ROEBLING'S DELAWARE & HUDSON CANAL AQUEDUCTS

ROBERT M. VOGEL

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Robert M. Vogel

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FIGURE 1.—The Delaware Aqueduct, 1970, in the early morning river mists. (Photograph by author.)

COVER: The Delaware Aqueduct, 1969. (Photograph by David Plowden.)

ROEBLING'S DELAWARE & HUDSON CANAL AQUEDUCTS

The nineteenth-century American civil engineer, John A. Roebling, is best remembered for his crowning work, Brooklyn Bridge, built to his design by his son, Washington, following the elder Roebling's death in 1869. Although an engineering monument of the highest order, Brooklyn Bridge must—if historical justice is to be done—share its notoriety with a small, relatively obscure suspension bridge that was Roebling's second work, and is his earlist still standing. Moreover, in all likelihood, the Delaware Aqueduct is the oldest existing American suspension bridge and may well be the oldest existing suspension bridge in the world (that retains its original principal elements). The sole survivor and largest of four suspension aqueducts erected by Roebling between 1847 and 1850 to carry the Delaware & Hudson Canal over rivers, the Delaware Aqueduct stands today only because of its strategic location. Following abandonment of the canal in 1898, the structure was converted to a private highway bridge, which function it continues to serve, spanning the Delaware above Port Jervis.

THE AUTHOR: *Robert M. Vogel is Curator of the Division of Mechanical and Civil Engineering in the Smithsonian Institution's National Museum of History and Technology.*

The Delaware & Hudson Canal

Unlike the Erie and most other American barge canals, the Delaware & Hudson Canal, opened in 1829, was built as an essentially one-way route to transport a single commodity — anthracite coal — rather than general freight in two directions.[1] It was projected by Maurice and William Wurts as a means of exploiting their great coalfields in northeastern Pennsylvania, a canal at that time being the only feasible way of getting the bulk coal to the seaboard. As New York was potentially the most profitable market area, the canal was planned to strike for the Hudson River, down which the coal could be readily transported to the city. Charters were granted to the Wurts' by the Pennsylvania and New York legislatures to improve the navigation of the Lackawaxen River—reaching practically into the Lackawanna coalfields at Honesdale and at its mouth joining the Delaware—and to build a line of water communication between the Delaware and Hudson rivers.

The Delaware & Hudson Canal Company was

[1] The canal company did, of course, avail themselves of the opportunity to carry whatever along-the-line general freight presented itself, and this business, while far less significant than coal haulage, was a worthwhile account. For example, in the year 1846 the goods transported were: coal, 318,000 tons; general merchandise, 28,000 tons; and lumber, 10 million board feet. (*Annual Report of the Board of Managers of the Delaware & Hudson Canal Company for the Year 1846.* New York, 30 March 1847).

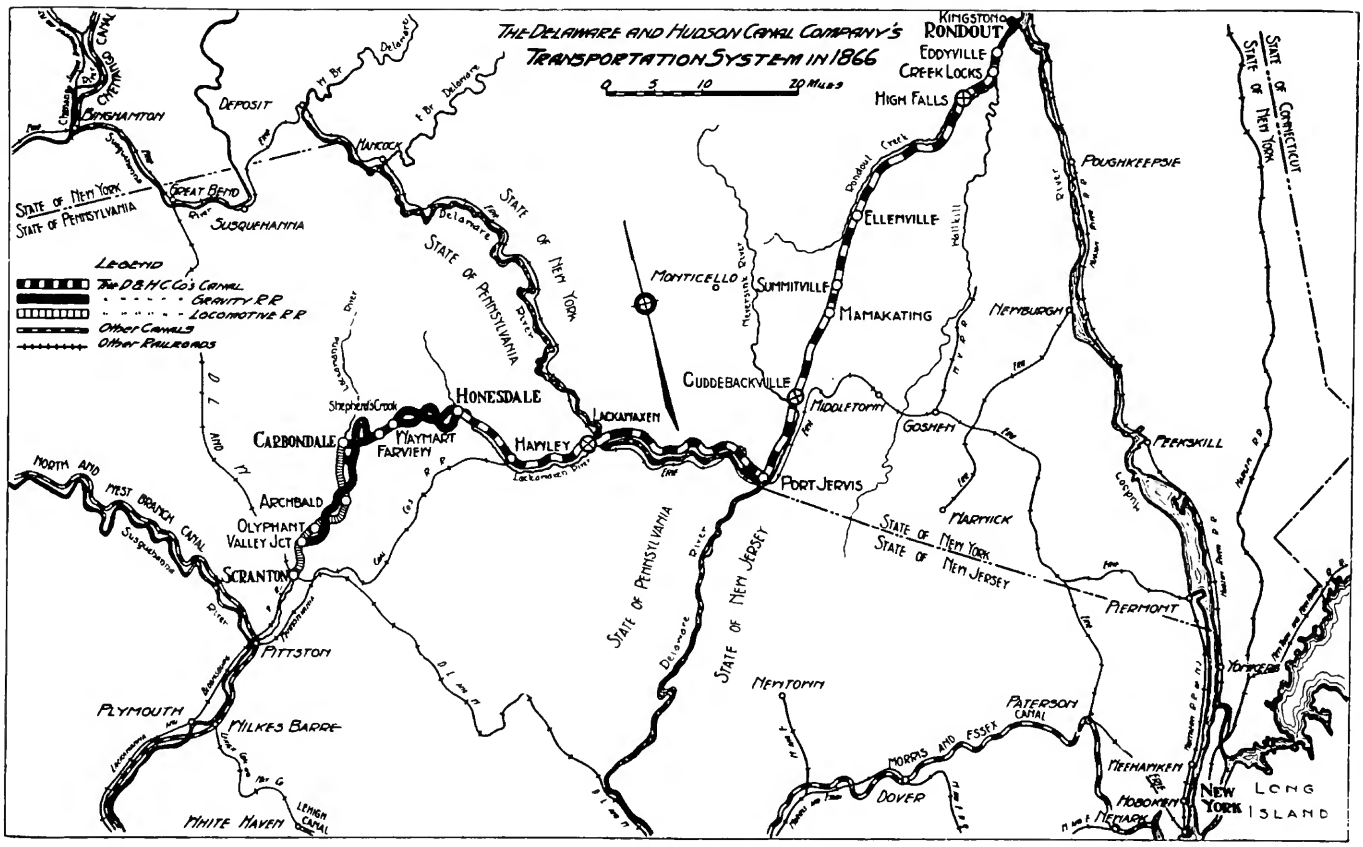


FIGURE 2.—The Delaware & Hudson Canal and Railroad System, 1866. (From *A Century of Progress: History of the Delaware & Hudson Company.*)

formed and in the spring of 1823 contracted with Benjamin Wright to survey and locate a suitable route. At the time, Wright was still serving as chief engineer of the Erie Canal. He was instructed to select a line from tidewater on the Hudson at Rondout (near Kingston), up the valleys of the Rondout, Neversink, Delaware, and Lackawaxen rivers to the coalfields. The total distance was 108 miles with a lockage of 1,086 feet.[2] Construction began in 1825—the year of the Erie's opening—with Wright acting as chief engineer and the later renowned John B. Jervis as his assistant. The entire canal was opened for business in October 1829. Seven thousand tons of anthracite passed its length during the first year. Operations reached their peak in 1872 when 2.9 million tons were moved.[3] From that time, competition from an expanding railway network rendered the canal obsolete with increasing rapidity, tonnage gradually declining until final cessation and abandonment in 1898.[4]

Improvements and Enlargements

When the canal was opened, it was the sole means for transporting coal out of the anthracite region. It

[2] This figure was 1,073 feet until the final improvement in 1875 when lock changes raised it. The difference in elevation between terminals was 343 feet.

[3] Noble Whitford in his *History of the Canal System of the State of New York* states that the peak year was 1868 with almost two million tons, but the higher figure and later year, from *A Century of Progress—History of the Delaware & Hudson Company 1823-1923* are more likely correct.

[4] The history of the Delaware & Hudson Canal has been well documented and related. The best account is Wakefield's extremely detailed, beautifully illustrated, and thoroughly enjoyable *Coal Boats to Tidewater—the Story of the Delaware & Hudson Canal.* See the bibliography for this and other works.

was shallow—four feet in depth—with a waterline width of 28 feet (soon increased to 32 feet) and a bottom width of 20 feet. The first boats held 20 tons of coal. With a supply assured, the use of anthracite for heating, iron smelting, and steam generation expanded rapidly, engendering more business for the mines and canal. As a result of this cycle of prosperity, the canal eventually reached its capacity. Even with the introduction of 30-ton boats, by 1841 the demand for coal had so increased that the canal's limit had been about reached. In that year, 192,000 tons were carried—27 times the first year's tonnage.

The Delaware Aqueduct was built as an integral element in an almost continuous program to increase the canal's capacity, therefore a brief survey of the various improvements will be useful for placing the aqueduct in its setting. The need for periodic enlargements had been assumed almost from the outset, but as in the construction of other pioneer American transportation ventures like the Baltimore & Ohio Railroad, the modest capital initially available and the uncertainty of later needs dictated that the first route incorporate many expediencies and compromises.

With the profits from the first decade's operation, it was possible to undertake a modest enlargement of the canal.[5] In November 1842, at the close of the boating season, work was begun to deepen the trench to five feet by dredging the bottom and building up the bank height with the spoil, permitting passage of 40-ton boats. The happy fiscal effects of the project, completed by 1844, were so pronounced that the canal management in 1845 began another increase—to produce a 5½-foot depth which would pass boats of 50-ton burden and result in an annual canal capacity of one half million tons. The cost of the project was $232,000.

Even this enlargement was recognized as inadequate practically before completion, for not only was the demand for coal increasing geometrically, but the progress of the Erie Railroad into the Delaware Valley and toward the coal regions in the mid 1840s announced the end of the canal's monopoly of anthracite transportation. Consequently, the company was compelled to operate as economically as possible in order that its rates might be competitive with the railway's, if not actually lower. The only available means of reducing coal transportation costs between Honesdale and the Rondout depot were by increasing the capacity of the boats and reducing transit time.

With the threat of competition from the Erie hastening them into already inevitable action, the Delaware & Hudson directors in 1846 authorized the most ambitious enlargement project in the canal's history. The plan was to increase both capacity and speed, the former by both further deepening—to 6 feet—and widening, so that boats of 98 tons could be accommodated. The annual capacity would be thus drastically raised to one million tons, about five times the canal's 1842 capacity, an indication of the growing importance of both anthracite and the canal in the coal industry. The estimated cost was $1.1 million. The principal consequence of the widening was the necessity for rebuilding all locks and aqueducts, the former being enlarged from the original size of 9½ feet by 75 feet to 15 by 90 feet. The lock-gate design was also changed to permit faster locking through.

The most significant improvement to the canal's operation, however, was to be a material reduction in the passage time by removal of the worst bottleneck in the system—the slack-water crossing of the Delaware between Lackawaxen, Pennsylvania, and Minisink Ford, New York, just above the mouth of the Lackawaxen. As capital originally had been inadequate to build an aqueduct for the purpose, a still pool had been formed by damming the Delaware, into which the boats were locked down on each bank. They then crossed the river either by momentum or hand haulage along a ferry rope strung between the banks, the mules being carried over separately on a small rope ferry. Under ideal conditions the crossing was slow and a serious operational snag; at worst, during high water in spring and fall, the passage was impossible and canal operations came to a halt for days at a time. A further hazard was conflict with the considerable traffic of timber rafts on the river. The raftsmen, forced to traverse the low canal dam either by shooting it on the flowage over the crest or passing through a sluiceway, in general were understandably hostile to the canal interests and constantly engaged

[*Text continues on page 6*]

[5] According to *A Century of Progress* the improvements were financed also by increased capitalization. Up to 1845 the share capital was $1.9 million. At the end of 1847—to finance the major enlargement then under way—it had been increased to $3.9 million, and by the end of 1850 to $6.6 million. The net profit for the year 1850 was about 12 percent on invested capital.

Development of the Suspension Aqueduct Design—Pittsburgh

The design employed by Roebling for all four Delaware & Hudson Canal aqueducts sprang forth fully developed in his first suspension structure, a 7-span aqueduct erected in 1844-1845 to carry the Pennsylvania State Canal over the Allegheny River at Pittsburgh. The executed plan, however, evolved only after passing through a number of design stages.

(Drawings courtesy Rensselaer Polytechnic Institute.)

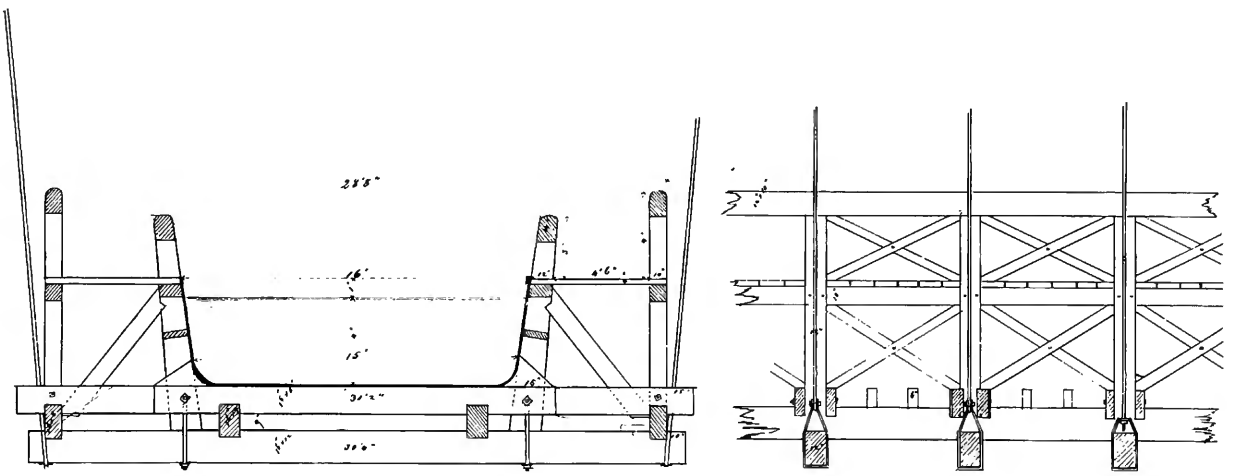


Figure 3.—As a means of achieving watertightness, Roebling in all early schemes proposed to form the aqueduct trunk of wrought-iron plate, a rational choice in a city already a major iron center. By supporting the suspended structure at its extreme width, the floor beams acted as simply supported beams of considerable length—about 29 feet—with the great load of water bearing at their centers. The beams had thus to be of inordinate depth. Roebling obtained this by building up a 40-inch beam from a 16- and two 15-inch sticks, blocked apart by the longitudinal stringers.

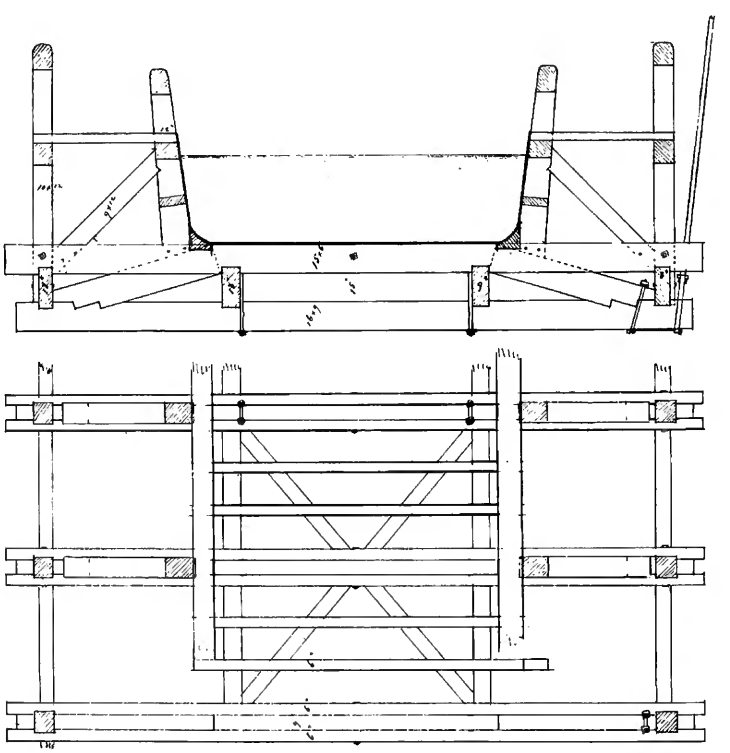


Figure 4.—Here the floor beams have been further stiffened by deepening to 46 inches and the addition of diagonal struts to transfer the trunk load more directly to the suspension points.

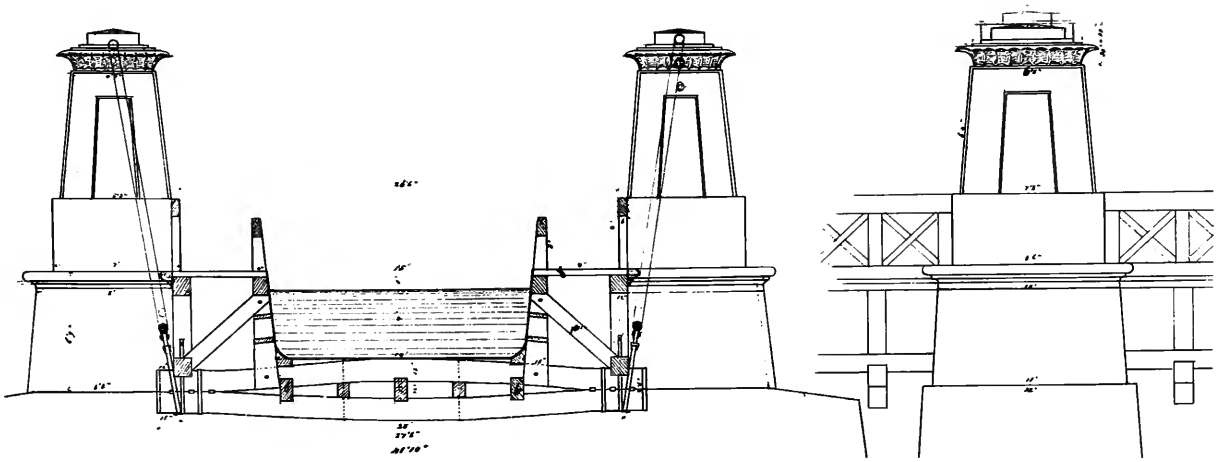


FIGURE 5.—In this design the floor-beam members were sprung into a simpler double-bowstring form of 36-inch depth. While somewhat less stiff than the previous plans, the longitudinal spacing of the frames was almost halved, from 7 feet to 3 feet 10 inches, producing greater overall strength. Roebling's predilection for the Egyptian Revival, ultimately manifested so strikingly in the magnificent stone towers of his Niagara Bridge (Figure 25), was first seen in several of the Pittsburgh preliminary designs. He estimated weights and costs for rendering in both marble and cast iron what he termed the "pyramids."

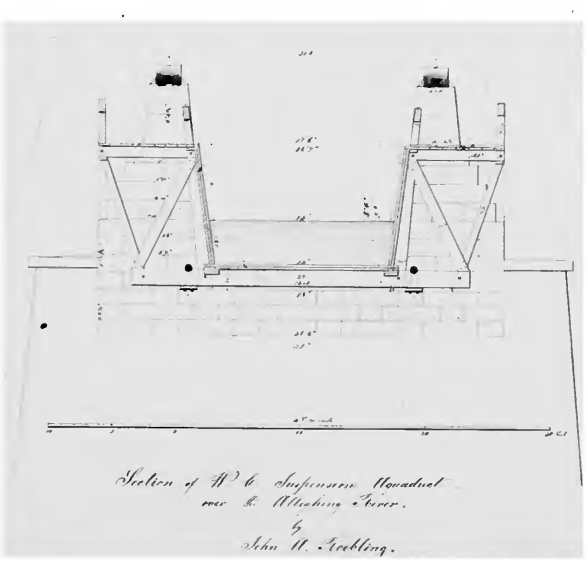


FIGURE 6.—The design finally developed and accepted as " part of the agreement of 28 August 1844 ." bore but tenuous resemblance to its predecessors. The principal change and improvement was moving the trunk system's points of suspension in from the outer ends of the floor beams to points just outside the trunk sides, effectively reducing the bearing length of the beams from 28 feet to 18, and increasing their load-supporting capacity about two and a half times. Moreover, they then acted as continuous beams. The weight of the towpaths and bracing, and the pressure of the water against the trunk sides acting through the inside diagonal struts, all bore downward on the cantilevered outer ends of the floor beams, materially counteracting the stress imposed by the water load at the center and further lowering the total stress in the beams. These transverse beams were finally reduced to pairs of 6 x 16s, spaced every four feet. The iron-plate trunk and the architecturally elaborated pyramids of iron or marble were casualties, presumably victims of harsh fiscal policy; but the double-diagonal wood-plank trunk sides and floor that replaced the iron added enormously to the vertical and lateral stiffness of the spans, and if cheaper, were certainly also better.

All elements of the Pittsburgh Aqueduct were proportioned and disposed to perform economically as well as effectively, resulting in a design of high efficiency. In the Delaware & Hudson spans three years later, Roebling found it unnecessary to make any appreciable modification of the plan. The Pittsburgh Aqueduct served well until abandonment of the canal in 1860, following which it was removed.

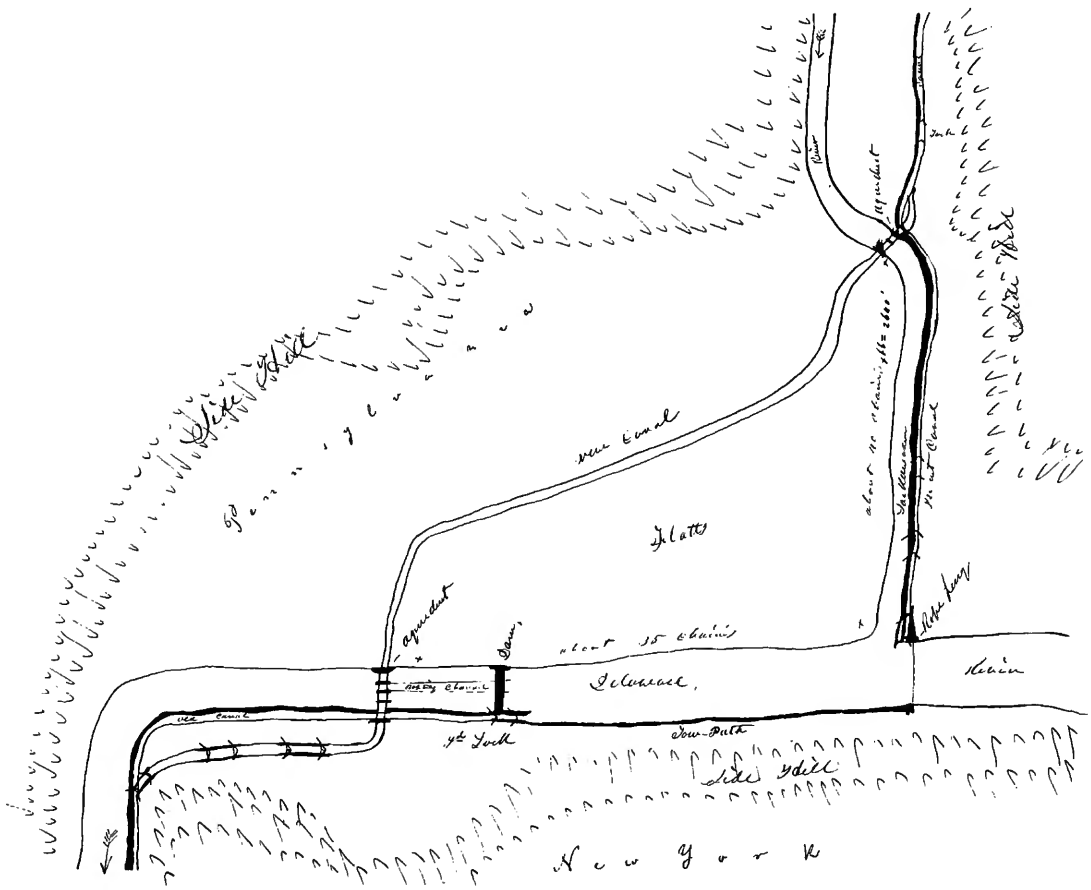


FIGURE 7.—R. F. Lord's plan for re-routing the canal at Lackawaxen in conjunction with an aqueduct crossing of the Delaware. Rough sketch sent to John A. Roebling 27 February 1847. (Courtesy of Rensselaer Polytechnic Institute.)

[*Text continued from page 3*]
the company in physical and legal harassment. An aqueduct had, in fact, been projected from the canal's beginning. The need now being pressing and the capital available, it was included in the enlargement plan.

Construction of the Delaware Aqueduct

R. F. Lord, chief engineer of the canal, in planning the enlargement relocated the canal route at Lackawaxen, establishing the aqueduct over the Delaware not above the mouth of the Lackawaxen River at the rope ferry site, but just below. This necessitated, in addition, construction of a second new aqueduct—over the Lackawaxen (Figures 7 and 8). Every Delaware & Hudson Canal scholar and author has speculated on Lord's reasons for planning the new route in that seemingly extravagant way, without having drawn any very convincing conclusions. There were obvious disadvantages to the scheme, notably the added cost of the second aqueduct and the fact that the piers of the Delaware Aqueduct would be subject to the collective flow and battering of ice from both rivers. Two reasons are most commonly assumed for the re-routing: political considerations; and riverbed and riverbank conditions unfavorable to the upstream location. The first, in the case of a private company under the scrutiny of its stockholders, seems unlikely, and there is nothing in the topography of the site lending much support to the second. More reasonable is a recent be-

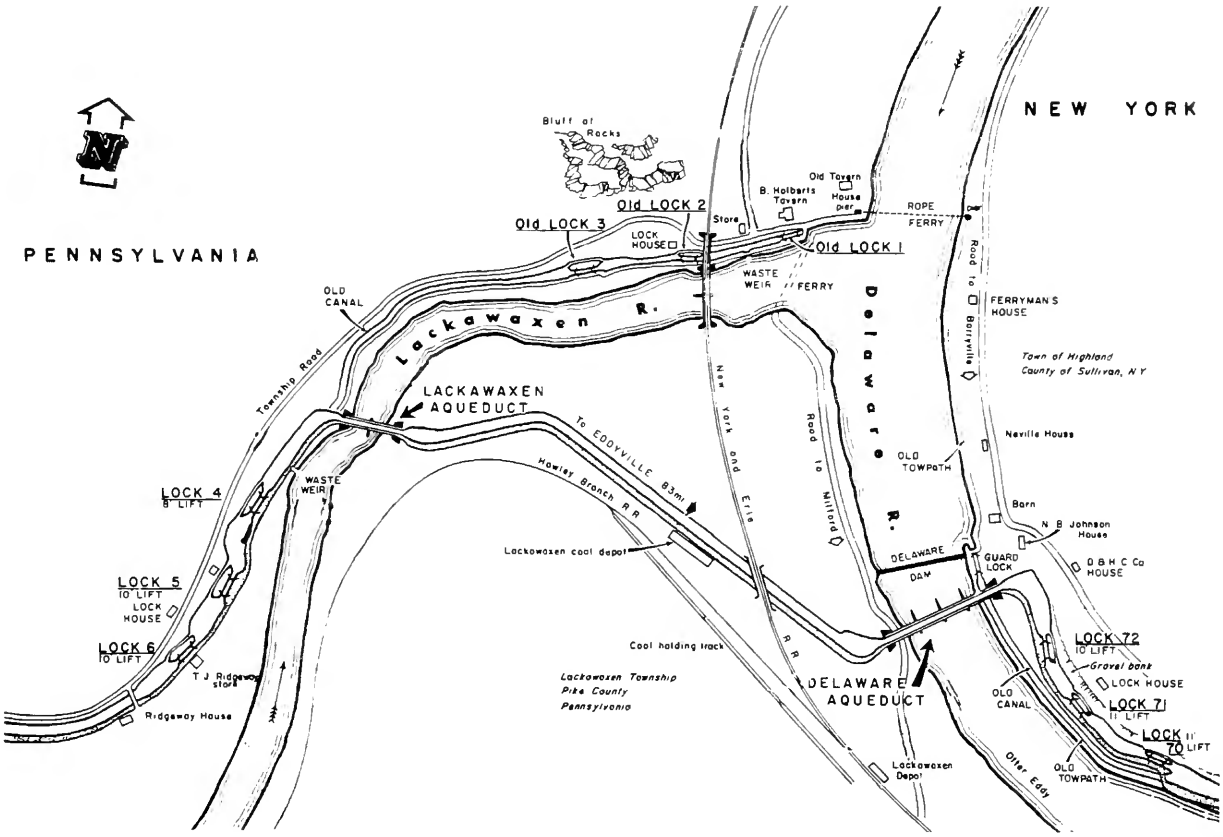
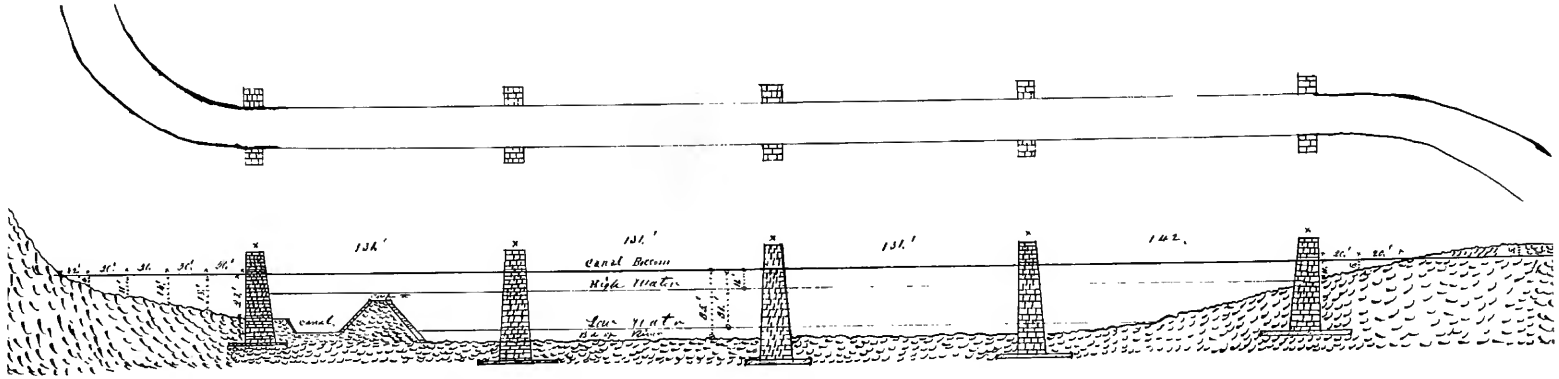


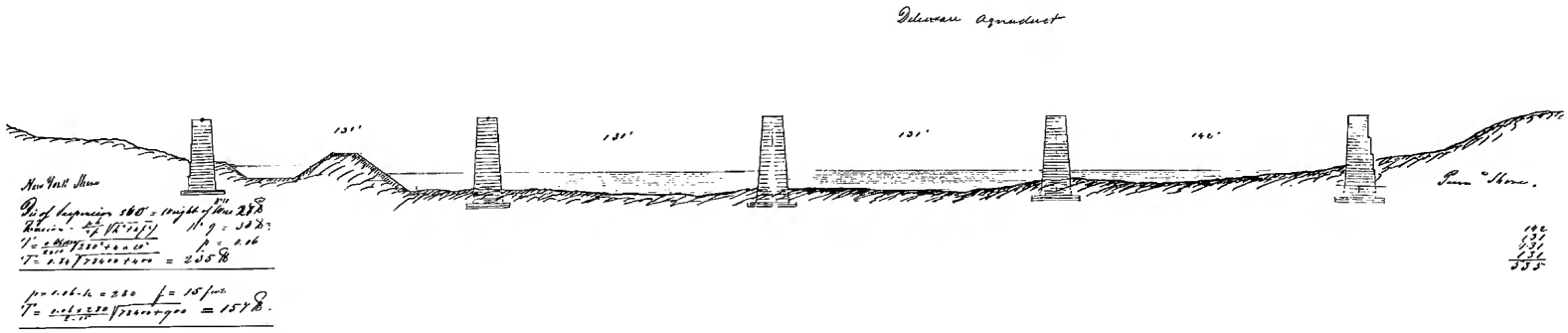
FIGURE 8.—The canal at Lackawaxen, about 1860, showing both the old canal and the new route across the "flats" between the new aqueducts. (Courtesy of Manville B. Wakefield, from *Coal Boats to Tidewater.*)

lief of Manville B. Wakefield, author of the definitive Delaware & Hudson Canal history, that if the aqueduct *had* been built at the ferry, practically opposite the Lackawaxen's mouth, the piers would have been in constant jeopardy from the great ice floes that annually came down the Lackawaxen, grinding across the Delaware to the eastern shore with great force. Damage from these floes necessitated practically yearly repairs to the lock and bank of the canal which had been there before the aqueducts.

Another likelihood, however, is suggested by the site conditions. Had the ferry location been selected, the aqueduct would have been right in the slack-water pool, with several consequences. First, there would have been less vertical clearance under the aqueduct for the rafts, probably an insufficient amount at spring high water when much of the rafting was done. Worse, the cofferdams used in building the aqueduct piers would have to have been considerably higher and heavier, and the entire problem of pier construction would have been a good deal more difficult in the deeper water of the dammed pool, quite possibly to a degree more than offsetting the added cost of the Lackawaxen Aqueduct. There is also the probability that in the twenty years the Delaware had been stilled above the dam, quantities of silt had been deposited in the pool so that there would have been that much more material to excavate before reaching a solid footing. Finally, the river, in addition to being deeper, was, on the evidence of contemporary photographs,



FIGURES 9 and 10.—Cross-sections of the ground and masonry at the Delaware Aqueduct site. R. F. Lord's rough sketch to Roebling of 27 February 1847 (above) and Roebling's refined drawing (below). (Courtesy of Rensselaer Polytechnic Institute.)



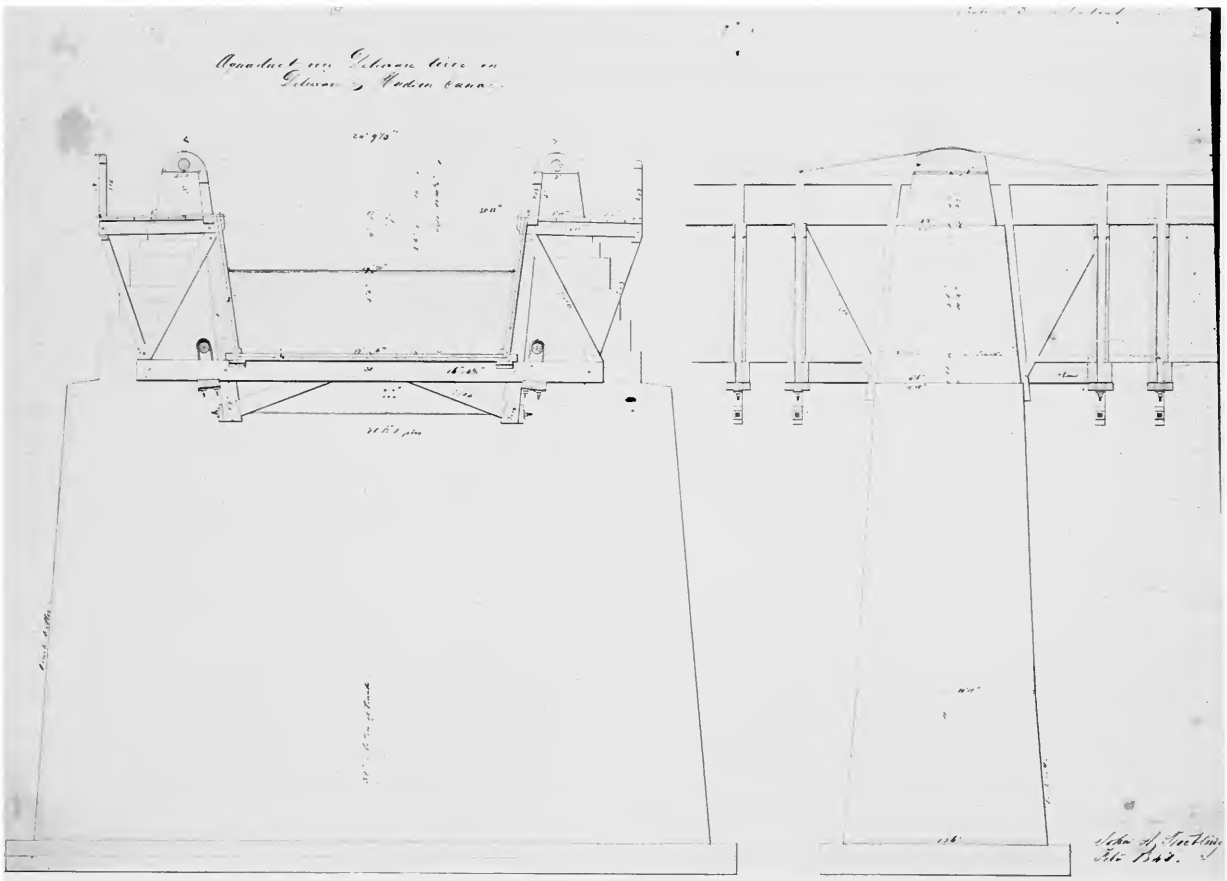


FIGURE 11.—The Delaware Aqueduct superstructure, February 1847. By the time of actual construction, Roebling had abandoned the plan to truss the floor beams as shown and had adopted saddle covers rectangular in cross section. Otherwise, the drawing reflects the aqueduct as built, and follows almost exactly the Allegheny Aqueduct design. (Courtesy of Rensselaer Polytechnic Institute.)

apparently somewhat wider above the dam, which would have necessitated a longer structure.

In February 1846, the canal directors authorized the two aqueducts at Lackawaxen, and by late December that year two proposals had been received. One was for a conventional, trussed, timber structure on masonry piers, in six spans. The other, submitted by John A. Roebling, a civil engineer, of Saxonburg, Pennsylvania, was for a wire-cable suspension aqueduct of four spans. The management inclined toward the latter scheme as it not only was cheaper, but more important, the longer spans meant two fewer river piers, and reduced impedance to floodwater and ice, as well as greater horizontal clearance for the river traffic. Another major advantage, not generally recognized by Delaware & Hudson historians, was that suspension spans, unlike either truss or masonry-arch spans, could be erected without falsework in the river, a matter of some significance at a site so subject to flooding and ice jams.[6]

[6] The cables were spun in place without support. When they were complete and the suspenders attached, the timber cross frames of the trunk were hoisted into position from barges anchored below, following which the rest of the suspended structure was easily laid down. The freedom from falsework continues to be one of the suspension bridge's great advantages. See Figure 36.

Roebling's plan was tentatively accepted on 6 January 1847. On the 29th[7] Lord arrived in Pittsburgh for a four-day visit to inspect a similar aqueduct built by Roebling in 1844–1845 to carry the Pennsylvania Canal over the Allegheny.

The Allegheny Aqueduct was the first bridge of any kind built by Roebling, who previously had done general civil engineering—mostly railroad surveys—and manufactured wire ropes for haulage on the inclined planes of the Pennsylvania state and other canal systems. The aqueduct replaced, and was erected on the piers of a seven-span timber structure[8] that had been damaged by ice. In order to have his design accepted, Roebling was obliged to take the construction contract as well, at his initial cost estimate. Completed in May 1845, the aqueduct was a resounding success, stilling considerable criticism. It served until abandonment of the canal in 1861.[9]

Lord was impressed with both the Allegheny Aqueduct and Roebling's Smithfield Street (Pittsburgh) suspension bridge built in 1845–1846 over the Monongahela. At Pittsburgh, Roebling introduced a practical method of constructing the cables by spinning in place the individual wrought-iron wires of which they were composed, compacting them finally into a cylindrical, virtually solid cable, in which each wire carried its full proportional load. The two continuous cables supporting the wooden canal trunk and towpaths were seven inches in diameter, each 1,175 feet long from anchorage to anchorage. The total weight of water in the aqueduct was 2,100 tons.[10]

[7] Lord's visit has been erroneously placed in December 1847 by all authors. This would hardly have been possible, firstly, because of the company's inducement to press the project forward with full steam, and secondly, because the date stone of the aqueduct reads 1847. It is unlikely either that the masonry would have been started before the formal acceptance of the Roebling design or that it could have been laid up in the river ice in the few weeks that would have remained in 1847 following a visit in December. Roebling's 1847 diary notes Lord's visit as 29 January—2 February, and Lord himself in a 15 March 1847 letter to Roebling refers to his return from Pittsburgh.

[8] The spans varied from 159′-6½″ to 162′-7″, the average length being 160′-8½″ (Roebling's measurements, ink drawing, Rensselaer Polytechnic Institute's Roebling Collection).

[9] Joseph White and M. W. von Bernewitz, *The Bridges of Pittsburgh;* A. A. Jakkula, *A History of Suspension Bridges in Bibliographical Form.*

[10] Ibid.

After his inspection trip, Lord concluded that Roebling's abilities were far ahead of their time. The contract for both final design and construction of the Delaware and Lackawaxen aqueducts was given to Roebling, for a combined price of $60,400, and work began almost immediately.

The contract price for the Delaware Aqueduct was $41,750, the Lackawaxen, $18,650. Roebling claimed a clear profit of $8,600. While about 14 percent of his actual cost, it is hardly excessive when we realize that his contracting profit included his engineering fee as well. Possibly because of their remote location, these structures cost considerably more, relatively, than the Pittsburgh aqueduct: $82 and $78 per foot versus $48.[11] Also, the greater the number of spans, the less the cost per-foot-of-length, for regardless of the number, four anchorages were required, the cost of which was a considerable item in the total.[12] Of Roebling's $24,900 price for the Neversink Aqueduct, $21,277 was shown as representing the actual cost with an unidentified sum of $3,623 added to make the total. He notes, however: "Reiner Gewinn [net profit] circa 5000," or about 25 percent. The figure for the High Falls span was nearly 29 percent.[13]

Aside from Lord's report and the natural advantages of a suspension aqueduct, a further factor no doubt influencing the Delaware & Hudson's selection of Roebling to build the aqueducts was their confidence in him resulting from the long and satisfactory use of Roebling wire ropes on the inclined planes of the company's gravity railroad at the west end of the canal.

Roebling's construction contract covered only the superstructure or suspended spans, "including all iron, timber and wire work, the company to do all masonry and cement."[14] His presentation and estimating drawings were apparently based on only general site information, for, shortly after his return from Pittsburgh, Lord sent Roebling detailed data on the bank and riverbed conditions for preparing the working drawings (Figures 8 and 9). With these in hand, Lord's crews in March 1847, despite the dual handicaps of weather and probably river ice, commenced the foundation

[11] Roebling, *Notes* (326), page 76.

[12] See also Appendix II.

[13] *Never Sink Aquaduct High Falls Aquaduct Oct. 1848 John A. Roebling.*

[14] Roebling, *1847 Diary,* 29 January.

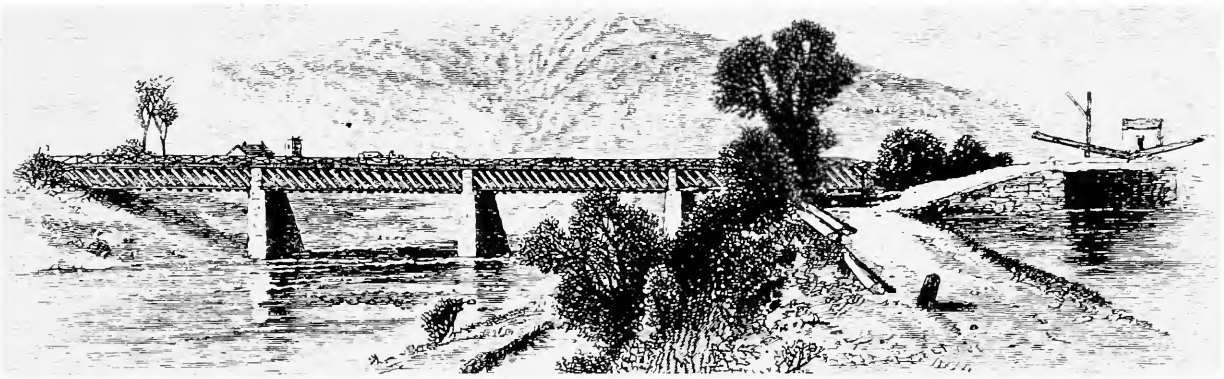


FIGURE 12.—At a time when public works wrought less havoc to the landscape than today, engineering structures could frequently be appreciated for their visual as well as their technical contribution, even in an area as scenically hallowed as the upper Delaware Valley. A contemporary view of the Delaware Aqueduct from William Cullen Bryant's *Picturesque America,* volume 2.

work and the laying of the pier and abutment masonry. Although the canal company was primarily responsible for that portion of the work, continual and careful coordination with Roebling—who spent most of this period at home—was necessary concerning the setting of the great iron anchor plates in the abutments. These huge castings resisted the pull of the chains of eyebar links that rose up through the masonry mass ultimately to restrain the main cables.

Roebling presumably visited the site periodically, but much of the consultation was conducted through correspondence. In late March, Lord advised him that "We are proposing to get the abutments for Delaware Aqueduct in a state of forwardness so that the anchors may be put down soon after 1st of July; and have the piers all done so that you can have a chance to commence the superstructure in the fall and pursue it during the winter." The substructure work on the Lackawaxen span lagged somewhat behind and Lord anticipated that the last of the four anchor plates there could not be placed until well into the winter, ". . . probably by building a roof over it [the abutment foundation] so that we can use a fire, hot water &c."[15] That excavation and masonry work could be carried on during that period, at that season, in that notoriously cruel climate, was something of a small miracle, and a sure reflection of the company's anxiety to capitalize on the improvement.

Roebling took up his work at Lackawaxen probably in the summer or fall of 1847, working on both aqueducts simultaneously throughout 1848. They were completed by about year's end in time for the opening of the 1849 canal season on 26 April. The aqueducts were, needless to say, an unqualified success structurally and operationally. The Lackawaxen Aqueduct, about half a mile west of the Delaware, was almost identical but had only two spans, each of slightly less than 115 feet, with a single river pier.

The aqueducts were designed, like the locks, to pass only a single boat, but nevertheless had a path on each side. Closely following the design used by Roebling at Pittsburgh, these aqueducts had a heavy wood trunk or flume holding between 6 and 6½ feet of water, 19 feet wide at the waterline. The trunk sides were built up of two thicknesses of 2½-inch, untreated, white-pine plank, laid tight on opposite diagonals and caulked up to the waterline, in effect forming a rigid, solid-lattice truss, but without functional top and bottom chords (Figure 11). The stiffness of these great trusses was such that they were capable of sustaining their own deadweight, leaving the cables to carry only the water load. The floor was also of double plank, carried by transverse double floor beams,

[15] R. F. Lord to John A. Roebling, 22 March 1847, in the Rensselaer Polytechnic Institute's Roebling Collection.

[*Text continues on page 15*]

FIGURE 13

THE DELAWARE AQUEDUCT SUSPENDER SYSTEM

All ironwork in the present suspender system is original. Unlike the plan adopted by Roebling for the Niagara and later bridges where wire-rope suspenders were hung from clamps bolted tightly around the unwrapped main cables, on the Delaware & Hudson aqueducts he first wrapped the cables for their entire length between the tower saddles and hung the doubled rod suspenders from small cast-iron saddles that simply sat on the cables. The scheme had the advantage of avoiding the many joints where the wrapping was interrupted at the suspender clamps, a problem in the later system (and today).

It was necessary, however, to prevent the saddles near the towers, where the cable slope was greatest, from sliding downhill by a series of restraining links engaging the saddles in a series. Adhesion was adequate to hold the saddles in place near the center of the cable span.

The long iron bushings between the suspender nuts and the bearing castings are recent, placed to compensate for the reduced thickness of the present deck system. (Drawings, courtesy of Rensselaer Polytechnic Institute; photographs, June 1969, by the author, for the Historic American Engineering Record and the Smithsonian Institution.)

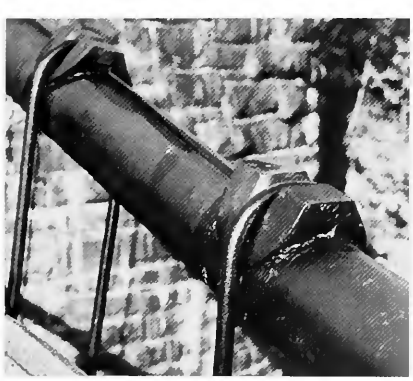


FIGURE 14

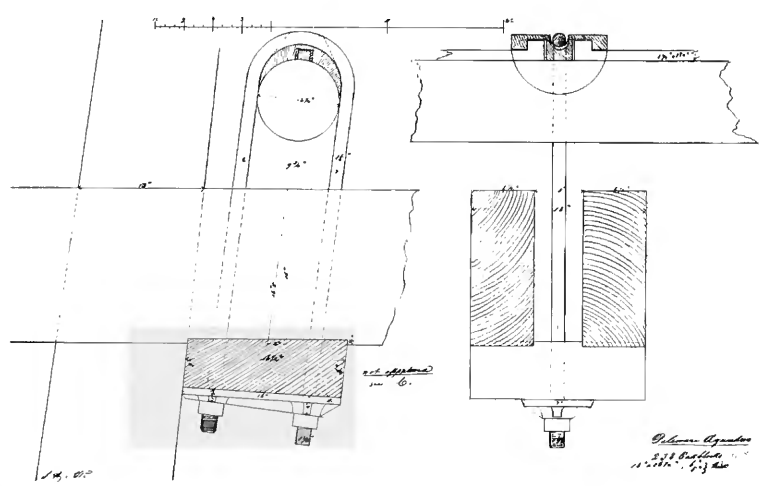


FIGURE 15.

FIGURES 15 and 17.—Roebling's pattern drawings for the restrained and unrestrained suspender saddles.

FIGURE 16

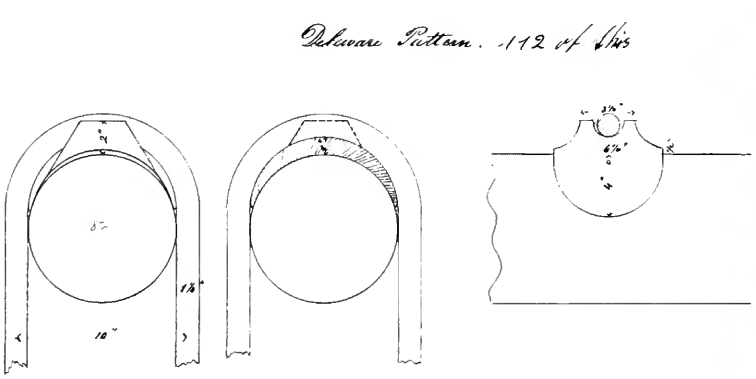


FIGURE 17

FIGURE 18

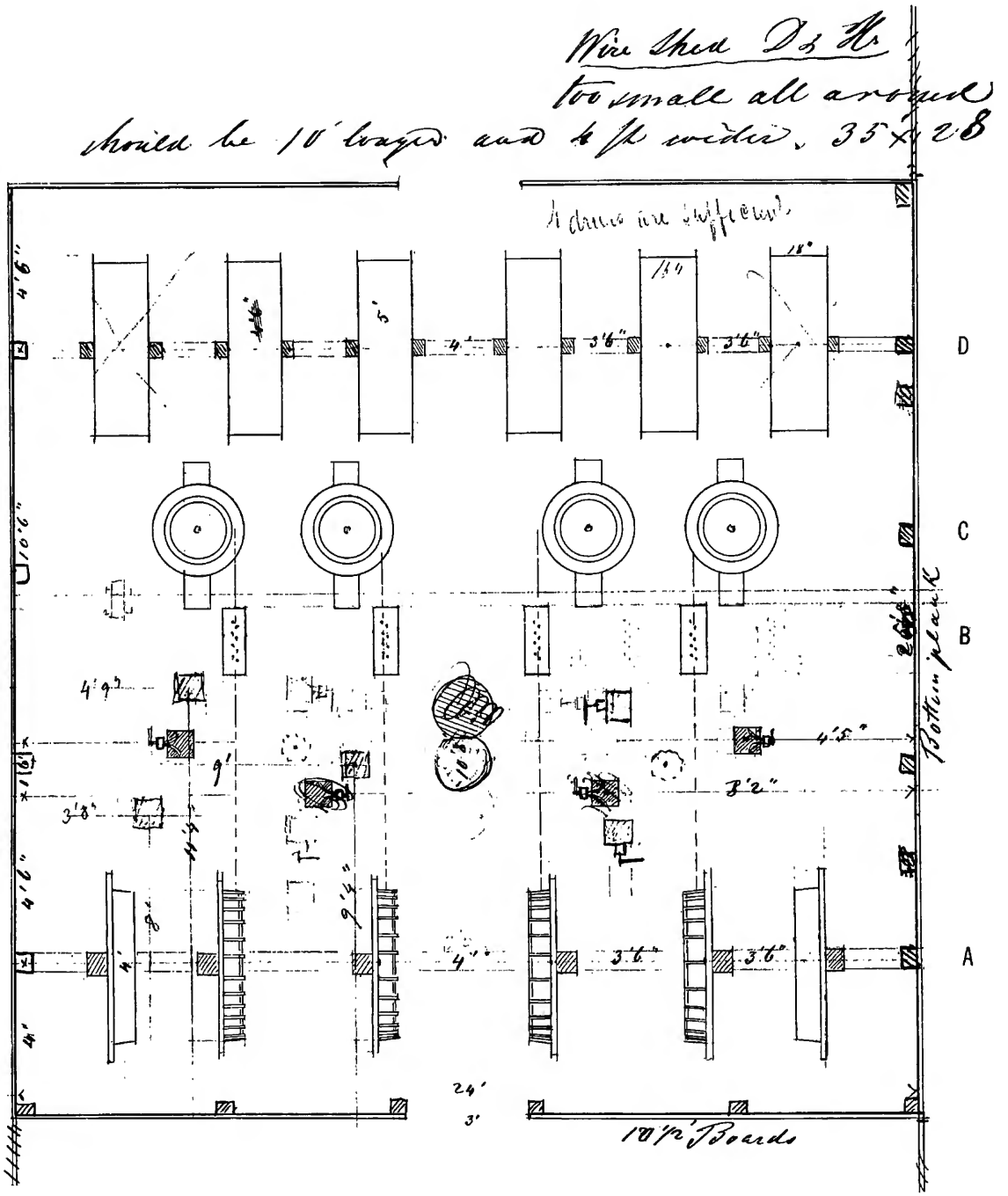


FIGURE 19.—Roebling's sketch plan for the wire shed at Lackawaxen. The coils of cable wire as received were placed on the front reels (A). The wire was drawn through the pins in the straightening blocks (B) by being wound upon the drawing drums (C), and finally reeled on the back drums (D). These were taken to the bridge site for spinning. Here, the wire was also given an initial coating of protective oil. (Courtesy of Rensselaer Polytechnic Institute.)

[*Text continued from page 11*]
in turn hung from the suspenders as in a conventional suspension bridge. The 8-foot towpaths were bracketed out from the sides, level with the trunk top.

All was supported by the continuous main cables, one on each side of the trunk, at the bottom of their dip slightly above floor level. The cables rise to be carried at each pier and the abutments over cast-iron saddles mounted on squat stone towers that stand about four feet above the trunk top. The suspenders are plain 1¼-inch-round, wrought-iron rods, doubled over the cables into stirrup form, the bottom ends threaded for the floor-beam nuts.[16] They bear upon the cables on small cast-iron saddles; those nearest the towers, where the cable slope is greatest, are prevented from sliding downhill by wrought-iron restraining links or stays (Figures 13–18).

In his account of the Delaware Aqueduct, David Steinman states that on this project Roebling for the first time used wire-rope suspenders or hangers (between cables and floor beams), an error which has been repeated by others. Although Roebling was indeed a manufacturer and avid proponent of wire rope, he did not employ it here. Its main uses, then as now, were in either running applications (elevators, hoists) or as standing (stationary) rope, where it enjoys the advantages over simple iron or steel rod of being more manageable in transport and erection, and considerably stronger. In the aqueduct(s), however, the hanger lengths being relatively short—a maximum of about 14 feet (when doubled)—handling would have been no problem, and the hanger spacing, dictated by the floor-beam spacing, was sufficiently close that the hanger loads were readily borne by simple wrought-iron rods at each point. Round bar stock was by then widely produced, and would have been far cheaper than wire rope. Wire rope is used for bridge suspenders today (and was by Roebling in later spans) when they are of great length and under stress greater than can be carried by simple rods of reasonable diameter. Neither condition being present in the aqueduct structures, there is no reason to suppose that Roebling would have incurred the added expense of wire rope. Furthermore, the nuts at the hanger bottoms are square and relatively thin, an early pattern suggesting that they are original, and all original aqueduct drawings show doubled rods over small saddles exactly as present today (Figures 13–18). Washington A. Roebling in his Rensselaer Polytechnic Institute thesis, "Design for a Suspension Aqueduct," (Figure 56) specified wire-rope suspenders, which may have been the source of Steinman's confusion. Even more likely, however, is a small drawing found recently in the Rensselaer Polytechnic Institute Roebling Collection. Although at one time in a folder on the Delaware Aqueduct, it is undated and unmarked as to project. It shows a wire-rope-suspender end socket. Notes refer to "upper" and "lower" suspenders, and the attachment of the suspenders to the main cables with "clamps," conditions not found at Lackawaxen, but definitely so at Roebling's Niagara railroad bridge of 1851–1855, where the upper and the lower decks hung from separate sets of suspenders that *were* of wire rope. The drawing apparently found its way into the wrong folder at some past time.

Roebling had also developed at Pittsburgh the method used to fabricate the cables and anchor them at their ends. It was used in every bridge he built (except the Smithfield Street), and has been used for major suspension bridges by most of his successors to the present day. [17] The 2,150 iron wires forming each of the Delaware Aqueduct's 8½-inch cables were individually spun in place. Each cable is composed of seven strands.[18] In his *Notes,* Robeling specified varying numbers of wires in the strands:

First strand	270 wires
Second strand	270 wires
Third or center strand	320 wires
Fourth strand	320 wires
Fifth strand	320 wires
Sixth strand	325 wires
Seventh strand	325 wires
Total	2,150 wires

The compacted diameter of the cables without outer wrapping was 8.36 inches, "intended to be 8½ inches." The weight per foot, without wrapping was

[16] David B. Steinman, *The Builders of the Bridge—The Story of John Roebling and His Son,* pages 101-105.

[17] Roebling patented the system after its successful application on the Pittsburgh Aqueduct (United States Patent 4945, 26 January 1847), *Apparatus for Passing Suspension Wires for Bridges Across Rivers, &c.*

[18] Roebling, *Notes* (326).

122.74 pounds, and the total length of each cable, 576 feet. Each strand was formed by carrying the wires across from anchorage to anchorage, over the saddles, in a bight of two wires at a time carried by a traveling sheave, so that at each anchorage a loop was formed which passed over a cast-iron strand shoe, pinned to the anchor bars, anchoring the strand. The strands are thus actually skeins formed of a single, continuous wire, spliced at the ends.[19] Between the towers the seven strands were compacted into cylindrical form, virtually solid, then varnished and served with a continuous wrapping of iron wire for protection from the weather. Where they splay out between the abutment towers and the anchor bars, however, the strand loops are exposed to view, clearly showing their formation as they join the strand shoes (Figures 20–23). Although photographs of the aqueducts in use show wood guards over these sections, the loops would still have been subject to a certain amount of condensation and other moisture. The exposure to the weather of so much area of such small-diameter strands, without wrapping, is in odd discord with Roebling's consistent advocacy of solid, single cables, with the interior wires protected overall by the envelopment of a close wrapping. It was, in fact, on this very point that he inveighed most critically against Charles Ellet, a contemporary and sometimes rival suspension-bridge builder, and other members of his school. Ellet favored, rather, cables composed of many small, separate wire bundles, because, he claimed, with a solid, wrapped cable it was impossible to so spin the individual wires that each carried its proportional share of the total load. Unwilling to encase any wires in masonry because of the difficulty in achieving the positive airtight seal needed to prevent corrosion, and aware that the stress on these back-span sections was less than on those carrying the suspenders, Roebling seems to have been satisfied to depend for weather protection upon the varnish and oil coating of the individual wires and on a heavy coating of the completed loops.

Tests made on samples of the cable wire removed from the High Falls Aqueduct, when it was finally dismantled in 1921, were reported by H. C. Boynton, a metallurgist at John A. Roebling's Sons Company.[20] The ultimate tensile strength was 94,166 pounds per square inch, well above Robeling's design requirement of 90,000. The condition of the wire at the time was described as slightly pitted but generally good, despite long exposure. Almost fifty years of additional exposure, without any protection, has taken its toll, for specimens recently gathered—surviving no doubt because of the site's remoteness—are badly pitted and unable to stand the bending test specified by Roebling for acceptability of wire.

Another of Roebling's principal reasons for favoring the solid wire cable was that it added considerably to the overall stiffness of the suspended structure in its resistance to the dangerous oscillations caused by gusting winds under certain conditions. Here again, this effect would have been of no consequence in the aqueducts' short, unloaded back spans between the end towers and anchorages, where there were no suspenders.

The anchor bars were carried down through the anchorage masonry, terminating in six-foot-square cast-iron anchor plates upon which the masonry bears, its dead weight resisting the pull of the cables. Roebling calculated the ultimate strength of the pair of cables at 3,870 tons and the stress on them (and thus on the anchors) from the loaded trunk at 770 tons.

While Roebling would not embed cable wires in masonry, he made a practice of doing so with his anchor bars, from the Pittsburgh Aqueduct on. By pouring a thin cement grout around the bars he felt confident of completely excluding air and moisture, assuring total freedom from corrosion. When the Pittsburgh Aqueduct was taken down in 1861, seventeen years after its abutments had been laid up, Roebling made a careful examination of all the iron in the structure. "The cement was solid to the iron, no trace of Rust."[21]

[19] At that early stage in its history, Roebling's wire-rope firm was not yet drawing its own wire (in fact, was not for another year to move to Trenton, its eventual seat, where it ultimately grew into a major industrial enterprise). The wire for the bridge cables, as for general wire-rope production, was purchased from the few United States drawers and from importers of European wire. Roebling drew on at least three firms for the great quantities needed in the two aqueducts at Lackawaxen, the bulk of the wire being received in the first nine months of 1848 while the cable spinning was in progress.

[20] H. C. Boynton, "Bridge Wire Tested After 75 Years," *The Iron Age,* volume 121 (9 February 1928), page 400.

[21] *Notes on Suspension Bridges 1860* (271).

The difference in the four span lengths of the aqueduct has been a matter of occasional speculation. The span lengths, from the Pennsylvania to the New York sides, are:

By the original design	*Shown by Roebling as built, in "Notes" (326)*	*As measured, August 1969*
142′–0″	141′–9″	141′–5″
131′–0″	131′–0″	131′–4″
131′–0″	131′–0″	130′–10″
131′–0″	131′–5″	131′–6″
535′–0″	535′–2″	535′–1″

The three spans closest to the New York shore are all so close to 131 feet that the present differences are obviously the result only of construction discrepancies and the shiftings of age and long service. The original design did indeed call for equal lengths of 131′–0″. But what of the odd 142-foot length of the first Pennsylvania span? That, too, is specified as early as 27 February 1847 in Lord's rough sketch (Figure 9), which is the earliest mention found on the subject of the aqueduct's relationship to the site. The correspondence between them does not make it clear whether Roebling or Lord made the basic determination of the span lengths. Undoubtedly they conferred during the Pittsburgh visit and perhaps reached a joint conclusion. That, however, does not answer the initial question. Although Lord obviously had far greater knowledge of the site conditions, his sketch shows a relatively level riverbed, with no particular circumstances on the Pennsylvania side that would have led to a span variation there. In a (presumably) later refined sectional drawing of the river and masonry (Figure 10), however, Roebling clearly *does* show a slight rise in the surface of the river bottom at the first Pennsylvania pier, and it was probably to take advantage of the shallower water at that point that the pier was placed there. Had the adjacent abutment been located farther out into the stream to make that span also 131 feet, it would have projected so far beyond the bank as to form an impediment to the flow of river and ice during high water.

The Other Aqueducts

In addition to the two aqueducts at Lackawaxen, the overall widening of the canal necessitated the replacement of two existing major aqueducts, over the Neversink at Cuddebackville and over Rondout Creek at High Falls near the canal's eastern terminus, both in New York. Both were part of the original construction, the Neversink Aqueduct a two-span timber truss designed by Jervis,[22] and the High Falls Aqueduct—the only one referred to by its place name rather than the stream-crossing name—a two-span, stone-arch structure.

From the time of his arrival at Lackawaxen, if not earlier, Roebling was considering that aspect of the improvement project and, by 28 December 1847, with his work on the first two aqueducts barely under way, he submitted the following proposals to Lord for the replacement structures:

Never Sink Aquaduct one span of 170 ft in the clear, diameter of cables 9⅝ inch, all stonework and rock excav to be done by Cy, myself to do all wood & iron work	$25,000
Never Sink 2 spans of 90 ft each in the clear Cables 6¾ inch	$18,000
High Falls one span 120 ft in the clear Cables 7⅝″	$16,500[23]

Although both structures were to have the same trunk dimensions and follow the general plan of the two Lackawaxen aqueducts, two major differences were proposed. The Neversink River at the aqueduct site could be reduced to no less than 170 feet between abutments. A single span would thus have been appreciably longer than even the 142-foot-long span of the Delaware Aqueduct, Roebling's longest to date except for the lighter Pittsburgh spans. He thus made the dual proposal for the crossing in both one and two spans, but strongly recommended the latter as cheaper, for even the added cost of the center pier would not have approached the $7,000 difference between the two schemes. In fact, he maintained that because of the greatly reduced mass of the anchorage masonry on both banks, even with the center pier the total masonry cost would not exceed that for the single-span plan, and might possibly be less.[24] (See Appendix V on page 42.)

[*Text continues on page 23*]

[22] Malcolm A. Booth, "Roebling's Sixth Bridge, 'Neversink'," *The Journal of the Rutgers University Library,* volume 30, number 1 (December 1966), page 13.

[23] *Suspension Aquaducts . . . Febr. 1847.*

[24] Ibid.

The Delaware Aqueduct Anchorages, Cable Connections, and Saddles

The method employed by Roebling to anchor the suspension cables at their ends and resist the great stress imposed by them on the anchorage system was in general based upon European practice, but with two significant improvements. The principal of these was the solid encasement of the iron anchor chains in cement grout to exclude air and moisture and thus prevent rusting. European engineers traditionally left open galleries around the chains and anchor plates to *permit* air circulation and, more importantly, inspection and painting. The soundness of the Roebling plan is reflected in the top anchor link at High Falls, thoroughly intact after being embedded in the masonry for at least seventy years. (Figure 37).

The other departure was placement of a solid timber grillage between the anchor plates and the superincumbent masonry mass, to act as a slight cushion between them and evenly distribute the stress between the two unyielding surfaces. Roebling patented the system after applying it on both Pittsburgh structures (United States Patent 4710, 26 August 1846). The timber, well below the water table, was not susceptible to rot.

The radial thrust of the chains, as they change angle from vertical at the anchor plates to the back span angle, is borne by a series of stone blocks set into the abutment side walls. The projection of these is seen in Figure 21, and in the ruins of the Neversink Aqueduct south anchorage in Figure 39. (See also Figure 46.)

Equal stress in all the anchor chain links in a section was obtained by drilling their eyes simultaneously, in a pile, to ensure equal length. (Drawing, courtesy of Rensselaer Polytechnic Institute; photographs, June and November 1969 for the Historic American Engineering Record and the Smithsonian Institution.)

Figure 20.—The Pennsylvania towers and saddles. Remarkable survivals are the guides that prevented snagging of the canalboat tow ropes as they passed over: the iron bar just above the back-span strand loops and the casting bolted to the tower corner on the river face.

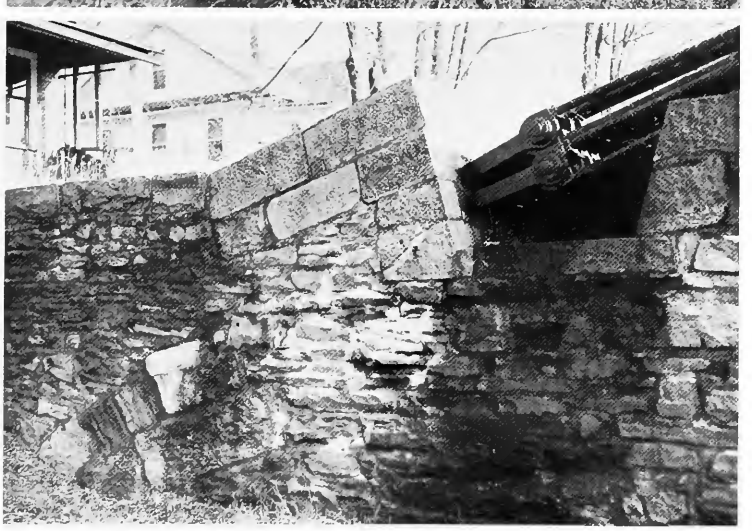
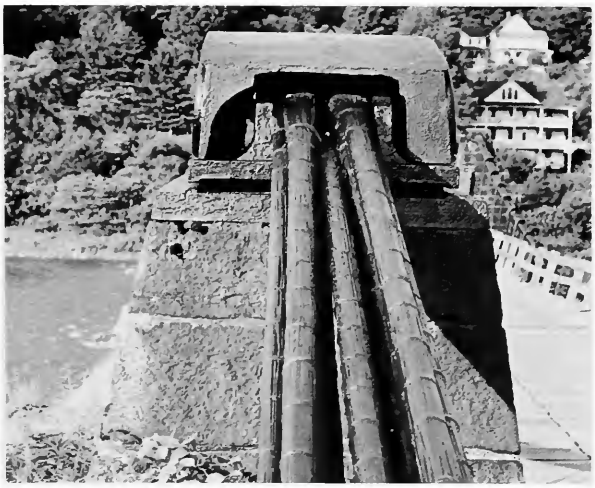


Figure 21.—The New York south anchorage, showing projection of the stone blocks supporting the knuckles of the curving anchor chain.



FIGURES 22 and 23.—Saddle, strand loops, and attachment of loops to anchor chains, Pennsylvania north anchorage.

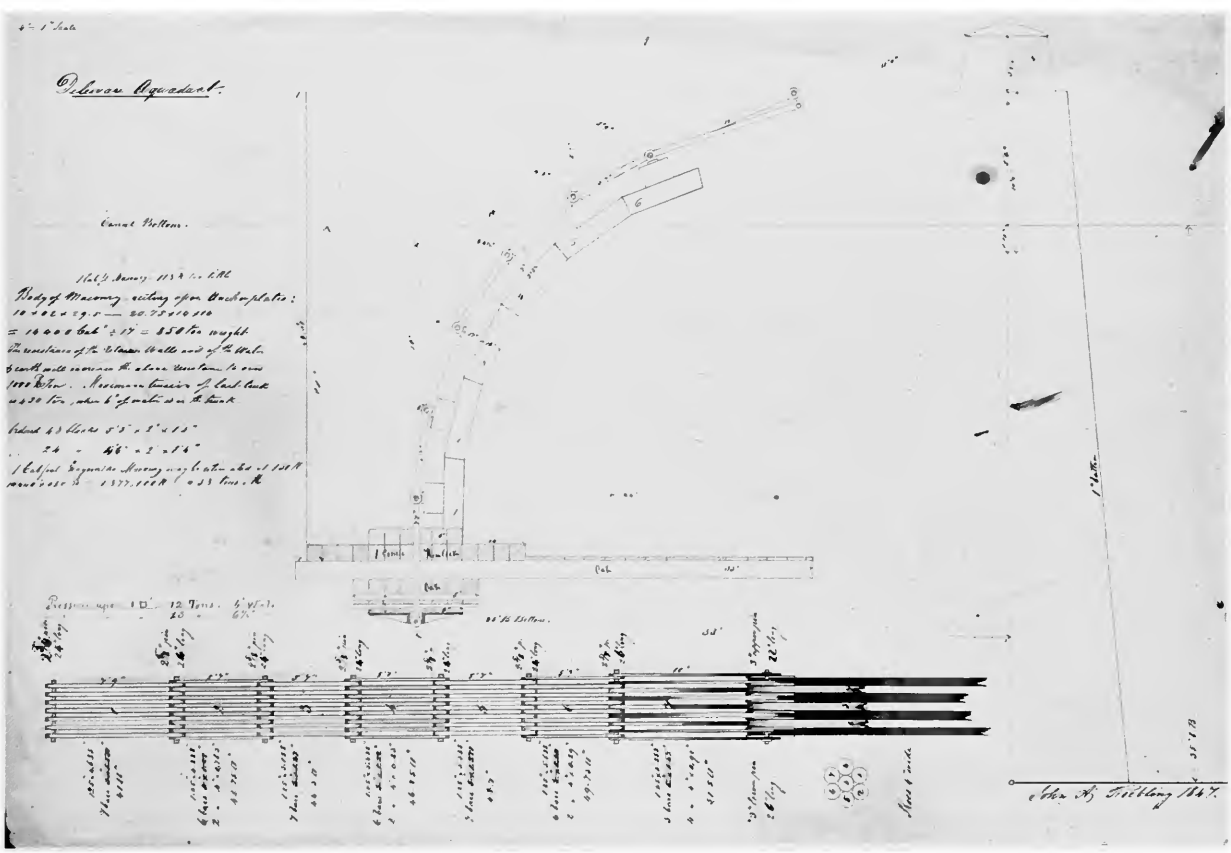


FIGURE 24.

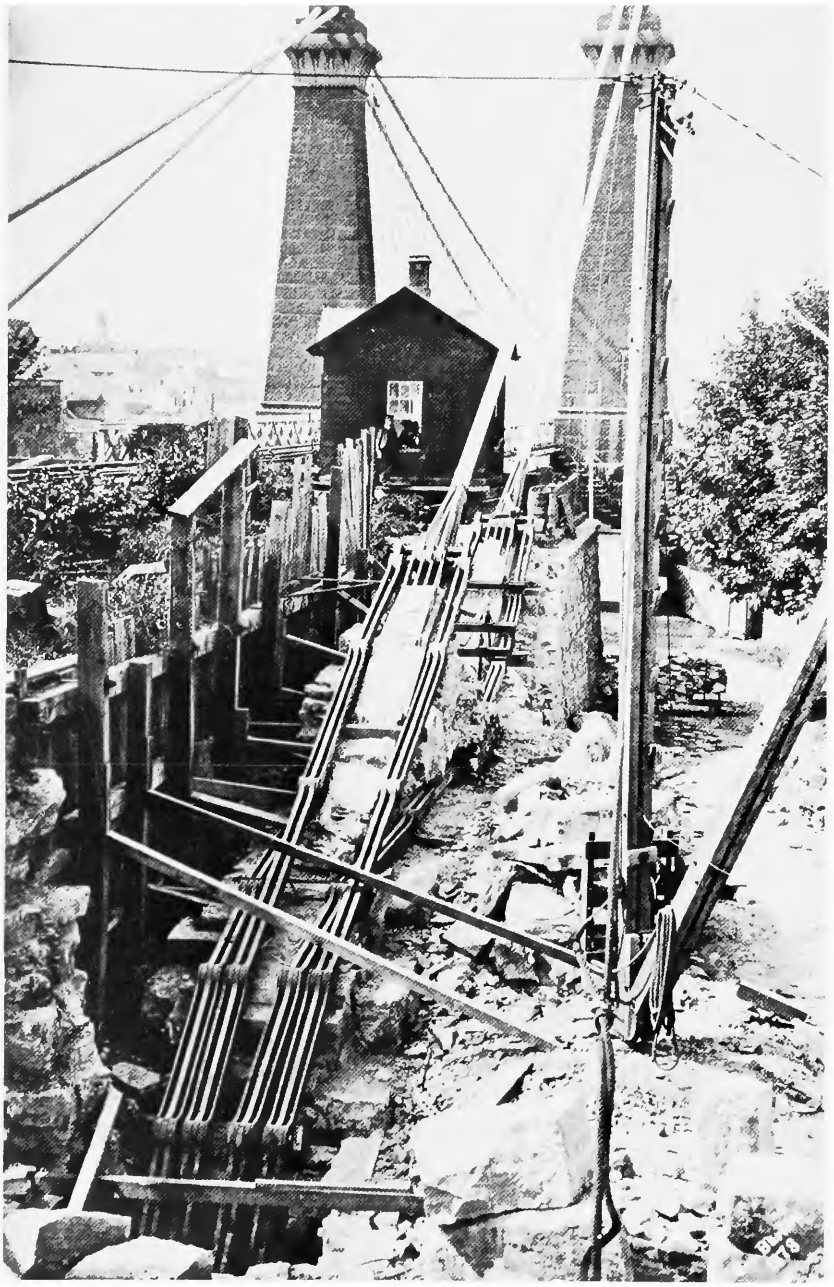


FIGURE 25.—A nearly full view of the anchor-chain and bearing-block system used by Roebling in all of his bridges, early and late, great and small, was provided in 1878 during replacement of some of the links of the Niagara Railway Suspension Bridge (1851-55). Despite cement grouting, leakage along the chains had caused some rusting. Shortly after the bridge's construction, Roebling found that the lime he had theretofore customarily used in the grout to cause a bond of calcification between the masonry and the links in the event that there was any leakage, would in time cause the hardened grout to slightly shrink away from the iron, actually leading to leakage. After 1860 he used plain cement grout only. (Photograph from Modjeski & Masters, engineers, in the Division of Mechanical and Civil Engineering, National Museum of History and Technology.)

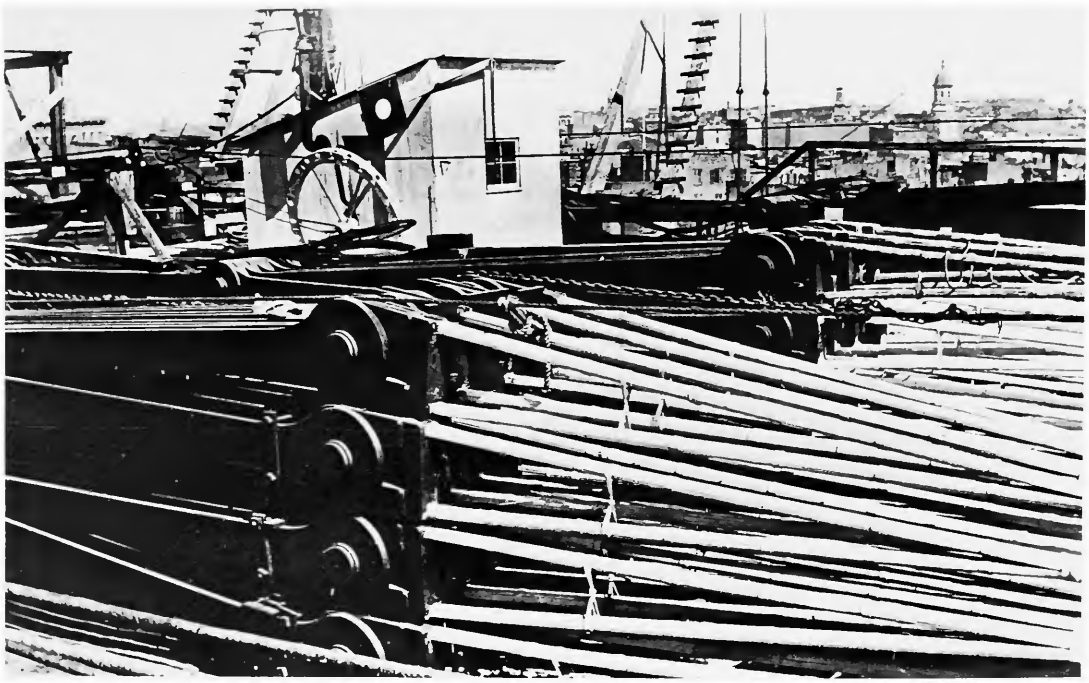


FIGURE 26.—Roebling's system of cable anchorage introduced at Pittsburgh and fully developed on the Delaware & Hudson aqueducts required no essential modification when thirty years later it was applied to a structure on the scale of the Brooklyn Bridge. Compare the details of anchor bars, shoes, and strand loops with those used at Lackawaxen (Figures 22 and 23). At New York, however, these elements were fully protected from exposure by masonry coverings. Behind the eyebars is the cable-wire spinning wheel. (From a lantern slide, Brooklyn anchorage, about 1877, in the Division of Mechanical and Civil Engineering, National Museum of History and Technology.)

FIGURE 27.—Delaware Aqueduct from above the mouth of the Lackawaxen, shortly before suspension of canal operations. The Delaware & Hudson dam, retained after construction of the aqueduct to provide feed water for the section of the canal to the east, is just in front of the aqueduct piers. (Photograph courtesy of the Delaware & Hudson Railway Company.)

FIGURES 28 and 29.—The downstream side of the Delaware Aqueduct before abandonment. Except for the canal's absence, Lackawaxen, Pennsylvania, seen across the river, has changed little over the years. In the lower view may be seen the Erie Railway's truss bridge over the Lackawaxen, built instead of Roebling's proposed suspension span (Figure 57), and the remains of the 1828 canal and the canal company's dam across the Delaware. (Upper photograph, courtesy of Jim Shaughnessy; lower, courtesy of Delaware & Hudson Canal Historical Society, Ghear Collection.)

[*Text continued from page 17*]

Despite the prospect of a substantial saving, the company for unknown reasons ultimately selected the single span, most likely under the impression that $7,000 was a cheap price for avoidance of the difficulties—such as ice floes, flood-born debris, and undermining—to be looked for with a river pier. The Lackawaxen River crossing offered no option, for there a single span would have been 230 feet in length. That apparently was more than Roebling cared to attempt at the time with loading of that magnitude, and there is no record that a one-span aqueduct was ever considered.

The other suggested deviation from the earlier methods arose from the fact that at High Falls the banks were constituted of good, solid "mill stone" rock. Roebling proposed to embed the anchor plates directly in the rock, saving the cost of building up artificial masonry masses above them. Because of the native rock's supposed impermeability, he was willing to carry the cable wire through it, connecting the strand loops directly to the plates eliminating the need for expensive anchor chains. The plan was to excavate adits or channels about sixty feet long and just large enough to get the plates down into place. Presumably, they would have been too small to permit the cables to be conventionally spun in place as the spinning wheel, cable reels, and other apparatus all had to be located either near the ends of the cables or beyond. Roebling's solution was a modification of the plan he had used in his second bridge, the highway span over the Monongahela at Pittsburgh, where he had prefabricated the cables on shore and then hoisted them, complete, into place. At High Falls, he proposed "The strands to be made in the Canal, and put into boxes, then rolled to the abutment and across on tresselwork, then hoisted in the saddles."[25] His suggestion that the strands be "made in the canal," was probably based upon the fact that the "boxes" could be rolled out in a straight line without turns from the southeast side of the creek. It was easier to attain equal tension in the wires by handling only one strand at a time than if the entire cable was treated as a unit. This advantage, however, was somewhat reduced since Roebling—because of the relatively small cable diameter—planned to use only four strands rather than the customary seven that compact more readily into the final circular section of the finished cable.

FIGURE 30.—One of the last boats through the canal crossing the Lackawaxen Aqueduct, about 1898, moving light toward Honesdale. On the Delaware and Lackawaxen aqueducts the towpath was widened around the midstream towers to provide a constant width; the path on the berm side, however, used mainly by common foot traffic, was not widened. (Photograph courtesy of Delaware & Hudson Railway Company.

Apprehension over being able to prevent moisture from reaching the buried wires, the uncertainty of achieving equal tension in all wires of all strands, the problem of erecting falsework in the river, and the apparent general decision to increase the clear span of the aqueduct from 120 to 130 feet (ultimately 135), necessitating larger cables, must in combination have been sufficient to scuttle the scheme. On 11 November 1848, as the aqueducts at Lackawaxen were nearly complete and ten months after his first proposal, Roebling submitted a second one for the replacement structures. It specified single spans of 160 feet clear for Neversink and 130 feet clear for High Falls, with

[25] Ibid.

FIGURE 31.—The Lackawaxen Aqueduct, looking northeast toward the Delaware. As at Pittsburgh, Roebling arranged the floor beams and side struts of the Delaware & Hudson Aqueduct trunks into simple trusses that both supported the overhanging towpaths and resisted the side pressure of the water on the trunk walls. (Photograph courtesy of Delaware & Hudson Railway Company.)

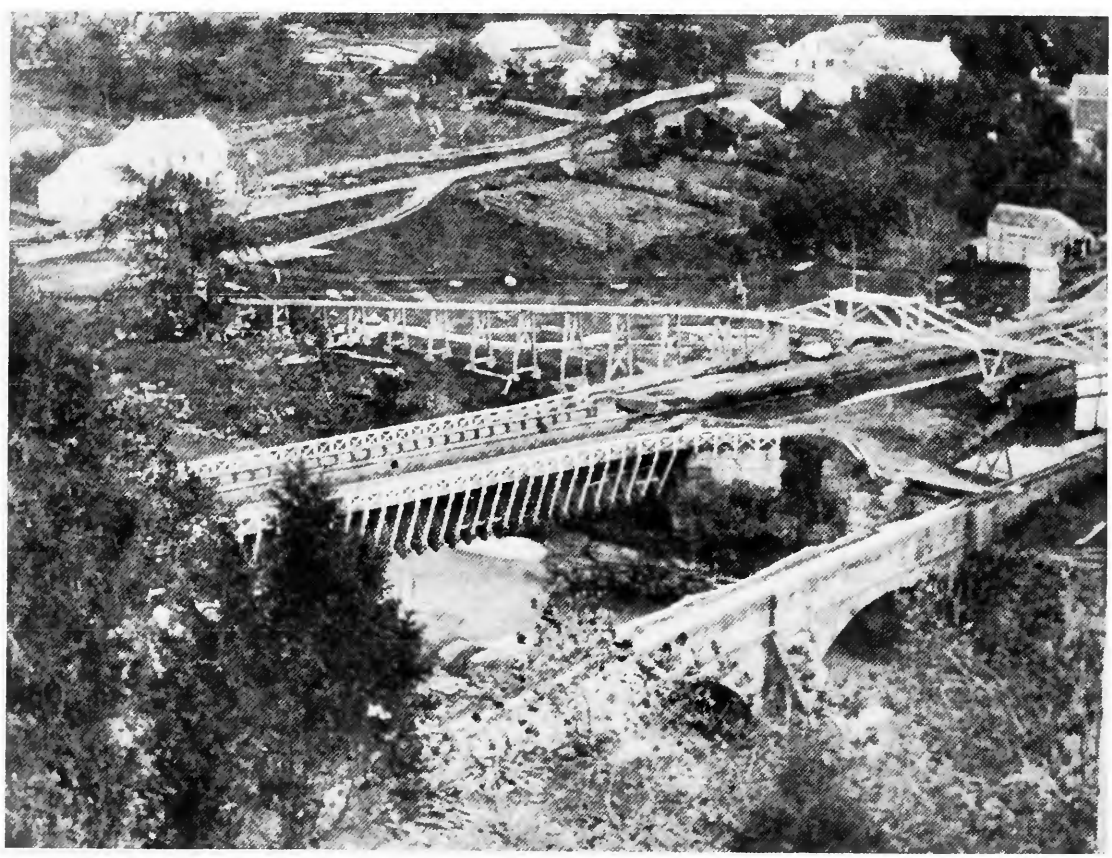


FIGURE 32.—High Falls, New York, and the aqueduct over Rondout Creek. To the right of the span is the original masonry-arch aqueduct it replaced. (Photograph courtesy of Delaware & Hudson Railway Company.)

cables anchored by chains, for $24,900 and $20,400, respectively.[26]

The proposal also established a schedule that called for the company to start their masonry work almost immediately, allowing Roebling to complete his superstructures by the end of 1849. The company was anxious to see the improvements brought into effect as soon as possible, and had accepted the proposal less than a month after its submission (even before knowing whether the first two aqueducts would conduct themselves as advertised). The company's crews, however, were employed on the canal proper until opening of the season and readmission of the water, and apparently it did not have the labor force to undertake its part of the projects until the spring of 1849. Work continued throughout 1849 and most of 1850, and both aqueducts went into service at the start of the 1851 canal season. The 9½-inch cables of the Neversink span were the largest that had been made for any suspension bridge up to the time. Comparative data on all four aqueducts are given in Appendix I.

Decline and Recent History

The 1847–1850 enlargement of the canal was spectacularly successful. In the Delaware & Hudson *Annual Report* for 1849, the management noted that "The two Wire-Suspension Aqueducts over the Delaware and Lackawaxen Rivers, are a part of the new work brought into use last year, and prove to be all that was expected or can be desired of such structures, and a great facility to the navigation."[27] With slight additional deepening and widening, the canal by 1852 was able to pass 130-ton-capacity boats, which had the coincident advantage of being large enough to be river-worthy. They could thus make the down-Hudson trip to New York directly, eliminating the expensive transshipment of the coal to schooners at Rondout, with the boats being hauled up and down river by tugs.

Chief engineer Lord estimated that the project, particularly the advent of the Delaware and Lackawaxen aqueducts, had avoided nine days stoppage of boating due to high water in the first year of operation, and cut a full day from the passage time. All in all, the company could reduce rates by half, bringing the transportation cost down to about fifty cents per ton. On this basis, the canal was able to compete quite successfully with the railroads for bulk coal haulage well into the 1870s. It has been noted that the peak year was 1872 when almost three million tons of coal were carried. From that time on, the competitive situation deteriorated rapidly for the canal. Whereas it had by then about reached its maximum practical capacity, the technology of the railroad was in a state of flourishing and seemingly unlimited advance. In the last three decades of the century, locomotive weights doubled, with corresponding increases in car capacity and train lengths, and decreases in rates.

The Delaware & Hudson management had the wisdom to march with rather than against this trend, and although the canal was operated almost to the century's end, it was under rapidly declining conditions as the company expanded its own rail network which it had commenced decades earlier. In 1898 the last boat moved over the waterway, and the following year the physical plant of the system was liquidated.

Of the four suspension aqueducts only the Delaware had any apparent adaptive usefulness. The Lackawaxen, Neversink, and High Falls (Rondout) spans were all simply abondoned and sooner or later demolished; the High Falls survived derelict until 1921 and the Lackawaxen even longer. Abutments and remains of anchor chains are evident at all three sites (Figures 34, 37–39).

The Delaware Aqueduct, however, being in a strategic location well away from any other road crossing of the river, was purchased privately and converted into a highway bridge. From the evidence of photographs, the process of adaptation was simplicity itself. The towpaths were sawn off, a low railing was run along the downstream side of the trunk floor to provide a separated pedestrian walk, a tollhouse was built at the New York end, some grading was done at each end for accommodation to the existing roads, and it was "Open For Business" (Figures 41–44).

The first private owner was Charles Spruks, a Scranton lumber dealer who specialized in the heavy timbers used as supports in the area's coal mines. Because his principal timberlands were in Sullivan County, New York, he purchased the aqueduct primarily to afford a simple means of getting the logs across the Delaware to the railhead in Lackawaxen. The collecting of tolls from common-road traffic was actually a sideline.[28]

[26] *Never Sink Aquaduct Oct. 1848.*

[27] *Annual Report, Delaware & Hudson Canal Company.* New York 1850, p. 3.

[28] Information from Mr. Edward H. Huber, Scranton.

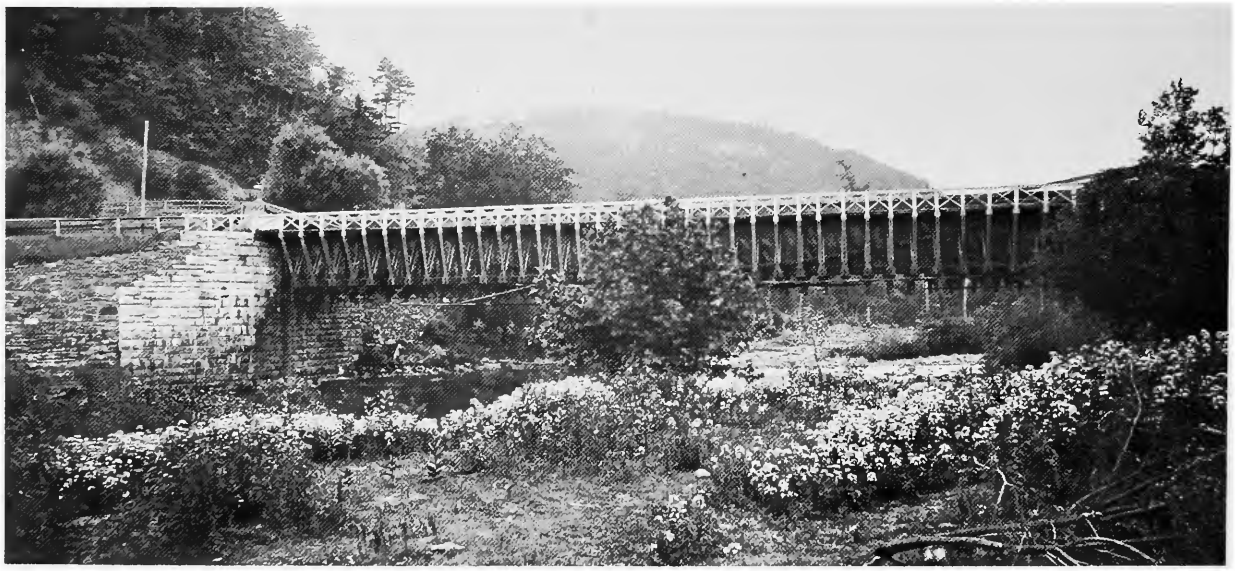


FIGURE 33.—Neversink Aqueduct at Cuddebackville, New York, which had the longest single span of the Delaware & Hudson suspension aqueducts. (Photograph in the Division of Mechanical & Civil Engineering, National Museum of History and Technology.)

About 1929 the bridge was purchased by the Federal Bridge Company of Washington, D.C., a toll bridge holding company, which operated it under the name of Lackawaxen Bridge Company, incorporated 10 January 1930. In late 1930 plans were announced by Colonel P. K. Schuyler, Federal's president, to rebuild the floor system for "highway traffic of the heaviest class."[29] It may have been at that time, or in about 1932, after a fire that destroyed the woodwork of the west (Pennsylvania) span and part of the one adjacent, that virtually all of the original timber was removed—trunk, floor beams, and all. The simple floor system of today was substituted, consisting of transverse floor beams hung from the suspenders, longitudinal stringers, and plain transverse plank decking.

The Lackawaxen Bridge Company was purchased in March 1942 by E. H. Huber of Scranton, who presently maintains the operation. A toll of twenty-five cents for cars and five cents for pedestrians is charged, with all passage free after the collector goes home at night. The fabric is in generally good condition. The masonry, except for an understandable minor deterioration of the upstream pier faces from river ice, is quite perfect. The floor system is good as the planking is periodically replaced, and the cables, despite unwinding of the outer wrapping in a few areas, are kept painted and appear as adequate as when spun. The posted allowable load of six tons is almost ludicrous in view of the fact that *each span* originally contained about 500 tons of water plus the additional dead load of the trunk and towpaths. True, it was an evenly distributed, non-moving, non-impact load, but there can be little doubt that the cable system today is not working very hard.

The Aqueduct's Relative Historical Status

There is good reason to believe that the Delaware Aqueduct is the oldest suspension bridge standing in the United States today. There are only two other possible contenders for the distinction: the famed Essex-Merrimack bridge designed by James Finley and erected in 1810 over the Merrimack at Newburyport,

[29] P. K. Schuyler, "Lackawaxen Suspension Bridge Rebuilt for Present-Day Use," in *Engineering and Contracting*, volume 69 (November 1930), page 421.

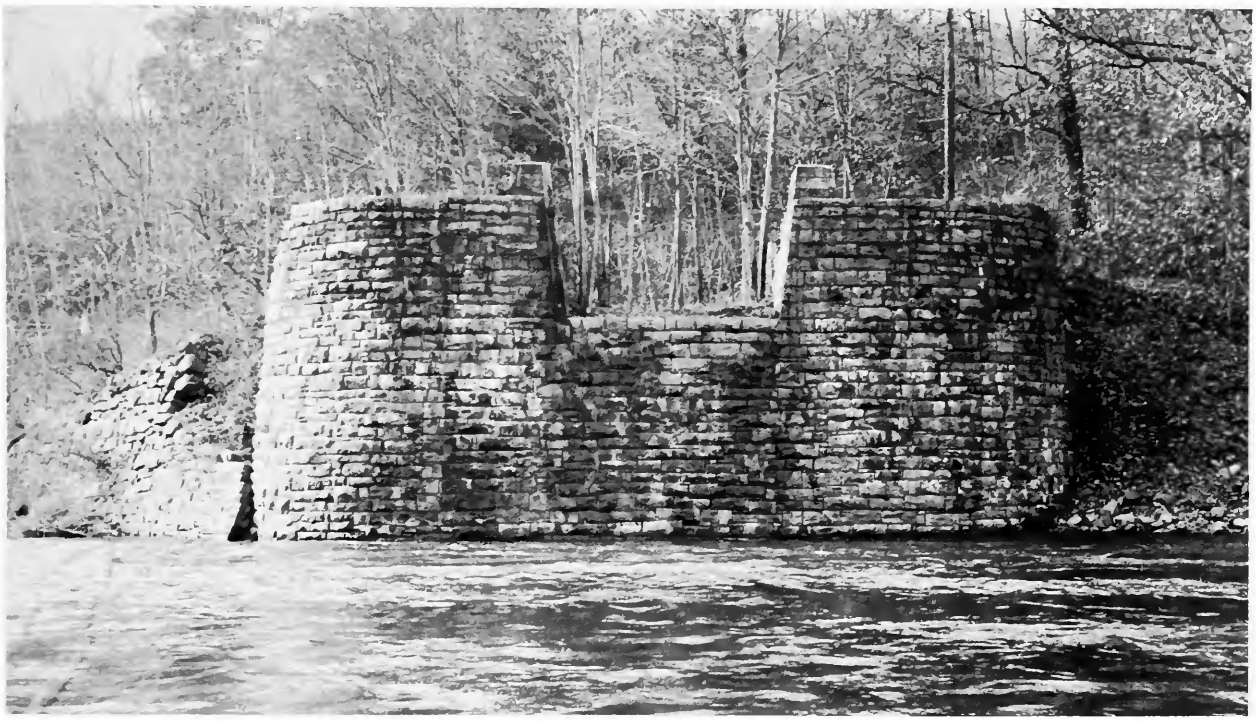


FIGURE 34.—Remains of the Lackawaxen Aqueduct. Only the west abutment survives, the east abutment and the midriver pier having been entirely demolished for the conveniently located supply of cut stone. (Historic American Engineering Record and the Smithsonian Institution.

Massachusetts (Figure 53); and the "Wire Bridge" over the Carrabassett River at New Portland in central Maine. At first glance it appears that the Finley bridge is clearly the oldest. In 1909, however, virtually the entire superstructure was replaced—the shape of the wood towers broadly reproduced in reinforced concrete; the four open-link chains replaced by four 3½-inch wire cables; and a new steel and timber deck fitted. The sole fabric remaining of the original structure is the pier masonry below deck level, so that we have a case not unlike that of grandfather's Original-100-year-Old ax which in its long history had five new heads and twelve new handles. The present bridge is plainly not that of 1810, and only loosely resembles it in general form.[30]

The "Wire Bridge" is a rather different case. It, too, has undergone a certain amount of rebuilding. The shingle and board sheathing of the timber towers has been replaced, the wood deck is new, and the original rod suspenders and clamps have recently been replaced by prefabricated wire ropes with new cable clamps. The majority of the tower framing and the main cables and their anchorage hardware, however, are entirely original, and if we recognize in these elements the heart and soul of a suspension bridge, it is not unreasonable to consider that the bridge is indeed the actual one of original date (Figure 54).

There is some conflict about the date, the positive resolution of which will require more research than has been done to date. Unfortunately, there was probably no more documentation generated at the time of the bridge's construction than there would have been for any other relatively small bridge, so that there is little expectation of any new contemporary evidence coming to light. Local tradition, based apparently on certain New Portland town-meeting minutes, main-

[30] Full details of the original and reconstructed bridges are in *Engineering News,* 3 August 1911, page 129 and 25 September 1913, pages 585-87.

tains emphatically that the "Wire Bridge" was built in 1842, using wire cables fabricated in Sheffield, England. The date appears on local roadside markers guiding tourists to the site, and in virtually all recent newspaper accounts of the bridge. Charles Ellet's wire bridge over the Schuylkill in Fairmount Park, Philadelphia, the first consequential wire suspension bridge in America, was built in 1842, and there is no technical reason why the Maine bridge could not also have gone up then. If it did, then it preceded the Delaware Aqueduct by a five-year margin and thus rightfully deserves the title of "The Oldest Standing."

Several factors, however, make that date seem entirely unrealistic if not unbelievable. First, a lack of historical authority weakens its probability. While the necessary technology and a certain degree of precedent did exist, the likelihood is not great of either being reflected in a structure, erected by local men, in what even today is a relatively remote region; it is, in fact, almost hopelessly slim. The second factor is the former presence of two very similar bridges in the immediate area, in the towns of Kingfield and Strong. At Kingfield, cables of ordinary chain were employed; at Strong, wire cables, as at New Portland, were used.

The Kingfield chain bridge is known to have been built in 1852–1853, the Strong wire bridge in 1856. (They were replaced in 1916 and 1922 respectively.) The striking similarity of all three spans—particularly in the architectural character of the shingled timber-frame towers—and the presence of three *suspension* bridges within a twelve-mile circle, in an area and a time almost exclusively of *timber truss* bridges, leads one to look for the connection among them that obviously must exist. The Kingfield span was designed and built, according to apparently reliable local evidence, by Daniel Beedy of Farmington;[31] the New Portland span by David Elder and Captain Charles B. Clark;[32] and about the Strong bridge, we do not know. Thus, there may or may not have been a common hand between the Strong span and either of the other two. In any event, what surely *must* have occurred was observation of the success and cheapness of the earliest of the three structures, with emulation by two other towns and either one or two other builders.

Assuming that the New Portland bridge was *not* built in 1842, the question is, which of the trio was the first? As the Strong bridge is known to have been later than the Kingfield, it was either Kingfield or New Portland. Whichever, its erection must surely have been regarded by the town's authorities as a rather unconventional solution to their bridging problem, its lack of local precedent evoking some trepidation. In that light, it seems so probable as to approach a dead certainty that there would not have been room for two experiments at once. Thus, not the added novelty of *wire* for the cables (despite its earlier use by Roebling and Ellet), but rather a material of far greater familiarity having characteristics of strength not only known, but highly visible: *chain*. In other words, it is suggested that the Kingfield bridge of 1852–1853 was the progenitor. Either of the wire bridges could then have been the second built. Even the Strong bridge of 1856, erected only three years later, might quite logically have been of wire. The elapse of that much time certified that the suspension system itself, in Kingfield's span, was furnishing good, safe service. More significant, Roebling's famed and widely publicized Niagara Railway Suspension Bridge was completed the previous year, carrying a mainline railroad on an 850-foot span, with wire cables.

Based on the lack of positive evidence supporting the 1842 date, and on the above reasoning, it is difficult to believe that the New Portland bridge was built a decade before the Kingfield bridge; it is quite easy, however, to visualize its construction a decade after the Strong bridge. An entry in the New Portland Town Report for 1 March 1866 states that David Elder, agent for the bridge, was paid $3,624.97.[33] The figure is too large for mere repairs, no matter how major, but is a perfectly reasonable one—considering the scale of the structure, the place, and the time—for construction of the complete bridge. L. N. Edwards (see footnote 31) mentions the bridge only cursorily, noting that it was built after the Strong bridge, although he gives no evidence for the statement.

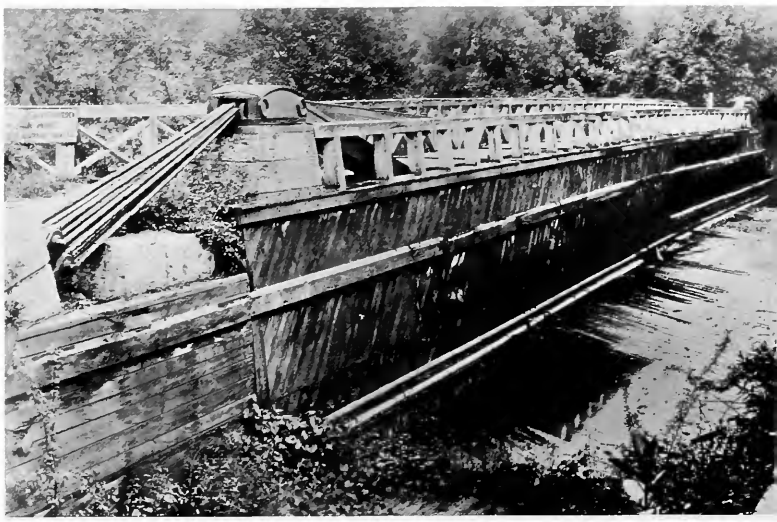
[*Text continues on page 33*]

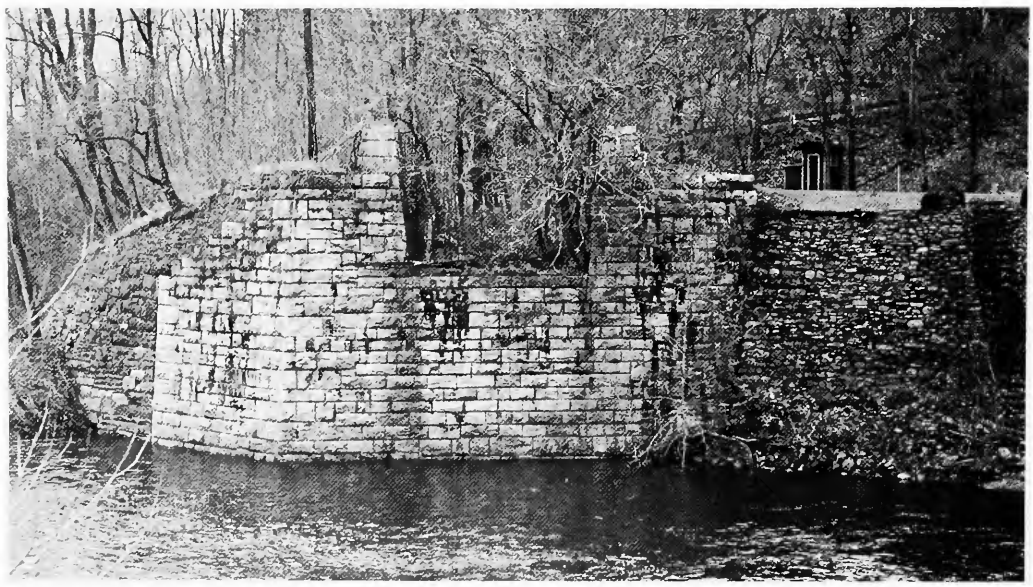
[31] Data on the Kingfield Bridge is from an unpublished typescript in the files of the Smithsonian Institution's Division of Mechanical and Civil Engineering, *Kingfield Bridges,* prepared in about 1945 by the well-known bridge historian Llewellyn N. Edwards of Glen Echo, Maryland. Most of Dr. Edwards' information is based on primary and local sources and is considered solid. An extract appears in his "A Brief Discussion of the Geology of Maine Rivers and Streams and a History of Six Early Maine Bridges," *Paper No. 15* of the Maine Technology Experiment Station, University of Maine, Orono, October 1934, pages 28-29.

[32] "Here's the Fine Old Suspension Bridge at New Portland, Me." *New England Construction,* May 1954, pages 62-63.

[33] Ibid.

FIGURES 35, 36, and 37.—Slow death at High Falls. After standing derelict but intact for nearly twenty years following abandonment of the canal, fire destroyed the aqueduct's woodwork about 1916, leaving the cables and suspenders in a state not unlike that during original construction, just before the first of the trunk frames had been hoisted into place. Today only the abutment masonry and portions of the anchorage eyebars remain. Even these have not been permitted a dignified final rest: the old-metal vandals have removed the stones from around most of the upper links and cut portions of them away. (Photograph at right, courtesy of Delaware & Hudson Railway Company; center, Delaware & Hudson Canal Historical Society, Ghear Collection; and bottom, Historic American Engineering Record and the Smithsonian Institution.)





FIGURES 38 and 39.—The masonry of both Neversink Aqueduct abutments survives, but all the upper sections of the anchor bars are gone. Just upstream on both sides of the Neversink are fragmentary remains of the predecessor two-span timber-truss aqueduct. As at High Falls, the canal was slightly realigned during the enlargement to permit construction of the new aqueduct without disrupting service on the old. On both of the later structures, the abutment wing walls are straight, meeting the face at an angle, unlike the earlier Delaware and Lackawaxen spans where the surfaces meet in a curve. (Historic American Engineering Record and the Smithsonian Institution.)

FIGURE 40.—Delaware Aqueduct and Minisink Ford, New York, shortly after the canal's abandonment in late 1898. Except for removing the berm wall on the outside of the curve at Lackawaxen to provide road access, nothing has yet been done to alter the structure for toll-bridge service. (Photograph courtesy of the Delaware & Hudson Railway Company.)

FIGURE 41.—Interior of the Delaware Aqueduct trunk after conversion to a toll bridge, about 1900. (Photograph courtesy of the Delaware & Hudson Railway Company).

FIGURES 42 and 43.—Early twentieth-century views of the Aqueduct from New York. (Photographs courtesy of the Delaware & Hudson Railway Company.)

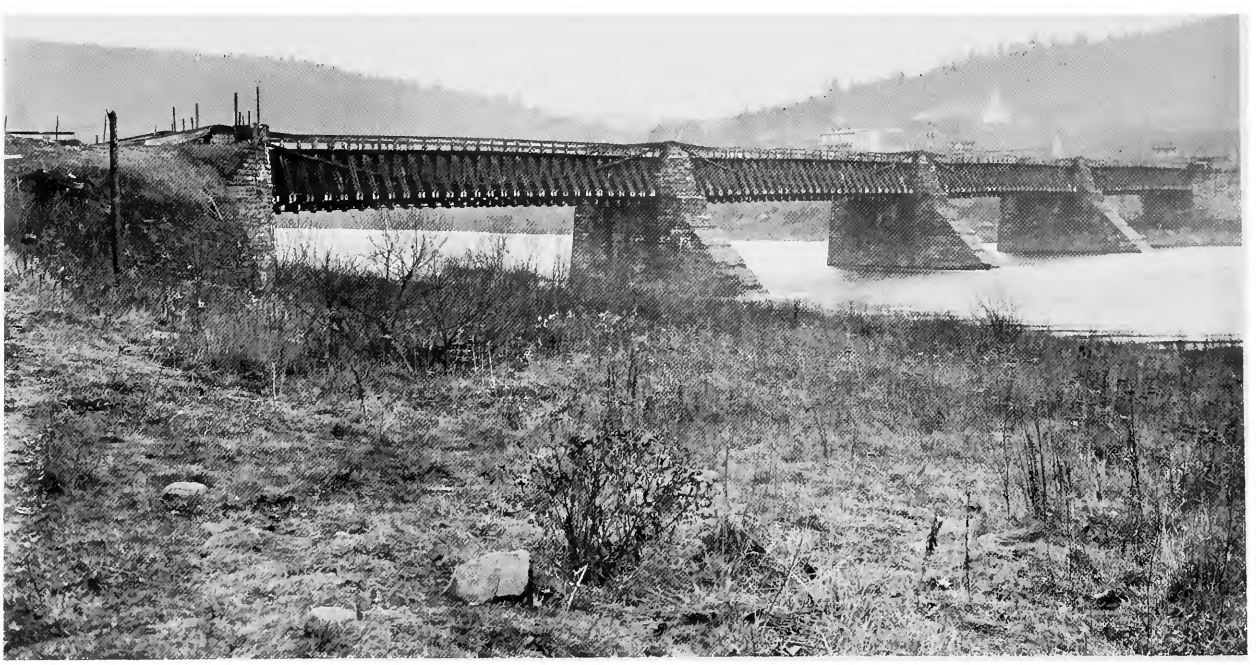


FIGURE 44.—View from Lackawaxen, about 1910. The towpaths have been removed in the alteration but not the tow-rope rail. During the canal period, the upstream faces of the piers were protected by pointed wooden ice-breakers. Renewed as needed, they prevented the deterioration that has occurred since. The pier faces were shelved to support the ice-breaker framing. The icebreakers are seen in Figure 27. (Photograph courtesy of the Delaware & Hudson Railway Company.)

[*Text continued from page 28*]

Finally, the town-meeting minutes of about 1842 that are purported to refer to this bridge speak of it as having been projected and built by a Colonel Morse; the structure, because of its novelty, being referred to locally as "Morse's Fool Bridge."[34] Thoroughgoing local inquiry, however, reveals that neither that name, nor Morse's in any form, has apparently ever been attached to the bridge, while a granddaughter of Clark does clearly recall family lore crediting her grandfather with its construction. So it would seem that the 1842 references are either to another, entirely different, bridge that had a short life and left no solid evidence of its existence, or to an earlier, never-built project for the same site.[35] Taken altogether there seems reason enough to discount the date of 1842, and consider the Delaware Aqueduct to be in fact America's earliest standing suspension bridge.

Its future seems reasonably secure. Although it, too, is in a remote area, it is happily situated between the Poconos and the Catskills, and still is the only crossing of the Delaware for ten miles upstream and four downstream so that enough vacation and local traffic uses it to make it an economic if not wildly profitable venture for its owner and worth adequate maintenance expenditures. It has been recognized as a historic landmark by the state of New York, which has erected a roadside marker, and was recently placed on the National Register of Historic Landmarks, fitting recognition for one of the nation's most significant engineering relics and the earliest extant work of the man who is the rightfully acknowledged father of the modern suspension bridge.

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[34] These statements are reported in an article on the New Portland bridge from *GRIT—Family Section,* 26 December 1965 (a Sunday magazine supplement), posted in the Hotel Herbert, Kingfield, Maine, noted in August 1969.

[35] For the data in this paragraph, I am indebted to Mr. Charles A. Whitten, C. E., of Augusta, Maine, who has closely followed the career of the New Portland bridge, and actively pursued its early history. He shares my serious doubts concerning the earlier date, as do all other bridge historians encountered. Jakkula, in his *A History of Suspension Bridges in Bibliographical Form,* curiously does not list it although he does the Strong and the Kingfield spans, using as his sole reference the Edwards article (footnote 31).

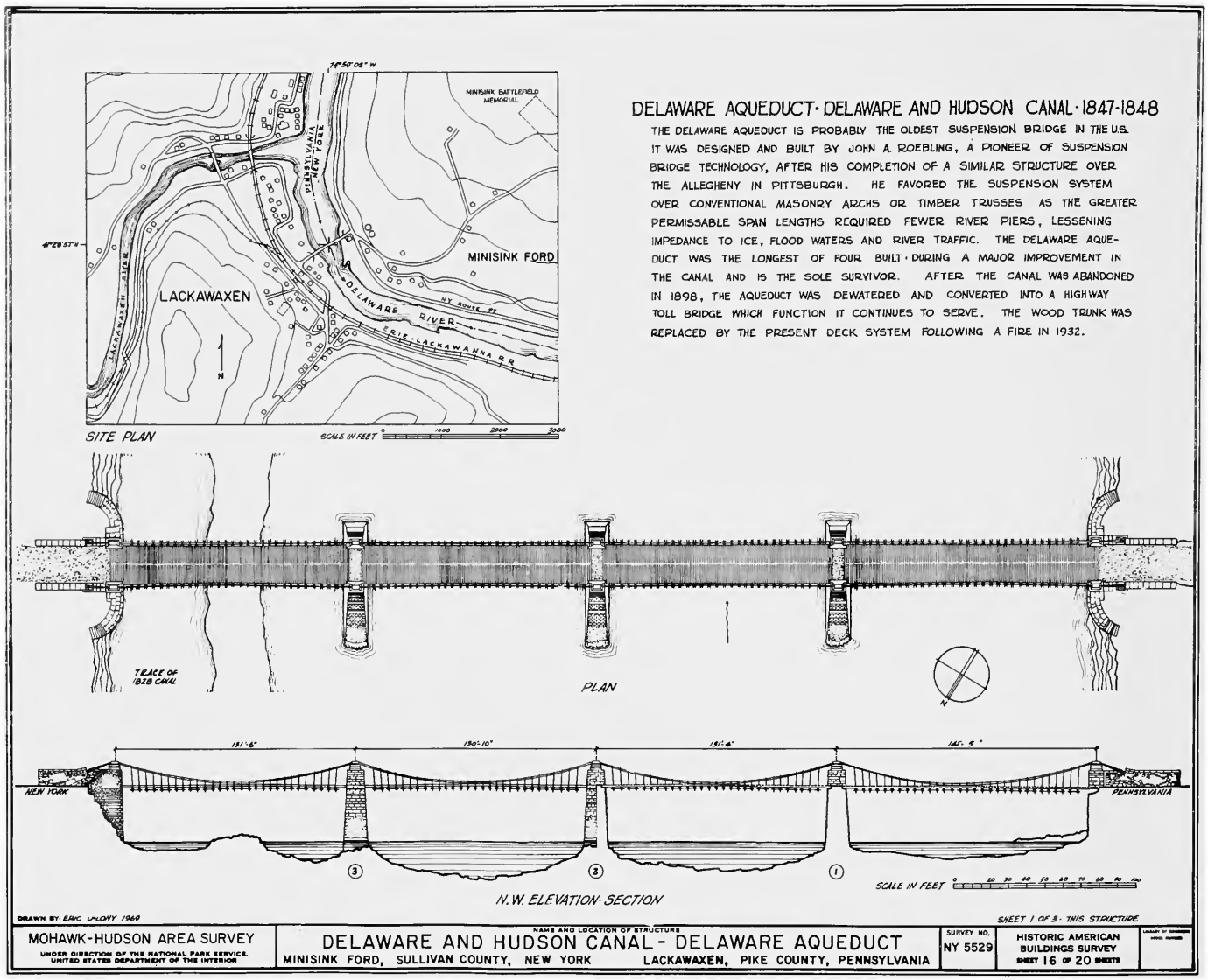

FIGURE 45.

FIGURES 45, 46, and 47 (overleaf).—The following three drawings were made in August 1969 by the Mohawk-Hudson Area Survey (M-HAS), sponsored by the American Society of Civil Engineers, the National Park Service, the New York State Historic Trust, and the Smithsonian Institution. The M-HAS was the first project of the recently formed Historic American Engineering Record, established to prepare and preserve graphic records of significant American engineering monuments.

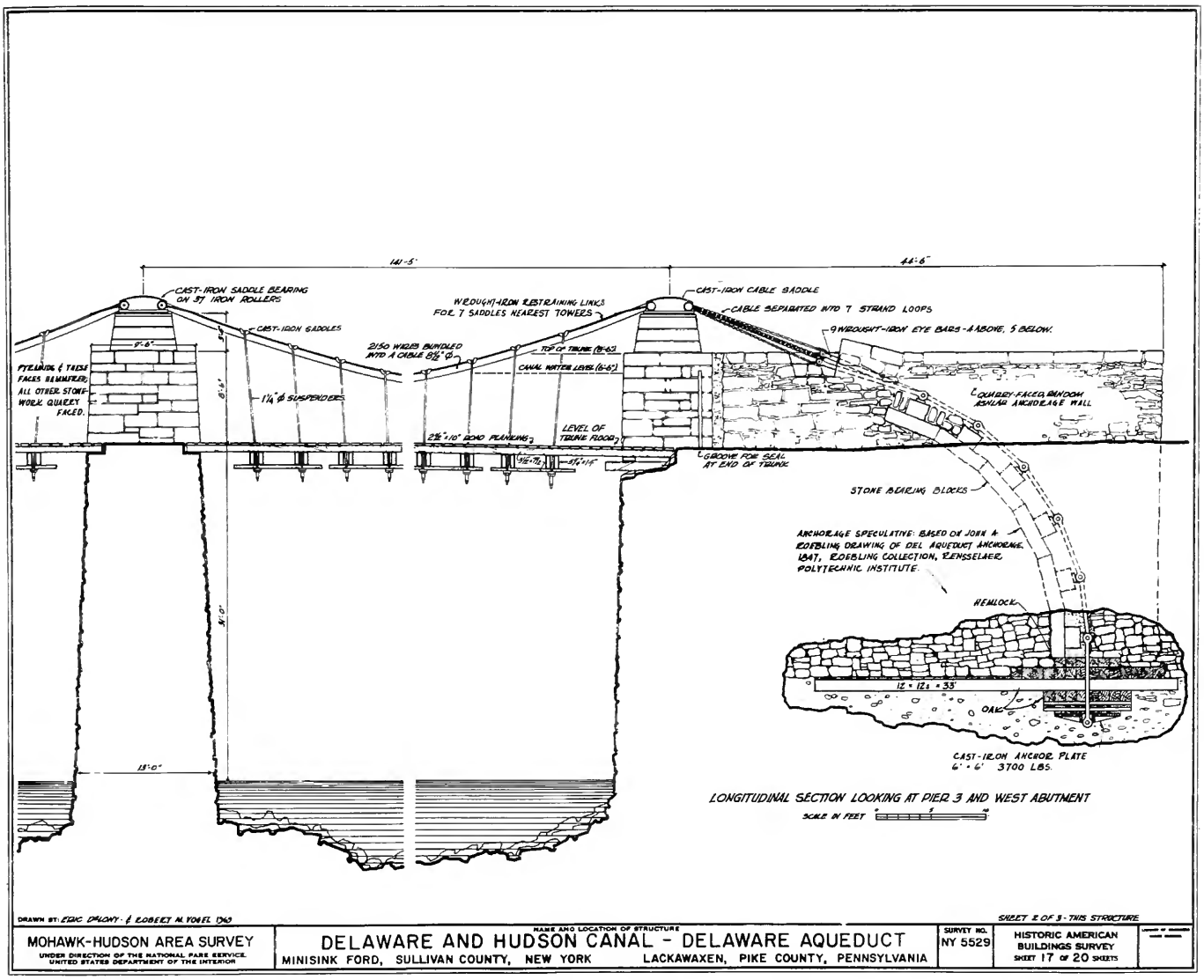
141'-5"
44'-6"
CAST-IRON SADDLE BEARING ON 3" IRON ROLLERS
CAST-IRON SADDLES
WROUGHT-IRON RESTRAINING LINKS FOR 7 SADDLES NEAREST TOWERS
CAST-IRON CABLE SADDLE
CABLE SEPARATED INTO 7 STRAND LOOPS
9 WROUGHT-IRON EYE BARS - 4 ABOVE, 5 BELOW.
2150 WIRES BUNDLED INTO A CABLE 8½" Φ
TOP OF TRUNK (8'-6")
CANAL WATER LEVEL (6'-6")
PYLONS & TOWER FACES HAMMERED; ALL OTHER STONE WORK QUARRY FACED.
1¼" Φ SUSPENDERS
QUARRY-FACED RANDOM ASHLAR ANCHORAGE WALL
2½" x 10" BOND PLANKING
LEVEL OF TRUNK FLOOR
GROOVE FOR SEAL AT END OF TRUNK
STONE BEARING BLOCKS
ANCHORAGE SPECULATIVE: BASED ON JOHN A. ROEBLING DRAWING OF DEL. AQUEDUCT ANCHORAGE, 1847, ROEBLING COLLECTION, RENSSELAER POLYTECHNIC INSTITUTE.
HEMLOCK
12" x 12" x 33'
OAK
CAST-IRON ANCHOR PLATE 6' x 6' 3700 LBS.
13'-0"
LONGITUDINAL SECTION LOOKING AT PIER 3 AND WEST ABUTMENT
SCALE IN FEET
DRAWN BY: EDWIN DALONY & ROBERT M. VOGEL 1969
SHEET 2 OF 3 - THIS STRUCTURE
MOHAWK-HUDSON AREA SURVEY
UNDER DIRECTION OF THE NATIONAL PARK SERVICE, UNITED STATES DEPARTMENT OF THE INTERIOR
NAME AND LOCATION OF STRUCTURE
DELAWARE AND HUDSON CANAL - DELAWARE AQUEDUCT
MINISINK FORD, SULLIVAN COUNTY, NEW YORK LACKAWAXEN, PIKE COUNTY, PENNSYLVANIA
SURVEY NO. NY 5529
HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 17 OF 20 SHEETS

FIGURE 46.

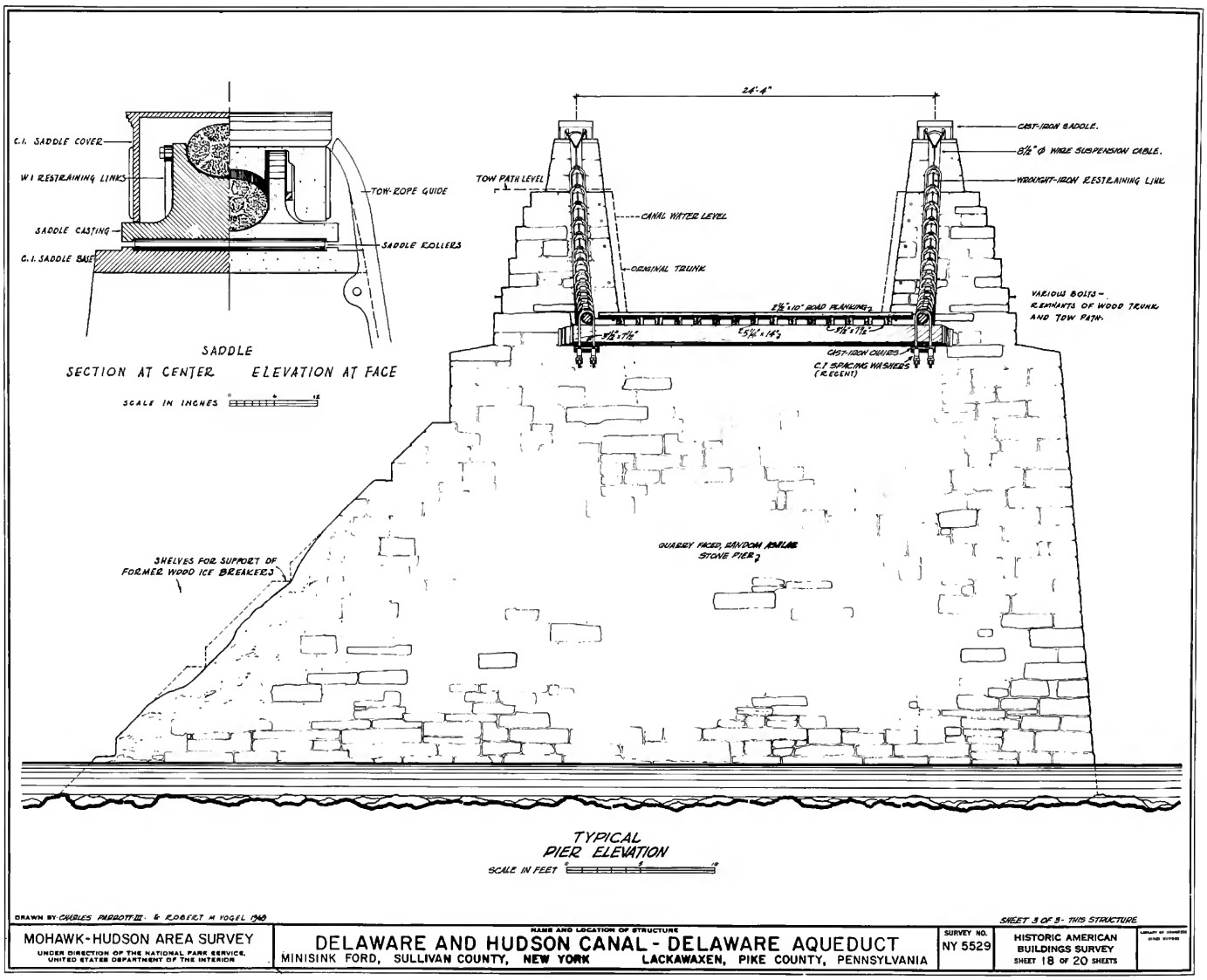
C.I. SADDLE COVER
W.I. RESTRAINING LINKS
SADDLE CASTING
C.I. SADDLE BASE
TOW-ROPE GUIDE
SADDLE ROLLERS
SADDLE
SECTION AT CENTER ELEVATION AT FACE
SCALE IN INCHES
24'-4"
TOW PATH LEVEL
CANAL WATER LEVEL
ORIGINAL TRUNK
CAST-IRON SADDLE.
8½" Ø WIRE SUSPENSION CABLE.
WROUGHT-IRON RESTRAINING LINK
VARIOUS BOLTS - REMNANTS OF WOOD TRUNK AND TOW PATH.
2¼" x 10" ROAD PLANKING
CAST-IRON CHAIRS
C.I. SPACING WASHERS (RECENT)
SHELVES FOR SUPPORT OF FORMER WOOD ICE BREAKERS
QUARRY FACED, RANDOM RUBBLE STONE PIER
TYPICAL PIER ELEVATION
SCALE IN FEET
DRAWN BY CHARLES PARROTT III & ROBERT M VOGEL 1940
SHEET 3 OF 3 - THIS STRUCTURE
MOHAWK-HUDSON AREA SURVEY
UNDER DIRECTION OF THE NATIONAL PARK SERVICE, UNITED STATES DEPARTMENT OF THE INTERIOR
NAME AND LOCATION OF STRUCTURE
DELAWARE AND HUDSON CANAL - DELAWARE AQUEDUCT
MINISINK FORD, SULLIVAN COUNTY, NEW YORK LACKAWAXEN, PIKE COUNTY, PENNSYLVANIA
SURVEY NO. NY 5529
HISTORIC AMERICAN BUILDINGS SURVEY
SHEET 18 OF 20 SHEETS

FIGURE 47.

THE DELAWARE AQUEDUCT TODAY, Figures 48-52. (Photographs by David Plowden.)

FIGURE 48.—The New York shore from Lackawaxen.

FIGURES 49 and 50.—Traffic during most of the year is steady though light, but dwindles from January to March. As the only crossing of the Delaware for fifteen miles, the bridge fills a decided local need as well as being unique point of interest.

FIGURES 51 and 52.—The contrasting massiveness of masonry piers and lightness of wire cables, so much the measure of the suspension bridge and so often extolled by poet and painter in the Brooklyn Bridge, is as fully marked at the aqueduct.

FIGURES 53.—Essex-Merrimack Bridge near Newburyport, Massachusetts, before and after. In the 1909 "rebuilding" of the 1810 structure, the entire superstructure was replaced with a loose replica, leaving of the original fabric only the pier masonry below deck level. (From Engineering News (25 September 1913), volume 70, page 585.)

FIGURE 54.—The "Wire Bridge," New Portland, Maine. While having undergone some rebuilding, the bridge is original in its principal elements and is a rare survival of an early suspension structure. (Photograph by David Plowden.)

LUMBER

WANTED, on THE DEL. & HUDSON CANAL.

PROPOSITIONS

Will be received until the 10th day of March next, for furnishing and delivering the following bill of Lumber, viz:

890	Pieces, 16 by 6 1-2 inches,—31 feet long,	104,910	feet Board Measure,
400	do. 14 by 7 inches at one end, 7 by 7 at the other,—18 ft. long,	69,200	do.
200	do. 7 by 13,—20 feet long,	30,400	do.
800	do. 2 1-2 by 10,—16 feet long,	16,600	do.
600	do. 2 by 10,—7 feet 8 inches long,	10,200	do.
400	do. 7 by 7,—12 feet long,	19,600	do.
400	do. 6 by 7,—6 feet 6 inches long,	6,800	do.
	1,600 feet Linial Measure, 7 by 7 inches, for Railing,	6,533	do.
	1,600 feet Linial Measure, 6 by 6 inches, for Railing,	4,800	feet Board Measure.
1,400	do. 6 by 7, any length over 20 feet,	4,900	do.
1,400	do. 5 by 5, do.	1,450	do.
	Plank, 25 or 26 feet long, 2 1-2 inches *uniformly* thick,	76,680	do.
	Plank, 14 feet 4 inches long, 2 1-2 inches *uniformly* thick,	76,680	do.
	Joice, 2 in. by 10, or 2 inches by 12, either 16, 20, or 24 ft. long,	22,400	do.
	Joice, 1 1-2 by 10 inches, 16 or 24 feet long,	19,200	do.
	Total Board Measure of Pine,	442,558	feet.

All the above bill to be of good sound White Pine, and work full size, free of shakes, rents or black knots, when counter-hewed, and delivered on the Pennsylvania side of the Delaware river above high water mark, between the mouth of the Lackawaxen and Delaware Dam (for Del. and Hud. Canal) by or before the first day of July next. Payment will be made when the Lumber is delivered on the bank as above stated, and approved and accepted to the satisfaction of the Engineer on Delaware and Hudson Canal for the time being. Proposals are desired to be in writing, stating the price per one thousand feet board measure, and directed to the subscriber, at the office of the Delaware and Hudson Canal Company, in Honesdale, Wayne county, Pa. For any information relating to the above bill of Lumber, apply to the Engineers or Superintendents on Delaware and Hudson Canal.

JOHN A. ROEBLING, *Engineer.*

February 23d, 1847.

FIGURE 55.—Invitation to supply lumber for the Delaware and Lackawaxen aqueducts. (Courtesy of Rensselaer Polytechnic Institute.)

I

Summary of Delaware & Hudson Canal Improvements

(From Whitford, Volume 1, page 1467)

Year of Completion	*Width at top (feet)*	*Width at bottom (feet)*	*Depth (feet)*
1829 (as first built)	28	20	4
1844	44	26	5
1852	48	30	6
1875	48	32	6

II

Comparative Data on the Four Delaware & Hudson Aqueducts*

	Delaware	*Lackawaxen*	*High Falls*	*Neversink*
Number of spans	4	2	1	1
Center-to-center span length (feet)	(see page 17)	114.37	145	170
Number of cables	2	2	2	2
Diameter of cables (inches)	8½	7+	8½+	9½
Total number of wires in each cable (see page 15)	2150	1624	2300	2880
Weight of cable per foot (pounds)	122.75	90	125.7	170
Weight of water in one span at 6′–6″ depth (tons)	489 (142-foot span)	424	538	632
Working tension on both cables (tons)	771	552	790	998
Ultimate tensile strength of both cables (tons)	3870	2900	4100	5200
Roebling's contract price	$41,750.	$18,650.	$20,400.	$24,900.
Cost per foot of suspended trunk (see page 10)	$78.00	$82.00	$141.00**	$146.00**

*Mostly from *Notes* (326), various pages.

**The per-foot cost of Neversink was greater because of the larger cables and anchorage ironwork, a function of the higher price normally paid for a longer than for a shorter span.

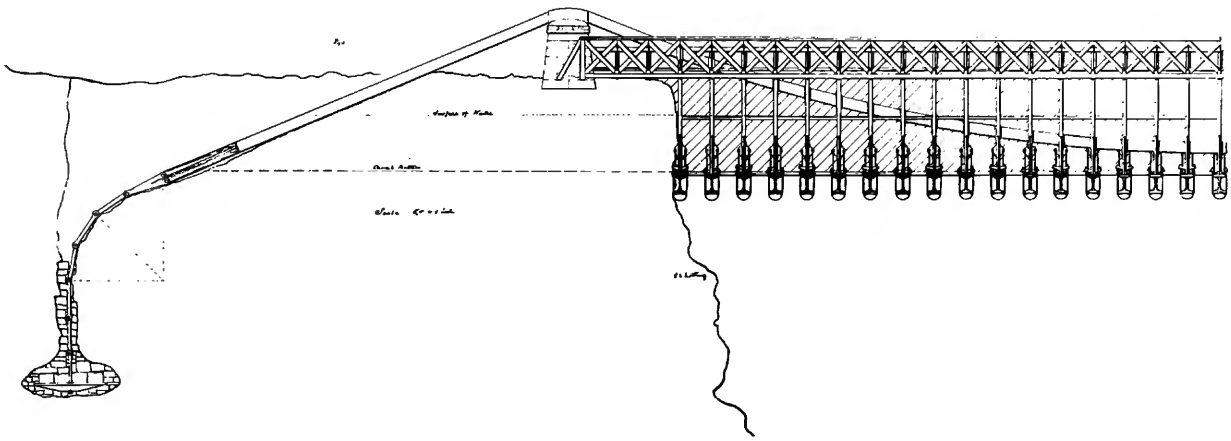

FIGURE 56.—Suspension aqueduct design by Washington A. Roebling. See Appendix III.

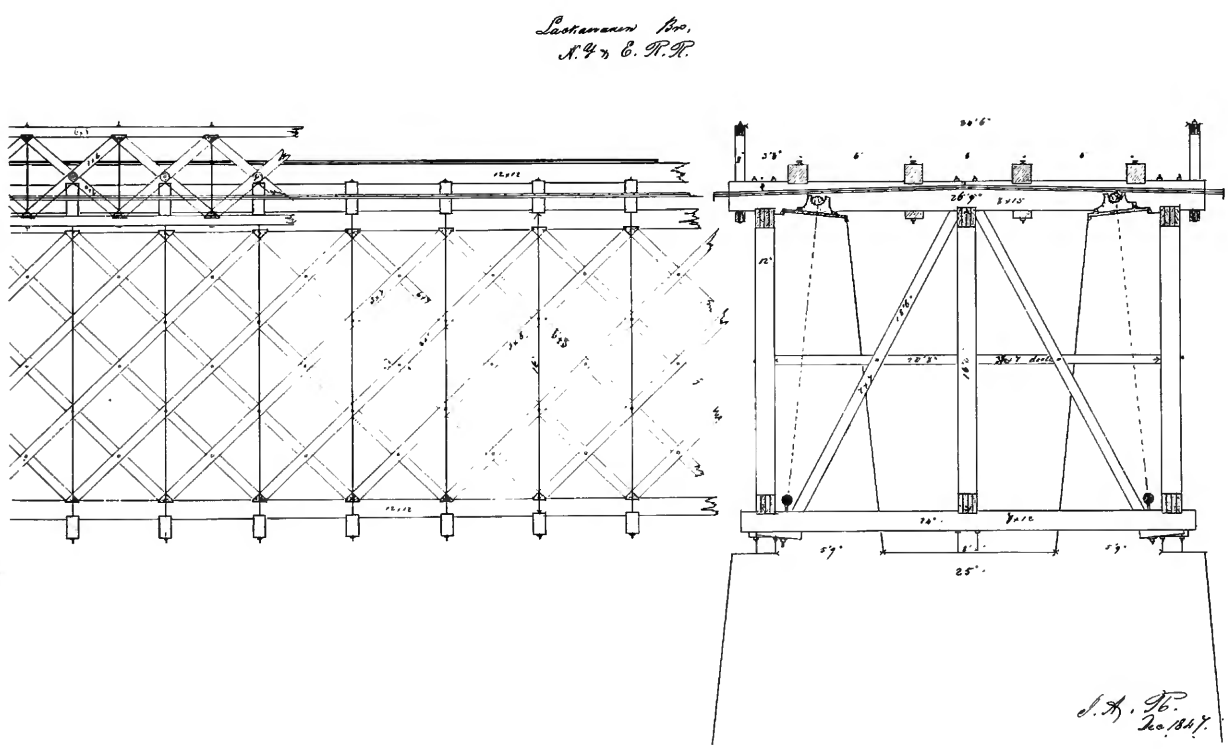

FIGURE 57.—Proposal for the New York and Erie Railroad suspension bridge at Lackawaxen. See Appendix IV.

III

Design for a Suspension Aqueduct

This design for a suspension aqueduct is from the senior thesis of Washington A. Roebling (1837-1926), class of 1857, Rensselaer Polytechnic Institute. While his design admittedly follows closely those of his father's Delaware & Hudson aqueducts, Washington Roebling proposed a number of modifications, necessitated principally by the greater loads imposed by a 164-foot span, 40-foot trunk width, and 7-foot water depth. The width, the same as that of the aqueducts on the enlarged Erie Canal, would pass two large boats abreast. The changes were mainly quantitative—use of two 14½-inch cables on each side of the trunk with other elements proportionately heavy—but the design also specified built-up wrought-iron plate girders for the floor beams and wire-rope suspenders, both significant departures from the Delaware & Hudson aqueducts. (Courtesy Rensselaer Polytechnic Institute.)

IV

Proposed Railway Suspension Bridge

This proposed suspension bridge was designed to carry the New York and Erie Railroad over the Lackawaxen River near the aqueduct site. Designed by Roebling while building the two aqueducts at Lackawaxen, it had many characteristics in common, particularly in the cable and anchorage systems. The deep, lattice-truss-stiffened deck closely forecast that used in his Niagara railroad bridge begun four years later. The estimated cost for the bridge, with two spans of 195 feet each, was $11,040 for a single-track structure and $22,080 for a double. (*Suspension Bridges Dec 1847 John A. Roebling,* page 27.) (Courtesy Rensselaer Polytechnic Institute.)

V

Neversink Aqueduct

Comparison of Roebling's Proposals for a 1- and a 2-span Structure*

	1 span	*2 span*	*1 span as built***
Clear span length (feet)	170	2 @90	160
Cable diameter (inches)	9½	6¾	9½
Cable length (feet)	261***	266***	203
Cable weight, both, with wrapping (tons)	46.5	23	36
Cable cost @ 10 cents per pound	$9,200	$4,600	$7,490
Anchor chain weight, total (tons)	13	4.5	22
Total cost	$24,900	$18,000	24,900

**Suspension Aquaducts . . Febr. 1847.* Data, about November 1847.
***Never Sink Aquaduct . . . Oct. 1848.*
***The early plans proposed running the cables on the west shore through chases in solid rock directly to the anchor plates, as had been proposed for the High Falls Aqueduct, without intervening anchor chains. Distance, saddle to plate, 62 feet.

VI

The Delaware Aqueduct Saddles

(See Figure 47)

Not all of the modifications to the Pittsburgh Aqueduct design made at Lackawaxen were for the better. In *Wire Cables & Machinery . . August 1848,* Roebling observes that the saddle pattern employed in the first two Delaware & Hudson aqueducts is unsatisfactory in having the seat for the cables too wide. At Pittsburgh, the space was just about as wide as the cable diameter so that the cable's circular section was preserved as it passed through the saddles. At Lackawaxen, he used a width of 11 inches causing the 8½-inch cables to flatten considerably at that point, destroying the roundness of the strands and cables near the saddles and causing unequal tension in the individual wires (see also Figure 22). Despite these misgivings, the saddles of the two later aqueducts apparently were cast from the same patterns for the same widening and flattening is evident at High Falls (Figures 35 and 36).

Bibliography

Delaware & Hudson Canal Aqueducts

BOOTH, MALCOM A. "Roebling's Sixth Bridge, 'Neversink'," *The Journal of the Rutgers University Library,* volume 30, number 1 (December 1966), pages 12-20.

BOYNTON, H. C. "Bridge Wire Tested After 75 Years," *The Iron Age* (9 February 1928), volume 121, page 400.

A Century of Progress—History of the Delaware & Hudson Company 1823-1923. Albany (J. B. Lyon Company, printers), 1925. Pages 108, 138-41, 195.

The Delaware and Hudson Canal—A Brief Chronology 1763-1915. The Canal Museum: Syracuse, New York, 1966. [Three mimeographed pages.]

Delaware & Hudson Canal Company. *Annual Reports* for various years, New York.

JAKKULA, A. A. *A History of Suspension Bridges in Bibliographical Form.* Agricultural and Mechanical College of Texas, College Station, 1941, pages 127-8 (Pittsburgh Aqueduct); 133-4 (Delaware); 138 (Rondout); 140 (Lackawaxen and Neversink). [General dimensions and brief descriptions; bibliographies.]

LEROY, EDWIN *D. The Delaware & Hudson Canal—A History.* Honesdale: The Wayne County (Pennsylvania) Historical Society, 1950. Pages 48-53.

List of References on the Delaware & Hudson, 1923. [Mimeographed list compiled by Bureau of Railway Economics, dealing mostly with the railroad but some canal references.]

"Mr. John A. Roebling," *Journal of the Franklin Institute* (6 November 1867), volume 54, page 411. [Describes briefly all four Delaware and Hudson Canal aqueducts as well as Roebling's six other bridges, including the nascent Brooklyn Bridge.]

SCHUYLER, P. K. "Lackawaxen Suspension Bridge Rebuilt for Present-Day Use," *Engineering and Contracting* (November 1930), volume 69, page 421 [Describes plans of Federal Bridge Company, which recently purchased bridge, to rebuild it.]

SHAUGHNESSY, JIM, *Delaware & Hudson—The History of an Important Railroad Whose Antecedent was a Canal Network to Transport Coal.* Berkeley, California: Howell-North Books, 1968. Pages 6-13. [General description of the four aqueducts and the canal in general.]

"Suspension Aqueduct on the Delaware & Hudson Canal," *American Railroad Journal,* volume 22 (13 January 1849). [Describes canal enlargement and gives statistics and rationale of structure.]

STEINMAN, DAVID B. *The Builders of the Bridge—the Story of John Roebling and His Son.* New York: Harcourt, Brace and Company, 1945; revised edition, 1950, pages 101-105.

United States Geological Survey quadrangle maps, 7.5 minute series, showing Delaware & Hudson suspension aqueduct sites: Delaware and Lackawaxen, *Shohola, Pa.-N.Y.*, 1965; High Falls, *Mohonk Lake, N.Y.*, 1964; and Neversink (Cuddebackville), *Otisville, N. Y.*, 1942.

WAKEFIELD, MANVILLE B. *Coal Boats to Tidewater—the Story of the Delaware & Hudson Canal.* Printed by Steingart Associates, South Fallsburg, New York, 1965. Pages 79-92.

WHITFORD, NOBLE E. *History of the Canal System of the State of New York.* Albany, 1906. 2 volumes. [Supplement to the *Annual Report of the State Engineer and Surveyor of the State of New York for 1905*].

"Wire Suspension Bridge," *American Railroad Journal* (7 July 1849), volume 22, page 421. [Physical description and dimensions.]

American Railroad Journal, volume 18 (9 October 1845), pages 648–649.

Roebling's Allegheny Aqueduct and Monongahela River Bridge

American Railroad Journal & Mechanics Magazine, volume 17 (1844).

JAKKULA, A. A. *A History of Suspension Bridges in Bibliographical Form.* Agricultural & Mechanical College of Texas, College Station, 1941, pages 127-130. [General dimensions and brief descriptions; bibliographies.]

MAHAN, DANIEL H. *An Elementary Course of Civil Engineering,* New York, 1867, pages 272-76. [There are earlier and later editions as well.]

"Mr. John A. Roebling," *Journal of the Franklin Institute* (6 November 1867) volume 54, page 411. [Describes briefly all four Delaware & Hudson Canal aqueducts as well as Roebling's six other bridges, including the nascent Brooklyn Bridge.]

STEINMAN, DAVID B., *The Builders of the Bridge—the Story of John Roebling and His Son.* New York: Harcourt, Brace And Company, 1945; revised edition, 1950, pages 78-100.

"Suspension Aqueduct on the Delaware & Hudson Canal," *American Railroad Journal* (13 January 1849), volume 22, pages 21-22.

WHITE, JOSEPH, and VON BERNEWITZ, M. W. *The Bridges of Pittsburgh.* Pittsburgh, 1928, pages 97-98.

UNPUBLISHED SOURCES

Two bodies of Roebling manuscript papers exist: The Roebling Collections in the Library of Rensselaer Polytechnic Institute, Troy, New York, and in the Special Collections of the Library of Rutgers University, New Brunswick, New Jersey. The former is a collection of vast scope and immense value, covering all of John A. and much of Washington A. Roebling's professional careers. There are many notebooks, letters, and reports, but the collection's crowning glory is a large number of drawings and sketches—design, presentation, study, and working. The entire collection was recently classified and cataloged by the author with a grant from the American Society of Civil Engineers. A published version is anticipated. The Rutgers Collection, while smaller, contains some material of great technical interest as well as personal items in the form of letters, diaries, and other documents. There is little graphic material. The collection is readily accessible and well cataloged. Oddly, the technical material in both collections overlaps to a considerable extent, the result apparently of haphazard handling and storage while the material was passing through various family hands.

The first nine references below are all manuscript notebooks. The first four are from the Rensselaer Polytechnic Institute Collection; the next five from the Rutgers. Various other Rensselaer Polytechnic Institute letters, notes and drawings are cited individually, for which the Library catalog number is given.

Rensselaer Polytechnic Institute Collection

Cash Book—Delaware & Hudson Aquaducts [*sic,* Roebling consistently spells the word this way] *July*

1847 to June 1850 [first entry, 24 July 1847 for labor and freight to Lackawaxen site]. Roebling Sci-Tech 300.

Diary for 1847 [entries only to February, but covering R. F. Lord's Pittsburgh visit]. Roebling Sci-Tech 283.

Notes on Suspension Bridges (no date, about 1844-1855) [Contains a great amount of data on his own and other suspension bridges, from observations, calculations, and publications. Much early design work for the Niagara Bridge, and both design and as-built data on the canal aqueducts.] Roebling Sci-Tech 326.

Notes on Suspension Bridges 1860 [Similar to 326 above.] Roebling Sci-Tech 271.

Rutgers University Collection

Ledger John A. Roebling [Pittsburgh] Aquaduct, Monongahela Bridge. [Also covers early work on the Delaware and Lackawaxen aqueducts, particularly the contract work done in Pittsburgh on the anchorage iron in mid-1847.]

Never Sink Aquaduct High Falls Aquaduct Oct. 1848 John A. Roebling. [Much additional design data and calculations.]

Suspension Aquaducts Delaware and Hudson Canal John A. Roebling Febr. 1847 Delaware A. Lackawaxen Never Sink High Falls. [Contains the basic design data for all four structures, including cost estimates for the Neversink and High Falls spans.]

Suspension Bridges Dec. 1847 John A. Roebling. [Principally design studies for bridge projects, e.g., over Genessee River, water-main aqueduct over East River, railroad bridge over Lackawaxen and Delaware & Hudson Canal (see Appendix IV); but also one page of post-mortem observations, with sketches, on Delaware Aqueduct cable making.]

Wire Cables & Machinery August 1848 Important General Remarks Construction of Delaware A: Cables Niagara Bridge. [Nine pages of extremely detailed post-mortem notes, remarks, and comments on the cable making procedure at Lackawaxen, compared frequently with that at Pittsburgh.]

Others

Letter to L. N. Edwards from L. A. Porter, Bridge Engineer, Pennsylvania Department of Highways, 26 September 1950, giving certain data on the bridge from the memory of a "Mr. Black." [Division of Mechanical and Civil Engineering, Smithsonian Institution.]

ROEBLING, WASHINGTON AUGUSTUS. *Design for a Suspension Aquaduct.* Senior thesis (manuscript), Rensselaer Polytechnic Institute. Troy, New York, 1857. [Original, Rensselaer Polytechnic Institute Library; microfilm and Xerox reproduction, National Museum of History and Technology Library, Smithsonian Institution.]

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