jervis planned to cover the puddled earth with a fore-embankment, a "triangular

PLATE XIV



Profiles of Two Designs for Croton Dam.

body of gravelly earth," graded at a slope of four horizontal to one vertical.

While Jervis was concerned with the stability of the dam's upstream side, he was even more concerned with its downstream face. The Chief Engineer believed that water passing over the weir represented "by far the most serious source of danger to the permanent stability of the work." For one thing, the water would wear down the granite face stone and wash out its mortar. Secondly, the falling water might undercut the structure by tearing away at the dam's gneiss foundation. Jervis documented this danger by citing the history of the Fort Edwards Dam built across the Hudson River. Water passing that dam fell perpendicularly onto the river's slate bed, and in only twelve years it had "taken rock of several tons weight and moved it, creating a chasm [10 to 20 feet deep] below the dam." To protect his dam from the destructive force of falling water, Jervis beveled the downstream face. The slope of one horizontal to six vertical diminished the water's effect by preventing it from falling perpendicularly over the weir. In addition to this measure, he planned for an apron:

> that will receive the force of the falling water, and materially destroy its power, and throw its remaining action so far beyond the base of the dam, as to produce no injury.[35]

With this apron in place, water could not abrade the back of the dam, because it would not come in contact with it.

Instead of running over the masonry, it would run over replaceable wooden planks afixed to the masonry. And the water could not tear away at the dam's foundation, because instead of impacting directly on the bed-rock at the toe of the dam, it would strike on top of heavy, interlocking timber cribs, filled with rubble stone and covered with thick planks.

In deciding on how much masonry to put into Croton Dam, to give it the requisite strength to stand against the river and its floods, Jervis apparently did not rely on any sophisticated computations or formulae. He relied on an engineering rule of thumb:

> If we were to erect a wall of the most substantial masonry, to stand alone against a column of equal height of water, it would require a thickness equal [to] half its height to resist the pressure. The same to sustain a bank of ordinary earth, would require by the most approved rules, two-fifths (2/5) of its height.[36]

To raise the Croton River 40 feet, Jervis had to build a dam whose main wall was 50 feet tall, measured from its lowest foundation to the top of the weir. According to the rule of thumb, the wall required an average thickness of half its height, or 25 feet, in order to stand safely against an equal column of water. In order to stand against dry earth, the wall would have required a lesser thickness of two-fifths of its height, or 20 feet. But in fact Jervis' wall had to stand against a "compound" pressure because of the fore-embankment. It had to stand against both earth and water:

> The earth embankment . . . [on the dam's upstream side] will be calculated to prevent the water from acting against it; but this earth, by becoming saturated with water, will from that circumstance act with more power [than dry, ordinary earth] to overturn or move the wall.[37]

To stand against the fore-embankment saturated with water, the rule of thumb instructed Jervis to build a main wall greater than 20, and less than 25 feet wide. The Chief Engineer called for a wall 30 feet wide at the base and 10 feet wide across the top. This wall had an average thickness of just 20 feet, so it was somewhat deficient in masonry. But Jervis did not intend to lay the wall in a straight line, as the rule of thumb presupposed. He planned to lay it along a curve, so the wall would function like an arch under a compressive load. Jervis substituted the curve for a thicker wall, and he assured the Commissioners that the curve would render the dam "perfectly secure against every contingency of pressure."

Despite his own assurance that the dam's design was structurally sound, Jervis was apparently dissatisfied with it. A month or two after submitting it, he wrote up the specifications for Croton Dam, and the specifications called for a main wall having the profile shown in Plate XIV, Figure 2.[38] This second design shared some important features with the first. It maintained the height of 50 feet and length of 100 feet, the fore-embankment, and the downstream apron. Yet in other respects it was very different.

The changes the Chief Engineer made in the dam's design signified the depth of his concern over what water passing over the structure could do to its foundation. Jervis obviously came to believe that water cascading over the first dam was not going to be thrown back far enough from the bulk of the masonry, or sufficiently slowed in its descent. Consequently, he changed the slope of the downstream face to 1¼ horizontal to 1 vertical. Besides throwing the water further downstream, this change greatly increased the amount of masonry in the dam. To partially offset this increase Jervis omitted the steps on the upstream face and planned to lay that side of the wall plumb. Yet even with the omission of the steps, the weight of masonry in the wall was now so great that Jervis could lay it in a straight line. The curve was no longer needed.

The dam's main wall ran between two masonry abutments. The northern abutment securely connected with the earthen embankment that closed off the remainder of the valley. Jervis located a waste gate in this abutment, 20 feet below the top of the dam. In the event that men needed to work on the top or back of the dam, this gate could be opened to lower the reservoir's water level, so that the men could proceed without fear of water passing over the weir. The Chief Engineer designed the southern abutment to serve as one of the two walls which enclosed the entrance to the aqueduct, or its gateway. If placed precisely on the aqueduct's grade line, the floor of this 20-foot-wide channel would have been 8 feet 5 inches below the top of the dam. But Jervis decided to sink the gateway's floor to 10 feet below the weir, so that during a drought, when the water level in the reservoir fell, the aqueduct could continue to draw water for a longer period of time.[39] Even when the reservoir was full, the sunken entrance would have its purpose: to keep leaves, branches and other floating debris from entering the aqueduct. As another guard against debris (and fish), Jervis located a timber screen at the head of the gateway.

After flowing into the gateway, water had to pass through two sets of vertical gates before entering the conduit. The wooden guard gates composing the first set were normally open. They would be closed only when it was necessary to shut of the water completely, so that men could inspect or repair the second set of gates. These 10 cast iron regulating gates, 18 inches wide and 3 feet tall, were normally open. By adjusting them up and down, a gate-keeper could control or regulate the amount of water allowed into the conduit. The Chief Engineer sheltered the guard and regulating gates in a small "stone house" next to the dam. Even in the design of this gatehouse, Jervis exhibited his concern for the safety of the aqueduct. In this instance, he protected it from intruders:

> The windows to be secured by a grating of iron rods, let in and leaded to the caps and sills. The doors to be . . . made of narrow pine plank tongued and grooved, and lined with boards, and well hung with suitable fixtures and locks, to render it secure against improper approach.[40]

While Jervis was busy designing and redesigning Croton Dam, he finished the other plans needed for the first part of the aqueduct. In numerous places its grade line passed beneath ground level, so on February 16 Jervis reported a plan for excavations and tunnels.[41] This report dealt with the size and shape of open cuts in earth and rock, and tunnel cuts through rock.[42] Where it was necessary to excavate earth to get down to grade line, Jervis required contractors to prepare trenches, 13 feet wide on the bottom, with sides carrying a slope of 3 vertical to 2 horizontal. In arriving at this plan for trenching, Jervis took three considerations into account. First, he did not want contractors to dig trenches that were any larger than necessary, because they were going to get paid for the cubic yardage of earth which they removed. Secondly, although the trenches were not to be too large, they also could not be too small. They had to provide adequate working space for the men laying the conduit. Thirdly, the Chief

Engineer had to protect the men and the conduit from sliding or collapsing earth. Jervis thought that most earth would stand safely at his prescribed slope, but he recognized that "tender or wet" earth might require trenches whose sides were inclined further from the vertical. In some instances, contractors might even have to shore up their trenches with timbers. But the engineering department, not the contractors, would specify any changes from the slope of 3 to 2. If a contractor chose on his own to dig a broader trench, he would not receive any payment for his extra labor. Jervis placed similar size and shape restrictions on the other types of cuts.

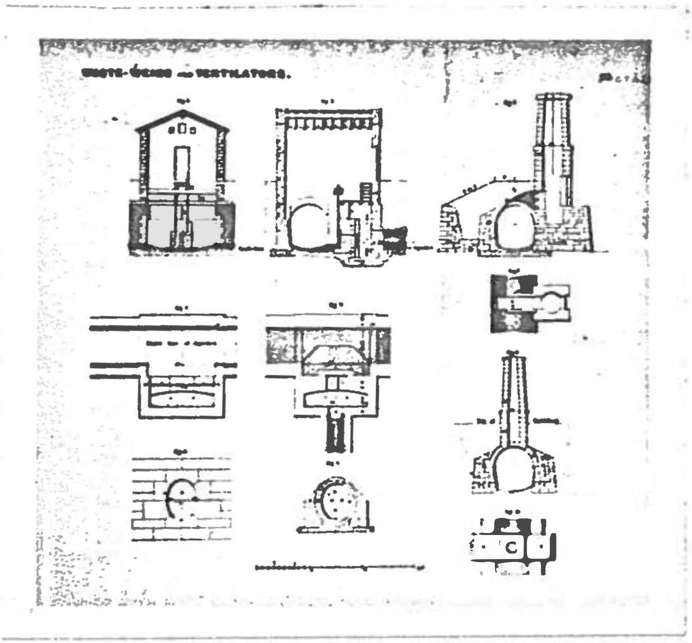
On February 25, the Chief Engineer presented the Water Commissioners with his last design report prior to the letting of contracts. For some time he had worried about the need to ventilate the aqueduct. Whenever water was let into the conduit, or whenever the water's flow might be blocked suddenly by an obstruction, he wanted to prevent the air in the conduit from becoming trapped and pressurized. Whenever the conduit was emptied, he wanted air to fill the space previously occupied by water, so that no vacuum formed. He also wanted to maintain the freshness of the water under transport.[43] It seemed to Jervis that ventilators would serve all these ends. Unfortunately, he did not know how many ventilators were needed to do these jobs effectively.

Jervis turned to the literature for an answer, and in this instance the literature failed him. Robert Stuart's Dictionary of Architecture gave 120 feet as the proper distance between ventilators; Peter Nicholson's Architectural and Engineering Dictionary said 240 feet; and John Leslie, in Elements of Natural Philosophy, wrote that ventilators should be 600 feet apart.[44] Besides reading these technical works, Jervis studied an unlikely source of information on ventilators, a book called Sketches of Turkey, written by "An American." Jervis read faily extensively in history, and he also read some of the popular travel books of the period, noting their descriptions of old and new civil engineering projects around the world. In this travel book he was quite taken by the anonymous author's description of ventilators, or "Hydraulic obelisks," used on an aqueduct running to Constantinople. The source, however, did not solve his problem. It provided yet another contradictory answer; the "Hydraulic obelisks" were placed 300 to 500 yards apart.

Since Jervis was unable to find "any definitive rule" regarding ventilators, he devised his own solution. He began with the premise that the spacings recommended in the literature had been adopted on successful aqueducts. Because the aqueducts had been successful, the various authors assumed their ventilator spacings were correct, "without considering that [ventilators] might have been sufficient at a greater distance." Working from this premise, and wanting to avoid the expense of superfluous ventilators, Jervis solved his problem in a most pragmatic way, with some assistance from Stephen Allen. He "guesstimated" that one ventilator per mile would suffice, but to be on the safe side he adopted an idea suggested by Allen. He left regular ventilator openings in the top arch of the conduit at quarter-mile intervals. These openings, covered with a removeable flagstone and earth, would "afford a convenient facility for erecting more ventilators, if experience should indicate their necessity or advantage."[45] As it turned out, the Chief Engineer's "guesstimation" was a good one; one ventilator per mile proved sufficient.

Jervis suggested that two out of every three ventilators take the form shown in Plate XV, Figures 9 and 10. He made these hollow stone "cylinders" tall enough to make it difficult for anyone to throw or drop things into the aqueduct, and to thwart such mischief he also placed an iron grating over each opening. Every third ventilator was to be a larger, dual-purpose structure after the plan shown in Plate XV, Figures 7 and 8. Jervis dubbed this an "entrance ventilator." Air could pass in and out of the conduit through an entrance ventilator, and so could authorized persons, through a "door of close double batten oak, well riveted . . . , and secured with proper iron

PLATE XV



Waste Weirs and Ventilators.

hangings, clasp, staples, and lock." Jervis made clear to the Water Commissioners his reasons for building these entrance ventilators:

> The plan of construction and the great freedom of the waters of the Croton from all earthy matter, renders it probable that repairs or the removal of earthy deposit will rarely be necessary. Still, it is not to be expected a hydraulic work of such extent will be entirely freed from such liability, and it would be inexpedient to construct it on a plan, that did not admit convenient entrance at suitable intervals. A ventilator and an entrance may be advantageously constructed together, and I have therefore prepared a plan to effect the double purpose.[46]

While his entrance ventilators served two purposes, the waste weirs which Jervis discussed in his February 25 report served three. These waste weirs, after the plan shown in Plate XV, Figures 1 through 6, initially resulted from the Chief Engineer's concern over the need for an efficient means of draining and refilling the aqueduct. He recognized that if the gates at the dam were left as the only means of regulating the water's flow, then whenever the water was stopped, New York would lose its running water supply for t o long a time. To demonstrate the utility of the waste weirs (Jervis placed six of them along the line), assume that the aqueduct is completed, and the conduit across Sing-Sing Kill Bridge needs repair. Instead of sending a messenger all the way to the dam to stop the water, men enter a waste weir just a quarter-mile above the bridge. Inside this structure, the conduit has no roofing arch, and two waste gates are set into the conduit's altered side wall. The men drop wooden stop planks across the conduit and open the gates, thereby diverting the water into a culvert which drains or wastes it into a nearby stream. Since the waste weir is so near the part of the aqueduct needing repair, workers can begin their task almost at once; they do not have to wait for a long column of water to pass them by. When the repairs are completed, men remove the stop planks and close the waste gates. The water again flows towards New York, starting from a point much closer to the city than the gates at the dam.

The waste weirs functioned primarily to stop and divert the water in the conduit, but because they had openings to the outside, they also functioned as ventilators. Wherever there was a waste weir, no regular ventilator was needed for a mile on either side of it. Finally, the waste weirs provided a means of automatically spilling surplus water. Jervis recognized that the gate-keepers at Croton Dam might "sometimes neglect their duty" and allow too much water to enter the conduit.[47] Consequently, he thought it best "to make every reasonable provision to mitigate the injurious influences of such neglect." Within the waste weirs, Jervis set the normally closed waste gates in masonry that served as a side wall for the conduit -- a side wall which rose only 5 feet 9 inches above the conduit's lowest point. The water in the aqueduct, if it exceeded a depth of 5 feet 9 inches, passed over this wall, fell into a well, and then ran off in a culvert. Jervis believed that for many years New York would not require any more water than the aqueduct could deliver at this maximum depth. When it did require more water, the height of the side wall could be raised by adding wooden flash boards.

Three days after submitting his report on ventilators and waste weirs, John Jervis formally reported to the Water Commissioners that:

> Plans for all the work required from the head of the Croton Aqueduct to the State Farm at Sing-Sing have now been submitted.[48]

The initial design work was complete, but Jervis and his engineers still had a great deal of work ahead of them before construction could begin. And, as always, they had to hurry. On the same day he reported that all needed plans had been submitted, the Chief Engineer and the Water Commissioners placed notices in four New York City newspapers, and in Albany, Utica, Hartford and Philadelphia papers. The notices advised that the process of letting contracts for work on the Croton Aqueduct would begin on April 10, 1837.[49]

NOTES -- CHAPTER FOUR

[1]Jervis, "Plan of Double Aqueduct," Dec., 1836, Jervis Papers.

[2]This was the minimum depth of the earth covering the conduit, used wherever the aqueduct lay at or above ground level. Where the conduit was buried, workers would backfill over the masonry until the natural ground level was restored.

[3]Jervis, "Report to the Board of Water Commissioners," December 23, 1836, Jervis Papers.

[4]Ibid.

[5]Both Douglass and Jervis preferred brick for the shallow inverted arch because, unlike stone, it did not have to be dressed or shaped.

[6]Jervis,"Report to W. C.," Dec. 23, 1836

[7]Jervis to Stephenson, Dec. 27, 1843, Jervis Papers.

[8]Even if Jervis had been able to read French and German, he would have had a difficult time trying to find some of these authors' works in the United States, because of their early publication dates.

[9]All these volumes are found in Jervis' personal library.

[10]Jervis, "Report to W. C.," Dec. 23, 1836; Jervis to Stephenson, Dec. 27, 1843; Jervis Memoranda Book entry for Dec. 12, 1837; and Jervis, "Calculations on discharge of pipes," n. d., Jervis Papers.

[11]Reminiscences of JBJ, p. 37.

[12]Jervis,"Report to W. C.," Dec. 23, 1836.

[13]Reminiscences of JBJ, p. 123.

[14]In "New York Water Works No. 1," Stephen Allen suggests that Douglass and Martineau had deliberately underestimated the aqueduct's cost, in order to promote their own employment on the project: "To show what dependence may be placed on the calculations of persons who are under expectations of benefit, by being employed on a work requiring

several years to compleat, I subjoin the estimate of Mssrs. Douglass and Martineau, of the cost of the whole work. Douglass states the total at $4,558,725. Martineau makes the cost 3,742,693. This is about one third the actual cost; although the gentlemen were requested to hide nothing from the public, but to make a full estimate, in order that there might be no blame resting on the Commissioners, under whose responsibility the work was to be performed."

15 For a fuller treatment of the opposition of Westchester residents to the aqueduct, see Blake, Water for the Cities, pp. 148-151.

16 Since New York City's ordinary expenses at the time amounted to only 1¼ million dollars per year, it is not hard to understand why the aqueduct seemed very expensive indeed. (Reminiscences of JBJ, p. 132.)

17 Jervis, "Report to the Board of Water Commissioners," Dec. 27, 1836, Jervis Papers.

18 Ibid.

19 Doc. No. 44, p. 430.

20 Reminiscences of JBJ, pp. 159-162.

21 Jervis, "Report to W. C.," Dec. 27, 1836.

22 Reminiscences of JBJ, p. 162.

23 See Tower, pp. 89-90. Also T. Schramke, Description of the New-York Croton Aqueduct in English, German, and French (New York, 1846), pp. 28-29.

24 Jervis, "Report on Sing-Sing Kill Aqueduct Bridge,' Feb. 8, 1837, Jervis Papers.

25 Acts of the Legislature . . . Croton Water, p. 14.

26 Reminiscences of JBJ, p. 128.

27 Jervis, "Report on Sing-Sing," Feb. 8, 1837.

28 Ibid.

29 Jervis' method of bolting together cast iron plates did not allow for expansion and contraction with changes in temperature. He later admitted that he should have used large iron pipes with faucet and spigot joints. (Reminiscences of JBJ, p. 128.)

[30]Carl B. Condit , American Building (Chicago, 1968), p. 73. Also see FitzSimons' "Introduction" to Reminiscences of JBJ, p. 11.

[31]See Jervis, "Specifications of the manner of constructing an Aqueduct Bridge across the Valley of Sing-Sing Kill," April, 1837, Jervis Papers.

[32]Jervis, "Report on Croton Dam," Feb. 13, 1837, Jervis Papers.

[33]Ibid.

[34]Some parts of Plate XIV, Figures 1 and 2 are based upon incomplete descriptions and are therefore conjectural. It is not known exactly how Jervis intended to join the aprons to the toes of the dams, and the exact height and breadth of the aprons remain unknown. In Figure 1, the exact configuration of the offsets on the upstream side is unknown.

[35]Jervis, "Report on Croton Dam," Feb. 13, 1837.

[36]Ibid.

[37]Ibid.

[38]Jervis, "Croton Aqueduct -- Specifications of the manner of building a Dam across Croton River," April, 1837, Jervis Papers.

[39]Because he lowered the aqueduct's entrance, Jervis had to adjust the declivity of its line. Instead of adjusting the entire line, he chose to reduce the declivity along its first five miles, reducing it from 13¼ inches to 7.15 inches per mile. To compensate for this reduction, along this stretch of line Jervis increased the height of the conduit so it could carry more water.

[40]Jervis, "Specifications of the . . . Dam across Croton River," April, 1837.

[41]Jervis, "Report to N. Y. Water Commissioners," Feb. 16, 1837, Jervis Papers.

[42]At the time of this report, Jervis anticipated that no tunnels would be cut through earth. This situation was encountered, however, so Jervis later designed a cross-section for the conduit appropriate for tunnel cuts in earth. The cross-section is shown in Plate XX, Figure 4. (Note how he put the side walls under compression.)

[43]Wegmann, Conveyance and Distribution of Water, p. 247.

[44]Jervis, "Plans for Ventilators and Waste Weirs," Feb. 25, 1837, Jervis Papers.

[45]Ibid.

[46]Ibid.

[47]Ibid.

[48]Jervis, "Monthly Report," Feb. 28, 1837, Jervis Papers.

[49]"Semi-Annual Report of the Water Commissioners, Jan. 1 to June 30, 1837," Board of Aldermen Document No. 14 (New York, July 3, 1837), p. 92. Also see "Croton Aqueduct -- Notice," Feb. 28, 1837, Jervis Papers.

CHAPTER FIVE

Because he had laid off two-thirds of his engineering department for the winter, including all of the axemen and rodmen, and several of the lesser-skilled assistant engineers, John Jervis had only five men to assist him in letting contracts. Edmund French and M. O. Davidson worked out of an office in Sing-Sing. In the New York office, Henry Anthony, A. B. Lansing and T. J. Carmichael labored beside the Chief Engineer. None of the men wanted for work.

In order to let contracts, Jervis split the aqueduct's long line into manageable units.[1] By the end of January he had decided to cut the line into four "divisions," each roughly 10 miles long, and he subdivided these into "sections," generally four- to five-tenths of a mile long, which contractors bid on. Under this plan, the line between the dam and Sing-Sing became the aqueduct's 1st Division, which Jervis cut into 23 sections. The sections did not have arbitrary boundaries; the Chief Engineer arranged them in a manner "most convenient for the prosecution of the work." Jervis took particular care to see that the boundary between any two sections did not cut across a major structure. He did not want two different contractors to be responsible for constructing opposite ends of a tunnel, bridge, or tall embankment.

In Sing-Sing, French and Davidson busily prepared a special map and profile of the 1st Division that contractors could study while preparing their proposals for work. Jervis informed his two assistants that the map should delineate the boundaries of the 23 sections, and that:

> On each section, there should be a brief description of the soil on the line, of quarries of stone in the vacinity, and any other circumstances that may not be apparent on viewing the map and profile.[2]

Contractors, of course, would be interested in the accessibility of the various sections, so French and Davidson located on the map all public and private roads that intersected or passed near the line. In doing this work, they learned that some sections were not very accessible at all, so Edmund French began negotiating with land owners for the right to build temporary roads across their properties.

In the New York office, Anthony, Lansing and Carmichael spent much of their time at drafting tables, preparing final sets of working drawings. When they were not drawing, they were busy "making detailed calculations of the several kinds of work" to be found in each section. Using their plans, geological reports, and a profile of the line, they estimated the total amount of earth and stone to be excavated; the cubic yardage of stone to be laid in foundation walls, protection walls, and culverts; the amount of earth needed for embankments and backfilling;

the cubic yardage of brick and stone needed for the conduit's interior, and so on. Jervis, meanwhile, prepared written specifications to supplement the information contained in the working drawings. Besides describing structures -- giving their materials, dimensions, and shapes -- the specifications established certain construction procedures which contractors would have to follow. To cover the 1st Division, Jervis wrote three specifications: one for general work, one for Croton Dam, and one for Sing-Sing Kill Aqueduct Bridge. In his 5½-page "SPECIFICATIONS of the manner of constructing the general work for the Croton Aqueduct," Jervis distilled a number of his design reports submitted to the Water Commissioners. The Chief Engineer instructed contractors as to how the following types of work would be done:

grubbing and clearing timber
excavating in earth and rock
tunnelling in earth and rock
laying masonry for culverts
laying foundation walls
embanking earth
laying protection walls
laying masonry for the conduit
back-filling
constructing ventilators and waste weirs

The general specifications were detailed for their time. For example, Jervis specified the minimum dimensions of the stone to be used in different types of work, whether it was to be laid dry or in hydraulic cement, and whether it was to be rubble, hammer-dressed, or cut stone. He also specified the maximum thickness he would allow in the joints between stones. A quotation regarding the use of cement serves to demonstrate the amount of control which the Chief Engineer intended to exert over the contractors:

> Cement -- To be used either in mortar or grout, shall be composed of the best quality hydraulic lime, that has not been manufactured more than two months previous to the time of using, and clean sharp sand, in such proportions, and made in such manner, as may be required by the said Engineer. If sand is not obtained from natural beds or banks of sufficient purity, it shall be screened and washed, until all loam, gravel, or other improper matter, is wholly removed; and then dried before it is used. The hydraulic lime may be inspected at the place of manufactory, by a person or persons duly authorized by the said Water Commissioners. It shall be transported from the place of manufactory, to the place where it is to be used, in tight casks, that will effectually prevent its injury from water; and no lime shall be used, that has been wet, or in any way damaged; nor until it shall have been tried and approved by the said Engineer, or some person under his direction. To guard against disappointment in the quality of hydraulic lime, two sheds shall be erected to protect the casks containing the lime from the weather, and the lime used from them alternately, after the said Engineer shall have ascertained, from trial, that the same is good.[3]

To go along with the three specifications, Jervis prepared three "Proposition" forms which contractors filled out in order to bid for work.[4] These forms listed each type of work to be encountered in the 1st Division, and a contractor noted on his "Proposition" the rate of compensation he required for each type of work on a given section. Assuming that a contractor's bid was accepted, his rates of compensation were incorporated into the "Articles of Agreement" concluded between the contractor and the Water Commissioners.

Jervis, apparently with no help from a lawyer, wrote the "Articles of Agreement," and his contract form stipulated a great deal more than just the compensation a contractor would receive.[5] It required the contractor to furnish all needed materials, which were to be "of a sound, durable and good quality, and approved by the Chief Engineer." The contractor could not subcontract any of his work, except the delivery of materials, and he had to construct his section "in the most substantial and workmanlike manner" and in strict accordance with the specifications. But if Jervis directed any "alterations in the [aqueduct's] form, dimensions, or materials," the contractor was bound to adopt the Chief Engineer's changes. If a contractor consistently neglected his work, or performed it in "an improper manner," Jervis could certify this neglect in writing to the Water Commissioners, and they, in turn, could declare the contract violated and abandoned.

Among numerous other provisions, the contract stipulated that hydraulic masonry, to assure its soundness, could be laid up only "between the 1st of April and the 15th of October, and at no other season," unless by the special permission of the Chief Engineer. Usually, all the work on a section was to be finished over three working, or summer seasons, and during that time the contractor and his employees were to remain sober and to interfere as little as possible with the lives of Westchester County residents:

> No public or private road . . . shall be obstructed by excavation or otherwise, until direction shall be given by the said Chief Engineer to complete the aqueduct across said road or highway; nor shall any crops of grain, grass, or vegetables, nor fruit trees, nor any dwelling-house or other building on said line of aqueduct be disturbed, unless by direction of said Engineer.
>
> And it is further agreed by the said contractor, that [he] will not allow any person in [his] employ to commit trespass on the premises in the vacinity of [his] work.
>
> And the said contractor further promise[s] and agree[s] that [he] will not . . . give or sell any ardent spirits to [his] workmen, or any other person, on or near the line of said aqueduct, or allow any to be brought on the work by the laborers, or any other person; and will do all in [his] power to discountenance its use in the vicinity of the work.[6]

On April 10, 1837 the engineering department made available to contractors the map and profile, the working drawings, and the specification, proposition and contract forms covering work on the Croton Aqueduct's 1st Division. Until April 14, contractors examined these materials in the New York office. Then they were moved to the Sing-Sing office, so contractors could conveniently study the aqueduct's line, its plans, and local stone quarries at the same time. Jervis and his assistants also traveled to Sing-Sing in order to answer questions regarding the work.[7] Sealed bids on the sections were originally due on April 24, but the Chief Engineer extended the deadline to April 26 to:

> accommodate the mechanics of this city [New York], whose information on this description of work, might not be as perfect as those who were accustomed to the execution of contracts on Canals, Railroads, and other large jobs.[8]

There was no lack of interest on the part of contractors; Jervis received five to eight propositions for each section. Because the contractors did not submit an overall bid for a section, the engineers had to spend long hours multiplying and adding in order to evaluate the propositions. For each section, the engineers had a table listing the estimated quantity of each of thirty or so different types of work. They took each estimate, multiplied it by the appropriate rate of compensation required by the contractor, and then added up all the products to arrive at a total dollar figure for the section. When all of this arithmetic was finished, it became clear that although the contractors were anxious to undertake the work, they were also very concerned with its novelty, with the high standards of workmanship demanded by the Chief Engineer, and with the surprising scarcity of good stone along the line.[9] The bids ran higher than expected.

Jervis prepared a list of all the bids and presented it to the Water Commissioners. Unfortunately, the Commissioners received the bids while the nation was in the midst of an economic panic which had severely depressed the money market. New York's issue of the first one million dollars of Water Stock initially had sold well, at rates 12½ per cent above par. But the market for Water Stock had collapsed, and the Commissioners found themselves with higher-than-expected bids and with too little money.[10] Conseqently, they could not put all of the 1st Divsion under contract. After consulting with their Chief Engineer, the Commissioners decided to enter into contracts for only 13 of the division's 23 sections. In each instance they contracted with the lowest bidder, if he was still willing to undertake the work. Nevertheless, "by the estimate of quantities, calculated at contract prices," Jervis determined that just these 13 sections would cost $922,000.[11]

Early in May the contractors began erecting workers' shanties and started opening local quarries. Laborers, far more than could be used at the start, flooded into the area, and because other work was so scarce, many of them offered to work only for their board.[12] While the contractors prepared for work, Jervis brought his engineering department up to strength. Since he had cut the line into four divisions, he organized his engineers into four field teams, each team or party supervised by a Resident Engineer who lived and worked on his division. Under each Resident, Jervis called for at least one 1st Assistant Engineer, one 2nd Assistant, and "one or two rodmen . . . and one or two labourers, as the condition of the work may require."[13] Later, when construction sufficiently progressed, as many as five skilled masons joined each team as inspectors of masonry. (See "Engineering Department Roster," Appendix III.)

The assistant engineers and laborers laid-off for the winter returned to work. New recruits, such as Peter Hastie, James Renwick, Jr. and William Jervis, joined the department.[14] The Chief Engineer named Edmund French the Resident Engineer for the 1st Division, and Henry Anthony assumed the same role for the 2nd, the next to be put under contract. Since construction on the 3rd and 4th Divisions would not start for some time, Jervis temporarily combined them under the charge of Peter Hastie. In completing the rosters of the field teams, Jervis tried to provide subordinates who were personally acceptable to the Residents. He took into account, for example, this request from Edmund French:

> I should be much pleased to have Mr. Churchill as 1st asst. or Mr. Zabriskie if he would like to join me. If I could have Wise in place of Righter I should also be pleased.[15]

The Chief Engineer granted considerable authority to his Resident Engineers. The contract form he had written stipulated that:

> In the case of the absence or inability to act, of the said Chief Engineer, the Resident Engineer having charge of the work embraced in this contract, shall have, and is hereby vested with all the powers herein given to the aforesaid Chief Engineer.

Since Jervis worked out of his home base in New York, and toured the line only every week or two, he left the Resident Engineers in charge of the day-to-day affairs within their respective divisions. The Chief Engineer made it clear to them that they were to exercise their full authority as managers:

> The particular management of your Division is committed to your care, and in whatever relates to the execution of the works or the energy, the efficiency, and business-like deportment of the Engineer department, under your direction, you must consider yourself responsible; and the undersigned will not be wanting in releasing you from any embarrassments, that may arise from inattention on the part of your assistants to your directions. While it is recommended to pursue a courteous deportment and to avoid every reasonable cause of dissatisfaction on the part of your assistants, it is at the same time urged, that you do not sacrifice or allow the interest of the work to suffer, from a delicacy that tends in the least to insubordination, or delinquency in duty.[16]

The Resident Engineers' greatest responsibility was to understand thoroughly the aqueduct's plans and specifications and to quickly check any contractor who deviated from them. Jervis provided his Residents with a simple and efficient means of enforcing the plans and specifications; he gave them control over the contractors' purse-strings. Once a month from April to October, and once every two months during the winter, The Resident Engineers provided Jervis with estimates of the quantities of work done by the contractors. Jervis forwarded these estimates to the

Water Commissioners, who paid the contractors accordingly. If a contractor's work was found unsatisfactory, the Resident Engineer admonished him -- and withheld his estimate until all errors were corrected.

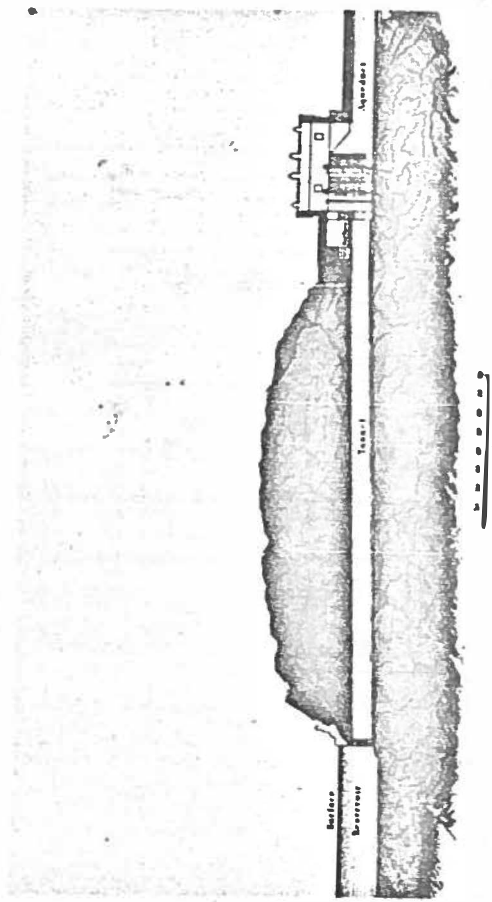
In late April and early May, Edmund French and his seven or eight member field team, split into two groups, prepared the 13 sections for ground-breaking. At 50-foot intervals they carefully conducted levels, noting at each station how far above or below ground the aqueduct's grade line ran. They carefully entered this information in field notebooks, and from it they calculated the contents of required excavations or embankments.[17] Then they set stakes in the ground marking the extreme breadth of the trenches and embankments. When this was completed on a section, it was ready to be worked. On May 16, a full two years after the Water Commissioners had been authorized to build the aqueduct, but just seven months after John Jervis had joined the project, contractors Young & Scott, working on Section 20, which included the Sing-Sing Kill Aqueduct Bridge, broke ground on the Croton Aqueduct.[18]

The engineering department had worked hastily to prepare the 1st Division for construction, and it did not take long for some problems to develop which were attributable to haste. A controversy quickly arose, for example, over Croton Dam. Jervis had designed the dam and let a contract on it, knowing only that it was to be located somewhere along the stretch of bluff rock below Garretson's Mill. He had not had a specific location for the dam, because Edmund French's work of sounding the Croton's bed had been halted by winter weather. Nevertheless, the Chief Engineer felt that his plan for the dam conformed well to this general location, and that "the essential principles of the plan would not be materially changed, by any probable change of location."[19] In May, June and early July, Jervis and French waited for the Croton to fall so that more of its bed would be exposed for examination. Finally, on July 31 they chose a specific site for the dam, one 400 feet downstream from the site Douglass had staked.

After choosing the dam's exact location, the Chief Engineer once again redesigned the structure. Perhaps its "essential principles" remained unchanged, such as the profile of the main wall and the use of an apron, but Jervis did modify the dam a great deal. Bed-rock across the channel proved so scarce, that in order to place the northern end of the dam on rock, Jervis had to reduce the length of the weir from 100 to 90 feet. He also had to carry the southern end of the dam so far into the bluff that a 12-foot-thick southern abutment was no longer necessary. The bluff itself served as a natural abutment, and part of the bluff, cut down and shaped, also served as part of the main wall.[20] Finally, stone masons no longer had to lay a gateway for the aqueduct, because a tunnel cut through the bluff would serve as the aqueduct's entrance.

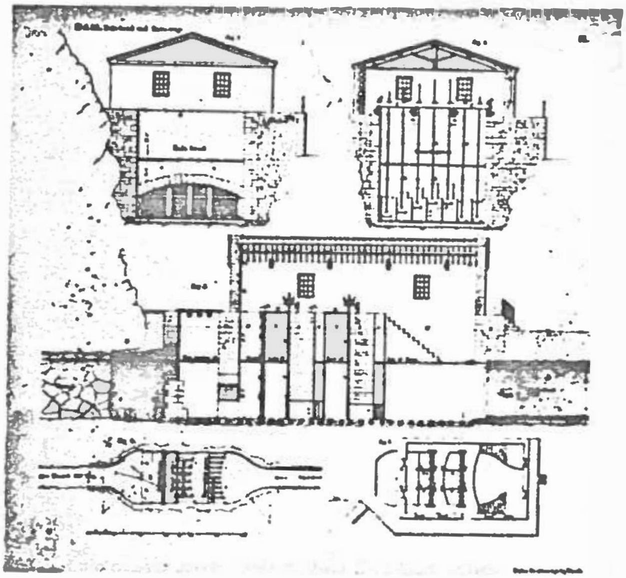
The contractors for Croton Dam -- Clark, Strover and Yates -- protested that all these changes were prejudicial to their economic interests. When signing their contract, they had expected to lay 13,000 cubic yards of masonry, at rates of $5.25 per cubic yard of stone in the main wall and $6.25 in the abutments.[21] Because the Chief Engineer's modifications greatly reduced the masonry in the dam, the contractors saw that they were going to be paid far less for their work than they had expected. They petitioned the Water Commissioners for redress. If they could not lay a full 13,000 cubic yards, then they wanted a higher rate of compensation for each cubic yard which they did lay. Upon receipt of this petition, the Commissioners requested an opinion from their Chief Engineer, and they received one which typified his hard-nosed approach to business. Jervis said that he had told the contractors, before they submitted their bid, that this very site for the dam <u>might</u> be adopted and cause some changes in the dam's plans. Moreover, they had signed a contract for the dam which bound them to abide by any alterations specified by the Chief Engineer. Conseqently, the contractors were not entitled to any extra compensation. If they maintained their protest, Jervis thought it would be best simply to declare their contract abandoned and to re-bid Croton Dam. The Water Commissioners did just

PLATE XVI



Section of tunnel leading from the Fountain Reservoir to the aqueduct's head gates.

PLATE XVII



Head Gates on Croton Aqueduct.

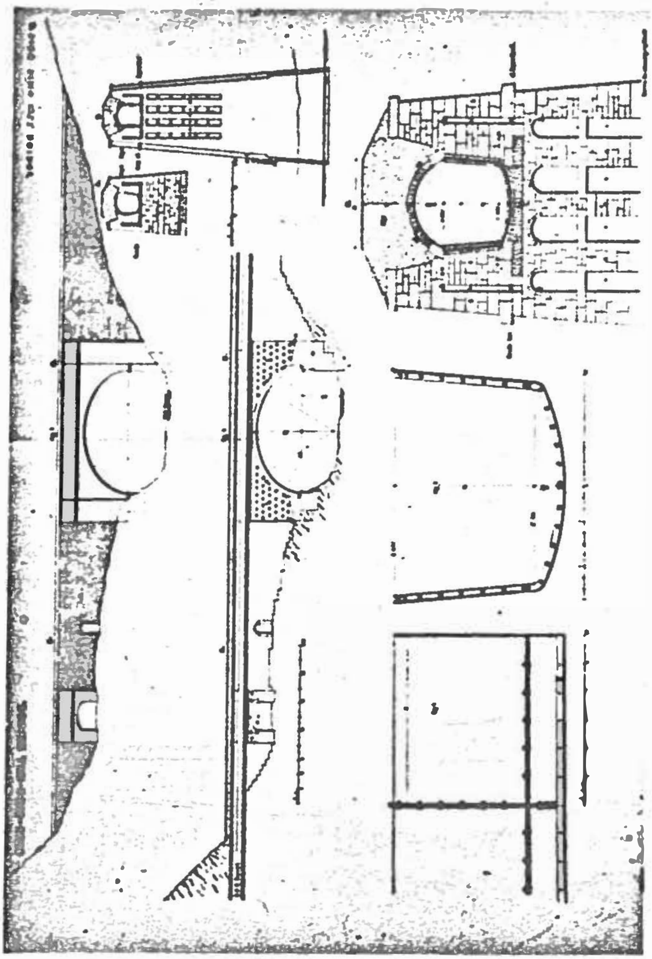
that.[22]

Jervis ran into a similar problem at the site of the Sing-Sing Kill Bridge. From geological data provided by Edmund French, when Jervis first designed the bridge he believed the abutments for the elliptical arch would stand on rock. But when contractors Young & Scott opened the ground, they discovered that rock was less extensive than supposed. In order to provide the abutments with the foundation that he wanted, Jervis had to increase the span of the arch from 80 to 88 feet.[23] (Plate XVIII.) To assure the stability of this larger arch Jervis changed its rise from 25 to 33 feet, and he specified the type of centering, or wooden scaffolding, that Young & Scott were to use in springing it. Jervis took his centering from the one used in building the Waterloo Bridge in London. The centering, shown in Plate XIX, worked well. When the arch stones were laid, and the scaffolding removed, the Chief Engineer was pleased that the soffit of the arch settled only half an inch.[24]

Another problem, an economic one, arose because of the unexpected paucity of good stone along the 1st Division. (This problem showed up later on other parts of the line.) Jervis wrote the Water Commissioners that he had interpreted T. J. Carmichael's report on local quarries too optimistically:

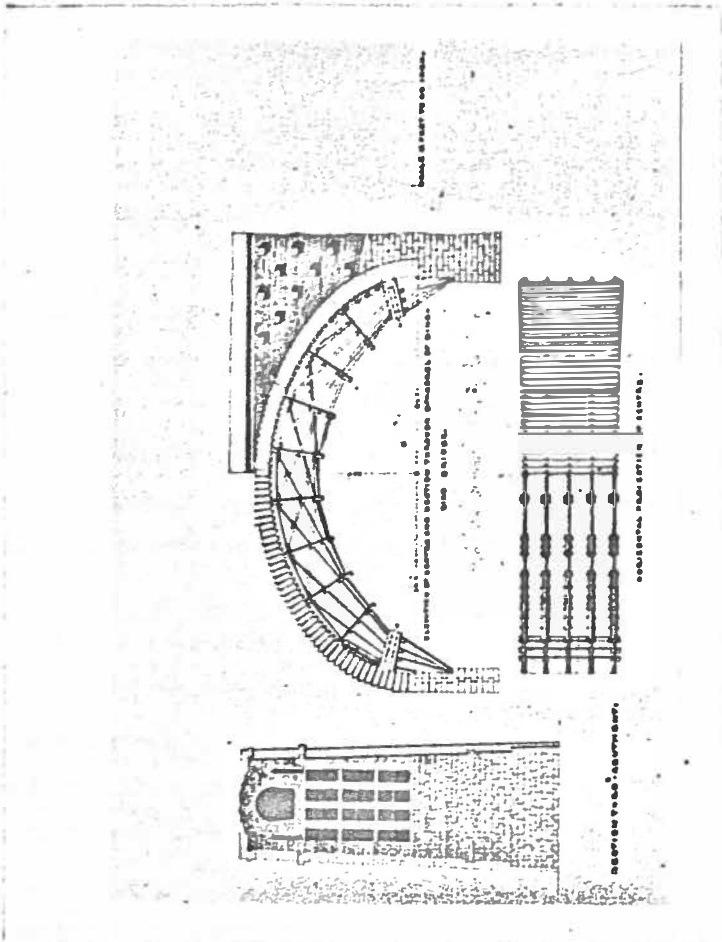
> In examining for stone suitable for the

PLATE XVIII



Sing-Sing Kill Aqueduct Bridge.

PLATE XIX



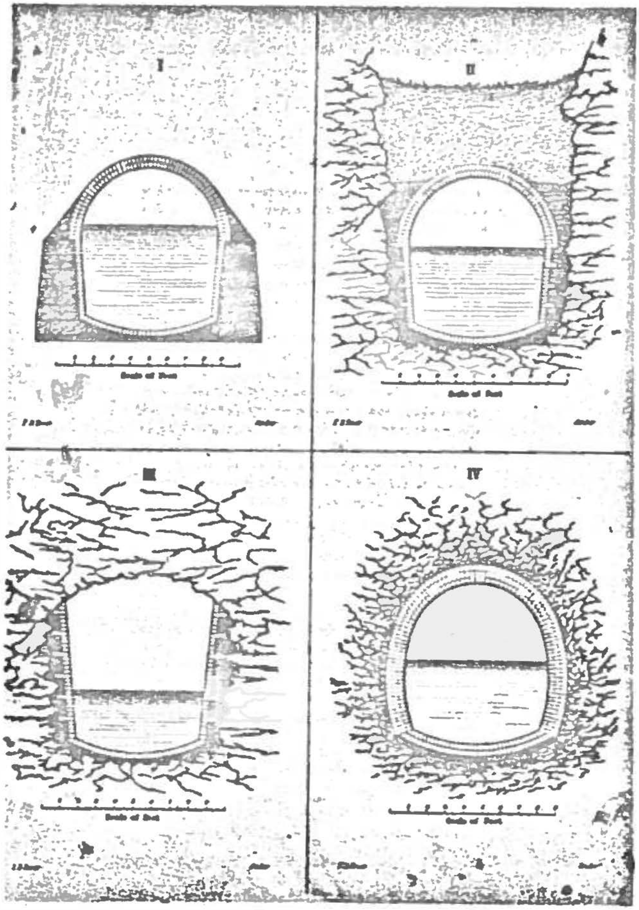
Wooden Centering for Sing-Sing Kill Aqueduct Bridge.

> various kinds of work on the Division offered for contract, I regret to say we have not been as successful, as from the partial examinations of last fall we had hoped to be.[25]

In particular, the engineers and contractors found too little stone in the region suitable for use in the conduit's interior, where it would be in constant contact with water. Because of this scarcity, Jervis had to abandon the idea of facing the conduit's side walls with stone and adopt, almost exclusively, sides faced with "hard burnt, weather brick, free from lime." Brick had one advantage; it made a smoother wall which presented less resistance to the flow of water. But this advantage was slight and did not compensate for the greater cost of brick.

Because he could not have the less expensive stone facing, and because the contractors' bids had run higher than expected, Jervis decided that he had to reduce the conduit's cost by paring more materials. In the summer of 1837 he altered the conduit's specifications, giving it the form seen in Plate XX, Figure 1. While the conduit's interior dimensions remained the same, Jervis cut the depth of brick in the bottom and sides from 8 inches to 4 inches, and he similarly reduced the thickness of the top arch from 12 to 8 inches. Altogether, he reduced the amount of brick per linear foot by 6¼ cubic feet, and the amount of stone and concrete by almost 4 cubic feet. Jervis

PLATE XX



Cross-sections of masonry conduit. Fig. 1: general cross-section, showing reduction of brickwork. Figure 2: form adopted in open cuts in rock. Fig. 3: form adopted in tunnels in rock. Figure 4: form adopted in tunnels in earth.

knew that there was some risk involved in this paring of materials, but he was "of the opinion the reduction thus proposed may with safety be adopted on three quarters of the line." Certainly the reduction was a significant cost-saver. He informed the Water Commissioners that:

> At the prices usually paid, this would make a difference of about half a million dollars over 35 miles of aqueduct.[26]

Between ground-breaking and the completion of the aqueduct, the engineering department had to cope not only with redesign problems, but with a whole range of problems seemingly inherent in such a large project. Contractors encountered difficulty in laying the conduit across marshy ground; its concrete foundation kept cracking. A 60-foot stretch of the roofing arch fell in one day, for no apparent reason. Careless contractors, blasting in rock, raised the hackles of Westchester residents whose homes were struck by flying debris. Shipments of hydraulic cement, upon testing, proved incapable of setting under water.[27] Contractors protested that the Resident Engineers' monthly estimates of completed work were too low. The Resident Engineers protested that some contractors required constant prodding to make them follow the specifications, and others attempted to back-fill over the masonry before it could be inspected. This was one practice which the engineers could not tolerate at all, because, as Jervis reported to the Water Commissioners, a close inspection of all the masonry was essential to the aqueduct's success:

> The works of ordinary masonry are generally laid up with mortar beds and joints that are imperfect, having the wall fair on the outside, and with numerous cavities in the interior. This method is entirely unfit for hydraulic masonry; but the workmen become so attached to it, that great vigilance is necessary to obtain that character of work which is indispensible for the aqueduct masonry. At first, the contractors and their workmen did not appear, in many instances, to understand the importance or practicability of complying with the directions given; this difficulty was surmounted, and they were left with no excuse for imperfect work. But experience has shown, that if we will have the work properly executed, there must be no abatement in the inspection of the materials and workmanship.[28]

One contractor laid a stretch of conduit on a Sunday, when no engineers or inspectors of masonry were working. Upon discovering this, the Resident Engineer insisted that the work come down. The contractor appealed to the Board of Water Commissioners, stating that the Sunday work had not been a deliberate attempt to slip anything past the engineers. Besides, he had not even known that his men were going to work that Sunday. The Commissioners sought out Jervis' opinion, and he backed his Resident Engineer: the work had to be taken down. The Chief Engineer also opined that if the contractor's men had indeed done the work without his knowledge, then instead of looking for any compensation from the Commissioners, he should sue his own employees for the cost of the wasted materials.

While Jervis could force inspection upon the contractors, neither he nor his Resident Engineers could force a code of conduct on the laborers who slept in shanties after working all day for little money at backbreaking tasks. At the peak of construction, nearly four thousand men toiled along the line at once. Most were Irish immigrants, newly arrived in this country, men who cared little for a contract which forbade them "ardent spirits." They were a hearty, hungry and thirsty lot. Or, as some Westchester residents characterized them, they were a noisy, riotous and drunken lot whose members stole fruits and vegetables and made it "unsafe and imprudent for a respectable female to walk on, or near, or along" the aqueduct.[29] Although many of the laborers initially had been glad to find any kind of work at all on the aqueduct, they soon came to chafe at the bit of their difficult existence, and occasionally they rebelled, interrupting the work on the line. One such rebellion occured during the first summer's construction, as reported in the Westchester Spy on August 30, 1837:

> The laborers on the New York Aqueduct at Croton, a few miles above Sing-Sing, made a strike for higher wages a few days since. They had received, heretofore, about 70¢ per day, which they found insufficient for their support. The contractors objecting to advance their wages, about 300 refused to work. A few however remained at the lower rates, which displeasing the others, a general fight ensued. Information of the row was communicated to the inhabitants of

> Sing Sing, where the military was ordered out, and several of the citizens armed themselves and marched to the scene of the action, but before they arrived there the laborers had separated, and no further disturbance took place. Several individuals were much hurt . . . .

In the spring of 1838, another labor revolt broke out on Section 15 near Sing-Sing. During the winter, when there was less work to do and the demand for laborers was low, the contractor for Section 15 had paid unskilled men only 68½ to 75 cents per day. When the contractor posted his pay schedule for April, he offered 75 to 81¼ cents per day, instead of the 87½ to 100 cents than his men wanted. Denied and angry, the laborers started marching north towards Croton Dam, picking up other men along the way before the magistrates of Mount Pleasant stopped them.[30] At about the same time as this strike, a riot broke out between the "Corkites" and the "Formanaghs," men who came from different counties in Ireland:

> The fight was most desperate, resulting in broken heads, and maimed bodies and limbs, and eventually in the death of one of their countrymen.[31]

The Water Commissioners did not condemn the laborers for these outbursts. They condemned the opportunistic Westchester residents who had first scorned the aqueduct, and who later converted their farmhouses into taverns. Despite the contractual ban on liquor, a "love of lucre" had:

> induced certain individuals, regardless of the injury inflicted on others, to open places of resort for the laborers where this enemy of man may be obtained, in any quantity for money.[32]

John Jervis joined the Commissioners in regretting the easy availability of the "enemy of man" in taverns along the aqueduct. But while Jervis was religious, he was neither puritanical nor unrealistic. He had written a contract which forbade liquor and required contractors to keep a check on their men, but when taverns and labor unrest sprang up, he was not surprised. Jervis recognized that he was a civil, not a social, engineer, and that some unpleasant realities, such as wild-cat strikes, could not be avoided. Put in another way, Jervis was unflappable:

> The usual wages now paid is 87½ cents per day for common labourers, and 1.50 Dollars for masons. Controversies between the contractors and their men in relation to wages are very common on public works, and we cannot expect to be exempt from them on the line of aqueduct.[33]

Despite the problems involved in inaugurating the construction of the aqueduct, when Jervis reviewed the first summer's progress on the 1st Division, he was pleased. Perhaps contractors had not moved as fast as he would have liked, but the work had gone well:

> We have had an opportunity of seeing specimens of nearly all the several kinds of work required for the aqueduct; and after having given the subject the most careful consideration, I see no important variation to propose . . . in relation to the plans or

> the character of the structures; and it affords me great pleasure to say, that I feel entire confidence in its stability and permanence, and its efficiency in answering the great object for which it is intended.[34]

The 1st Division, of course, represented only a fraction of the aqueduct's line. So while Edmund French's engineering team had worked the 13 sections there, the rest of the engineering department had forged ahead with the work that had to be done on the line from Sing-Sing to central Manhattan.

NOTES — CHAPTER FIVE

[1]Jervis, "Report to Water Commissioners," Jan. 31, 1837, Jervis Papers. Also see Doc. No. 14, pp. 95-96.

[2]Jervis, "Report to W. C.," Jan. 31, 1837.

[3]Jervis, "SPECIFICATIONS of the manner of constructing the general work for the Croton Aqueduct," April, 1837, Jervis Papers.

[4]Examples of the "Proposition" forms for general work, Croton Dam, and Sing-Sing Kill Bridge are found in the Jervis Papers.

[5]Jervis, "Croton Aqueduct -- Articles of Agreement," April, 1837, Jervis Papers.

[6]*Ibid.*

[7]Jervis, "Monthly Report," April 29, 1837, Jervis Papers.

[8]*Doc. No. 14,* p. 92.

[9]*Reminiscences of JBJ,* pp. 123-124.

[10]*Doc. No. 14,* pp. 92-94;

[11]Jervis, "Monthly Report," April 29, 1837, and "Result of letting: 26th April 1837," Jervis Papers.

[12]Jervis, "Monthly Report," June 30, 1837, Jervis Papers.

[13]Jervis, "Report to W. C.," Jan. 31, 1837.

[14]Jervis to Board of Water Commissioners, April 15, 1837, Jervis Letter Book.

[15]French to Jervis, Feb. 2, 1837, Jervis Papers.

[16]Jervis, "Circular to Resident Engineers," May 30, 1837, Jervis Papers.

[17]In a sense, French's team was repeating work that had been done before, but they were doing it more carefully. They were actually measuring the work that contractors would do, instead of just estimating.

[18] Jervis, "Monthly Report," May 31, 1837, Jervis Papers.

[19] Jervis, "Report in Relation to Clark, Yates & Co.," Aug. 31, 1837, Jervis Papers.

[20] Jervis, "Croton Dam Specifications at letting of 6th November," Jervis Papers.

[21] Jervis, "Report in Relation to Clark, Yates & Co."

[22] See Water Commissioners, "Resolution," Sept. 12, 1837; "Croton Dam Notice," Oct. 3, 1837; and Jervis, "Abstract of Proposals at letting of 6th Nov. 1837," Jervis Papers.

Croton Dam was re-bid on Nov. 6, 1837. The firm of Crandall & VanZandt submitted the lowest bid which amounted to $85,389.

[23] Jervis, "Monthly Reports," July 31 and Aug. 31, 1837, and "Report in relation to the claims of Young & Scott," Oct. 13, 1837, Jervis Papers.

At the same time he changed the span of the arch, Jervis added the hollow spaces seen in the bridge's parapet walls. The spaces were to help insulate the aqueduct, and also to help drain any moisture out of the structure. R. F. Lord, an engineer on the Delaware and Hudson Canal, suggested the idea of the hollow spaces to Jervis.

[24] _Reminiscences of JBJ_, pp. 128-129.

[25] Jervis, "Monthly Report," April 29, 1837.

[26] Jervis, "Report Proposing Variation in Masonry of Croton Aqueduct," Aug. 12, 1837, Jervis Papers.

[27] An example of this problem is found in William Jervis to John Jervis, March 30, 1839, Jervis Papers: "A cargo of cement delivered on the line to several contractors -- from a new manufactory -- (Taylor and Little) -- I have tested samples out of about 20 barrels -- and not more than half would set in water after _two hours_ -- some of the balls fell to pieces after standing _four_ hours . . . ."

[28] Jervis, "Report on the progress and condition of the Work on the Croton Aqueduct," Dec. 26, 1838, Jervis Papers.

[29] Quoted from Blake, _Water for the Cities_, p. 149.

[30]"Semi-Annual Report of the Water Commissioners, Jan. 1 to June 30, 1838," Board of Aldermen Document No. 5, (New York, July 2, 1838), p. 57.

[31]Ibid., p. 59.

[32]Ibid., p. 58.

[33]Jervis, "General Report," May 22, 1838, Jervis Papers.

[34]Jervis, "Report for October and November," Nov. 30, 1837, Jervis Papers.

CHAPTER SIX

The engineering department took no break at all after letting contracts on the 1st Division. Even before ground was broken there, Jervis turned his attentions towards the rest of the line, where most of the difficult engineering problems still lay.

Under the direction of the Chief Engineer, H. T. Anthony's field party worked the 12-mile-long 2nd Division. They set stakes, located access roads, sampled the soil, prepared maps and profiles, and estimated the quantities of different types of work that were needed. Peter Hastie's team started work on Manhattan. Major Douglass had located the two reservoirs on the island, but he had never finalized the line from the Harlem River to the reservoirs. Hastie surveyed the island in search of the best route, one adapted to natural ground levels and to New York City's street plan, which had already been drawn up for the northern part of Manhattan, even though the region was still sparsely settled:

> Mr. Hastie is prosecuting the surveys of the Island, which on account of the importance of avoiding, as far as practicable, interference with the arrangements and grade of streets, requires a very minute examination.[1]

Besides working on Manhattan, Hastie's men re-examined the southern part of Douglass' line in Westchester County. They altered it a little in a few locations, and then re-staked its center-line. T. J. Carmichael, meanwhile, hired six temporary laborers, rented three small boats, and started taking soundings of the Harlem River's bed about a mile north of McComb's Dam, hoping to find a line of rock going clear across the channel.[2]

Throughout the summer of 1837, Jervis had several tasks of his own, besides overseeing the 1st Division. Although that division's specifications for general work covered most of the structures needed on the 2nd, 3rd and 4th Divisions, The Chief Engineer still had to prepare special designs for a number of large structures. In preparation for this work, he continued to read about water-supply systems. He studied several articles in encyclopedias and engineering dictionaries, and he read William Matthew's Hydraulia: An Historical and Descriptive Account of the Water-Works of London, and the Contrivances for Supplying Other Great Cities (London, 1835). To supplement Hydraulia, Jervis obtained a series of reports on the London water works that had been printed by order of the House of Commons between 1821 and 1834.[3]

Jervis also sought to familiarize himself more thoroughly with hydraulic works on this side of the Atlantic. He studied Philadelphia's Fairmount Works and read some of the annual reports published by the city's Watering Committee. He studied articles in Engineer and Architect's Journal which described the Alexandria Aqueduct Bridge being built across the Potomac at Georgetown. When it came to these American works, Jervis was not content to avail himself only of the literature. In May 1837 he visited Philadelphia and spoke with Frederick Graff, the superintendent of the Fairmount Works. In September he personally examined the Alexandria Aqueduct Bridge and interviewed Captain Turnbull, its engineer.[4]

In studying other works, Jervis was not searching for a panacea to solve all of the technological problems which still confronted him. Virtually all the works he investigated were on the whole far different from the Croton Aqueduct. Philadelphia, for example, used water-driven pumping engines, not gravity, to fill its reservoirs, and the Alexandria Aqueduct Bridge fell along a transportation canal, not a water-supply system. In researching these works, Jervis sought out particular details, small pieces of technology that he could perhaps transfer to the Croton Aqueduct. Wherever the Chief Engineer saw a potential problem, he sought out a tried and practicable solution. When he interviewed Captain Turnbull at Georgetown, Jervis inquired into the system of coffer dams used in bridging the Potomac, because he had his own large river to cross -- the Harlem.[5] In Philadelphia, he was interested in the city's experiences with large iron pipes, because he thought he might use pipe along certain parts of the line from the Harlem River on in. He wanted to discuss the relationships between water pressure, inside diameter, and wall thickness, and he wanted to discover just how durable cast iron pipe really was. In the company of Frederick Graff, he also examined Philadelphia's reservoirs:

> Mr. Graff devoted several hours to explanations, and answers to questions, which he seemed to enjoy as a pleasure and which his practical familiarity rendered highly interesting.[6]

By August 8, 1837, Henry Anthony's team had completed preparatory work on the 2nd Division, and the Water Commissioners had accumulated sufficient monies to let additional contracts. The Chief Engineer and the Commissioners published a notice that the remaining ten sections in the 1st Division, and sections 24 through 53, composing all of the 2nd Division, were ready for contractors to examine. Jervis accepted proposals until September 5, and again he received a number of bids, ranging from eight to sixteen, for each section. The Commissioners let contracts on the remainder of the 1st Division which amounted to $695,000; the contracts for the twenty sections in the 2nd Division amounted to $1,237,000.[7]

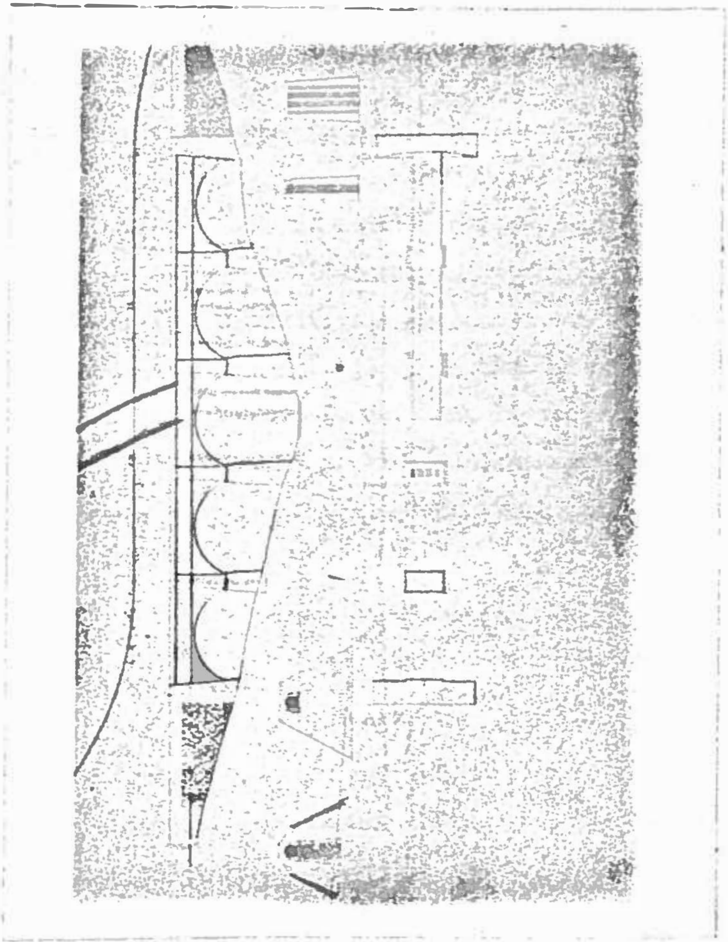
Within the 2nd Division, Mill River, running in Sleepy Hollow just outside Tarrytown, posed the greatest natural obstacle. The deep part of the hollow was approximately 300 feet wide, and Mill River's bed fell 72 feet below the aqueduct's grade line. Major Douglass had intended to cross Mill River with a bridge having five arches, each arch spanning 70 feet. When Jervis first examined the site, he also thought a bridge would be needed to span the hollow:

> The great elevation of the grade line above the bottom of the valley, and the fact that a stone bridge had been proposed [by Douglass], . . . , had given me an impression in favor of a bridge. Accordingly, I had a plan made for a stone bridge, with 5 arches, each of 60 feet span, and an estimate made of the probable cost of the work. It appeared probable that a bridge with 60 feet arches . . . would be the most economical.[8]

The bridge Jervis proposed for Mill River is shown in Plate XXI. The Chief Engineer estimated that this structure would cost $142,700. To test its true economy, he decided to calculate the approximate cost of a bridge having six arches with reduced spans of 50 feet. As it turned out, he thought the second bridge would cost in the neighborhood of $140,000, or slightly less than the first. But because he was none too fond of aqueduct bridges in the first place, Jervis next estimated the cost of crossing the hollow with an embankment having a double culvert (two arches of 16 feet) to accommodate Mill River. The Chief Engineer arrived at a figure of only $97,000 for the embankment, so he dispensed with any and all plans for a bridge at this site. (To see how Jervis estimated the costs of these structures, see Appendix IV.)

In two respects, the Chief Engineer little-regretted his decision to go with an embankment at Mill River. First, it was significantly cheaper, by some $43,000. Secondly, he considered an embankment less difficult to construct

PLATE XXI



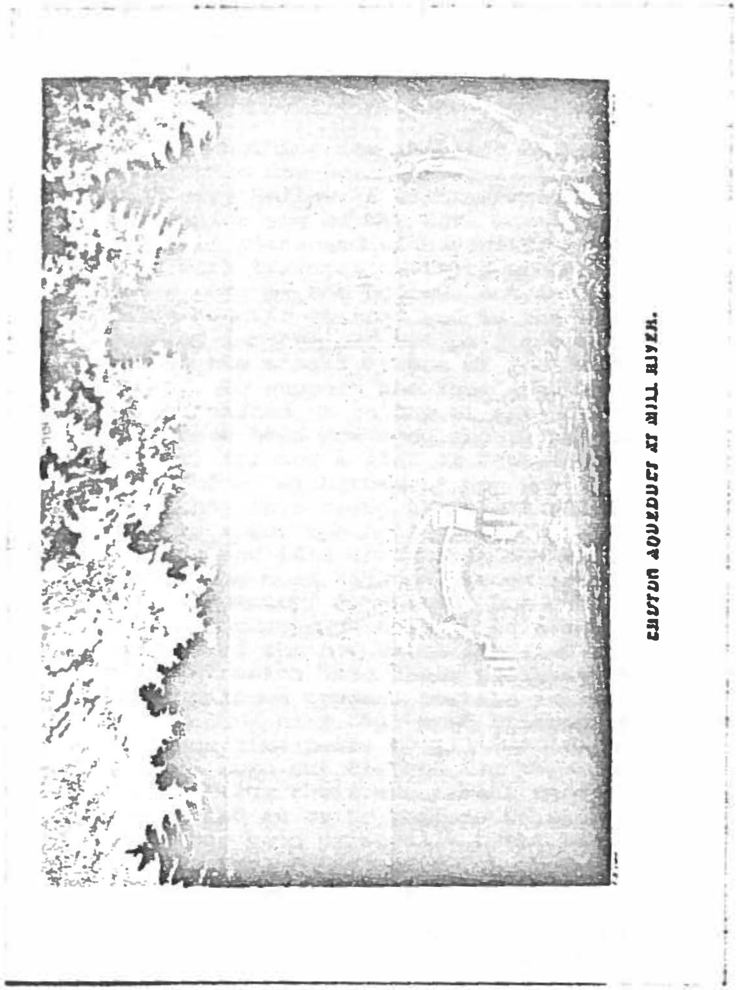
Jervis' Proposed Five-Arch Bridge at Mill River.

and less susceptible to settlement, frost, and other "contingencies that ultimately may derange, or impair the uniform efficiency of the aqueduct." Yet in one respect Jervis did regret his decision; a bridge would have been "a much superior work, in point of architectural beauty." One part of Jervis, the pragmatic engineer, wanted an embankment for the sake of economy and stability. Another part of him, the proud engineer-architect, wanted the esthetic over the utilitarian structure. As almost always happened on the Croton project, in the case of Mill River the pragmatic engineer won out, due in part to the fact that the line crossed Mill River in an isolated spot. Few people would ever see the aqueduct here, tucked away in a wooded Sleepy Hollow:

> The location does not appear to me, one that would justify the extra cost of a bridge merely to improve the architectural appearance of the work.[9]

Jervis, no doubt for the sake of economy, ultimately chose to accommodate Mill River with a single, 25-foot culvert under the embankment, instead of the double culvert he had initially envisioned. Mill River Culvert is seen in Plate XXII. While this structure was under construction, it attracted the attention of no less a luminary than Washington Irving. The aqueduct passed right by his Sunnyside residence in Westchester, and Irving watched over the work and talked with Henry Anthony and his assis-

PLATE XXII



Mill River Culvert, the tallest embankment along the aqueduct. The stones rising to the top of the structure were not nearly as rectangular as depicted in the illustration, and they were not laid up in such regular courses.

tant engineers. The author used Mill River Culvert as the subject of a fanciful tale that he spun out in 1840 to a friend in New York:

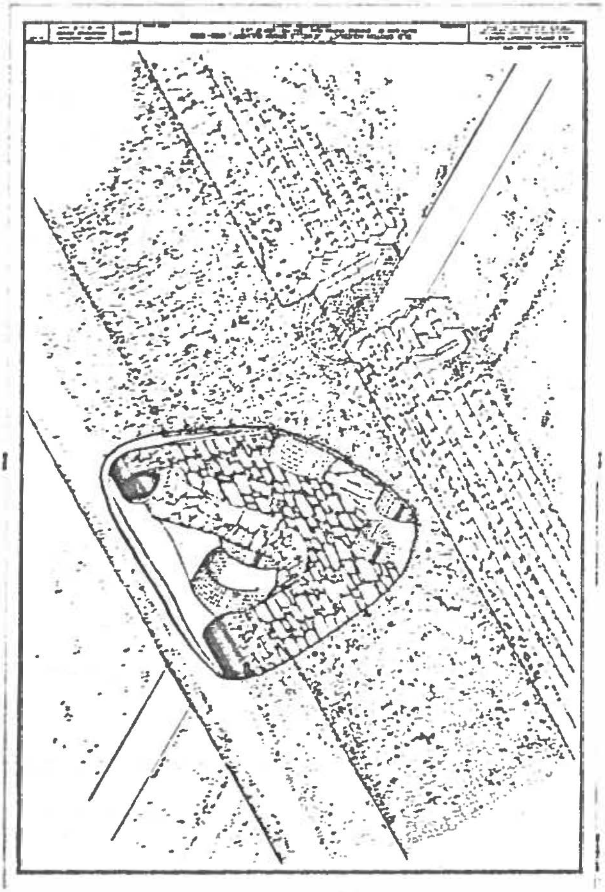
> We have nothing new in these parts excepting that there has been the devil to pay of late in Sleepy Hollow; a circumstance by the bye, with which you of New York have some concern, as it is connected with your Croton Aqueduct. This work traverses a thick wood about the lower part of the hollow, not far from the old Dutch haunted church, and in the heart of the wood an immense culvert or stone arch is thrown across the wizard stream of Pocantico [Mill River], to support the Aqueduct. As the arch is unfinished, a colony of Patlanders [Irishmen] have been encamped about this place all winter, forming a kind of Patsylvania in the midst of a "witherness." Now whether it is that they have heard the old traditionary stories about the hollow, which, all fanciful fabling and idle scribbling apart, is really one of the most haunted places in this part of of the country; or whether the goblins of the Hollow, accustomed only to tolerate the neighborhood of the old Dutch families have resented this intrusion into their solitudes by strangers of an unknown tongue, certain it is that the poor paddys have been most grievously harried for some time past, by all kind of apparitions. A wagon road cut through the woods and leading from their encampment past the haunted church and so on to certain whiskey establishments has been especially beset by foul fiends, and the worthy patlanders on their way home at night have beheld misshapen monsters whisking about their paths, sometimes resembling men, sometimes hogs, sometimes horses, but invariably <u>without heads,</u> which shows that they must be lineal descendents from the old goblin of the Hollow. These imps of darkness have grown more and more vexatious in their pranks; some occasionally tripping up, or knocking down the unlucky object of their hostility. In a word, the whole wood has become such a scene of <u>spuking</u> [spooking?] <u>and diablerie,</u> that the paddys will not any longer venture out of their shantys

> at night, and a whiskey shop in the neighboring village, where they used to hold their evening gatherings, has been obligued to shut up for want of customers. This is a true story and you may account for it as you please. The Corporation of your city should look into it, for if this harrying continues I should not be surprised if the Paddies, tired of being cut off from their whiskey, should entirely abandon the goblin region of Sleepy Hollow, and the completion of the Croton Water Works be seriously retarded.[10]

Happily, no goblins interfered with the Irishmen who worked on Jewells Brook Culvert, the second most impressive structure in Henry Anthony's division. This structure, located near present-day Irvington, 17½ miles from Croton Dam, is shown in section in Plate XXIII. Jervis engineered Jewells Brook Culvert, which he called "one of the most arduous undertakings on the line," to solve three basic problems. First, to maintain the aqueduct's grade line it had to support the base of the conduit some 50 feet above ground. Secondly, it had to allow Jewells Brook free passage. Thirdly, and to the dismay of the Chief Engineer, "at heavy expense" it had to span a country road that could not be relocated.

In building this culvert, laborers first cleared all timber, vegetable matter, and loose, spongy earth from the valley's floor. Then they prepared the foundations for the 6-foot culvert and the 14-foot road arch. When the culvert and road arch had been turned, they began laying the dry foundation wall for the conduit. While

PLATE XXIII

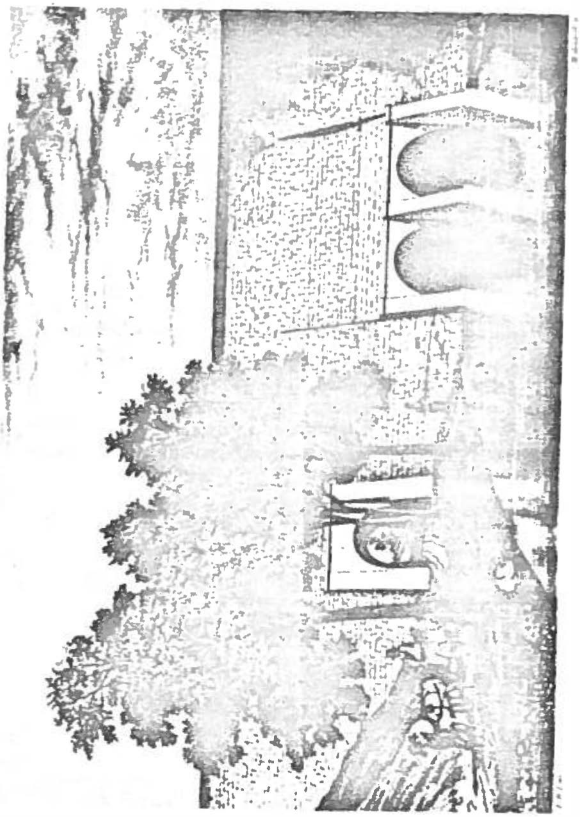


Jewells Brook Culvert.

raising that wall, they simultaneously carried up the contiguous earth embankment, flanked with stone. At all times they kept the embankment at least two feet below the foundation wall, so that inspectors could examine the manner in which the wall was being laid. When the wall reached the requisite height, it was capped with a layer of concrete. Skilled masons then laid the conduit, and when they were finished, laborers carried earth up and over the top arch. The stepped, stone buttresses seen at the base of the embankment were not in the original plans. After some particularly tall embankments had been completed, such as this one and the one at Mill River, Jervis and his Resident Engineers recognized that buttresses were needed to prevent the steep embankments from sliding.

During the winter of 1837-38, whenever the weather permitted it, contractors along the first 21 miles of the line continued to work. Although they could lay no hydraulic masonry, they cleared timber and brush from the line, excavated, tunneled, built foundation walls, protection walls and embankments, and gathered materials for the upcoming spring.[11] William Jervis, now Resident Engineer on the 3rd Division, prepared that part of the line for contract. The 3rd Division included yet another large embankment, with culverts and a road arch, for crossing the Sawmill River valley at Yonkers. (Plates XXIV and XXV.) While William Jervis worked on his division, Peter

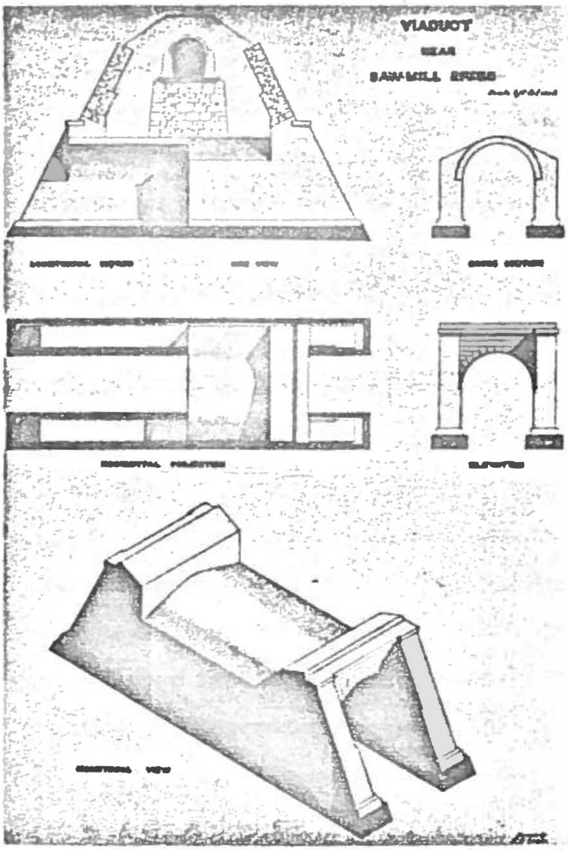
PLATE XXIV



CROTON AQUEDUCT AT YONKERS.

Sawmill River Culvert: two 25-foot culverts to carry the river under the aqueduct, and a single 20-foot road arch.

PLATE XXV



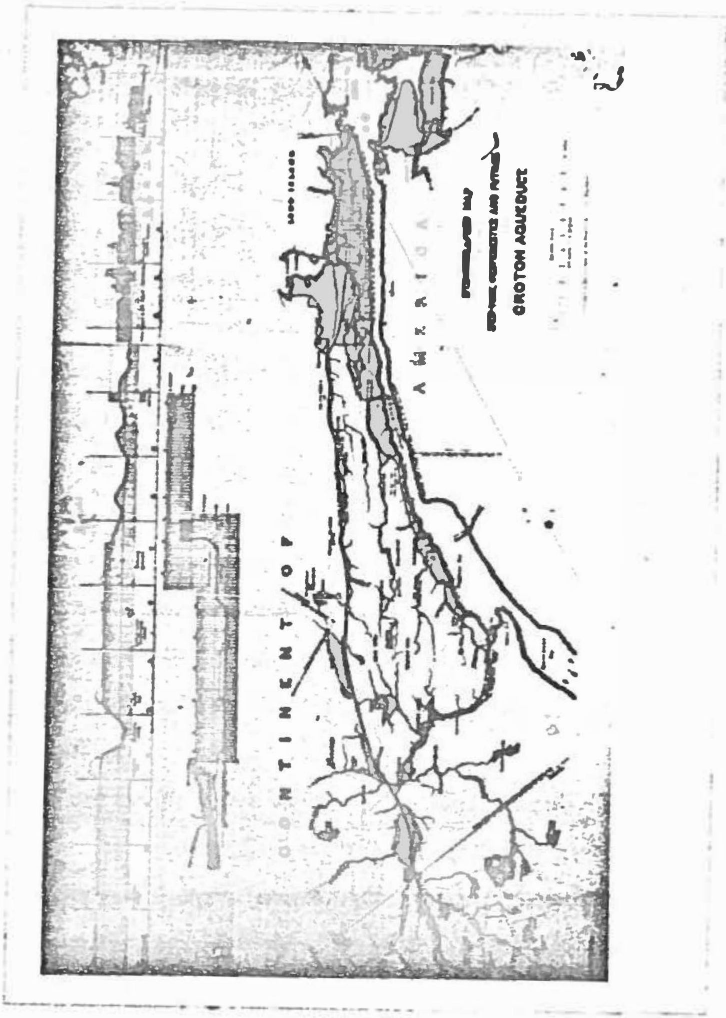
Viaduct at Sawmill River.

Hastie prepared the small portion of the 4th Division which lay north of Harlem River. John Jervis, meanwhile, assisted by Horatio Allen, his new Principal Assistant Engineer, tackled the single most difficult stretch of the line, running from the northern bank of the Harlem River to the Distributing Reservoir in central Manhattan. T. J. Carmichael had sounded out the Harlem's bed, and Hastie had routed the line on the island. Now the Chief Engineer designed the structures which fell along that line. (Plate XXVI.)

Quite naturally, Jervis started with the problem of designing a crossing for the Harlem River's valley. The valley had a breadth of 1450 feet, measured along the aqueduct's grade line. Measured down from grade, the valley fell to a maximum depth of about 150 feet. Along the valley floor (composed of bed-rock, boulders, sand and mud) the Harlem River ran in a channel which ranged from 560 to 620 feet wide, depending on the state of the tides. At mean tide, the top surface of the river was 118 feet below grade.

Major Douglass had always intended to maintain the aqueduct's grade across the Harlem by constructing a high masonry bridge. John Martineau, on the other hand, while serving as a consultant in 1834-35, had suggested crossing the Harlem with a low masonry bridge supporting an inverted syphon of iron pipes. Ever since they had received Mar-

PLATE XXVI

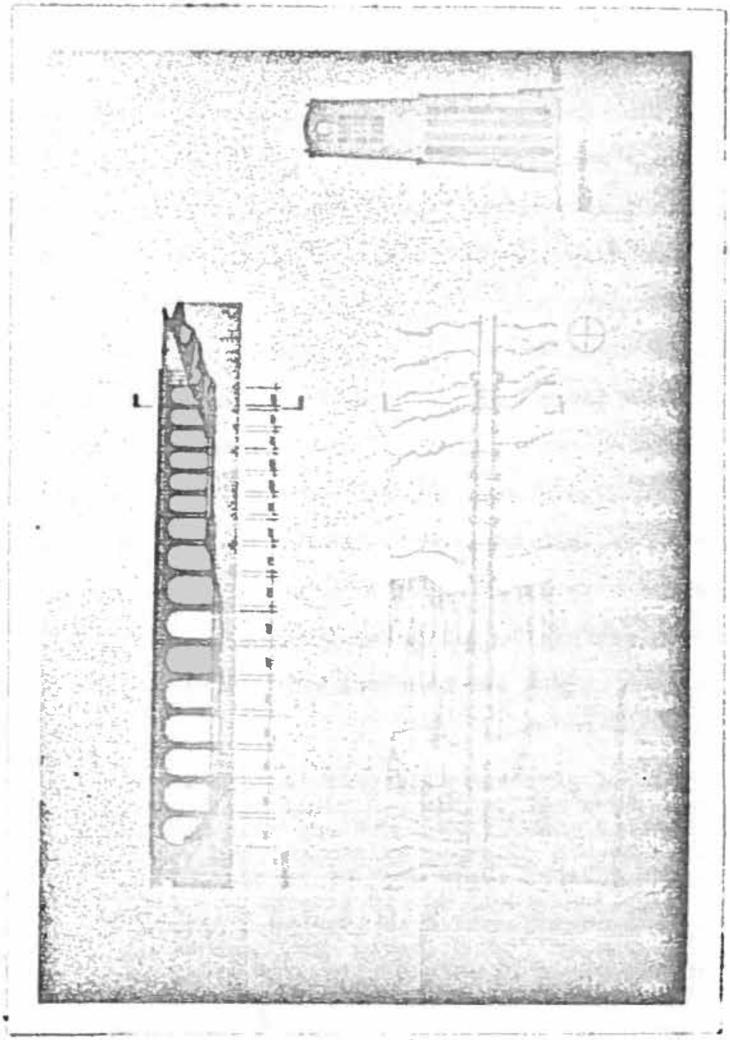


Route of the Croton Aqueduct, and Profile of the Line on Manhattan.

tineau's suggestion, the Water Commissioners had favored the inverted syphon plan, because it appeared much less expensive. Nevertheless, near the end of 1837 they still wanted to test the economy of Martineau's idea, so they instructed Jervis to provide them with two plans for the crossing: a high bridge and a low bridge. In compliance with the Commissioners' instructions, on December 12 Jervis submitted his "Report in relation to the Plan for Crossing Harlem River."[12] Plate XXVII is an elevation of the high bridge which Jervis reported. It was to have had sixteen semi-circular arches supported on piers. Seven of these piers stood in the river's channel, and the others stood on table land. The foundations of the river-bed piers rested 18 to 32 feet beneath the Harlem's surface at flood tide, and the height of the structure, from the lowest foundation to the top of the parapet walls, measured 163 feet.

In deriving this design, the Chief Engineer attempted to "effectually combine stability, permanence, symmetry and economy."[13] For Jervis, combining these qualities proved most difficult when selecting the arch spans. Without question he preferred small masonry arches on aqueduct bridges; he believed they were easier to construct and more permanent. Yet in designing this bridge, his preference for small arches had to yield, at least in part, to his desire to cross the Harlem with a bridge

PLATE XXVII



High Bridge Across Harlem River Proposed by Jervis, 1837.

having as few piers as possible. Because of the bridge's height, the piers would be very costly. Of even greater concern, a contractor would have a difficult time preparing their foundations. On the table land, about half of the piers would stand easily on rock, but the others would have to stand on artificial foundations, on wooden piles driven deeply into sand and capped with concrete. Founding the river-bed piers would prove even more difficult. Jervis anticipated that all of the river piers would stand on rock, but in a sense that was small consolation. To reach the rock, a contractor would have to erect a $13,000 or $14,000 coffer dam for each pier, evacuate up to 32 feet of water from within the dam, and then remove a heavy layer of mud or sand from the river's bottom.

To demonstrate the feasibility of sinking piers in the Harlem River, Jervis informed the Water Commissioners that:

> Works of this kind have recently been accomplished in this country. The rail road bridge over the Schuylkill, near Philadelphia, has one of its piers on a hydraulic foundation of 29 feet deep; and the foundations of several of the piers . . . for the Potomac Aqueduct, have been put down in 28 to 35 feet [of] water, under the direction of Capt. Turnbull, of the U. S. Engineers, which shows the practicability of executing such works.

But after assuring the Water Commissioners of the practicability of sinking piers in a deep river, Jervis immediately added a word of caution. It was a feasible task, all right, but one fraught with uncertainties:

> at the same time, a history of their progress also shows that there is much contingency in their execution, and we are thereby admonished to make large estimates for similar work.[14]

After weighing the merits of small arches against the merits of fewer piers, Jervis called for smallish 50-foot arches over the table land. The piers supporting these arches would be shorter and easier to construct, so he could make do with more of them. Over the river, he called for larger arches spanning 80 feet and a consequent reduction in the number of piers. Between the arcades of 80- and 50-foot arches, Jervis specified one 70- and one 60-foot arch. These two "transitional" arches improved the structure's symmetry or balance by muting the contrast between the river and table-land arcades.

The Chief Engineer's high bridge carried several unusual internal features. Jervis intended to construct the piers under the 50-foot arches of solid hydraulic masonry, but he left hollow spaces in all the other piers:

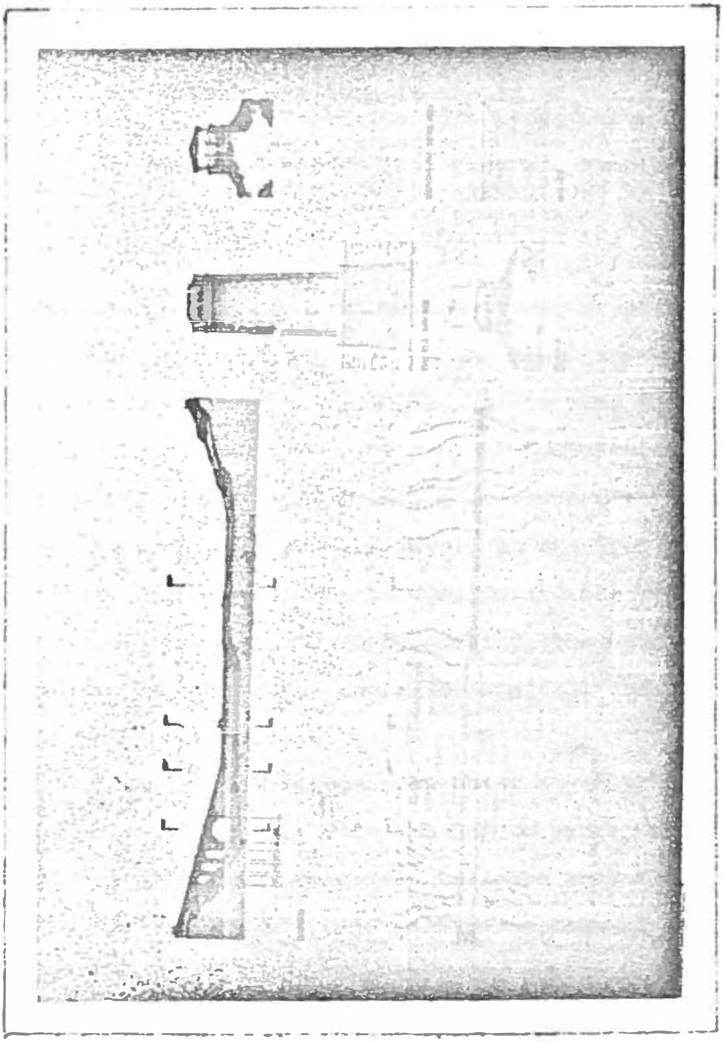
> The piers for the large arches, from their great height, should be constructed hollow, in order to ensure stability, at the least expense. A greater width of pier is required to give support to the arch, and resist its horizontal thrust, than is required to bear the vertical weight of the super-incumbent mass. In ordinary cases, particularly for arches of small span, it is the usual practice to give the proper breadth of pier, by filling the interior with rubble masonry, only dressing the face stone. But in piers of great height, de-

> signed for arches of large span, this method is not advisable, for the following reasons:
> The interior masonry not being dressed as well as the exterior, is liable to settle more, and eventually force the face stone to bulge outward, and injure, if it does not destroy the work. A second reason is, the tendency that a large mass of masonry has to prevent the uniform and early hardening of the cement.[15]

The high bridge shared some of its other internal features with few, if any, other bridges in America, with the exception of the Chief Engineer's own Sing-Sing Kill Aqueduct Bridge. Again, Jervis lined the conduit over the bridge with cast iron plates. To guard the conduit against frost and to help drain any moisture out of the masonry, he left insulating, hollow spaces in the parapet walls. Finally, he reduced the dead-load on each arch by using interior spandrel walls, instead of a solid fill over the arch barrel.[16] All things considered, this bridge represented a great engineering challenge to John Jervis -- a challenge that would not come cheaply. He estimated that the high bridge would cost $935,745.

After outlining the high bridge in his December 12 report, Jervis next considered the possibility of crossing the Harlem with iron pipes supported on a low masonry bridge, a bridge which would not maintain the aqueduct's grade line. This structure, shown in Plate XXVIII, took the misleading name of "inverted syphon" or "syphon bridge" because it resembled the bent tube of a syphon, turned upside down. It would not, however, function in the manner

PLATE XXVIII



Proposed Syphon Bridge (Inverted Syphon) for Crossing Harlem River, 1837.

of a true syphon:

> It is called an "inverted syphon." The term has no doubt been given for convenience . . . . At the same time it should be borne in mind . . . , [that its iron pipes] have nothing of the peculiar principle of the syphon. In their action, they are simply pipes, through which the water flows by the well known principles of hydraulics, which are the same that will operate in its distribution through the city.[17]

The standing water in an elevated reservoir creates a pressure that can be used to force the fluid through a city's mains or distributing pipes. In the same fashion, the water in the cast iron pipes on the Westchester side of the syphon bridge would create a pressure causing the water to rise, or seek its own level, in the iron pipes on the Manhattan side of the bridge. Unlike the water in the masonry conduit, moved by gravity, the water crossing the syphon bridge would totally fill the pipes and flow under pressure.

To design the low bridge, the Chief Engineer first had to determine how many pipes it had to carry, and how large the pipes had to be. Jervis believed that the masonry conduit could deliver up to 60 million gallons of water daily to the Harlem River. The inverted syphon had to be capable of delivering all of that water across to Manhattan. Jervis began with the idea of laying just one large pipe, but he finally decided to use multiple pipelines, each with an inside diameter of 36 inches:

> The width of the bridge must depend on the width required for the pipes; and this again, will depend on the diameter of the pipes. A single pipe, sufficiently large to carry the whole quantity of water, would be accommodated on the most narrow bridge. There are, however, objections to this: a single pipe would place the successful action of the aqueduct on its good condition; consequently, interruption would be involved in any necessary repairs; which it is important to avoid, by every reasonable means in our power; and very large pipes would be more liable to imperfections than smaller ones. Water pipes of cast iron have not, that I am aware of, been larger than three feet diameter. The principal iron mains, in the water works of London, are of this size; and the same are used in a part of the water works of the City of Glasgow, in Scotland. I can see no reason why this particular limit has been adopted, unless experience has decided it to be the most economical. There certainly can be nothing impracticable in going to four feet, so far as the making the casting is concerned, for experience in casting cylinders for steam engines has demonstrated this; and were there any particular necessity for this dimension, I should have no fear that it might be successfully accomplished. But in view of all the circumstances of the case under consideration, I have arrived at the conclusion, that three feet pipe will be most appropriate.[18]

Given the length and diameter of the pipelines, the depth to which they fell in crossing the valley, and the fact that Jervis terminated them on a level two feet below their start, hydraulic formulae predicted that each 36-inch pipe would discharge approximately 15 million U. S. gallons per day.[19] Consequently, Jervis made the bridge wide enough to handle four pipes; the four together could transport the desired 60 million gallons per day to Manhattan. But as a cost-cutting measure, he recommended to the Water Commissioners that only two pipelines be laid across the bridge at first, because their water discharge would "probably be sufficient for the next fifty years." The city could add the third and fourth pipes when they were actually needed.

Jervis planned to commence the pipes in an influent pipe chamber. Within this chamber, the entrance to each pipe was guarded by a cast iron gate that could be raised or lowered independently of the others. The 9-foot-long pipe sections, generally having a wall thickness of one inch, descended into the valley on a foundation wall which nearly paralleled the natural terrain. In the center of the valley the foundation wall leveled off at a height four feet above the Harlem's flood tide. Here Jervis located a stopcock and a waster on each pipe that could be opened to wash any accumulated sediment out of the line. After passing this level stretch, the water began to rise towards Manhattan, passing over a semi-circular arch spanning 80 feet which rose 50 feet above flood tide. The water then passed over an arcade of three arches of 35, 30, and 25 feet. From the abutment of this arcade, the pipes again ran on a foundation wall until reaching an effluent pipe chamber, where the water discharged back into the masonry conduit.

Jervis estimated that the low bridge across the Harlem River would cost $426,000 -- or a full half-million dollars less than a high bridge. Given such a savings, he unhesitatingly recommended that the Water Commissioners approve the construction of an inverted syphon:

> It appears the plan by pipes has largely the superiority in point of economy. In my opinion it will be fully as efficient. The pipes will decay, by the action of time, more rapidly than stone masonry, especially if the masonry can be kept from injury by frost. But as only two, or half the pipes, are required to be put down at present, it may be assumed, that if the $66,000 saved by this, is invested at five per cent., it will produce a sum that will forever maintain the pipes, to the full extent that may be wanted. The high bridge will be more exposed to casualties that may, at some future period, seriously interfere with the successful operation of the aqueduct. It is, however, greatly superior, in point of architectural magnificence, and maintains two feet greater elevation. These are the only two points of superiority I have been able to discover, and can therefore have no hesitation in recommending the plan by pipes as decidedly the most appropriate.[20]

On December 27, fifteen days after reporting on Harlem River, Jervis submitted his "Report in relation to the Location of the Line of the Croton Aqueduct, from Harlem River to the Reservoirs."[21] This report, based upon Peter Hastie's surveying work of the previous summer, was far from complete. The Chief Engineer had not yet had time to finalize the plans for all the large structures on Manhattan, especially the reservoirs. Jervis discussed in greatest detail the problem of carrying the aqueduct across Manhattan Valley, which he considered one of the "most formidable obstacles, in point of expense, on the line of the aqueduct."

The aqueduct encountered Manhattan Valley two-and-an-eigth miles below Harlem River. The valley was a broad depression, 4180 feet wide, which fell to a maximum depth of 103 feet below grade. It had always been supposed, by Douglass, the Water Commissioners, and for a while even by Jervis, that Manhattan Valley required an aqueduct bridge. Some persons, including some of the Water Commissioners, actually looked forward to the construction of a bridge across the valley, because it would have to be an impressive structure.[22] Jervis was not unaware of this sentiment:

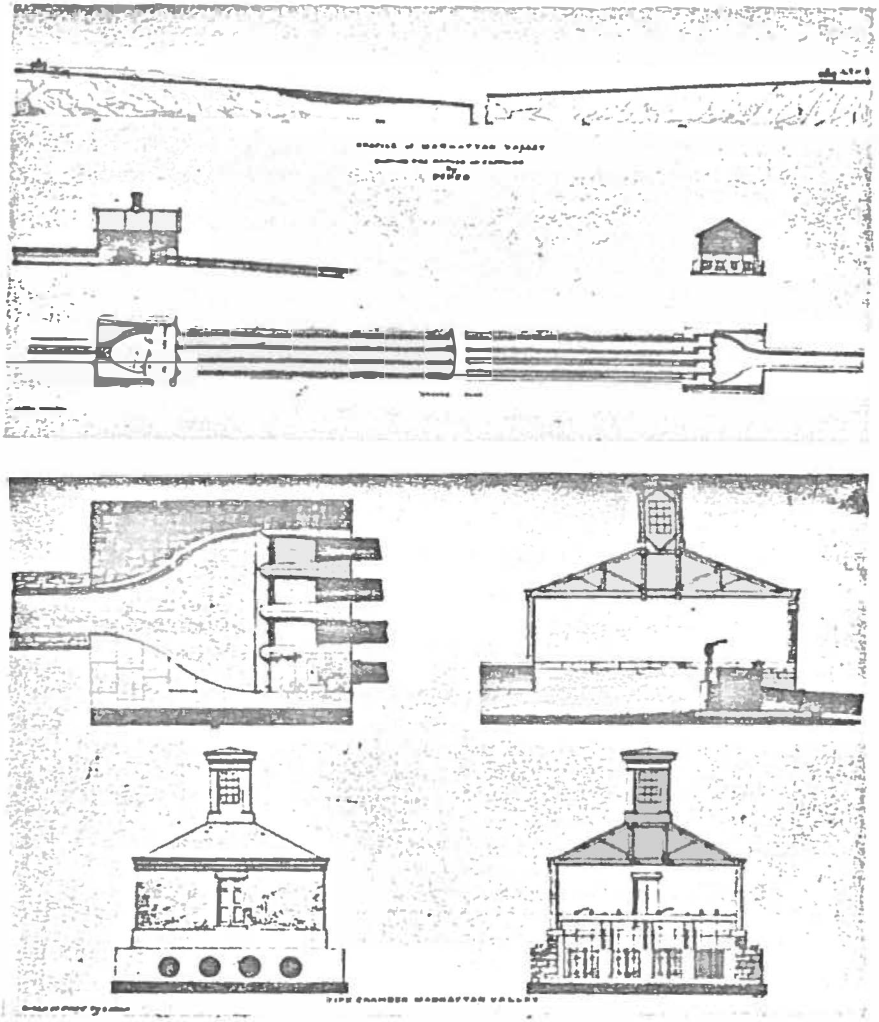
> The wish . . . has been expressed by many citizens, that the established inclination of the aqueduct should be maintained across this valley, on a bridge of substantial masonry, that would do credit to the architectural taste and enterprise of the city.[23]

Jervis knew that he had disappointed the devotees of long arcades when he had opted for the syphon bridge across the Harlem, instead of the high bridge. Consequently, he perhaps felt some real pressure to placate the esthetes by constructing a monumental bridge across Manhattan Valley. But the Chief Engineer's careful examination of the site resulted in a predictable conclusion; a bridge would be too expensive. Figuring on arches of 50 feet, patterned after the table-land arches in his high bridge design for the Harlem River, Jervis estimated that a bridge across Manhattan Valley would cost between $983,000 and

$1,386,000.[24] So the Chief Engineer opted for a less expensive means of crossing the valley; he opted for another inverted syphon, shown in Plate XXIX.[25]

This structure shared certain characteristics with the Harlem River's syphon bridge. Jervis called for influent and effluent pipe chambers, waste gates in the bottom of the valley, and he again recommended that only two 36-inch pipes be laid initially, saving the expense of a second two pipes until they were actually needed. Yet there was an important difference between the two structures. To boost the flow rate through these longer pipelines, Jervis terminated them on a level three feet below their start;[26] he had terminated the Harlem pipes only two feet below their start. Yet even with its increased declivity, the inverted syphon at Manhattan Valley could not discharge as much water per day as the syphon bridge. Jervis calculated that four pipes laid across this broad valley could discharge up to 45.6 million U. S. gallons daily, or only three-fourths of the water that could be transported across the Harlem and onto Manhattan. This reduction was not only acceptable to the Chief Engineer; it was purposeful. New York's population was still clustered on the southern end of Manhattan, and the Distributing Reservoir to be located on 42nd Street would serve that part of the island. But the population was moving northward, and someday the entire island would

PLATE XXIX



Inverted Syphon at Manhattan Valley.

be thickly settled. When that day arrived, Jervis believed that a reservoir, drawing a portion of the aqueduct's water, would be needed north of Manhattan Valley. So from the valley southward, the Chief Engineer believed it inexpedient to maintain an aqueduct capable of discharging a full 60 million gallons daily.[27]

The major advantage of the inverted syphon at Manhattan Valley was its cost. Jervis estimated that two pipes could be laid for $304,000, and four pipes for $454,000. The structure's major disadvantage was its sacrifice of three feet of elevation over a run of only four-fifths of a mile. This compared unfavorably with the masonry conduit ahead of the inverted syphon, which fell only 13¼ inches per mile. Because the loss of any elevation along the line resulted in an equal loss of elevation for the city's future Distributing Reservoir, and therefore diminished the effectiveness of that structure, Jervis tried to keep such losses to a minimum. In the case of Manhattan Valley, fortunately he was able to regain 8½ inches of the elevation he lost over the inverted syphon's run. Because the masonry conduit south of Manhattan Valley would not have to deliver a full 60 million gallons daily, Jervis could reduce its declivity:

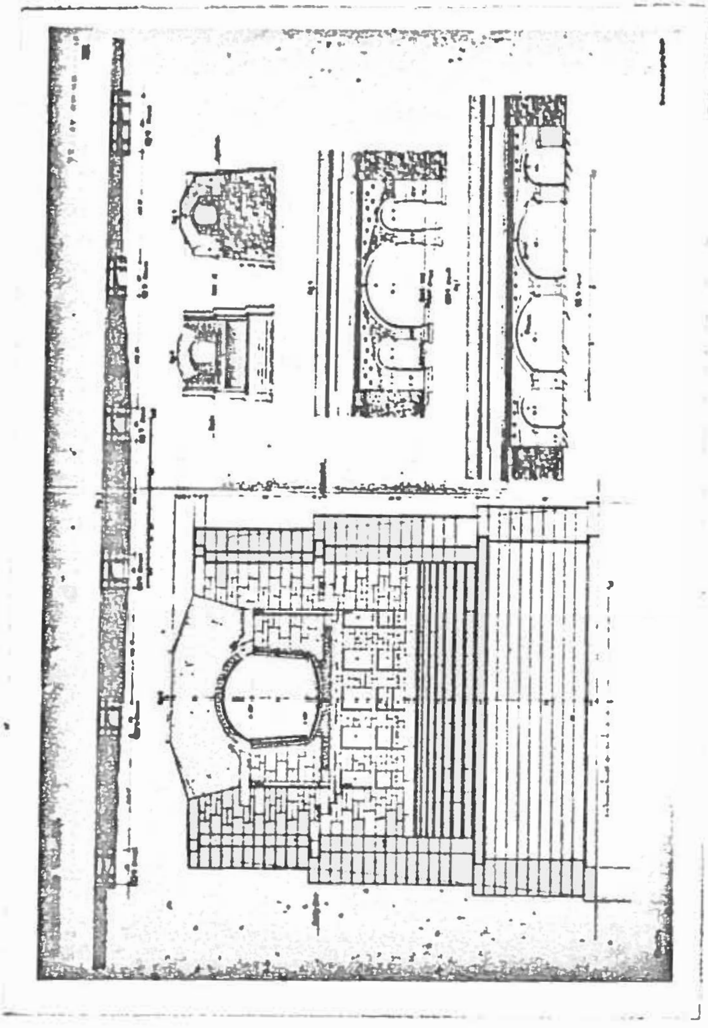
> [We can] regain, in part, the elevation we lose by using pipes across the valley, by reducing the declivity in the aqueduct from

> the effluent pipe chamber to the receiving reservoir, from 13¼ inches to 9 inches per mile. This section of the aqueduct is about 2 miles in length. With this declivity, the aqueduct will discharge about 40 million imperial gallons per day.[28]

When Peter Hastie ran the aqueduct's line between Manhattan Valley and the Receiving Reservoir, he traversed a rural area. The area's future, though, had already been mapped out, and the map showed how a grid of city streets would someday cut rural acreage into city blocks. The streets were coming, and Hastie, Jervis and the Water Commissioners felt obliged to take them into account. Wherever possible, Hastie passed the conduit underground in this district, in order to avoid the construction of expensive road arches. He was quite successful in this effort, except where the line encountered Clendenning Valley: 2,000 feet wide, in places 50 feet deep, and the future site of 96th through 101st Streets. To accommodate these streets, the Chief Engineer proposed the structure shown in Plates XXX and XXXI.

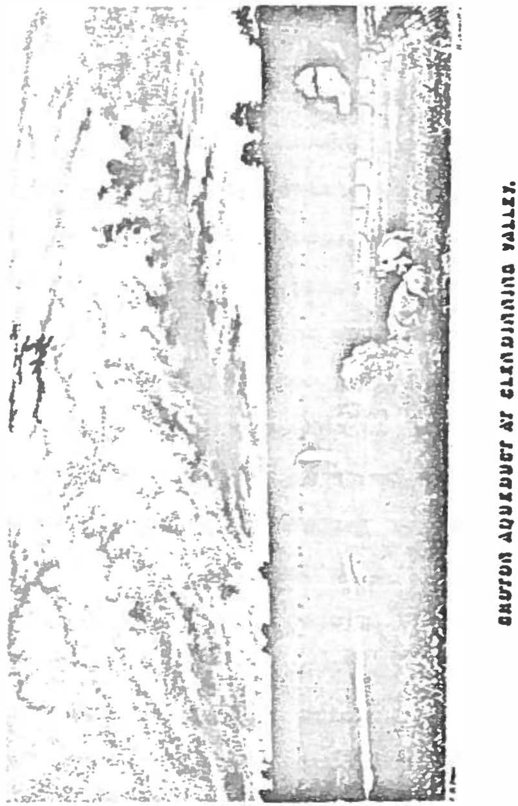
Because Clendenning Valley was not exceptionally deep, and because he wanted to sacrifice as little elevation as possible in crossing this obstacle, Jervis chose not to initiate another inverted syphon. He wanted to maintain the aqueduct's new declivity of only 9 inches per mile, so he had to design some kind of supportive structure to carry the masonry conduit over the valley. In Westchester County, the Chief Engineer had used massive

PLATE XXX



Croton Aqueduct Across Clendenning Valley.

PLATE XXXI



Road arches and foundation wall across Clendenning Valley.

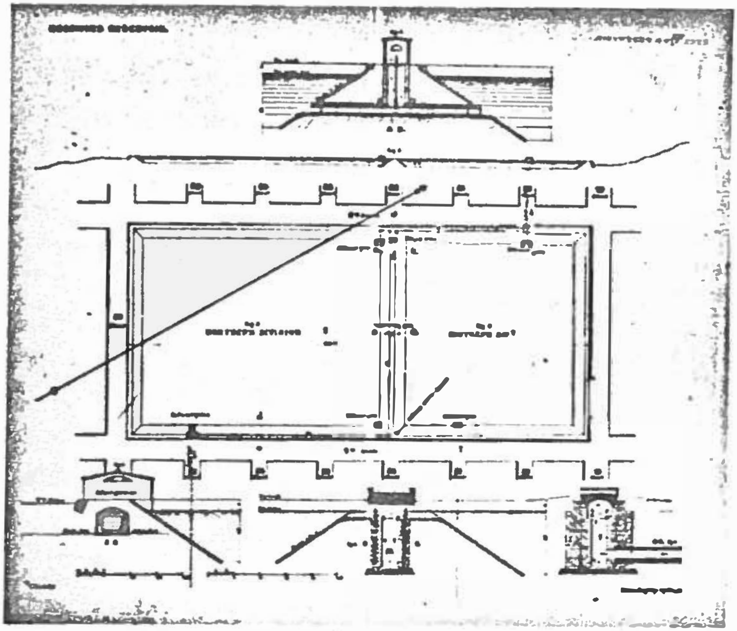
embankments to cross depressions of comparable depth, such as the valleys at Jewells Brook and at the Sawmill River. But while that type of construction sufficed in the "backwoods" of Westchester, Jervis thought it inappropriate for this site, which would someday be in the midst of a dense population. An embankment would consume too much space, or valuable real estate, on Manhattan, and its road arches (or road culverts) would not be "in accordance" with other street bridges in the city.[29] But while the Chief Engineer did not want the supportive structure to be too bulky or too plain, he also did not want it to be too ornate, too expensive, or too much of a threat to the stability of the aqueduct. In short, he did not want an arcade of masonry arches stretching for 2000 feet. After sorting out what he did not want, Jervis was left with a structure similar in many ways to the one he designed for the Sing-Sing Kill valley. Instead of designing one long aqueduct bridge, he opted for six small bridges connected by a foundation wall laid in mortar.[30]

On the city map, 96th was laid out as a principal street, 100 feet wide; 97th through 101st Streets were to be 60 feet wide. Jervis, thankfully, was not obliged to build road arches the full width of the future streets. He decided to accommodate 96th street with two arches, each spanning 27 feet. For the other streets he proposed a single arch of 30 feet. On both sides of each of the carriage-ways, Jervis located small arches for pedestrians. Eden though the road bridges at Clendenning Valley were quite small, the Chief Engineer believed they needed protection from water leakage and frost, so he initiated the same safe-guards he had used on the Sing-Sing Kill Bridge. He lined the conduit over the arches with cast iron, and he left hollow spaces in the parapet and interior spandrel walls.

Seven-eigths of a mile below Clendenning Valley, the aqueduct's line reached York Hill (in present-day Central Park), whose crest was roughly bounded by 6th and 7th Avenues and by 79th and 86th Streets. Major Douglass had selected York Hill as the site of the Receiving Reservoir, because it was the southernmost parcel of land on Manhattan that was both large enough and high enough for the massive structure. In his December 27th report to the Water Commissioners, Jervis concurred with Douglass' site selection, and he presented the rudiments of his design for the reservoir. The design was admittedly sketchy, because he had not had time "to mature and prepare definite plans." When the definite plans were readied a few months later, the Chief Engineer specified a Receiving Reservoir of the form shown in Plate XXXII.[31]

For a short while, Jervis no doubt considered the possibility of eliminating this structure from the aque-

PLATE XXXII



Receiving Reservoir on York Hill.

duct's line. The reservoir's main purpose was to store water, up to 190 million U. S. gallons of water, but this water would be needed only if and when there was a suspension of the daily running supply provided by the aqueduct. In a sense, then, the Receiving Reservoir was not absolutely necessary. In deciding to go ahead with it, Jervis once again demonstrated his conservative, careful approach to engineering:

> should [the aqueduct] . . . be able to perform its office without interruption, very little storage reservoir would be required. But in a work of this magnitude, whatever might be the care and skill exhibited in its construction, it would not be prudent to hazard so important an interest, to contingencies that no sagacity may now anticipate.[32]

Jervis fully believed that he had designed the Croton Aqueduct in a manner which guarded against structural failures, but he was wise and humble enough to recognize that failures might still occur. So he went ahead with the Receiving Reservoir, seeing it as yet another safe-guard, an expensive one that would cost approximately $310,500. For this price, he happily received a few other benefits, besides safety. The water in the reservoir, through contact with air, would regain any freshness it might have lost in traveling the 38 miles from Croton Dam. And through settlement, the water would lose any impurities it had carried with it. Finally, when the city moved up north to surround the structure, it could serve as a distributing reservoir and deliver water to the neighboring community.

New York's Receiving Reservoir was certainly one of the largest structures of its kind in the world. Along the tops of its exterior walls, from outside edge to outside edge it measured 1,826 feet long and 836 feet wide.[33] The walls formed a perimeter which extended for over a mile. The structure covered seven city blocks, and the surface area of the water was 31 acres. In designing this reservoir, Jervis took several potential dangers into account.[34] First, he was concerned that its long walls might burst under the pressure exerted by the standing water. To prohibit this type of failure, he enclosed the water within heavy earthen embankments which were flanked by stone protection walls. The embankments were 18 feet wide on the top and carried a slope of 1½ horizontal to 1 vertical on the inside face, and a slope of 1 to 3 on the outside. Seoondly, Jervis worried that water might leak through the walls and undercut the structure, so he made the central portion of each wall out of impervious, puddled earth. Thirdly, to prevent water from ever spilling out of the reservoir and eroding its walls, he incorporated a waste weir into his plan. Whenever the water rose to within four feet of the top of the reservoir, it would pass over a weir, fall into a well, and automatically discharge through a sewer.

Jervis believed these three basic security measures were sufficient to protect the reservoir, but he still worried: what if a failure occurred, despite these measures? The Chief Engineer wanted an extra measure of safety, and he gained it by dividing the reservoir into two compartments, a Northern and a Southern Division which were separated by a broad wall, and yet connected by a network of pipes with stopcocks. Normally, the two divisions would function together. An open equalizing pipe set into the reservoir's dividing wall would cause them to share the same water level. Both would receive water from the masonry conduit, and both would discharge water that continued further down the aqueduct. But if a failure occurred, say in the Northern Division, or if that division needed simple cleaning or maintenance, then "togetherness" would give way to independent action. Gate-keepers would close the Northern Division's influent gate and close the equalizing pipe in the dividing wall. While the Northern Division drained, water would continue to enter and leave the Receiving Reservoir through its Southern Division.

The Receiving Reservoir was asymmetrical. The Northern Division covered four city blocks, and the Southern only three. But although they differed in area, the divisions were nearly equal in capacity, because the Southern held water at a greater depth. It held 25 feet of water, while the Northern held only 20. This peculiar arrangement resulted from the natural lay of the land on York Hill. The northern end of the hill provided Jervis with much higher ground than he needed or wanted. Here, instead of raising walls to enclose the Northern Division, the Chief Engineer literally had to sink most of the structure into the hill, and because the hill was essentially solid rock, this excavation entailed heavy expense. To help trim this expense, Jervis decided to cut the northern end of the hill down just far enough to provide him with 20 feet of standing water, instead of the 25 feet he really wanted. The southern end of the hill was lower to begin with, so by both excavating and raising walls, Jervis obtained a deeper basin for the Southern Division.

Finally, the architectural style of the massive reservoir is worth noting. No stylistic catchwords used to describe American architecture of the period fit it. The Chief Engineer's phrase for the reservoir's style, "plain and substantial," fits it best. Yet in one way Jervis did relieve the appearance of total utilitarianism and the tediousness of the structure's heavy, rough-hammered stone facing. He called for railings along its top, and for grass between the railings. He capped the reservoir with a green path, 18 feet wide, that visitors could stroll along while enjoying the view of this man-made, 31-acre pond.

Below the Receiving Reservoir the aqueduct's line crossed a two-mile stretch of very irregular terrain before reaching the site of the Distributing Reservoir. (Note the profile of Manhattan shown in Plate XXVI.) As Jervis noted:

> From the Receiving Reservoir south, the country falls so much below the grade level as to leave no doubt in my judgment, of the propriety of continuing the aqueduct, by means of iron pipes, to form the connection between the receiving and distributing reservoirs.[35]

Jervis was so convinced of the need for iron pipes along the aqueduct's home-stretch that he never bothered to estimate the cost of crossing it with an embankment or bridge. Instead, he concentrated on the question of how many pipes he should lay between the two reservoirs. To decide this question, Jervis first had to estimate how many persons the Distributing Reservoir would ultimately supply with water, and what their daily per capita consumption would be. In his December 27th report, Jervis provided the Water Commissioners with his figures:

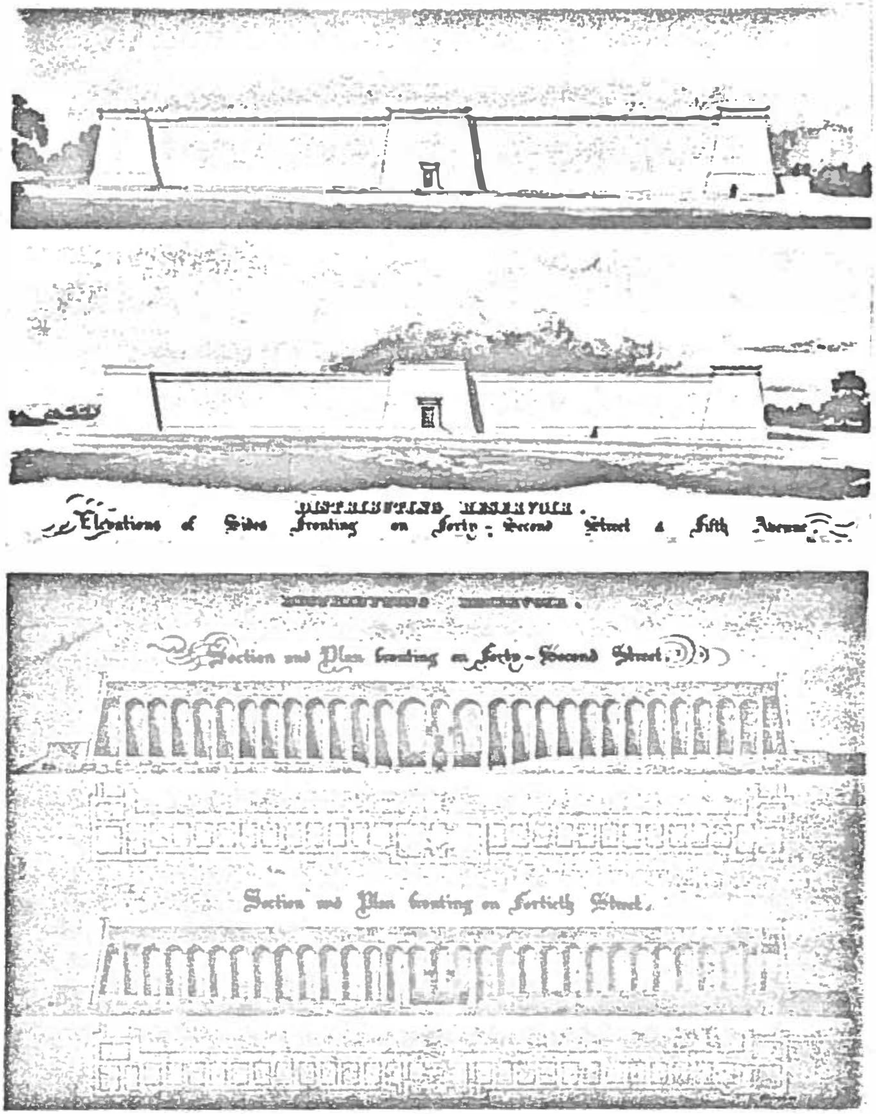
> It may be estimated that 700,000 people will utimately derive their supply from the distributing reservoir on Murray's Hill, which will depend on the connecting pipes under consideration. At 30 /Imperial/ gallons for each inhabitant, 21 millions will be required for the daily supply.[36]

Planning once again to use 36-inch pipes, Jervis initially supposed that three pipes, with a fall of six feet between the reservoirs, would be sufficient to meet lower Manhattan's needs. Later, however, he decided that the fall between the reservoirs could be reduced to only four feet. And, as usual, he recommended that only two pipes be laid at first, saving the expense of a third pipe for later.

The Chief Engineer intended for the effluent gates at the Receiving Reservoir to be normally open, providing a constant flow of water into the pipelines. Where the pipes bottomed out in three locations, he located stopcocks and wasters. Where they rose on two peaks, he provided cocks to bleed any air caught in the pipes. After rising and falling for two miles, the pipelines terminated at the Distributing Reservoir on Murray Hill. Unlike the York Hill reservoir, the Distributing Reservoir was not, primarily, a storage facility.[37] Its primary function was to improve the efficiency of the city's future distribution system by providing an elevated head of water as close as possible to the population it would serve. Major Douglass had chosen the Murray Hill site, on the west side of 5th Avenue, between 40th and 42nd Streets, because south of Murray Hill, all high ground disappeared.

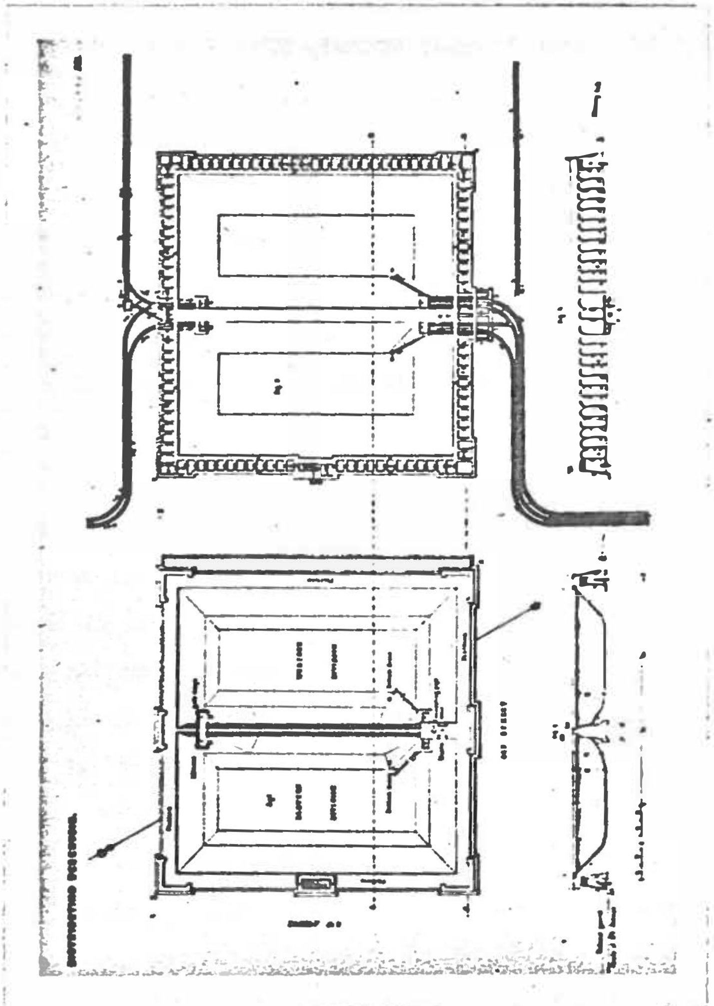
Jervis' Distributing Reservoir shared certain characteristics with his Receiving Reservoir.[38] (See Plates XXXIII and XXXIV.) In particular, the Chief Engineer provided a weir to waste surplus water automatically, and he split the structure into two divisions which could operate independently or in unison. Yet when compared with

PLATE XXXIII



Distributing Reservoir on Murray Hill.

PLATE XXXIV



Distributing Reservoir on Murray Hill.

the York Hill structure, the Distributing Reservoir was diminutive. Four-hundred and thirty-six feet square at its base, when filled with 38 feet of water the structure's capacity was about 24 million U. S. gallons, or only one-eigth the Receiving Reservoir's capacity. And the dissimilarities went far beyond questions of scale. Jervis enclosed the Receiving Reservoir with earth embankments faced with stone. When designing the Distributing Reservoir he switched to masonry walls.

This switch was prompted by several considerations. Unlike the York Hill structure, much of which was sunk into the ground, virtually all of the Murray Hill reservoir stood above ground, so its walls had to be taller. Because they stood against 38 feet of water, instead of 20 or 25 feet, they also had to be stronger. If these had been the only considerations, Jervis still could have used earth embankments to enclose the reservoir. After all, he had chosen to close off the northern side of the Croton Valley with an embankment, and that earth would have to stand against as much as 50 feet of water in the Fountain Reservoir. But in the Croton Valley, and on York Hill, Jervis had had room for broad embankments. He did not have room on Murray Hill. This site was none too large, and it was surrounded by streets which Jervis did not want to encroach upon. The walls for the Distributing Reservoir had to be tall and strong, but at the same time as thin as possible. Consequently, Jervis turned to hydraulic masonry.

After choosing his material, Jervis still had to decide upon the proper cross-section for the reservoir's walls. He briefly considered the propriety of solid walls, but he dismissed the idea. Walls of solid hydraulic masonry would be very expensive, and the cement in the walls' interior might take a long time to ripen or set properly.[39] To avoid these liabilities, Jervis next turned to the idea of double-walling each side of the reservoir, using two narrow, parallel walls, instead of a single, thicker wall. He would fill the space between the two walls with stone chips and gravel.[40] While this type of double-wall probably would have worked, the Chief Engineer conceived of yet another plan which provided surer support for the innermost of the two walls. Instead of using a compacted fill between the walls, he decided to connect them with masonry cross-walls, as seen in the illustrations. By turning a small arch in each cross-wall, Jervis gained another important advantage: the advantage of inspection. A man could walk inside the reservoir's walls and check for water leakage. The Chief Engineer certainly guarded against this problem. He specified that the reservoir's floor was to be 12 inches of concrete; over the concrete floor, and carried up against the walls, he laid puddled earth; over the earth, he laid 15 inches of hydraulic masonry. The chances of water penetrating all these barriers seemed slight, but Jervis nevertheless welcomed a means of discovering any leakage which did occur.

Besides differing from the Receiving Reservoir in its wall construction, the Distributing Reservoir differed in its style and represented a deviation from the Chief Engineer's architectural precepts. Jervis believed that a large work should appear, above all else, well-conceived and substantial. Its appearance should clearly demonstrate that its designer's mind was swayed most heavily by functional considerations. He wrote that a large structure should be "relieved only by such ornamental parts, as are necessary to the stability and preservation of the work." Indeed, the engineer believed that on a large work the application of ornamentation for its own sake could give "the appearance that some important parts . . . [had] been neglected."[41] Yet Jervis chose to embellish the facade of the Distributing Reservoir with an Egyptian cornice. He admitted that a plain rectangular cornice, costing $10,000 less, would "answer every purpose of usefulness," but in this rare instance he argued that there was more to consider. The reservoir would have a "commanding situation in the midst of a dense population."[42] It would serve as a symbol, as "a representative of a great work." For these reasons, Jervis felt that the reservoir on Murray Hill merited the architectural embellishment he had denied other structures.

The effluent pipes on the 40th Street side of the Distributing Reservoir connected with the water mains the city was laying in lower Manhattan. The Water Commissioners had been charged with building an aqueduct to deliver Croton water to New York; they had not been charged with the task of distributing that water throughout the city. Where the water mains began, John Jervis' responsibilities ended. So in the latter part of the winter of 1837-38, the Chief Engineer believed he had already discharged his most pressing and difficult duties. Half of the aqueduct was under construction, and he had finished, or nearly finished, plans for the other half of the line. The Water Commissioners had already approved these plans, and early in the working season he could put the 3rd and 4th Divisions under contract. After that, his engineering department would only have to monitor the work until the Croton Aqueduct was completed. That, at least, was the plan. Unfortunately, things did not work out as well as the Chief Engineer had hoped. In particular, one of his engineering designs sparked a long and public debate, and another of his structures failed catastrophically, causing him the greatest embarrassment of his professional career.

NOTES -- CHAPTER SIX

[1]Jervis, "Monthly Report," Sept. 30, 1837, Jervis Papers. Also "Monthly Reports," April 29, and June 30, 1837.

[2]T. J. Carmichael to Jervis, May 6 and 13, 1837, Jervis Papers.

[3]These publications are found in Jervis' personal library.

[4]Jervis Memoranda Book, entries for May 22 and Sept. 18, 1837.

[5]Besides visiting Capt. Turnbull, Jervis acquired _Drawings Accompanying the Report of Captain Turnbull on the Survey and Construction of the Alexandria Aqueduct_ (1838).

[6]Jervis, "Monthly Report," May 31, 1837, Jervis Papers.

[7]Jervis, "Names of Contractors and Results of the letting of 5th September, 1837," Jervis Papers; "Semi-Annual Report of the Water Commissioners," July 1 to Dec. 30, 1837," _Board of Aldermen Document No. 55_ (New York, Jan. 4, 1838), pp. 347-349.

[8]Jervis, "Report on Crossing Mill River Valley," June 5, 1837, Jervis Papers. (In the "Index" to the Jervis Papers, this document is incorrectly dated as having been written in January, 1837.)

[9]_Ibid._

[10]Letter, March 17, 1840, Manuscript Collection, Sleepy Hollow Restorations.

[11]_Doc. No. 55,_ p. 364; Jervis, "General Report," March 12, 1838, Jervis Papers.

[12]This report, in manuscript form, is found in the Jervis Papers; it was published under the same title in _Doc. No. 55,_ pp. 389-406.

[13]_Doc. No. 55,_ p. 392.

[14]_Ibid.,_ p. 393.

[15]*Ibid.*, p. 392.

[16]*Ibid.*, pp. 394-395.

[17]Jervis, "Navigation of Harlem River," March, 1838, Jervis Papers.

[18]*Doc. No. 55*, p. 399.

[19]*Doc. No. 55*, p. 400. Also, Jervis, Memoranda Book entry for Dec. 12, 1837.

To be precise, Jervis terminated the pipes on a level 2 feet 3½ inches below their start. Two feet of fall were added to the line's normal declivity of 13¼ inches per mile, which, over the run of the syphon bridge, amounted to 3½ inches.

[20]*Doc. No. 55*, p. 406.

[21]In manuscript form, this document exists in the Jervis Papers. The report was published under the same title in *Doc. No. 55*, pp. 407-435.

[22]*Doc. No. 55*, p. 377.

[23]*Ibid.*, pp. 423-424.

[24]*Ibid.*, pp. 410-414.

[25]For more technical details regarding this structure, see Jervis, "SPECIFICATIONS of the manner of constructing the preparatory work to form a Foundation for large Iron Pipes . . . across MANHATTAN VALLEY," Sept., 1838, Jervis Papers.

[26]Actually, Jervis added 3 feet of fall to the aqueduct's regular declivity across the valley, so the total fall amounted to approximately 3 feet 10 inches.

[27]*Doc. No. 55*, pp. 415-416.

[28]*Ibid.*, p. 416.

[29]*Ibid.*, p. 426.

[30]For a more detailed description of this structure, see Jervis, "Specifications: Clendenning Valley," Sept., 1838, Jervis Papers.

[31]For more detailed information, see Jervis, "SPECIFICATIONS of the manner of building a RECEIVING RESERVOIR at YORK HILL," Sept., 1838, Jervis Papers.

[32] Doc. No. 55, p. 429.

[33] See Schramke, pp. 49-53.

[34] Jervis to McNair, April 24, 1841, Jervis Letter Book. In this letter, Jervis attempted to find out the cause of a breech in the Shaws Water Works' reservoir near Greenock, Scotland. He wanted to know if it had burst because of water pressure, or if it had been undercut by leakage or eroded by a spill-over.

[35] Doc. No. 55, p. 430.

[36] Ibid., pp. 430-431.

[37] Ibid., p. 432.

[38] See Jervis, "SPECIFICATIONS of the manner of building a DISTRIBUTING RESERVOIR on MURRAY HILL," Sept., 1838, Jervis Papers.

[39] Reminiscences of JBJ, p. 129.

[40] Doc. No. 55, p. 432.

[41] Jervis, "Report on Sing-Sing Aqueduct Bridge," Feb. 8, 1837.

[42] Jervis, "Report on Cornice for Distributing Reservoir," July 28, 1840, Jervis Papers.

CHAPTER SEVEN

On March 24, 1838, the Chief Engineer and the Water Commissioners advertised for bids on Sections 54 to 79, which composed all of the aqueduct's 3rd Division. They also advertised for bids on Sections 80 to 85, or that part of the 4th Division which lay north of the Harlem River. Jervis received proposals until May 7, and he and the Commissioners were pleased that over thirty contractors bid on some of the individual sections, because the "competition was spirited, and the prices lower than those demanded at the previous lettings."[1] The Commissioners let the thirty-two sections between the village of Hastings and the Harlem River for $1,600,000. This left them with only twelve sections not under contract, and they hoped to get that work under way quickly. Unfortunately, their hopes were thwarted by a controversy over Section 86 — the Harlem River crossing.

On January 4, in their Semi-Annual Report covering the second-half of 1837, the Water Commissioners had publicly endorsed their Chief Engineer's intention to build a syphon bridge across the Harlem.[2] They stressed the structure's economy, the fact that it would cost a half-million dollars less than a high bridge. They emphasized that the syphon bridge could be constructed more readily, because its contractor would not have to sink numerous bridge piers, a type of work "attended with many unforeseen difficulties and casualties." And they expressed the belief that the syphon bridge would be safer from the dangers of water leakage, frost, and settlement. The Commissioners seemingly presented a strong case in favor of the inverted syphon, but it failed to convince some important people. Their report sparked a debate over the Harlem River crossing which was carried on in the press, in the Common Council, and in the State Legislature.

An anonymous author laid out the debated issues in a letter published in the New York American on March 9, 1838. This letter faulted the syphon bridge on several counts. From a stylistic point of view, it was unimpressive; it would "deprive the work of all that would render it an ornament to the city and the age in which we live."[3] Technically, the inverted syphon was a risky "experiment." It might fail to deliver the desired amount of water to Manhattan. Its pipes might deform or burst from the pressure of the water under transport, and they most certainly would corrode and be short-lived. But the syphon bridge's most damning fault, according to this letter, was that it would block off most of the Harlem and close the river to all traffic except those vessels small enough to pass through its 80-foot arch which rose only 50 feet above high water.

Stung by this criticism, the aqueduct's engineering department suddenly started functioning in a public relations capacity. Jervis and his Principal Assistant, Horatio Allen, fired off their own letters to the press, and they rebutted the criticism point-by-point. Allen answered the charge that the syphon bridge lacked style, that it was not an "ornament." Allen did not deny the charge, because he knew it was true. Instead, he tried to turn the structure's utilitarianism to advantage. He praised Jervis for:

> the soundness of that practical judgment, which, not lead away by the exciting magnificence of a structure on which one's name would be a justifiable object of ambition, wisely prefers a more humble, but more substantial, more certain, and more durable plan.[4]

Jervis and Allen both refuted the allegation that the inverted syphon was an "experiment." They cited European precedents near Genoa and Lyon which had proved successful, and the Chief Engineer mocked the sophistry of anyone who believed that water would not flow in abundance through his iron pipes:

> This is certainly a new position in hydraulics, and it throws the labors of Bosset, Drs. Buat, Prony, Etylwein, and Robison, into the background.[5]

Allen, meanwhile, defended the structural integrity of the iron pipes and allayed the fear that they might burst:

> By reference to "Renwick on the Steam

> Engine," it will be seen that such a pipe will bear without "change of shape" a pressure of more than 800 pounds.[6]

One other engineer stepped forward to defend the inverted syphon: Frederick Graff, the highly respected superintendent of Philadelphia's Fairmount Water Works. Jervis had consulted Graff on the use of iron pipes, and it seems likely that the Chief Engineer encouraged Graff to speak out when their use became controversial. Graff was quoted in the New York Evening Post on March 13:

> The plan you have adopted in passing over Harlem River with iron pipes is, in my opinion, preferable to the high aqueduct. The manner /in which/ you have planned the whole structure, together with the arrangement of the pipes cannot but succeed to give a copious flow of water.[7]

In a letter published in the New York American, Jervis confronted what had become, and would continue to be, the crucial issue in the dispute over the Harlem crossing -- would the syphon bridge ruin navigation on the river? This issue caught the Chief Engineer totally by surprise. When designing his low bridge, he had given little or no thought to its impact upon river traffic, simply because there was no traffic. In the 1700's, ships' captains had avoided sailing the Harlem, because it followed a winding course and in places was only five feet deep. Since about 1800, they had stayed off the river for an even better reason; it was impassable, due to man-made obstructions. Jervis stressed this fact in his letter:

> There is at present no navigation west of McComb's Dam, nor has there been any for near/ly/ forty years. It is now obstructed by the dam and bridge near the Spuyten Duyval Creek, called King's Bridge, and by the Fordham Bridge on one side of the aqueduct line, and by McComb's Dam and Harlem Bridge on the other side.[8]

The opponents of the syphon bridge admitted that the Harlem River had long been useless as a commercial shipping route. Nevertheless, they wanted to scrub the structure in favor of a bridge which would provide a higher and wider clearance for ships, because they hoped to improve the river. They wanted to dredge its channel and remove existing obstacles, or circumvent them with canals. Someday, they hoped, the Harlem would become an important connector between the Hudson and East Rivers, a connector which would spawn and support businesses and industries on the northern end of Manhattan. A certain percentage of these visionaries even backed their hopes with investments; they had purchased land on both sides of the river, speculating on a boom in the region's development.

Jervis did not share the speculators' dreams, but he recognized that they formed an influential group which had connections in both the Common Council and State Legislature.[9] So in his letter to the _American,_ the Chief Engineer attempted to appease this interest group. Although he fully believed the syphon bridge's 80-foot arch would suffice "for any navigation that may be anticipated," he offered to increase its span to 120 feet and its rise to 65 feet. With these changes, the arch could accommodate a much wider range of vessels, should the Harlem ever be opened to traffic. The speculators could keep their dreams; Jervis could keep his syphon bridge, in a modified form.

The first governmental body to pass judgment on the inverted syphon was the State Legislature's Committee on Grievances. On April 5, the committee reported on a memorial it had received which sought, through a legislative act, the forced abandonment of the syphon bridge. The committee disappointed its petitioners; its members concluded that with a 120-foot arch, the syphon bridge would not interfere with any foreseeable Harlem River traffic.[10] Jervis and the Water Commissioners were particularly pleased to receive this support, because they already knew that the Common Council's attitude was far less favorable. On March 31, the Council's Committee on Roads and Canals had summoned Jervis to defend his structure, and the meeting had not gone well for the Chief Engineer:

> Committee complained that I ought to have gone forward with the High Bridge & saved all the trouble and discussion between the different plans -- intimating that I might be afraid of undertaking the High Bridge.[11]

On April 23 the Committee on Roads and Canals, as expected, reported its displeasure with the syphon bridge.

Its members again intimated that Jervis might be afraid of tackling a high bridge. "No want of experience," they wrote, was a "satisfactory reason against underta ing the work."[12] The committee found that the Chief Engineer's and Water Commissioners' reasons for favoring the syphon bridge were unimportant, when weighed against "the propriety of preserving the navigation of the river." Whigs and Democrats alike stood squarely with the speculators. They noted that the syphon bridge would decrease property values along the Harlem. It would permanently injure the river and therefore injure the commercial and industrial development of northern Manhattan. In concluding its report, the committee urged Common Council to:

> request the Water Commissioners, in constructing the aqueduct across Harlem River, to leave at least three hundred feet of the channel open . . . , and that they build the bridge over the river in such a manner as to allow the free passage of sloops.[13]

On May 8, the Water Commissioners answered the Committee on Roads and Canals by submitting its own report to the Common Council. Legally, the Council could not demand the abandonment of the syphon bridge. Only the State Legislature, which had created the Board of Water Commissioners could do that. But the Commissioners felt obliged to honor the Council's opinion on this important matter, so they attempted to sway that opinion. They reiterated the structural and economic merits of the inverted syphon. They stressed that most vessels, short of 90- or 100-ton sloops, could pass easily under its enlarged arch. The bridge could handle the two-masted craft used around the city for transporting manure; nearly all 40- or 50-ton market boats; several hundred miscellaneous vessels then navigating the Hudson and East Rivers; and all steamboats. The Water Commissioners also raised the point that three years earlier, Common Council had approved their original plan for the aqueduct, and:

> an important part of the plan adopted by the Common Council, and ratified by a large majority of the electors of this city, was the crossing of the Harlem River by inverted syphon.[14]

If the Council wished to withdraw its prior approval, the Commissioners said they would abide by the decision. But they urged the Council to decide between a high bridge and a low bridge as quickly as possible, so they could get on with the work. Unfortunately, the Commissioners got neither a quick decision, nor a final one. In mid-July the bicameral Council split on the issue. The Aldermen chose not to interfere with the Commissioners' plans; the Assistant Aldermen urged the construction of a high bridge. Since no clear mandate came out of Council, the Water Commissioners went ahead on their own and instructed Jervis to implement the syphon bridge.

Jervis proceeded as directed. On October 9, 1838, the

West Point Foundry Association successfully competed against six other American and three British firms and won the contract to furnish all the iron pipes needed on Manhattan, including all the pipes which would be laid across the syphon bridge.[15] On October 23, Jervis and the Commissioners let contracts on the aqueduct's last twelve sections, numbers 86 through 97. These contracts amounted to $2,100,000 -- exclusive of the cost of the pipes to be supplied by the West Point Foundry. The Commissioners let Section 91, the Manhattan Valley crossing, for $142,000. They let Section 94, which included the aqueduct bridge at Clendenning Valley, for $298,000; Section 96, including the Receiving Reservoir, for $566,000; and the Distributing Reservoir, Section 97, for $360,000. Another contract valued at $360,000 went to Ellsworth, Mix & Co. for the syphon bridge across the Harlem River on Section 86.[16] Jervis had received eleven bids on the syphon bridge, despite the fact that its undaunted opponents had published the following warning in several New York newspapers:

> Harlem River -- To Masons, Builders and Contractors . . . . We the subscribers, owners of land adjoining the Harlem River and in the vicinity thereof, and interested in keeping the navigation of said river unobstructed; to prevent innocent contractors being injured by an agreement to erect said bridge for the Water Commissioners, do give the public notice, that we will use every means the law will justify, to prevent any and all persons obstructing the water at the natural channel of said river.[17]

Because Ellsworth, Mix & Co. received the syphon bridge contract so late in 1838, the firm completed little work on the structure before winter set in.[18] Actually, it was fortunate that the contractor got off to a slow start. The opposition, true to its warning, continued to hound the State Legislature for an act which would block the syphon bridge, and by the end of 1838 Jervis was quite certain that the opposition would eventually win its way. On December 29, he summed up the situation in a letter to J. J. Abert, an engineer working on the Alexandria Aqueduct Bridge across the Potomac. Jervis had fought against the high bridge every step of the way; in the coming months he would continue to fight it. Yet in his letter to Abert, the Chief Engineer expressed a surprising aquiescence. All along, it seems, a part of Jervis had wanted the high bridge, which would "give prominence to professional character as a work of art."[19]

> It now appears the navigation is esteemed of so much importance (that is, the facilities of improving it) that it is quite probable we shall be required to construct the high bridge, or essentially to maintain our grade over the valley. I cannot say by any means that I regret this -- as you know Engineers are prone to gratify a taste for the magnificent when there is good reason for the execution of prominent works.[20]

On May 3, 1839, the opponents of the syphon bridge finally did win their way, when the State Legislature passed "An Act Prescribing the Manner in which the Croton Aqueduct shall pass the Harlem River." The act stipulated that:

> The Water Commissioners shall construct an aqueduct over the Harlem River, with arches and piers; the arches in the channel of said river shall be at least 80 feet span, and not less than one hundred feet from the usual high water mark of the river, to the underside of the arches at the crown; or they may carry said aqueduct by a tunnel under the channel of the river, the top of which shall not be above the present bed of the said river.[21]

For the Chief Engineer, it was literally time to go back to the drawing board, and on June 1 he presented a new plan for crossing the Harlem, one that met, but did not exceed, the State Legislature's requirements.

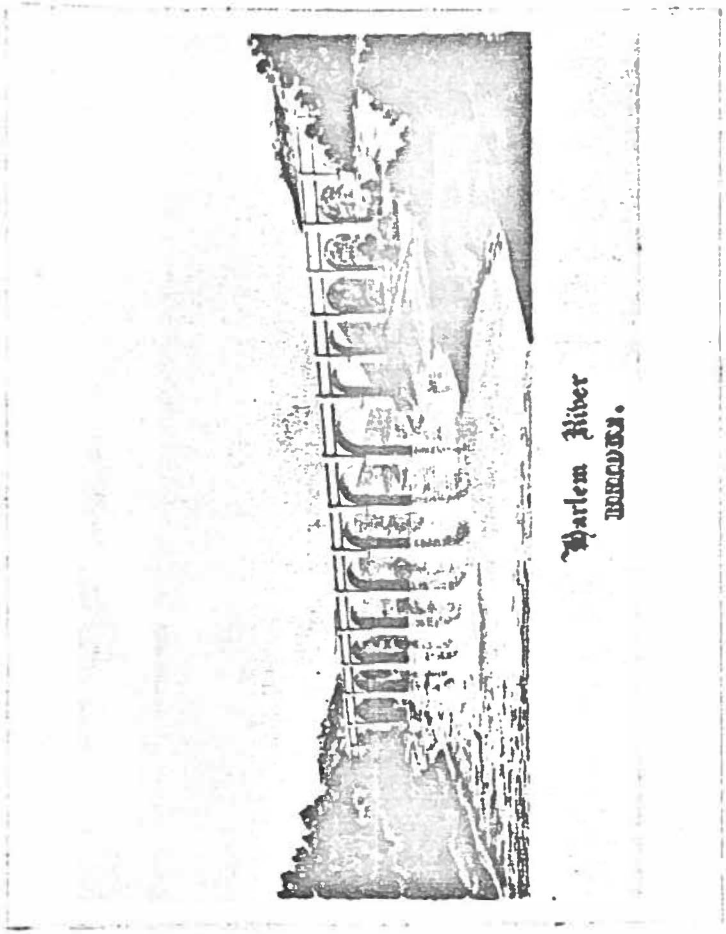
Jervis did not adopt the option offered by the Legislature of a tunnel under the river. He thought the construction of a masonry tunnel large enough to accept an inverted syphon with four 36-inch pipes would be a very uncertain process. To document the problems which might plague a Harlem River tunnel, Jervis cited the history of Marc Brunel's tunnel under the Thames in London:

> The history of this work is . . . such as to admonish us of the uncertainty in estimating for work done under a heavy pressure of water. It was commenced in 1825, and then estimated to cost 160,000 pounds sterling. November, 1837, 12 years after its commencement, there had been expended 264,000 pounds, and it was then estimated to require an additional sum of 350,000 pounds to complete it, which, if correct, will make the final cost 614,000 pounds, or near[ly] four times the original estimate.[22]

Jervis felt that under the best of circumstances, a contractor might be able to construct a tunnel under the Harlem in four years at a cost of $424,000. But because he feared that serious construction problems would in fact be encountered, he added fifty per cent for contingencies.[23] This raised the estimated cost of a tunnel to $636,000, and there was no guarantee that its real cost would not rise far above that figure. In addition, Jervis believed a tunnel would incur high maintenance costs, because salt water would inevitably percolate through its masonry and rapidly corrode its iron pipes. So Jervis decided against a tunnel, and that decision left him with no alternative except to cross the Harlem with a high bridge.

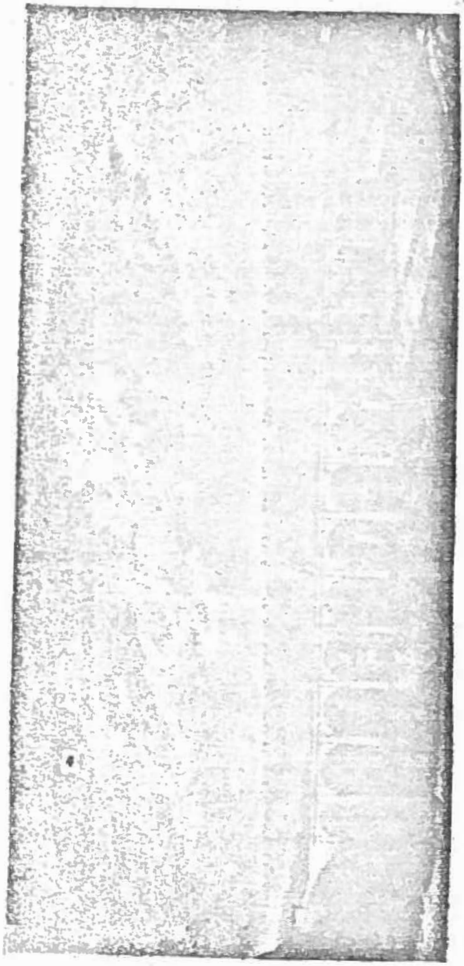
Jervis, of course, already had a high bridge design on hand, the one he had worked out a year-and-a-half earlier at the request of the Water Commissioners. But that design actually exceeded the height requirement set by the State Legislature, so he chose not to use it, at least not _en toto_. He designed a second, somewhat lower bridge which is shown in Plates XXXV through XXXVIII. The second bridge retained some important internal features, such as hollow piers and the use of interior spandrel walls to support the deck, and its arches, piers, pilasters, parapets and water table exhibited a style consistent with that of its predecessor. Nevertheless, the Chief Engineer's second high bridge differed significantly from his first. Of primary importance, it was twelve feet lower. Jervis dropped the undersides of the arches to

PLATE XXXV



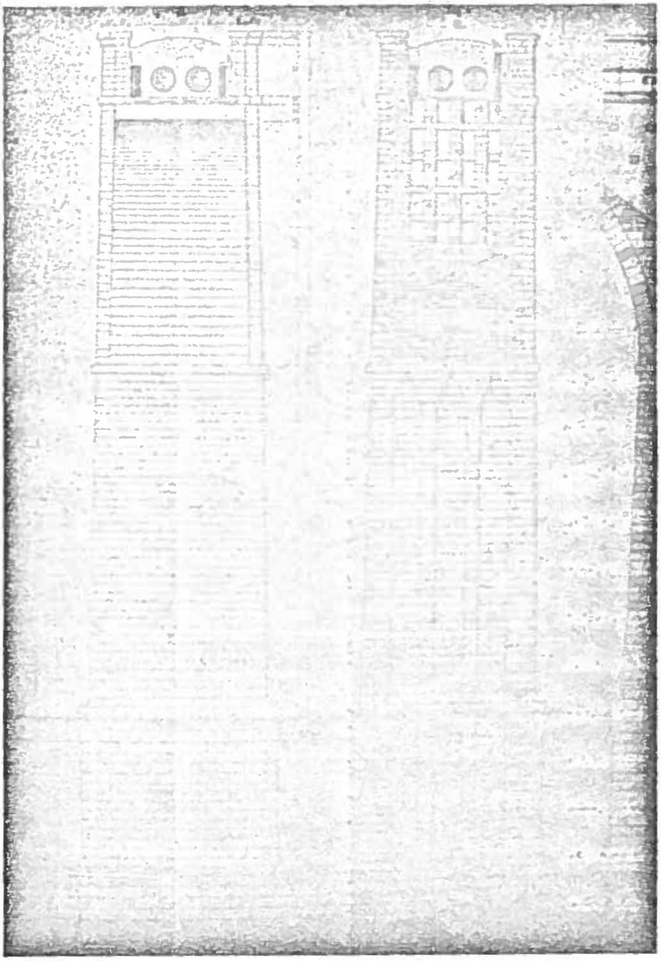
High Bridge Across Harlem River.

PLATE XXXVI



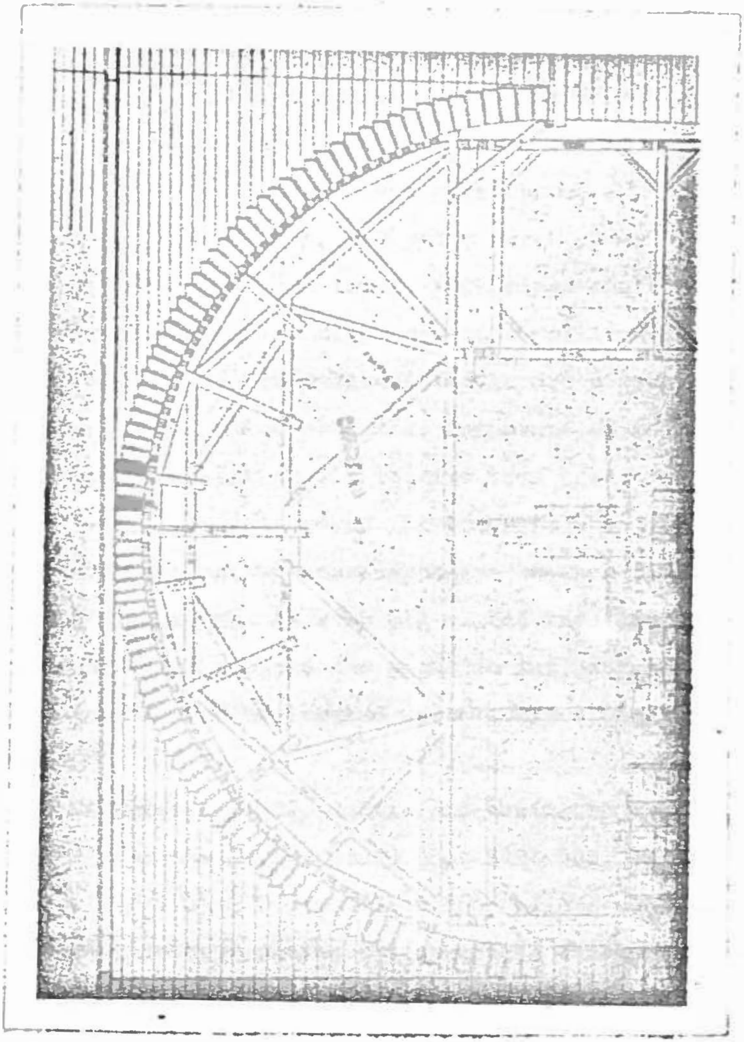
High Bridge Across Harlem River.

PLATE XXXVII



High Bridge Across Harlem River.

PLATE XXXVIII



High Bridge Across Harlem River.

the minimum height of 100 feet above high water, as demanded by the Legislature. Because the bridge now fell short of maintaining the aqueduct's grade line across the valley, Jervis dispensed with the masonry conduit between its parapet walls and substituted a shallow inverted syphon which could carry water under pressure.[24] Jervis calculated that two 48-inch pipes could handle the masonry conduit's discharge of 60 million U. S. gallons daily, so he designed the bridge's deck to accept pipes of that number and size. But since he believed that New York would not really require that great a discharge for upwards of fifty years, he chose to economize by initially laying two less-expensive 36-inch pipelines across the bridge. As with all of his inverted syphons, he started and stopped the pipes in influent and effluent gate houses, and he located waste cocks along their lowest level.[25]

In December 1837, Jervis had estimated that a high bridge over the Harlem would cost $936,000. In June 1839, he estimated that his modified high bridge would cost $837,000. So by reducing the structure's height, the Chief Engineer anticipated a savings of about $100,000. Still, his modified structure could hardly be called an economical means of carrying two iron pipelines over the river. Jervis could have greatly reduced the cost of a high bridge only by substituting timber construction for masonry, and he chose not to do that, because a timber bridge would decay too rapidly, and it would always be vulnerable to a catastrophic fire.

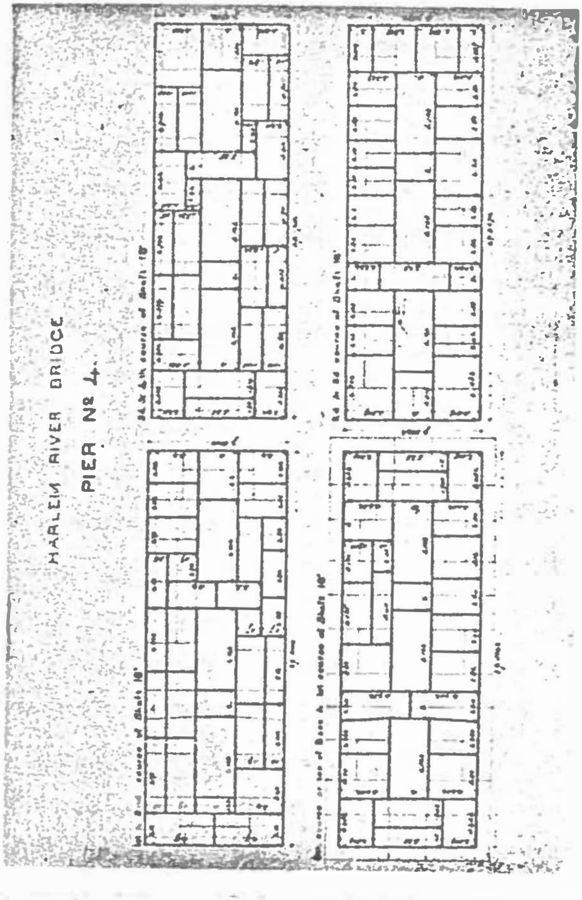
The Water Commissioners approved their Chief Engineer's new plan for the high bridge, but only with great reluctance, only because they had to "obey the law":

> We still apprehend much embarrassment in sinking piers 25 feet through mud and water, and in raising them up to the proper height for springing the arches; and we still believe, the plan proposed by us of a syphon bridge . . . , was the preferable plan, both as to its cost, security, permanence of structure, and ease of construction.[26]

The Commissioners declared the Ellsworth, Mix & Co. contract for the low syphon bridge abandoned, paid that firm for the work it had done, and on June 15, 1839 advertised for bids on the high bridge. In preparation for contract work, the engineering department prepared meticulous plans for the structure, going so far as to produce working drawings which showed the dimensions and alignment of each stone in each bridge pier. (Plate XXXIX.) On August 13, the firm of Law, Roberts and Mason won the high bridge contract with a surprisingly low bid of $755,000.[27]

By the end of 1839, when the Harlem or High Bridge was still in its nascent stage, contractors had already finished 54 of the aqueduct's 97 sections. They had completed 26 miles of the masonry conduit, finished 7 tunnels, 114 culverts, and laid 115,000 cubic yards of

PLATE XXXIX



Alignment of Masonry in High Bridge Pier.

foundation wall and an equal amount of protection wall. The Water Commissioners reported that, "The progress of the work has rather exceeded than fallen short of our expectations."[28] They had paid requisitions amounting to almost four million dollars, and they expected to expend another five million to carry the aqueduct to completion. Jervis and the Commissioners hoped to see all of the sections finished, excepting High Bridge, by the end of 1841 or at least by mid-1842. With so much work behind them, and with the long debate over the Harlem crossing finally concluded, they thought the aqueduct might be concluded routinely. Unfortunately, more trouble lay ahead.

On March 17, 1840, Governor Seward, a Whig, ousted Stephen Allen's Board of Water Commissioners and installed a five-member Whig Board chaired by Samuel Stevens.[29] The move was blatantly political, an attempt to spread the glory of finishing the aqueduct over to the Whig party, but at least the Governor chose an able man to succeed Allen. Samuel Stevens, like his predecessor, came to his position with a long history of involvement in New York's quest for an abundant water supply. While serving on the Common Council in the late 1820's and early 1830's, Stevens had been an outspoken advocate of a centralized, municipally-funded water system. Nevertheless, the change in the Board was a cause of great concern to Jervis, a Democrat who had achieved his professional success while working on state canal projects controlled by other Democrats in Albany.[30] The Whig Board would have its own ideas about the aqueduct, and it might even want its own Chief Engineer. The deposed Commissioners, bitter over their own removal, saw that a purge might also take Jervis off the project. Believing such a move would be unwise and unjust, in a report covering their last months as Commissioners they urged their successors to retain Jervis:

> We leave with them our efficient and highly esteemed Engineer, John B. Jervis, Esquire, for whose services in the successful prosecution of the work, the public are greatly indebted. The industry and ability with which he has conducted this great enterprise, will carry his name to future time . . . . We cannot forbear expressing the hope, therefore, that our successors will avail themselves of the talents and acquired knowledge of Mr. Jervis, for the further prosecution of a work of so much importance to the city.[31]

Immediately after taking their places on the Board, Stevens' men apparently did go on a kind of head-hunting expedition, but it was of short duration. The new Commissioners were naturally inquisitive as to why the aqueduct was costing at least twice as much as the original estimate, so they investigated the manner in which the first Board had let contracts. They examined account books, records of all bids received, and they questioned contractors, trying to find any hint of favoritism or graft.[32] The new Commissioners found no evidence of impropriety, but they did conclude that a few of the adopted plans were too expensive. They started to challenge those plans, and thereby set the stage for a possible confrontation with the Chief Engineer. But the confrontation never came about. The Whig Commissioners acted wisely and in good faith. They urged no cost-cutting measures which jeopardized the security of the work, so Jervis cooperated with them and altered some of his structures.

The Commissioners believed that the Receiving Reservoir was unnecessarily large, that New York would not require such an abundant storage facility "for a century to come, if ever . . . ." Consequently, they ordered the abandonment of $75,000 worth of rock excavation in its floor, a move which reduced the structure's capacity.[33] They also ordered the elimination of $10,000 worth of excavation along the route of the pipelines between the Receiving and Distributing Reservoirs. The most visible cost-cutting alteration sponsored by the new Commissioners was seen at Clendenning Valley, where they chose to abandon the road arches over 96th, 97th and 101st Streets.[34] Jervis substituted a solid foundation wall for these three arches, in order to gain an estimated savings of $52,000. In the summer of 1840 the Commissioners raised objections to the costliness of another structure along the line, and again their objections generated no conflict with the Chief Engineer. The Board objected to the unnecessary expense of crossing the Harlem River with the High

Bridge, and it made an abortive attempt to initiate a lower structure.[35]

Jervis' willingness to cooperate with the new Board's economy drive defused a potential conflict and preserved his position. In not too long a time, he and the Whig Commissioners established a working relationship based on mutual respect:

> Every day I was becoming more acquainted with the new board and they with me. I soon thought I saw in them a practical sagacity that would not allow them to do any very absurd thing, and I came to have great respect for some members of the board . . . .[36]

This working relationship, tenuous at first, grew stronger after it survived some serious tests. On July 18, 1840, the New York American called for the removal of Jervis and the reinstatement of Major Douglass. The paper claimed that Douglass had originated the aqueduct's plans and that Stephen Allen's Democratic Commissioners had removed him not for professional reasons, but because they considered Jervis, "an élève of the Albany Regency, a more suitable instrument to subserve their political interests than a Whig."[37] Douglass made his own effort to regain the Chief Engineership in October, through a letter which gained wide distribution through the press.[38] He claimed his removal had been politically inspired, and he opined that the aqueduct would fail if left in his successor's hands. Jervis was stung by this criticism, just as he continued to be stung throughout his life by the false notion, held by many, that Douglass had designed the aqueduct, and that Jervis had only built it. The Whig Commissioners, as Jervis later noted, were also affected by the criticisms of the Chief Engineer which surfaced in 1840, but they nevertheless retained him for the duration of the project:

> The criticisms of Major Douglass and others . . . made a strong impression on the board of commissioners. I well recollect one morning Mr. Samuel Stevens . . . came into the office (his desk and mine were in the same room) with an expression that indicated much anxiety. I was writing at my desk. I laid down my pen to see if I could ascertain the cause. Casual conversation ensued, which soon brought up the aqueduct. Mr. Stevens, with a significant sigh, remarked that it would be sad, if after spending so much money, the aqueduct should be a failure. I replied that it would be sad indeed; that I had no doubt of its success; that my experience and investigation gave me confidence; that it was impossible for me to explain to him, for he could not be expected to follow the scientific reasoning or see the force of experience in such matters; that he must have faith, and if he did not think I was capable of conducting the work successfully it was his duty to engage an engineer on whom the commissioners could rely. Here was a clear case for reinstalling Mr. Douglass if the board had thought proper. I took no measure to influence them other than by a strict attention to my duties as engineer of the works. It is well known the board did not make the change.[39]

While the tensions between Jervis and the Whig Commissioners subsided over the course of 1840, a controversy erupted between the Commissioners and the Democratically controlled Common Council over the issue of who should lay the city's water mains. Stephen Allen's Board had never wanted or sought control over the 130 to 160 miles of pipes needed to distribute Croton water throughout the city. Only in a sense did the first Commissioners assist the city in laying pipes -- by sharing the revenue gained from the issuance of Water Stock. In 1836, the Legislature had authorized New York to issue 2½ million dollars of stock to fund construction of the aqueduct. Periodically, as the work progressed and more contractors had to be paid, the city went back to the Legislature with requests to issue more Water Stock. On March 29, 1838, for example, New York received permission to issue an additional three million dollars worth. But not all of this revenue went to the Water Commissioners. The city diverted part of it into its own treasury to defray the costs of laying water mains. Under the provisions of an act passed by the Legislature on March 24, 1838, this practice was perfectly legal.[40] But by 1840 the Whigs had gained control of the Legislature, and they found the same practice unacceptable.

On April 27, 1840, the Legislature granted New York permission to issue another three million dollars of Water Stock, but this time it attached a string. The city government could expendnone of the revenue, even to cover the costs of water mains, without the approval of the Water Commissioners for each expenditure.[41] For the new Commissioners, this amounted to an invitation to step in and take over control of the pipe-laying efforts. They did step in, and willingly -- too willingly, as far as the Common Council was concerned. Early in May the Commissioners charged, with justification, that the city was installing pipes too slowly (only 35 miles of pipe had been laid), and they instructed Jervis to draw up his own plan for a network of pipes to cover lower Manhattan. Common Council strongly objected to this abrogation of its responsibilities and in August countered the move by establising a Croton Aqueduct Department with the power to contract for the laying of distribution pipes. The politicians fought over the issue until April, 1841, when the State Legislature settled the dispute in favor of the Council's Croton Aqueduct Department. While the politicians had squabbled, Jervis and Horatio Allen had only half-heartedly proceeded with plans for a distribution system, because as Jervis admitted to the Commissioners:

> I have no desire to increase the duties and responsibilities of my charge, and would greatly prefer to see the distribution well conducted without my aid.[42]

In the summer and fall of 1840, the Chief Engineer did not want to divert his attention to water pipes. They were an unwanted burden. He wanted to concentrate on completing the aqueduct, and in particular he wanted to concentrate on the serious problems which were being encountered at the High Bridge site.

When the contracting firm of Law, Roberts and Mason started sinking the piers for High Bridge, the company immediately ran into problems even more severe than Jervis had anticipated. The early soundings of the Harlem River had predicted that all of the river-piers and at least half of the land-piers would be founded on rock. Unfortunately, this prediction proved very inaccurate:

> It had been supposed a rock foundation would be found for the piers of the bridge. Rock in places was found on each side of the river, and though the soundings in the river had not in all cases met rock, it was supposed it would be found within limits that could be reached. But more thorough examination failed to show rock in some places after going eighty feet below high water. What was originally supposed in some cases to be rock . . . proved to be only large boulders that lay very thick in the mud and sand, and below these a bed of sharp sand.[43]

The existence of numerous 4,000 to 12,000 pound boulders posed one problem for the contractor and the Chief Engineer; the lack of a solid rock floor in the valley posed another. In order to sink a river-pier, Law, Roberts and Mason first had to lay bare its river-bed site by enclosing it within a box-like coffer dam. Driven into the river's bed, and rising three feet above high water, each coffer dam was to serve as an impervious barrier. Once a steam-driven pump evacuated the inside of the dam, the space was to remain dry so men could enter the structure to work on a pier's foundation. But the boulders interfered with the installation of the coffer dams. The contractor used a heavy, falling weight to drive each dam's 9- to 12-inch thick sheeting timbers into the river bed. When these timbers struck a boulder, despite their size they often splintered to pieces, or else they came to rest in such a way that water too easily found its way into the dam's enclosed working space. Consequently, a great deal of time and effort had to go into the arduous task of "lewising" the boulders.[44] Workers drilled a hole into a boulder, sunk a metal plug into the hole, attached a line, and then, using a portion of the coffer dam as a support, hoisted the boulder out of the way.

While the task of removing boulders prolonged the construction time of High Bridge (which was not completed until 1848), the lack of bed-rock in the valley threatened the stability of the entire structure. Several of the piers were founded on gneiss or marble, but five of the land piers and five river-piers had to stand on groups of tapered, oak piles driven thirty to forty-five feet into sand. Jervis knew that many bridges had been constructed on piles, but none of them, to his knowledge, had been as large or as heavy as High Bridge. Under its great weight he feared that the piles might yield or sink unevenly and cause cracks in the masonry. He had no precedent to allay this fear; he "could find no specific experiments that warranted full confidence for this bridge."[45] For Jervis, the conservative builder, this represented the worst kind of predicament. He could not bring himself to go on with the work, blindly hoping for the best. Before he would allow Law, Roberts and Mason to start raising piers, he had to assure himself that the piles would provide the structure with firm support. In order to gain this assurance, he instructed Horatio Allen to determine experimentally the load that a pile could bear without permanently yielding. Jervis apparently designed the experiment, but his Principal Assistant did all of the calculations and worked out the mechanical details.

In May and early June, 1840, Allen experimented on four different piles which had been driven into sand by a 1200-pound hammer falling from a height of 30 feet.[46] To test-load each pile he used a hydrostatic press of his own design. He positioned the press directly over the pile, and to check the upward thrust of the press he fastened it down with heavy timbers and with iron straps bolted to a number of adjacent piles. Before he actually applied any load, Allen attached a long lever to the pile which indicated and magnified any movement. If the pile sank one inch, the lever would move 20 inches.

With the apparatus in position, Allen started a pump which forced water into the press and activated two rams. The larger "working" ram, 12 inches in diameter, bore directly against the head of the test pile. The smaller "calibration" ram, only eight-tenths of an inch in diameter, bore against a lever carrying weights of up to 1300 pounds. Because the cross-sectional areas of the rams varied by a factor of 228, so did their respective pressures. At all times the working ram exerted a pressure 228 times greater than the calibration ram. Allen used this relationship to determine just how much load he was applying to the pile. Assume, for example, that he loaded or held down the calibration ram with a weight of 500 pounds. At the instant when the small ram started to lift the 500-pound weight, Allen knew that the working ram was exerting a load of 114,000 pounds on the head of the pile (228 times 500). By noting the position of the indicator, he also knew if the pile had yielded under the load.

As a result of Allen's experimentation, Jervis confidently went ahead with High Bridge, believing it would stand safely on piles driven into sand. Allen concluded that as long as a pile yielded less than one inch under the last blow of the 1200-pound hammer which drove it into the ground, then it would not sink or permanently yield under a weight of less than 60 tons. Since the large piers would stand on many piles, clustered together, that load-bearing capability was sufficient to support the bridge. But although Jervis had gained confidence in the structure, he knew that he and his engineers had to exercise great vigilance over its progress. The new Water

Commissioners, too, quickly came to appreciate the magnitude of the problems involved in constructing High Bridge:

> It is a fact not to be disguised that the erection of this bridge is not only a stupendous but is a Herculean task for our city to execute, and requires more engineering talent, inspection, and watchfulness than any other part, or we might almost say, all the other parts of the aqueduct put together.[47]

All things considered, 1840 was not an easy year for the Chief Engineer. He had faced the change in the Commissioners, public criticism, and the problems at the Harlem River crossing. But by the end of the year Jervis appeared to be out of the woods. Contractors had completed more than three-fourths of the line. They had finished all of the 1st Division, with the exception of Croton Dam, which was nearly done, and the engineers had tested the division. Several times in the fall, Edmund French had allowed water to flow from the dam to the waste weir in Sing-Sing. The 2nd Division was completed, except for Mill River Culvert. The 3rd Division was done, and so were all of the sections in the 4th Division north of the Harlem River. At the Harlem, Law, Roberts and Mason had successfully sunk four coffer dams and raised two piers above high water. On Manhattan, contractors had not carried their work as far as their counterparts in Westchester, but the Manhattan Valley crossing was half-done; Clendenning Valley was two-thirds of the way to completion; and both reservoirs were half-finished. In their Semi-Annual Report covering from March to the end of December, 1840, Samuel Stevens' Water Commissioners expressed satisfaction with this progress, and they also expressed confidence in their Chief Engineer and his designs. For example, they said this about Croton Dam:

> It is believed to be durable in its character, and possessed of sufficient strength to resist the Croton . . . , a stream occasionally rendered by freshets, very powerful and turbulent.[48]

The Commissioners could not have known it, but in their evaluation of Croton Dam they unwittingly foreshadowed the next crisis which Jervis would face. The new year began with a catastrophe. On January 8, 1841, Edmund French wrote his Chief Engineer:

> I am sorry to inform you that the water about 3 o'clock this morning rose over the top of the embankment of the dam and in a few minutes swept the whole embankment and protection wall away. The masonry of the dam alone is standing.[49]

It had been a snowy winter along the Croton. In the first days of January, 15 to 18 inches of snow lay along thr frozen river and its feeders. Then, on January 5, the weather warmed, and as the snow and ice began to melt, it started to rain. For 48 hours it rained incessantly, and by January 7 a disastrous flood rushed down the Croton towards the aqueduct's Fountain Reservoir. An immense amount of water passed over Croton Dam, but the masonry weir was not long enough. It could not discharge water as fast as it was arriving, so the water in the Fountain Reservoir rose at a rate of 14 inches per hour. Finally, at 3 o'clock in the morning of January 8, the water stood 15 feet above the weir and began passing over the embankment which closed off the northern side of the valley. The rushing water quickly destroyed the embankment, and with the embankment gone, all the water in the reservoir suddenly spilled down the Croton. It destroyed homes, bridges, and small industries, and three persons drowned in what was the worst flood in the river's history.[50]

An embarrassed and regretful Chief Engineer journeyed to the dam with Samuel Stevens to inspect the damage:

> On passing over the hill as the road entered [Croton] valley, the view was indeed sad and the aspect was severe in the extreme . . . . No one without such experience could imagine the severity with which this scene, with its attending circumstances, affected me.[51]

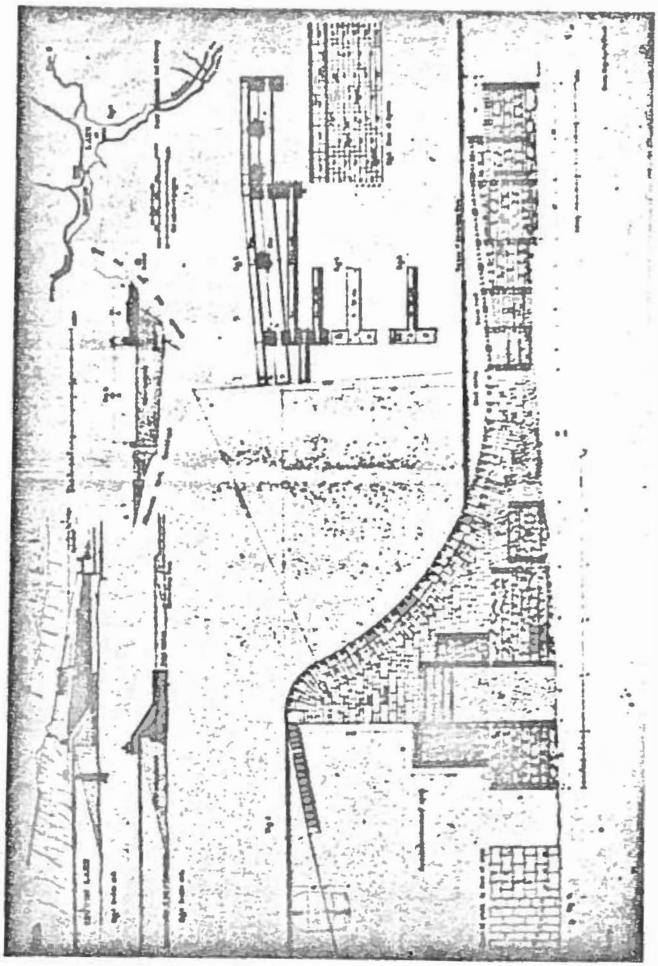
Jervis took some solace in the fact that the masonry had held in the face of the great flood. He took solace in the fact that if the catastrophe had to happen, at least it was best that it happened when it did, before New York had become dependent on the aqueduct for its water. But Jervis was not long in mourning. He had to correct his all-too-obvious error as fast as possible, so the aqueduct could still open by the middle of 1842. In his first designs for Croton Dam, Jervis had avoided carrying its masonry beyond rock and onto gravel, because to his knowledge no masonry dam as tall as this one had ever stood on gravel.[52] But now he had no choice except to build on gravel, in order to make the overflow weir longer.

Jervis designed a 180-foot-long extension for Croton Dam which is shown in Plate XL. (Plates XLI and XLII show the entire dam upon completion.) Jervis founded the extension on interlocking timber cribs filled with stone, placed along both sides of a solid wall of hydraulic masonry, which, during the initial phases of construction, had served as part of a coffer dam used to enclose the work site. The most notable feature of the extension is the face of the overfall. Jervis had taken great precautions to break the fall of water passing over the original dam, founded on rock. For the extension, standing on gravel, he recognized an even greater need to prevent falling water from undercutting the masonry:

> The idea occurred to me that some plan must be adopted by which the water in its passage from the lip of the dam could be turned gradually from a vertical to a horizontal position by the time it reached the apron . . . . I finally hit upon the plan of forming the lower face of the masonry on an O.G. [ogive] or reversed curve that would carry the water down on a smooth volume from its starting at the lip to the apron. . . . This method was very favorable in modifying the form and giving a direction more easily managed to this heavy column of falling water . . . .[53]

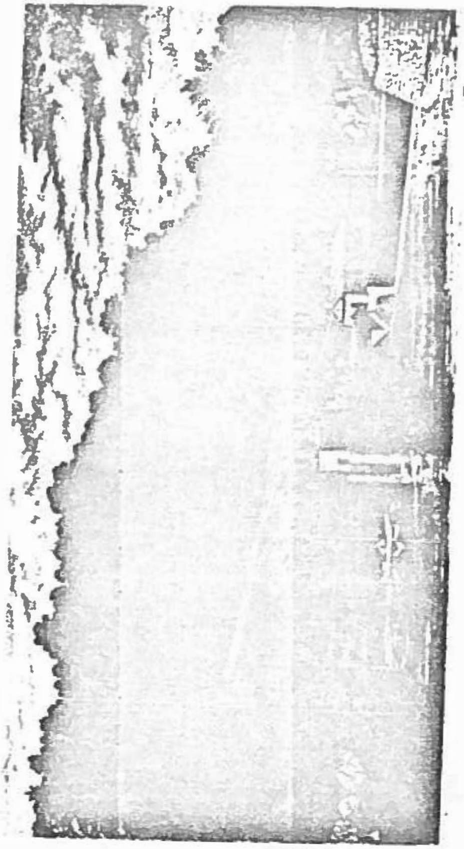
In addition to using a reversed curve for the overfall, Jervis checked the falling water by placing a low secon-

PLATE XL



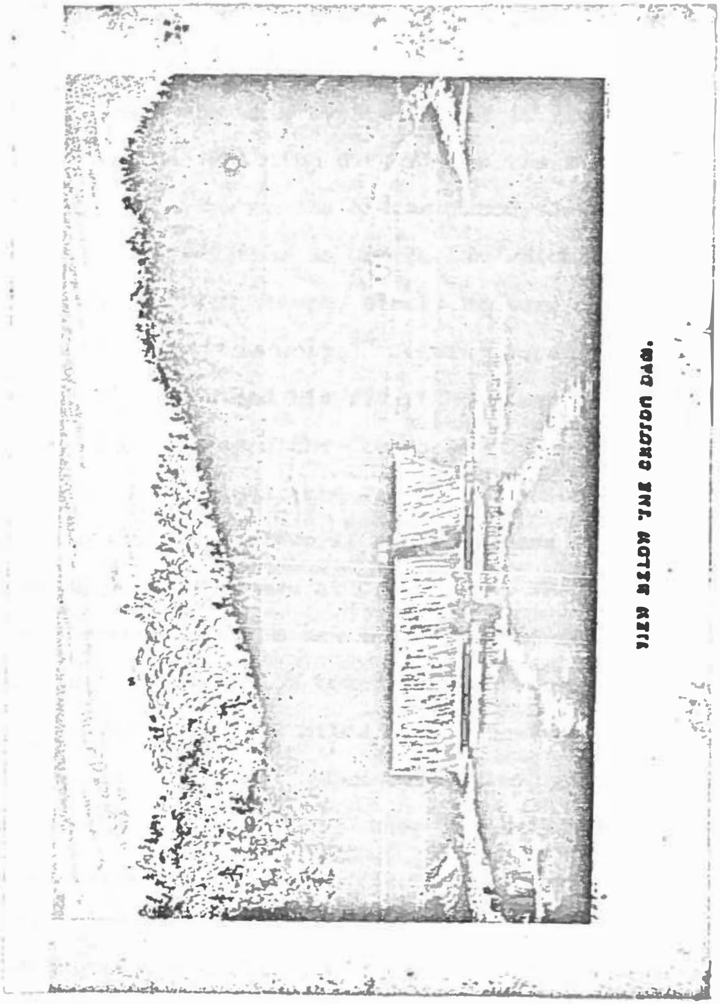
Profile of Croton Dam Extension.

PLATE XLI



View from above Croton Dam.

PLATE XLII



View from below Croton Dam.

dary dam 300 feet below the main dam. The secondary dam created a pond of still water which rose just above the main dam's apron. This pool broke the force of the water passing over the weir by preventing it from falling off the apron and impacting directly on the river bed.

Within a few months of the flood, Jervis let a contract on the addition to Croton Dam which amounted to $127,000, and McCollough, Black, Hepburn & Company energetically began the work.[54] Jervis' worst hour as an engineer had passed, and his finest hour was to come in a year's time, when he opened the Croton Aqueduct.

On June 8, 1842, the Water Commissioners, Jervis, Horatio Allen, and several other members of the Engineering Department met at Croton Dam. They entered the gate-house beside the dam and descended into the aqueduct for an inspection tour. Between June 8 and June 10 the men walked the 33 miles of the conduit from the dam to the Harlem River.[55] When they exited at the influent gate-house at High Bridge, they inspected the 36-inch pipe that had been laid across the Harlem on top of the coffer dams which surrounded the unfinished bridge piers. This temporary pipe would carry water over to Manhattan until High Bridge was completed. On June 22, Jervis and three assistants again inspected the conduit in Westchester County, but this time they did not walk it. The head gates were opened, allowing 18 inches of water to course down the aqueduct. The four-man party climbed aboard a small boat dubbed the "Croton Maid," and they floated down to the Harlem River.

In the course of these last inspections, the engineers discovered few flaws in the masonry, only small fissures easily sealed with hydraulic cement. The structure was sound and could be put into service. On June 27, the engineers opened the gates to the Receiving Reservoir's Northern Division, and for the first time Croton water began to fill the man-made basin. A 38-gun salute heralded the arrival of the water. New York's Mayor Morris attended the celebration, as did Governor Seward, the Water Commissioners, members of Common Council, and other dignitaries.

Jervis, cautious as always, let water proceed down the system gradually, making sure that each part of the line was indeed ready to receive it. On July 2, he opened the Receiving Reservoir's effluent gates and let water flow into the iron pipes leading to the Distributing Reservoir. On July 4, early in the morning when the dignitaries were still in bed, Jervis rallied his engineers to oversee the opening of the aqueduct's southernmost structure. One of his assistants, Fayette B. Tower, a man infinitely more romantic than the Chief Engineer, described the scene:

> At an hour when the morning guns had aroused but few from their dreamy slumbers, and ere yet the rays of the sun had gilded the city's domes, I stood on the topmost wall of the reservoir and saw the first rush of the water as . . . [it] entered the bottom and wandered

about, as if each particle had consciousness.[56]

Throughout July 4, New Yorkers strolled along the top of the Egyptian-styled reservoir and watehed it slowly fill with Croton water. Within a matter of days, as soon as the Distributing Reservoir was sufficiently filled, Jervis opened its effluent gates and water ran into the city's mains. The city had not yet laid all of the needed pipes, and few property owners were hooked up to the system. But the city's Croton Aqueduct Department continued to lay mains; plumbers advertised the advantages of inside plumbing; hydrants stood out on street corners; and a number of fountains sent the Croton water 40 to 50 feet into the air. The distribution system was not complete, but the aqueduct was nevertheless a visible success, a success which the city officially celebrated on October 14.

On that day, church bells and cannon fire resounded throughout New York. Thousands of citizens lined the streets to watch a long parade headed by barouches carrying the Governor, the Mayor, Samuel Stevens, Stephen Allen, other members of the Whig and Democratic Boards of Water Commissioners, and Common Council members. Companies of soldiers and firemen followed on foot. The parade ended at City Hall, where public officials pronounced the magnificence of the Croton Aqueduct. John Jervis, too, had ridden at the front of the parade, but the day really did not belong to him, to his engineers, or to the "worthy mechanics with the hammer and trowel, who laboured in the construction of the noble work."[57] The day of public celebration belonged to the politicians. But if Jervis felt at all slighted, he could take satisfaction in reflecting on the most-recent Semi-Annual Report put out by the Whig Commissioners, the men who for a time had considered removing him from his position:

> in an especial manner we are indebted to him [Jervis] for the great attention and untiring industry and talent he has brought to bear in the successful execution of this work, which will remain an enduring monument of his judgment and skill . . . .[58]

NOTES -- CHAPTER SEVEN

[1]"Semi-Annual Report of the Water Commissioners, Jan. 1 to June 30, 1838," Board of Aldermen Document No. 5 (New York: July 2, 1838), pp. 49-50.

[2]Doc. No. 55, pp. 371-372.

[3]Quoted from Blake, Water for the Cities, p. 153.

[4]Ibid., p. 153.

[5]The quote is from a letter written by Jervis which appeared in the Journal of Commerce. See clipping in Jervis Memoranda Book, entry for March 17, 1838.

[6]See clipping in Jervis Memoranda Book, entry for March 17, 1838.

[7]Quoted from Blake, Water for the Cities, p. 153.

[8]Clipping, Jervis Memoranda Book, entry for March 17, 1838. The manuscript text of this letter is found as "Navigation of Harlem River," March, 1838, Jervis Papers.

[9]Reminiscences of JBJ, pp. 126-127.

[10]Blake, Water for the Cities, pp. 153-154.

[11]Jervis Memoranda Book, entry for April 2, 1838.

[12]Committee on Roads and Canals, "Report," Board of Aldermen Document No. 88 (New York, April 23, 1838), p. 621.

[13]Ibid., p. 627.

[14]Water Commissioners, "Communication relative to the Croton Aqueduct," Board of Aldermen Document No. 2 (New York, May 14, 1838), p. 32.

[15]Jervis, "Original Draft of Notice respecting Cast-Iron Pipe," May, 1838, and "Form of Contract for Cast Iron Pipe," Oct. 9, 1838, Jervis Papers.

The Water Commissioners agreed to pay the foundry $70 per ton for straight pipe, and $75 per ton for curved pipe. The pipe was to be cast in a vertical position from remelted pig iron and proof-tested before delivery.

[16]"Semi-Annual Report of the Water Commissioners, July 1 to Dec. 31, 1838," Board of Aldermen Document No. 25 (New York, Dec. 31, 1838), pp. 238-239.

[17]Ibid., p. 253.

[18]Jervis to Mix, Searle & Co., Dec. 4, 1838, Jervis Papers.

[19]Reminiscences of JBJ, p. 143.

[20]This letter is found in the Jervis Letter Book.

[21]Acts of the Legislature . . . Croton Water, pp. 20-21.

[22]"Report of the Chief Engineer on Plans for Crossing Harlem River," Board of Aldermen Document No. 10, (New York, July 1, 1839), p. 152.

[23]Ibid., p. 154.

[24]Ibid., p. 144.

[25]Jervis made other changes in the high bridge, besides dropping it 12 feet and adopting an inverted syphon. For example, the superstructure he designed to support iron pipes was lighter and less massive than the one he had designed to support a masonry conduit. Because the superstructure was lighter, he was also able to diminish the thickness of the arch stones. One other change was the reduction in the number of arches from 16 to 15. In his original high bridge plan, Jervis had called for "transitional arches of 60 and 70 feet to stand between the arcades of 80- and 50-foot arches. He eliminated the "transitional" arches in his second high bridge and went only with arches spanning 80 and 50 feet.

[26]"Semi-Annual Report of the Water Commissioners, Jan. 1 to June 30, 1839," Doc. No. 10, p. 126.

[27]"Semi-Annual Report of the Water Commissioners, July 1 to Dec. 31, 1839," Board of Aldermen Document No. 42 (New York, Jan. 6, 1840), p. 442.

[28]Ibid., pp. 439-441.

[29]Other appointees to the new Board of Water Commissioners were John D. Ward, Zebedee Ring, R. Birdsall and Samuel Childs.

[30]Jervis totally disclaimed the idea that he was a "political" engineer. In his Reminiscences, p. 156, he wrote: "In no way had I ever attempted to make politics a basis or means of occupation." While his allegiance to the Albany Regency certainly did him no harm in developing his career, it does seem the case that Jervis eschewed mixing politics and engineering. For instance, Jervis hired a Whig, Horatio Allen, as his Principal Assistant. And there is no mention of politics in any of the letters to and from Jervis which deal with openings in the aqueduct's engineering department.

[31]Board of Aldermen Doc. No. 65 (New York, March 30, 1840), p. 645.

[32]Reminiscences of JBJ, p. 155.

[33]"Semi-Annual Report of the Water Commissioners, March 20 to Dec. 31, 1840," Board of Aldermen Document No. 39 (New York, Jan. 11, 1841), p. 518.

[34]Water Commissioners, "Resolution," July 10, 1840, Jervis Papers; also Doc. No. 39, pp. 518-521.

[35]Doc. No. 39, pp. 524-526.

[36]Reminiscences of JBJ, p. 157.

[37]Quoted from Blake, Water for the Cities, p. 159.

[38]New York Courier and Enquirer, Oct. 28, 1840; New York Times & Star, Oct. 30, 1840.

[39]Reminiscences of JBJ, p. 167.

[40]Acts of Legislature . . . Croton Water, p. 20.

[41]Ibid., pp. 21-22.

[42]Jervis to Samuel Stevens, Oct. 13, 1840, Jervis Letter Book.

[43]Reminiscences of JBJ, p. 143.

[44]Ibid., pp. 144, 146-147.

[45]Ibid., p. 144.

[46]"Report of H. Allen on his experiment in Driving & the resistance of piles at Harlem Bridge," June 9, 1840, Jervis Papers. In Reminiscences of JBJ (fn., p. 144), Neal

FitzSimons notes that, "This experiment may well have been the first full-scale test of pile foundations in the United States."

[47] Reminiscences of JBJ, p. 148.

[48] Doc. No. 39, p. 513.

[49] French to Jervis, Jan. 8, 1841, Jervis Papers.

[50] "Appendix," Doc. No. 39, pp. 532-535.

[51] Reminiscences of JBJ, p. 133.

[52] Ibid., p. 134.

[53] Ibid., p. 134.

[54] For a description of how the contractor actually built the extension of the dam, see Reminiscences of JBJ, pp. 134-139.

[55] "Semi-Annual Report of the Water Commissioners, Jan. 1 to August 1, 1842," Board of Aldermen Document No. 9 (New York, August 8, 1842), p. 81.

[56] Tower to Helen M. Phelps, July 5, 1842, John Wolcott Phelps Papers.

[57] Tower to John Wolcott Phelps, Oct. 10, 1842, Phelps Papers.

[58] Doc. No. 9, p. 89.

EPILOGUE

> "Now it should not be forgotten that all the works of men are subject not only to unforeseen imperfection, but to the corroding tooth of time, and therefore liable to fail. The present aqueduct has shown some failure, and has demanded attention, though it has for 40 years afforded, without material detention, a supply for the most part much greater than it was supposed necessary . . . ." -- John Jervis, 1882[1]

Before 1842, the citizens of New York City had lived for well over half a century with an inadequate supply of wholesome water. Because of this shortage, residents had been inconvenienced in their domestic lives and too little protected from the serious dangers of fire and disease. Then the Croton Aqueduct opened, and the city luxuriated in its bountiful water supply by erecting numerous fountains in public parks. New Yorkers were rightfully proud of their new aqueduct, whose final cost approached ten million dollars. In 1842 it was the longest modern aqueduct in the world, and it performed well. When Jervis designed it, he expected a daily delivery of up to 60 million U. S. gallons. When he gaged its actual flow, he discovered that the masonry conduit could safely deliver up to 75 million gallons per day.[2] Since New Yorkers in 1842 consumed only one-sixth of that amount, the aqueduct appeared, if anything, even larger than necessary. Citizens thought that the Croton Aqueduct would surely meet all of the city's water needs for years and years to come. Unfortunately, it did not.

In 1830, when New York began its successful drive for a municipally controlled water system, 202,000 persons resided in the city. In 1840, New York had 312,000 inhabitants. That figure swelled to 515,000 in 1850, and to 813,000 in 1860. After 1860, with the exception of the Civil War years, the city's population increased by an average of over 20,000 persons per year. In 1900, New York had 1,850,000 inhabitants.[3] Just as the city's population increased at an astounding rate, so did the daily per capita consumption of water. Jervis and the Water Commissioners had estimated that each New York City resident would require no more than 30 gallons per day. But that estimate did not anticipate new industries which used increasing amounts of water. It did not anticipate all the fountains in the parks, or the mischievous, street-wise children who opened hydrants and left them running. And it certainly did not take into account the new amenities: private baths and showers, water closets and urinals. Finally, the estimate did not reflect the city's proclivity for wasting a resource, one it began taking it for granted. Although not foreseen in the 1830's, wastage soon became a serious problem, as the President of the Croton Aqueduct Board reported in 1848:

And how is the waste to be prevented? Who

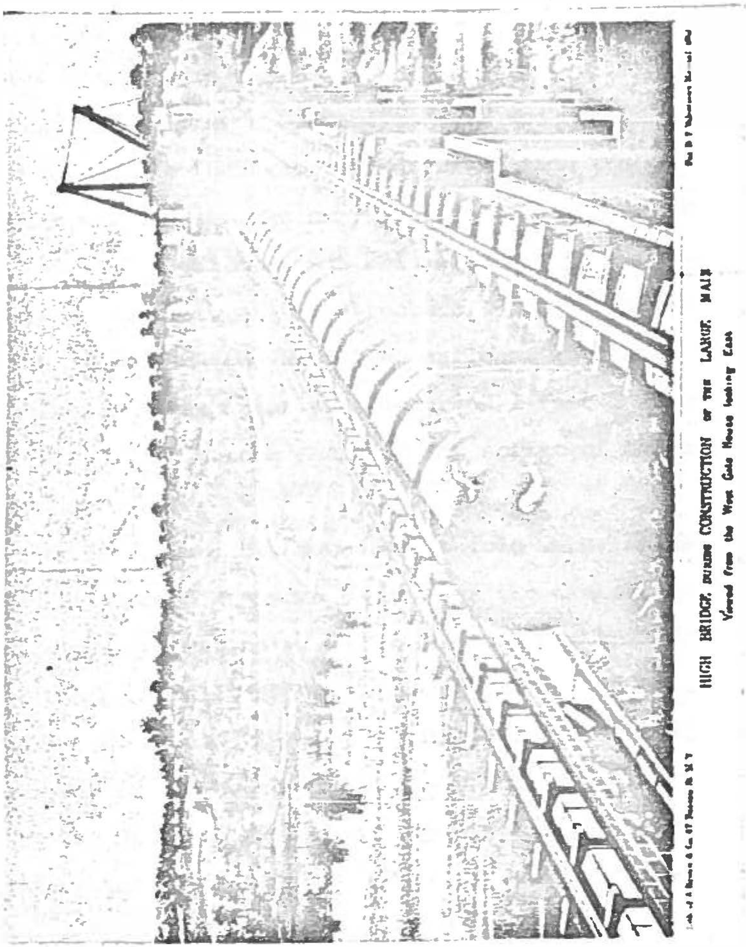
Waste

> is strong enough to contend against the livery and omnibus stables, the constant running of fire and free hydrants, the street washers, the self feeding urinals in secret places, consuming about 600 to 1000 gallons every 24 hours, without any justifiable cause or motive, the public houses with large taps, and all the various sources of profusion and waste in the factories, streets, and buildings of the City?[4]

By 1850, a year after Jervis left the Croton Aqueduct, New York had already reached a level of water consumption that the Chief Engineer had not expected it to reach until the 1880's or 1890's. Individuals used an average of 78 gallons daily, and the city as a whole consumed about 40 million gallons per day.[5] Because the demand for water continued to accelerate, the city soon encountered bottlenecks in its supply system wherever Jervis had installed pipelines. To relieve these bottlenecks, in the 1850's the city laid a huge main across High Bridge (Plate XLIII), a 48-inch pipe across Manhattan Valley, and a third pipe between the Receiving and Distributing Reservoirs.[6] During this same decade, the city also found itself short of water-storage facilities. The Receiving Reservoir -- a structure once believed to be unnecessarily large -- proved to provide an insufficient reserve during periods of drought, so in 1858 the city let a contract for a new 96-acre reservoir in Central Park capable of ponding over a billion gallons of water.

By the 1860's, the Croton Aqueduct was already deliv-

PLATE XLIII



Laying Large Main Across High Bridge, 1852.

ering 75 million gallons per day -- its maximum safe discharge, according to Jervis. Instead of building a needed second aqueduct to augment its water supply, the city flirted with disaster by sending more and more water through the one aqueduct it had. By filling the masonry conduit with water, the city obtained a daily delivery of 105 million gallons. But this discharge played havoc with the stability of the structure, so by 1874 New York cut the flow back to 95 million gallons.[7] To achieve this discharge, it ran water at a depth of 7 feet 5 inches; the water fell just a foot short of the soffit of the roofing arch.

By 1880, New York faced a two-fold water crisis. First, it needed far more water than the Croton Aqueduct could provide. Secondly, there was the very real danger that the physically abused aqueduct might fail catastrophically and cut off the city's water for a long period of time. Jervis had not designed the aqueduct to carry any 95 or 105 million gallons per day. He had pared the amount of stone and brick in the conduit in order to trim its cost, and for a run totaling six miles across low areas he had opted for a foundation wall laid dry, instead of a wall of solid hydraulic masonry. By 1880, in some low areas the foundation wall sagged as much as 12 inches, creating dangerous fissures in the conduit's floor and sides, and in many locations the roofing arch required concrete reinforcement, because it had cracked under pressures it was not designed to take. In a belated response to this crisis, Isaac Newton, then the aqueduct's Chief Engineer, readied plans for a New Croton Aqueduct capable of delivering an additional 300 million gallons daily.

While planning the new aqueduct, in 1882 Newton consulted John Jervis, then 87 years old and living in retirement on his farm in Rome, New York. After building the Croton, Jervis had served as a consulting engineer for Boston's Cochituate Aqueduct, and he had served as a chief engineer and officer of several railroad companies. The elderly engineer played no real role in developing the New Croton Aqueduct, aside from staunchly supporting the need for such a structure. In his 1882 consultant's report he censured the city for having waited so long to commence a second aqueduct:

> For several years, instead of adding to the supply as population increased, the over-strained capacity of the present aqueduct has been the same, and no addition has been practicable to the supply needed for the largely increased population. This situation is alone sufficient to demand an additional channel of supply. A serious failure in the present aqueduct, which has been a source of anxiety for several years, may arrest its functions.[8]

In his report, Jervis admitted that he had erred in adopting a dry foundation wall for the Old Croton, and he offered suggestions as to how its faulty sections could be repaired or bypassed.[9] It was clear, however, that in the main Jervis believed that mismanagement and poor maintenance, and not poor designs, had brought his aqueduct to its uncertain, fragile state.

When John Jervis died in 1885, the Old Croton still functioned as Manhattan's only important source of water. It carried this burden until the city opened the New Croton Aqueduct in 1893. The two aqueducts together thoroughly exhausted the resources of the Croton River, and yet Manhattan's population continued to swell, and the city grew by encompassing other boroughs. Consequently, as new water crises arose, New York had to go further and further to obtain additional water from such sources as the Catskill Mountain watershed and the Delaware River.

Jervis believed he had built the Old Croton Aqueduct to operate for centuries; it operated for a little more than one. In the first decades of the 20th century, some portions of the line were closed down for a time, and other parts, particularly on Manhattan, were drastically altered or even demolished.[10] Still, the aqueduct continued to deliver water to the island -- at a reduced rate of 35 million gallons per day -- until 1955. For ten years after that, it delivered a mere trickle -- .8 million gallons daily -- to a Westchester community. Then, on September 13, 1965, the head gates on the Old Croton were closed for good.[11]

Although the aqueduct did not come close to matching the longevity of some of the Roman aqueducts, it was by no means a failure. Despite some mistakes, Jervis had done a difficult job well. Although it may now be easy to fault the Chief Engineer and the Water Commissioners for the fact that the aqueduct too soon proved inadequate for New York's needs, such critical hindsight is more than a little unfair. John Jervis, an early engineer dedicated in his own way to changing the fabric of American life, could not have foreseen just how widespread and revolutionary some changes were to be. The engineer, after all, had no control over the dynamic growth of a city, and no control over the way its citizens chose to squander their water.

NOTES -- EPILOGUE

[1]"Report of John B. Jervis on the Plans Proposed by Issac Newton," New York Water Supply (New York, 1882), p. 4.

[2]Reminiscences of JBJ, p. 130; Jervis to Stephenson, Dec. 27, 1843, Jervis Papers.

[3]Weidner, Water for a City, p. 54.

[4]"Quarterly Report of the President of the Croton Aqueduct Board," Board of Aldermen Document No. 18 (New York, Nov., 1848), p. 359.

[5]Weidner, Water for a City, p. 56.

[6]Reminiscences of JBJ, p. 149.
Note that the city, in relieving the bottleneck across High Bridge, disregarded Jervis' original intentions. He faulted the city for laying one large main across the structure, instead of laying the two 4-foot pipes which he had designed the bridge to accept.

[7]New York City, Report to the Aqueduct Commissioners (New York, 1887), p. 25; Card file, "Old Croton Aqueduct," NYC Division of Water Supply Control.

[8]"Report of Jervis on the Plans Proposed by Isaac Newton," p. 3.

[9]Ibid., pp. 15-16.

[10]Today, traces of the Old Croton Aqueduct are virtually nonexistent on Manhattan. The Main Branch of the New York Public Library stands on the site of the Distributing Reservoir, and the masonry conduit and the road arches at Clendenning Valley are long gone -- having been replaced by pipelines in the 1870's. High Bridge still stands, but in 1937 a single steel span replaced five of its masonry arches.
The Old Croton Aqueduct has fared better in Westchester County. Jervis' Croton Dam still exists -- but stands under water. It was flooded in 1906 by the New Croton Dam. Other structures, thankfully, are still visible, such as Sing-Sing Kill Aqueduct Bridge, Mill River Culvert, Jewells Brook Culvert, and Sawmill River Culvert. (The last structure has been modified considerably.) The line of the aqueduct is now under the auspices of the Taconic State Parkway, and in many parts of Westchester it serves as a kind of recreational trail used by bikers and horseback riders.

[11]Card file, Division of Water Supply Control.

APPENDIX I

"Inventory of Articles in
Office at Sing-Sing"

Source: Edmund French,
November, 1836, Jervis Papers

1 theodolite (missing 2
  magnifying glasses)
1 level
1 compass
1 pr. new level rods
1 pr. old level rods
4 shod range rods
2 unshod range rods
1 large drawing board
2 2nd size drawing boards
1 3rd size drawing board
1 large drawing table
1 small office table
1 large office table
1 large stationery case
1 small bookcase
2 T-squares
1 4-ft. rule
2 2-ft. rulers
1 1-ft. ruler
4 drawing horses
2 stools
1 100-ft. chain
1 66-ft. chain, 4 pins
2 chain stretchers
2 hatchets
1 stove, scuttle & poker
6 candlesticks
3 chairs
1 washbowl & pitcher
1 crowbar
1 tin map case
1 set of maps of line to Harlem
1 set of profiles
  profiles of ravines to Harlem
  profiles of tunnels
2 blank account books
1 large blank book
1 book of copies of payrolls

APPENDIX II

"Inventory of Articles belonging to the Commissioners of Water"

Source: Jervis, October 28, Jervis Papers

(Articles "placed under the care of the Chief Engineer.")

31 feet of boring rods with joints
1 auger
1 sounder diamond pt.
3 wrenches
2 keys for working the rods
1 pair of shears for working the rods
1 double, 1 single block and rope for working rods
1 pair leveling staff with targets
6 new marking pins
1 4-pole chain
1 chain of 100 feet
1 pair chain poles
1 pair mahogany leveling staffs
2 tape measures, 60 & 66 feet
1 plumb bob
1 leveling instrument, complete
2 tape lines measuring 66 & 90 feet
1 crowbar
1 spade
1 padlock
1 pickaxe
4 ranging staffs
4 draft boards
1 tin sauce pan & 3 tumblers
5 satinwood rules
2 T-squares
5 rods
1 small case
1 table and lock
2 benches, wall straps & hooks
1 map case
1 wash bowl, pitcher & broom
1 counter brush
1 large table
6 Japaned candlesticks
1 drawing table
1 surveyor's compass & tripod
1 box of colors
1 drawing table 12 feet long
1 drawing table 8 feet long
1 4½-foot drawing board
2 pair wooden horses
6 large portfolios with leather flaps
1 pair leveling staffs

APPENDIX III

Engineering Department Roster
(Sept. 1836 -- March, 1840)

Sources: "Schedule of Pay," Sept. 1836; "General Report," March 12, 1838; "Report of Tour on Line," March 8, 1839; "Report on Organization of Engineer Department," March 20, 1840, Jervis Papers. Also, "Semi-Annual Report," January to June, 1837 and 1838.

<u>Chief Engineer</u>

Douglass, David Bates (1835-1836)
Jervis, John B. (1836-completion)

<u>Principal Assistant Engineer</u>

Allen, Horatio (Born 1802, the son of Benjamin Allen, mathematics professor, Union College. Graduated from Columbia College, 1823. Before Croton project, worked on Chesapeake & Delaware Canal; Delaware & Hudson Canal; and Chief Engineer, South Carolina Railroad. After Croton project, proprietor of Novelty Iron Works, consulting engineer for Brooklyn Bridge, President of American Society of Civil Engineers.)

<u>Resident Engineers</u>

Anthony, Henry T. (Started as Assistant to Traverser on Douglass' 1833 survey.)

French, Edmund (Graduated West Point, 1828. Started as Assistant Engineer under Douglass.)

Hastie, Peter (Had served under Jervis on Chenango Canal.)

Jervis, William (John Jervis' brother; started out as 1st Assistant.)

<u>1st Assistants</u>

Churchill, M. (Started as Leveller under Douglass.)
Crane, B. F.
Davidson, M. O. (Started as rodman under Douglass.)
Henry, John E. (Started as a rodman; had worked for Jervis previously.)
Lansing, A. B. (Perhaps started as Leveller under Douglass.)
Moffit, R. C. (Started as rodman.)

1st Assistants (continued)

Renwick, James, Jr. (Son of renowned professor of science at Columbia College. Started as 2nd Assistant. Later became noted architect, designer of St. Patrick's Cathedral in NYC, of Smithsonian Institution in Washington.)
Righter, C. A. (Started as rodman under Douglass.)
Tower, Fayette B. (Wrote Illustrations of the Croton Aqueduct, 1843.)
Tracy, Edward (Started as 2nd Assistant; worked with Jervis on Chenango Canal.)
Zabriskie, J. J.

2nd Assistants

Anderson, William
Anthony, Edward
Brook, L. (Started as rodman.)
Buchanan, Wm. (Started as rodman under Douglass.)
Campbell, John (Started as rodman.)
Isherwood, B. F. (Started as rodman.)
Routon, Edward
Sickells, T. E. (Started as rodman.)
Wise, George O. (Started as rodman under Douglass.)

Draftsmen

Carmichael, Thomas J. (Started under Douglass; resigned in order to contract for work on aqueduct.)
Pearson, Charles
Schramke, Theoph (Wrote Description of the New-York Croton Aqueduct, 1846.)
Wells, Joseph (Started under Douglass.)

(Inspectors of masonry and men who never rose above the rank of rodman are not listed.)

APPENDIX IV

Estimates of Three Means of Crossing Mill River

Source: Jervis, "Report on Crossing Mill River," June 5, 1837, Jervis Papers.

Bridge with five 60-foot arches

	Cubic Yardage	$/Yard	Amount
arches	875	25	21875
spandrels	2394	7	16758
water table	52	30	1560
masonry above water table	2689	10	26890
pilasters below water table	59	20	1180
piers	1888	15	28320
abutment walls	2424	10	24240
slope wall	624	2	1248
earth embankment	3686	.20	737
foundation wall	1436	2	2872
conduit arches	94	10	940
masonry, side walls	224	6	1344
cornice at spring of arch	42	25	1050
centering			3000
excavation of foundation			500
340 ft. of cast iron lining @ $30/ft.			10200
		TOTAL:	$142,714

Bridge with six 50-foot arches

	Cubic Yardage	$/Yard	Amount
arches	779	22	17138
spandrels	2189	7	15323
water table	52	30	1560
pilasters below water table	52	20	1040
masonry above water table	2688	10	26880
cornice at spring of arch	42	25	1050
2 solid piers	612	15	9180
3 hollow piers	1548	15	23220
abutment walls	2424	10	24240
slope wall	624	2	1248
earth embankment	3686	.20	737
foundation wall	1436	2	2872
conduit arches	94	10	940
masonry, side walls	224	6	1344
centering			2500
excavation of foundation			500
340 ft. of cast iron lining @ $30/ft.			10200
		TOTAL:	$139,972

APPENDIX IV
(Continued)

Embankment with double culvert

	Cubic Yardage	$/Yard	Amount
upper arch of culverts	596	20	11920
reversed arch of culverts ..	307	20	6140
abutments and pier..........	651	12	7812
parapets, wings and pilasters..............	130	12	1560
masonry between arches......	404	6	2424
spandrel backing............	102	6	612
embankment below grade.....	69161	.25	17290
backfilling above grade.....	5406	.25	1351
foundation wall...........	13193	2.50	32982
slope wall.................	3175	2	6350
brick arch, conduit.........	253	10	2530
side walls, conduit.........	590	6	3540
spandrel backing, conduit....	65	6	390
concrete....................	124	6	744
excavation of foundation........................			500
timber foundation of culverts..................			1000
		TOTAL:	$97,145