TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XVIII.

JANUARY TO JUNE, 1888.

NEW YORK:

PUBLISHED BY THE SOCIETY.

1888.

PLATE XL.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

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387.

(Vol. XVIII.—June, 1888.)

THE CONSTRUCTION OF THE POUGHKEEPSIE BRIDGE.*

By JOHN F. O'ROURKE, M. Am. Soc. C. E.

Some years ago, when the scheme of bridging the Hudson River at Anthony's Nose was a subject of frequent discussion, it was suggested by the Poughkeepsie newspapers that the physical, geographical and commercial advantages of their city made it the best point at which to locate the proposed crossing. The idea grew among the citizens, and through their efforts, the Legislature of 1871 was induced to grant a charter for its construction. In it was a clause prohibiting piers in the river.

During 1871 the promoters had surveys made and the engineering features examined. Eminent authorities were consulted as to the possibility of spanning the 2 600 feet between the shores with a suspension bridge. Among others, Captain Eads declared the span too long for practicability and recommended four piers in the river, not less than 500 feet apart in the clear. These facts were presented to the Legislature of 1872, and the charter was amended so as to permit of their construction.

In 1873, the Pennsylvania Railroad, represented by J. Edgar Thomson and A. D. Dennis, subscribed $1 100 000; the capital stock being

*The substance of this paper was presented at the Convention of 1887, but was withdrawn for revision by the author.

$2 000 000. The control passed into their hands and the immediate building of the bridge seemed assured.

The charter required that the work should be begun before January 1st, 1874, so a part of the foundation of a pier was built on Reynolds' Hill, near the site of the present east anchorage pier, and on December 17th, 1873, in the presence of a distinguished company, the corner-stone was laid with elaborate Masonic ceremonies and general rejoicing. On February 22d, 1887, this stone, with its contents untouched, was removed, and placed without ceremony or addition, in the southwest corner of the anchorage pier adjoining.

The financial world was at that time suffering depression from the panic, and money was hard to get for anything, however promising. During the following winter Mr. Thomson died, and the Pennsylvania Railroad voted that no new work should be undertaken without the consent of the stockholders. This was not to be had, so the directors could do nothing, and the project rested until 1876, when a contract was entered into with the American Bridge Company of Chicago, and the actual work of building begun.

The first river pier from the west shore was built by them to a height of 20 feet above water; the crib of the next pier sunk through 55 feet of water and 40 feet of river bed, with its top 1 foot above high water; and a third crib built, 36 courses high, but not placed, when the company suspended work in 1878.

From then, nothing was done but to keep the charter alive by extensions of time, until 1886, when a number of gentlemen, forming the Manhattan Bridge Building Company, took up the project. They acquired the rights of the American Bridge Company's assignees, and made a contract with the Union Bridge Company for the entire structure complete.

In September, 1886, operations were begun. A line, practically the same as the old one, was adopted, surveys and borings were made, and a profile obtained, from which the location of the piers was determined.

The former design was for rectangular trusses of equal lengths. The location of the second span of the new design was fixed by the existing pier; and its length of 525 feet by the 500 feet of clear span and the 25 feet of masonry required. The same length of span to the west, would place Pier 1 in the West Shore Railway tracks. A pier on the east slope of the railway would be inadmissible. The most available site was on the bluffs west of the highway, and this was selected. By this time a cantilever design had been decided on, and the 530 feet center to center of end pins necessary to reach these bluffs was made common for all three cantilever spans. This clear span, with the half-widths of towers added, made the spans next the shores 548 feet and the center span 546 feet, which with the two connecting ones, of 525 feet, center to center of piers, located Pier 6 in the face of the rock on the east shore. The total length between anchorages was thus established at 3 093 feet 9 inches, the total length, including viaducts, 6 767 feet 3 inches.

The charter fixed the bottom of trusses at 130 feet above high water; so the height of trusses proportionate to the spans required the adoption of 212 feet above high water as the grade of base of rail. The west approach has a rise of 66 feet per mile westward out of the valley of the Hudson, and the same grade was adopted on the viaducts, since it did not further limit the size of trains.

After the adoption of the general design, the next thing was an accurate location. The West Shore road-bed is level and advantageous for base lines. Two were laid out there, each about half a mile long, intersecting the center line at a common point. The triangles had a point on center line on the east shore for a common vertex, and were nearly isosceles. The bases were measured with a common 100-foot steel ribbon with brass handles, and without a spring balance or leveling attachment. Chaining in the sunshine was avoided, so correction for temperature was exactly determined. Plugs were driven flush with the ground every hundred feet, line taken, and then, with the chain suspended, and under strong tension, a distance point was decided on after a few trials. On level ground, like the West Shore road-bed, errors of over a half inch to the mile would be carelessness.

The angles were measured with a Heller & Brightly tunnel transit. Twenty repetitions were made at each station, a reading was taken every time and the difference from the preceding obtained, to guard against errors caused by the slipping of the plates. One-twentieth of the twentieth reading gave the angle to the fraction of a second. A third triangle was measured from the south base line with a vertex on center line 82.07 feet west of that used before.

The angles of the north triangle had a deficiency of 7 seconds, those of the south triangle balanced exactly, and those of the third had an excess of 1½ seconds.

The distances as calculated were respectively 2608.66 feet, 2608.78 feet, and 2608.68 feet, average 2608.71 feet. 2608.82 feet was the distance subsequently obtained by measuring across on the ice. Some more recent triangulation of two points on the eastern shore, invisible from each other, for use in locating cribs 4 and 5, incidentally gave this distance as 2608.60 feet, although great accuracy was not intended. The triangulation to crib 3, pier 2, and upon the west bluffs, was equally satisfactory, several independent triangles differing from each other only minutely.

These triangles are all shown on the accompanying map, Plate LVI.

Work proper was begun October 8th, 1886, excavating for foundations of Pier 1; that for Pier 6, October 20th; east and west anchorages, November 10th.

Masonry of Pier 6 was begun December 6th, 1886, and finished February 17th, 1887; Pier 1, January 7th, 1887, finished March 17th; east anchorage, February 8th, finished March 23d, and west anchorage, January 26th, finished May 9th.

All shore work is first-class bridge masonry, the hearting being generally concrete. Built in each anchorage pier are four iron girders, underneath which are cross-girders, connected with eye-bars to the pedestals of the shore arms. The piers are heavier than is necessary to resist any possible effort of the cantilever spans to lift them.

The borings show the river bottom to be composed, for more than 100 feet below high water, of various combinations of mud, clay and fine sand, too soft for building upon. Underlying this pasty stuff is a very firm and hard stratum of rather coarse sand, beneath which is gravel, and about 140 feet down, solid rock extending from shore to shore.

The general design of a pier is a crib and grillage, extending from the gravel to 10 feet below high water, on this is the masonry to 30 feet above high water, upon which is a steel tower 100 feet high to pedestals of trusses. Plates XLIV, XLVI, XLVII and L.

The cribs are practically alike, so No. 5 will be described. The base is 60 x 100 feet, and the height 104 feet. It is built of 12 x 12-inch white hemlock, except the bottom course, which is of white oak. The lower part or shoe is composed of five prisms of solid timber, 20 feet high, the cross-sections of which are triangular with the bases on top, the vertices lying in the five cutting edges which divide the bottom into two rectangles each, 30 x 100. The top surface of this shoe is 10

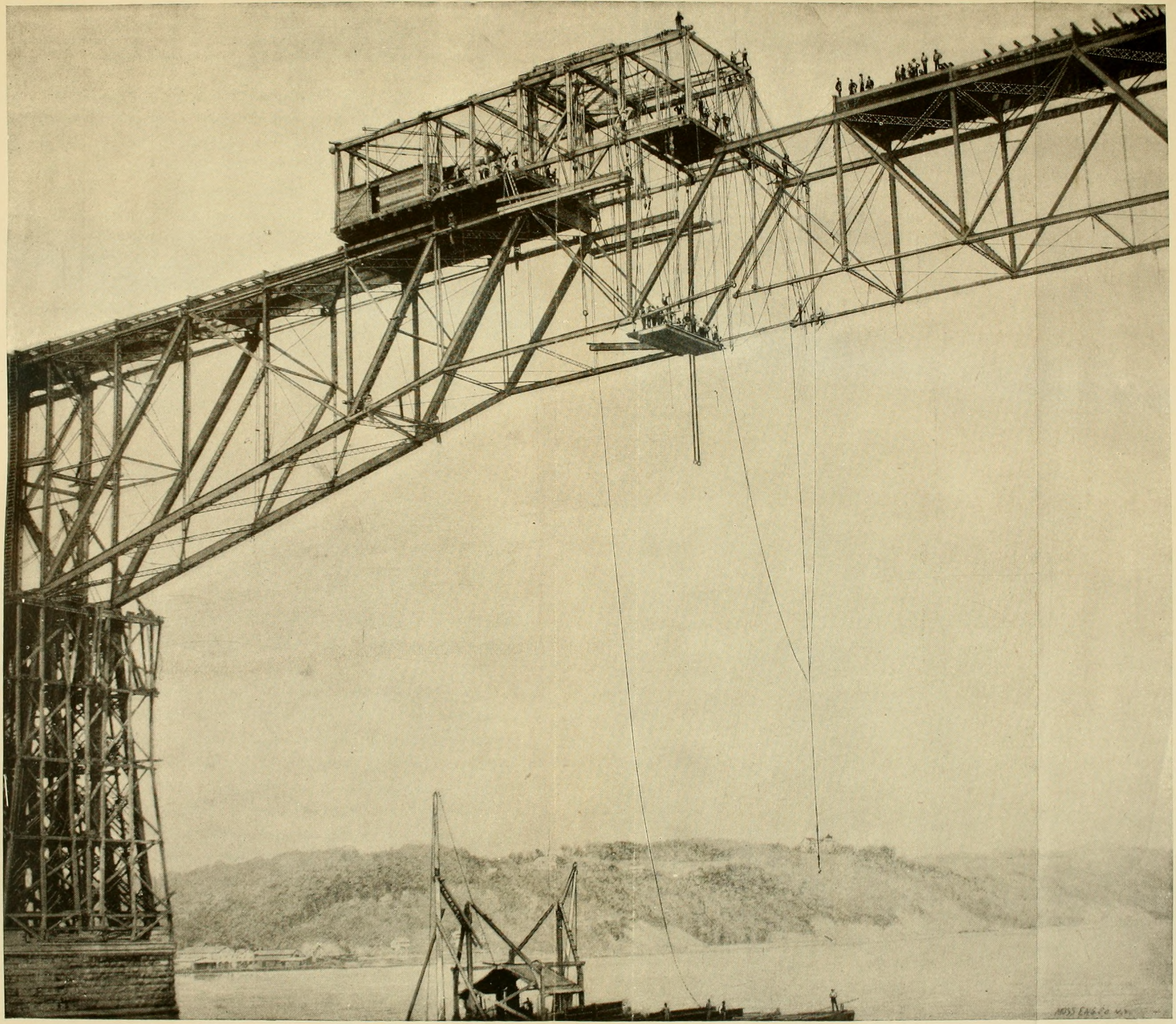


PLATE XLI.

feet wide at the sides, 9 feet at the ends and 16 feet in the middle. These prisms inclose two truncated pyramidal spaces, the tops of which are 12 x 82 feet. These spaces are divided into fourteen smaller ones, by six bulkheads of timber, 2 feet thick, that are built into the solid cribbing from the cutting edges up. These subdivisions are called the dredging chambers, and are 10 x 12 feet on top. Upon the shoe rest the weighting pockets. The walls of these are of 12 x 12 timber, 2 feet thick, and built along on the edges of the top surface of the shoe, and on the bulkheads of the dredging chambers. They, in every instance, intersect each other and extend from out to out of the crib. The building is done without halving, by laying all the longitudinal timbers of one course across the intersections, the transverse ones being cut the length of the spaces between. The next course is laid with the transverse timbers running across the intersection, while the others are fillers.

The drift bolts used are 1 inch round by 30 inches long, 450 to each course. The number was determined by learning from experiment that a 1-inch bolt driven into a $\frac{15}{16}$ hole adhered about 422 pounds per linear inch. It was assumed that the buoyancy of all the parts above the solid cribbing could act at once on all the bolts through that joint. The number of bolts giving a safe excess of resistance was made uniform for all the courses.

The openings over the dredging chambers are the passages through which the dredge bucket descends. They are called the dredging pockets.

Cribs may be built for some height on ways and launched, or they may be built on the ice about three courses high and cut in. Building is continued alongside a wharf until the draft is nearly the depth of the river, when it is taken to the pier site, anchored, set, the weighting pockets loaded with gravel to keep the top at a convenient distance above the water, and built upon until it is embedded in the mud. Weighting, building and dredging are then carried on with more or less continuity until the crib has reached its final resting place.

The borings give an approximate idea of how far a crib should go to reach a reliable bottom, sufficiently close for general plans, but the dredge bucket is better, and a close attention to its working and contents gives a true idea of the character of the strata.

Twenty feet below high water was adopted as the depth to which the top of the crib was to be sunk, so it follows that it must be finished off, while it has yet about twenty feet to go. When dredging begins there is no side friction. The material is soft, and the crib follows the dredging easily and evenly. When the crib has penetrated perhaps 20 feet into the bottom, the material is more compact and side friction has become considerable. It no longer moves steadily, but by intermittent, though gradual descents. Toward the end the crib hangs until the bottom is undermined, when it drops sometimes as much as 10 feet at once, its motion being like that of a weight set free on the surface of a thick, soft cushion; and it comes to rest without jar. The dredge can only dig well holes, whose areas are about one-fourth that of the bottom of the crib, and it must depend upon the material falling in from the sides for the greater part of the excavation. These holes are often 30 feet below the cutting edge when in hard material, which is not sand, so a timely knowledge is obtained of how far down the crib should go, and to what height it should be built. The top course timbers floor over the entire surface, except the dredging pockets, after the weighting pockets have been filled flush with the course below. Upright timbers, about thirty feet long, are then fastened to the inner sides of alternate pockets to indicate to the dredge runner their position when under water, and clusters of piles are driven around the crib for the dredge to lie against when the former is below the surface of the water. Toward the end the dredging must be done with great care, and only a few bucketfuls removed from each pocket as the dredge goes round and round the crib. It was found that when out of level in hard material a crib righted itself if the material was left highest on the high side, as the momentum in falling is greatest there. In soft material, the crib settling slowly along with the dredging, that keeping the bottom low under the high part, remedied the difficulty. When the crib has made its final descent all the loose material is dredged out, and filling the dredging chambers and pockets with concrete is begun.

The concrete is lowered into place in boxes carrying a cubic yard; a tag line attached to a trip unlatches them at the proper time, and it is deposited without being scoured. These boxes are hung over the ends of scows, from which project the mixers. The latter are simply rectangular boxes of plate iron, provided near each end with cast-iron collars, each grooved to retain itself on a couple of wheels, and are turned by means of a small engine which forms part of the machine. A jet of water inside and a curved pipe to the level of the mixing deck for feeding, completes an effective machine. The mixer is set at an inclination of about 4 degrees, so that the concrete may pass along as it is rapidly turned over and over. On the deck of the scow gravel is mixed dry with 1½ barrels per cubic yard of cement, whence it is wheeled in barrows or cast into the feed pipe. By this method 400 cubic yards are placed by two outfits in ten hours. The accompanying drawing, Plate XLVII, shows the operation at Crib 3. When the crib is filled with concrete to within 2 feet of the top of pockets, the remaining part is filled with broken stone and leveled by divers.

The floating caisson is then towed to place over the crib, fastened with four anchors, and the masonry begun. When the caisson is just afloat at high water only, it is accurately set, and masonry and loose stone enough to hold it down put in before the next high tide. Then an exact location of the pier is made, using a suspended piano wire to lay out the span. From this point on the work is ordinary building until the masonry is completed and ready for the steel tower. The ashlar is in courses varying in thickness from 2 feet 9 inches to 1 foot 10 inches. The use of concrete backing, with large stones imbedded in it, enables about 125 cubic yards per day to be laid, and gives a pier which is practically a monolith.

Domestic cement is used in the concrete for the cribs, Portland cement in the masonry. The mortar is mixed of one part cement and two parts sand, and the concrete backing contains 1½ barrels per cubic yard. All cement is rigidly tested in the manner recommended by the American Society of Civil Engineers. Ten per cent. of the barrels are sampled.

The testing machine used was designed by the writer for this work. Its capacity, which can be readily increased, is 1 000 pounds, and it is simple, compact and reliable. From the drawing attached, Plate XLIII, it can be easily duplicated by an ordinary mechanic.

It is worthy of note that the best results were obtained when the opening between the jaws of the clips had been increased to 1¼ inches. With a smaller opening the briquettes broke where held, instead of at the smallest section. Even with the enlarged opening the older briquettes often break at the clips.

Pier 2, as before stated, was built to 20 feet above high water by the American Bridge Company. It was 22 by 68 feet, and was to have been carried to top of bridge. The steel towers designed by the Union Bridge Company require piers 25 by 87 feet, and consequently the old masonry was too small. (See Plate XLVIII.)

The crib of this pier is like the one described, differing only in that it is 10 feet narrower, that all the pockets are filled with concrete, and that it has iron cutting edges. It was begun in August, 1876, and launched in March, 1877.

During that season it was brought to place and completed. Its upper eight courses were calked, and a coffer-dam was built upon it. This was begun while the top was yet out of the water, and continued as the crib settled.

When in place, the cutting edges were 100 feet below high water, and the top 30 feet below same. After the dredging chambers and pockets were filled with concrete, the coffer-dam was pumped out. The upward pressure of a 38-foot head proved greater than the united resistance of drift bolts, concrete and weight of everything above bottom line of calking. The whole mass above that line lifted at the north end, hinging at the south end. As the water entered it settled back, but the bolts and débris prevented its closing, and left a space of about 8 inches at the north, which runs out to nothing before reaching the south.

A bearing below this rupture was obtained by sinking a pneumatic caisson 8 feet through the crib. It is 16 feet high, and the top is 22 feet below high water. Upon this rests the masonry.

To remove this masonry from the top of the caisson, or to in some way avoid doing so, and yet construct a good homogeneous base for the larger pier, was the problem.

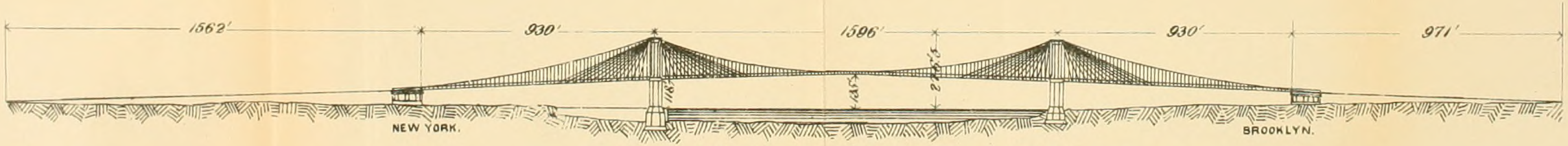
The crib is 50 by 100 feet, the pneumatic caisson 29 by 74 feet and 8 feet higher, so it was decided to sink a coffer-dam 43 by 96 feet 6 inches down on the top of the crib, fill up the inside with concrete to a point a little below that from which it would be necessary to remove the stone, pump out the coffer-dam, take down the old masonry, tie together securely the coffer-dam, concrete and old pier, and cover the whole with more concrete, upon which the new masonry was to rest.

The building of this coffer-dam was begun January 20th, 1887. It is substantially two thicknesses of 12 x 12 timbers laid horizontally and separated by vertical timbers of the same size. The horizontal timbers were fastened through each post with ¾-inch round by 36-inch screw-bolts, the ends being held down by ¾-inch square by 24-inch drifts.

PLATE XLII
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII No 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

Forth Bridge.

Poughkeepsie Bridge.



New York and Brooklyn Bridge.

Illinois and St. Louis Bridge.

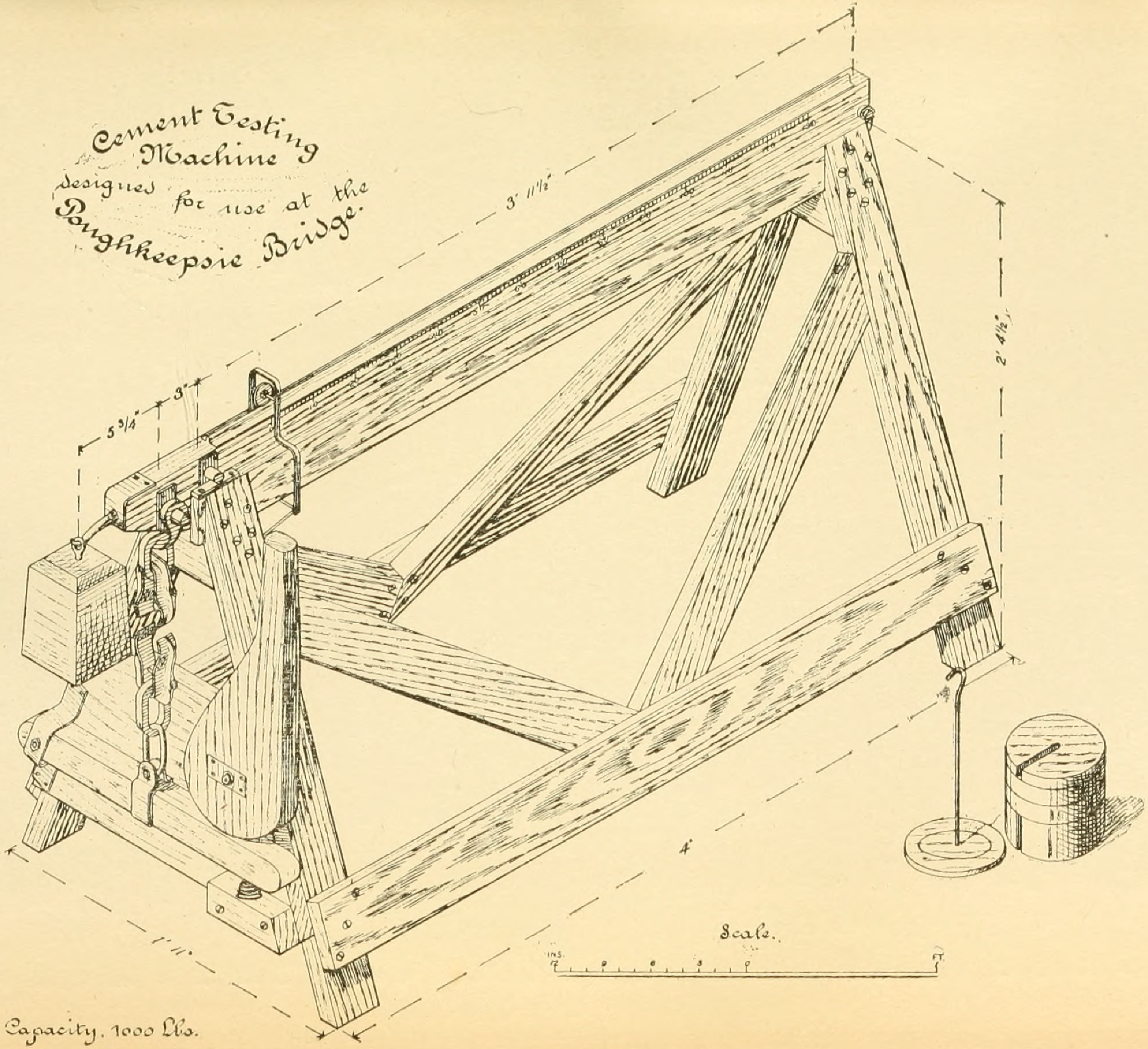

Cement Testing Machine
designed for use at the
Poughkeepsie Bridge.
3' 11½"
2' 4½"
5 3/4"
3"
4'
1' 11"
Scale.
INS.
FT.
Capacity. 1000 Lbs.

PLATE XLIII.

The bottom course had 12 x 12 fillers, making it solid, so that the spaces between the posts were pockets. These were filled 16 feet high with concrete, and the remainder with clay.

Building it was begun on the ice, and after three courses were laid it was cut in. About one-third of it floated above the water, and every course was calked on the outside before immersion. When some twelve courses were laid, concreting the pockets was begun and carried on at a rate to keep the top conveniently high above the water. This concrete was lowered in boxes 10 x 16 x 36 inches, and discharged through the bottom by means of a latch and tag line. When the filling changed from concrete to clay, the latter was shoveled in and rammed as well as could be done. It may be said here that it was a mistake to use clay, for it could not be rammed solid, and was constantly escaping and giving trouble. The coffer-dam was finished March 1st, 1887. In a few days it was brought to a good bearing on the crib, and all the inequalities under it were leveled by the divers with concrete in bags. Some of the concreting inside the dam was done while the ice would bear, after which, until the latter went out, work was suspended. When the river was again clear, concreting was resumed and carried up to 12 feet below high water Then the dam was pumped out and the old masonry removed to 9.5 feet below the same. Across the top of this were laid $1\frac{1}{2}$ x 2-inch iron bars; attached to each pair were semicircles 5 feet in diameter of the same size iron, having $\frac{1}{2}$ x 8-inch plates riveted on their inside. These hung over the masonry to a foot or two below, and were attached to the coffer-dam with stirrups of 2 x $\frac{3}{4}$-inch iron. The bolts of the dam have the nuts inside, so the ends of the stirrups simply took the place of the washers. Four similar bars run lengthwise through the pier, and are fitted to the ends of the dam in the same way. Everything was then wedged to a bearing, the water was admitted, and the whole covered with concrete to a foot above the old masonry. After a few days had been given the concrete to harden, the dam was again pumped out, and the new masonry begun. All the concrete used was composed of two parts of Alsen's Portland cement, three parts sand and six parts screened gravel. It was all deposited in water, and samples brought up by the divers as the work progressed, showed it to be as good as if it had been deposited in air.

The crib of Pier 3, as before stated, was 96 feet high, and the cutting edge down to 95 feet below high water when the Union Bridge Company

PLATE XLIV.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XVIII. No. 387.
O'ROURKE ON
POUGHKEEPSIE BRIDGE.

took the work. Some rotten timbers in the three top courses were replaced by sound ones, and four feet of solid cribbing was added, to bring it to a height of 100 feet, after which the dredging was begun. This went very slowly at first, and the crib did not settle until sand was reached, the buckets making only wells down through the clay. The sand, however, flowed into the holes, and the clay being undermined, the crib settled six feet at one end and four feet at the other. This was four weeks after dredging began. For the next two weeks it went down with comparative uniformity, when it again hung, the cutting edge being at elevation 118 feet. This is the level of hard sand, and as it was desired to get it into the latter a few feet, the dredging was continued. On May 21st it dropped between 7 and 8 feet, canting, at the same time, a couple of feet to the west. It had been leaning in that direction from the first, and the result of this last move was to make the center of crib 5 feet east of center of span, 1 foot higher on the east than on the west, and 1 foot higher on the north than on the south. The crib being 60 feet wide and masonry 25 feet, there is yet 12½ feet of crib outside the masonry on the east. As the resultant of pressures and center of bottom of crib practically agree, we felt no doubt of its perfect stability, yet for convenience in construction a week or more was spent dredging to the rock, and outside, on the east, to bring it level, but the crib remained immovable. The masonry is laid on a bed of Portland cement concrete, the top of which is level when the caisson rests on the crib.

Crib 4 had been moored nine years at the Whale Dock, Poughkeepsie. It was towed from there on Thanksgiving Day, 1886, to the south end of Crib 3. Five feet of rotten timber were removed, and then building upon it was begun with the thirty-second course and continued to the fifty-sixth, when it was ready for anchoring in place. This is a difficult operation under the most favorable circumstances, with the dead load of more than 5 000 tons. It is an unwieldy bulk, having a large vertical outside area submerged, and several thousand square feet additional of walls inside against which the current from underneath would act. It was drawing 52 feet of water.

The first preparation was to place anchors in the river and to leave the ends of the cable accessible. These anchors, as shown by the drawing, Plate LVII, are simply cribs, measuring on the inside 6 x 6 x 6 feet, and contain 8 cubic yards of broken stone. They are composed of 3 x 8-inch hemlock planks, 10 feet long, piled on each other so as to leave the above inside dimensions. Through the corners are eyebolts of 1¼-inch round iron, which serve the double purpose of binding the whole together and carrying the rope slings to which the cables are attached. There are also light screw-bolts through the middle of the sides to carry a cross-piece for reinforcing the bottom. When ready for filling these cribs are placed on greased ways on a scow, in the manner shown, usually one on each corner, and fastened with rope to the deck. They are filled with stone, the tops are put in, and, if not done before, slings of 7-inch rope are spliced through each pair of eyes and wrapped with sail cloth where liable to chafe. The slings are then gathered in iron thimbles, round which the cables are bent, and fastened with three clips each. They are then ready for launching.

The mode of placing is to tow the scow out to a range line marked on the nearest shore and shift about on that until signaled by a transit-man, when the rope attaching the anchor to the deck is cut, allowing it to slide overboard. The cable is slowly paid out until the end is brought to the pier site and buoyed, or made fast to a scow, in either case marked with a tag.

In the beginning three up-stream and three down-stream anchors, with two lighter ones for each side, were thought sufficient. At the first attempt to set Crib 4 there was delay in unmooring, and the spring freshet just setting in made the ebb tide early, so it had commenced running when we got away. Before proceeding far it grew too strong for the steamer, and the latter dropped back to Crib 3. Preparations were made to draw the crib up again where it had been. Two more steamers were attached, a cable to Crib 3 was put on a capstan and a line was connected to the cable of one of the anchors. The tide grew too strong, however, the new 9-inch towing hawser attached to the largest steamer broke, then the capstan was dismantled as the crib commenced to drift, and soon it was going down the river dragging three steamboats and one anchor with perfect ease. The crib was drawing within a few feet of the depth of the river in the deepest place and grounded once or twice, but the tendency in such cases is to follow the trend of the stream. It had gone three miles when the tide turned, after which it was brought back at midnight to Crib 3 without accident. This was, perhaps, the most difficult feat accomplished in connection with the work. A full and very bright moon, and an entire absence of wind alone rendered it possible.

This experience and the fact that the freshet was hourly growing stronger gave a different idea of the force to be contended with. The number of up-stream and of down-stream anchors was increased to five, the ends of the cables were this time placed on a scow at the pier site, and on the afternoon of April 11th the crib was again towed out. The five up-stream anchors were fastened on before the tide grew strong, but when it did, the crib commenced dragging them slowly. Then surging set in, and soon the northeast cable parted, after that the northwest one, and then it dragged the other three anchors very readily. There was just time to fasten the five down-stream anchors when the crib brought up on them and was held. So it stood for three days, until the same number of anchors was again ready. Two of the up-stream anchors were behind clusters of piles. This time the crib was securely moored in place after several hours' hard work. There was some motion when the cables were drawn up tense. It was expected to stop this by grounding, but the bottom scoured as fast as the crib settled. On the 19th it commenced surging badly and dragging the anchors, and on the morning of the 20th parted the cables of the anchors behind the piles, dragging the others 300 feet down stream. On the next ebb tide several more cables were parted, the crib commenced to drift slowly down stream, and it seemed as if it would get away. The freshet at this time was so great that the tide did not run up stream in rising, and when the ebb was at its strongest, seemed to run in surges, one moment backing off from the cribs smooth and gentle, and the next breaking at one or both corners in angry potholes. The crib surged and dragged and plunged with exceeding force, and it seemed as if nothing could hold it. New anchors were being constantly attached, scow loads of which were following it up. In launching them allowance had to be made for the distance the crib would drift while the ends of the cables were being brought aboard and fastened, so that they would just reach and give the most favorable lead. Soon there were ten on which held. Two steamers kept the crib from turning around, and so things stood until the 22d. At this time half the anchors were parted, and she had to be brought up before the preparations were entirely complete, or else go out with the next tide. The crib was now drawing 56 feet, and on the way back to place had to crush several of the lost anchors. We were now very expert in handling cables, and soon had six anchors on her bow, as the up-stream end might be called. A cluster of piles was in front of each up-stream anchor. There were also five side anchors, two cables attached to Crib 3, and three anchors down-stream, when we left late that night, but in spite of all, the crib surged badly and two steamboats were kept pulling to steady it. The next morning two additional bow anchors and four more side anchors were put in. When they were all tightened up to perhaps 10 tons' tension each, the crib was immovable. Then it was felt that she had made her last trip. Two days more were occupied in setting her in position, clamping the cables permanently on horns outside, equalizing the tension, and removing the tackle.

It may be asked why we so underrated the forces to be controlled. At first, there was nothing to guide us but the experience of the builders of the first two cribs, and we used precisely what succeeded with them. Modifications were made as the necessity seemed to grow, and success was finally achieved when the working strength of the cables was nearly 1 000 tons. Their aggregate length was about three miles. Such a freshet in the Hudson is unexampled, and the work was done when it was at its worst.

The current, as measured, was about 2½ miles per hour, on an average, but there were times when it seemed more than twice that. There is no way of obtaining the exact pressure due to this cause under the circumstances, but one of the effects observed may give a good approximation to the stresses in the cables. When the tide was strongest, the end of the crib opposed sank two feet deeper than in still water, the other end rising about 6 inches. This is probably due to the vertical components of the stresses in the up-stream cables. The displacement was 2 000 cubic feet, or about 60 tons, of which, perhaps, 40 tons go to that end. Length of cable is to depth of water as eight to one, which would give, approximately, 320 tons as total stress in cables at north end, of which, perhaps, 240 tons went to the eight up-stream cables, the remainder to those side ones which were a little up-stream. So it would appear the cables were worked up to their limit, which was shown also by the strands drawing in places.

The anchors of Pier 5 were placed eight up-stream, six down-stream, and eight at the sides, as shown by drawing, Plate LVIII. The use of piles in front of them was abandoned, since the anchors never drew up to the clusters, except when the crib dragged from surging. They were placed in groups, so as to draw in nearly the same line. For putting the cables under tension, an engine having six spools was used with great success,

PLATE XLV.

as several could be tightened at one time, more equally, and to a greater strain than with men. This crib was towed out and made fast on the afternoon of May 25th. On that of the 26th it was placed exactly in position. No trouble was encountered at any time. The tide was not so bad as when Crib 4 was set, but the ebb was yet abnormally strong. The anchors were those used on Crib 4. They were lifted with a pile-driver, towed to their new positions and deposited without mishap. Notwithstanding the rough usage they had undergone, only one of those raised was found to be broken.

The dredging proceeded very evenly on Cribs 4 and 5. The daily progress of each, including building, loading and dredging, was about one foot per day. It is possible, by building during the day, and dredging and weighting by night, to double the speed.

This method of sinking foundations is applicable wherever mud, clay, or sand, has to be penetrated. While the bottom remains unsafe for founding on, it can be dredged, so there is practically no limit to the depth that may be attained.

It is not intended, in this paper, to treat of the design or manufacture of the superstructure, but some notes regarding the erection may be interesting. There are four sets of false-work for the main bridge, two sets for the shore arms, and two for the connecting spans. The former extend to the bottom of the upper chord. Their noteworthy features are great height, and the permanent character of the framing and bolting necessary to secure stability.

For the connecting spans, the depth of the water and the character of the river bed necessitate the use of compound piles 130 feet long. There are 22 bents of 24 piles each. They are made of two yellow-pine piles, with the butts dressed for a distance of 10 feet to an octagonal cross-section of 12 inches' diameter. These are spliced with eight pieces of spruce 4 x 5 inches x 20 feet long, fastened flatwise with $\frac{7}{16}$-inch boat spikes, 8 inches long, driven 1 foot apart. It occasionally becomes necessary to draw some of these piles. The bond is broken by additional driving. The first few blows upon the pile, with a 6 500-pound hammer and a fall of 4 feet, hardly move it, although when driven it went a foot with the final blow. When started in this way, it would hold together to be drawn out; and could then be suspended horizontally from the middle without showing less stiffness at the splice than elsewhere.

There are 528 piles for a span, arranged in sets of three under each post, firmly braced above low water, and fastened to the masonry at each end. The load on each pile will be about 5 tons, which the hammer test mentioned shows to be much less than its carrying capacity.

The caps of piling are 12 feet above high-water, and from them the trestle work extends to the bottom chord, an elevation of 130 feet. Details of this trestle are shown by accompanying drawings.

The deck of the false-work is occupied by four tracks. The two outer tracks are of 8-foot gauge, and upon these runs the large traveler for the erection of the span, which extends entirely across the space between these two outer tracks. The two rails next inside of these outer tracks are occupied by a hydraulic riveting apparatus, which spans the space, 19 feet wide, between these two rails. A single track of 4 feet, 8½-inch gauge at the center of the false-work, carries the cars conveying the material.

The traveler is composed of four bents, 95 feet high, 56 feet wide at the bottom, 62 feet at the top, and set 22 feet apart between centers. It encloses an opening 38 x 82 feet 6 inches, inside which the trusses are erected.

Some of the pieces to be handled weigh more than 20 tons each, so the derricks and rigging of the false-work and travelers must be proportionately strong. Two falls, of 16-inch triple-blocks, and 1¼-inch rope, are used in raising the very heavy pieces. Some of the engines have six spools, and handle independently that number of lines.

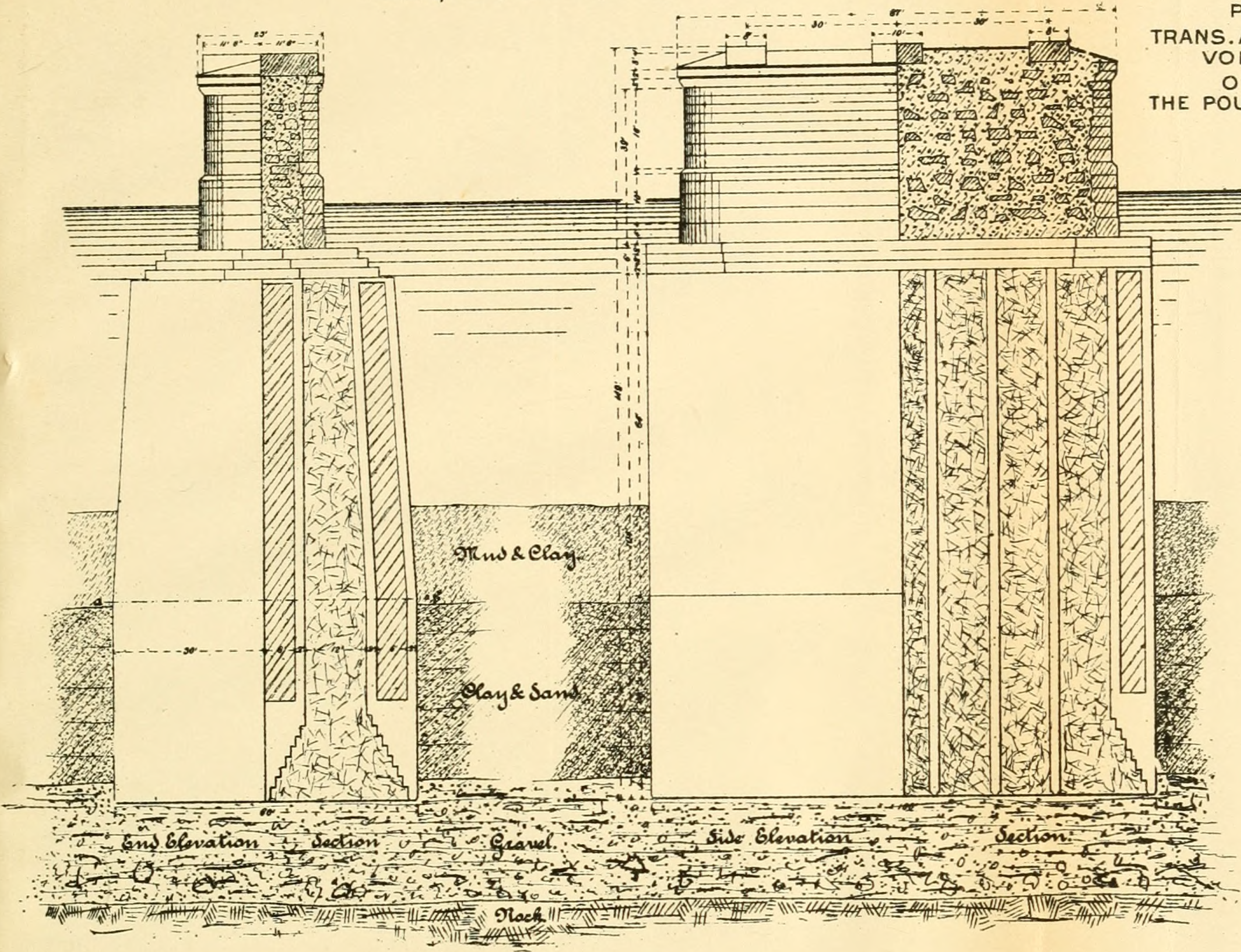
The hydraulic riveter is carried on a small traveler, so spanning the two middle tracks as not to interfere with the transportation of materials on them. It consists of a boiler, engine and pump, by which power is supplied to the accumulator in the form of water supporting a heavy weight. The jaws are hung with differential pulleys from a worm gear set upon projecting timbers of the deck, which revolves like a turn-table. By this means the jaws are readily adjusted to any rivet in the bottom chord.

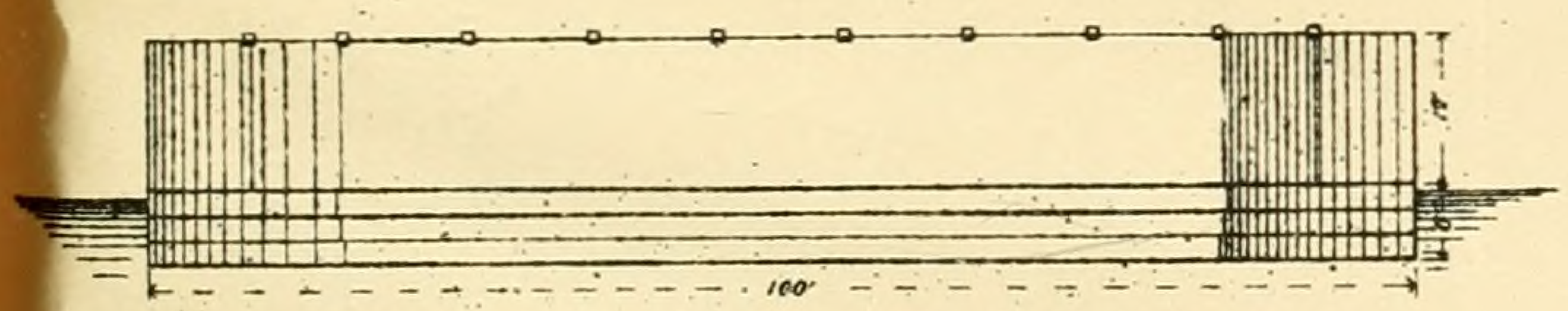
The towers at the ends of the span are first erected. Next, commencing at the fixed end, the bottom chord is laid along in place on camber blocks. The traveler then erects the span, commencing at the middle, and finishing each half successively.

From the shore arms and connecting spans 160-foot cantilevers are erected by means of projecting travelers, almost identical with those

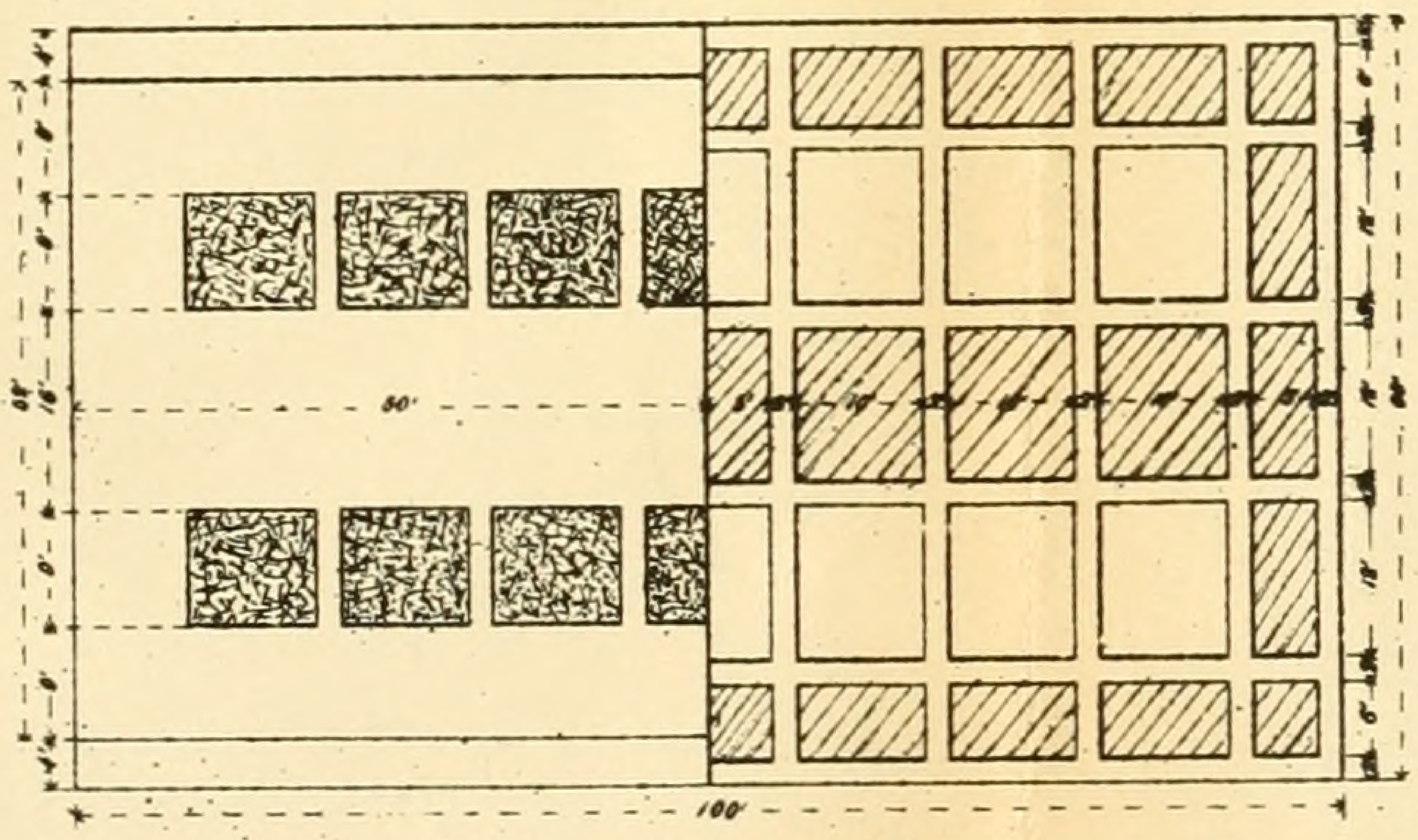
Crib, Grillage and River Pier, Poughkeepsie Bridge. –

PLATE XLVI
TRANS. AM. SOC. CIV. ENG'NS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

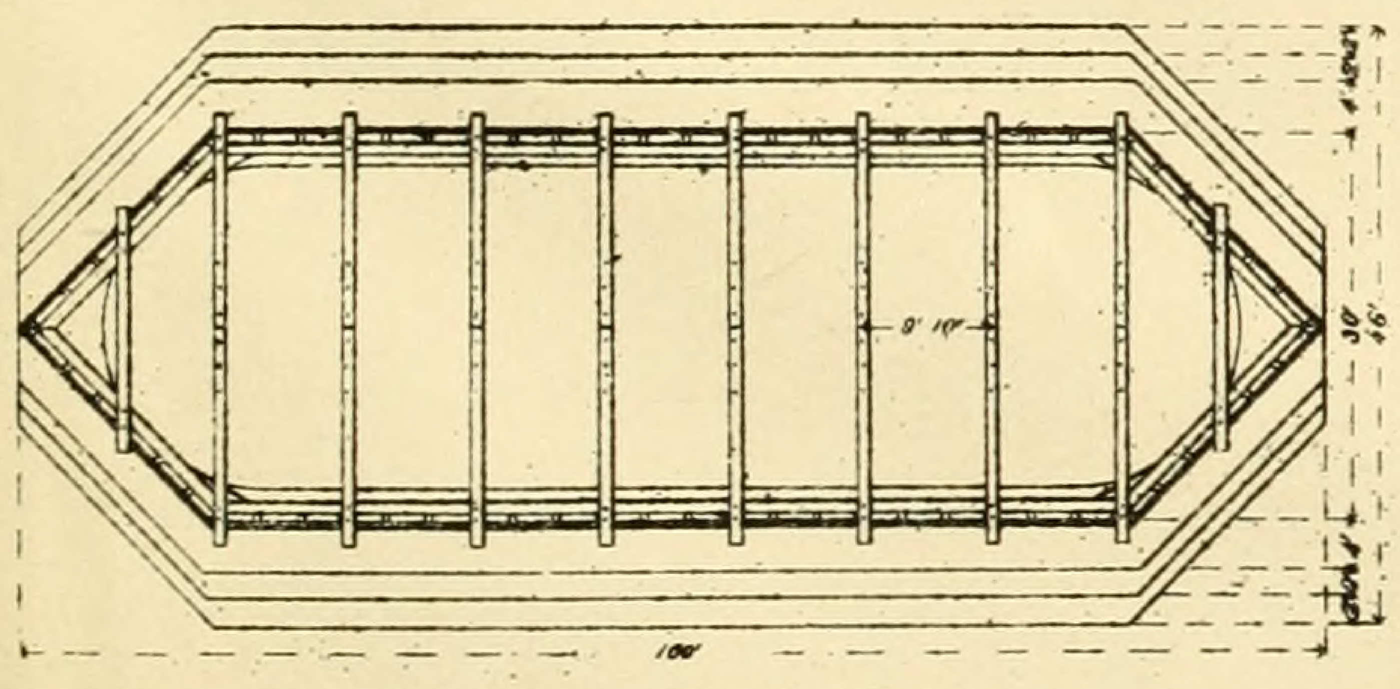




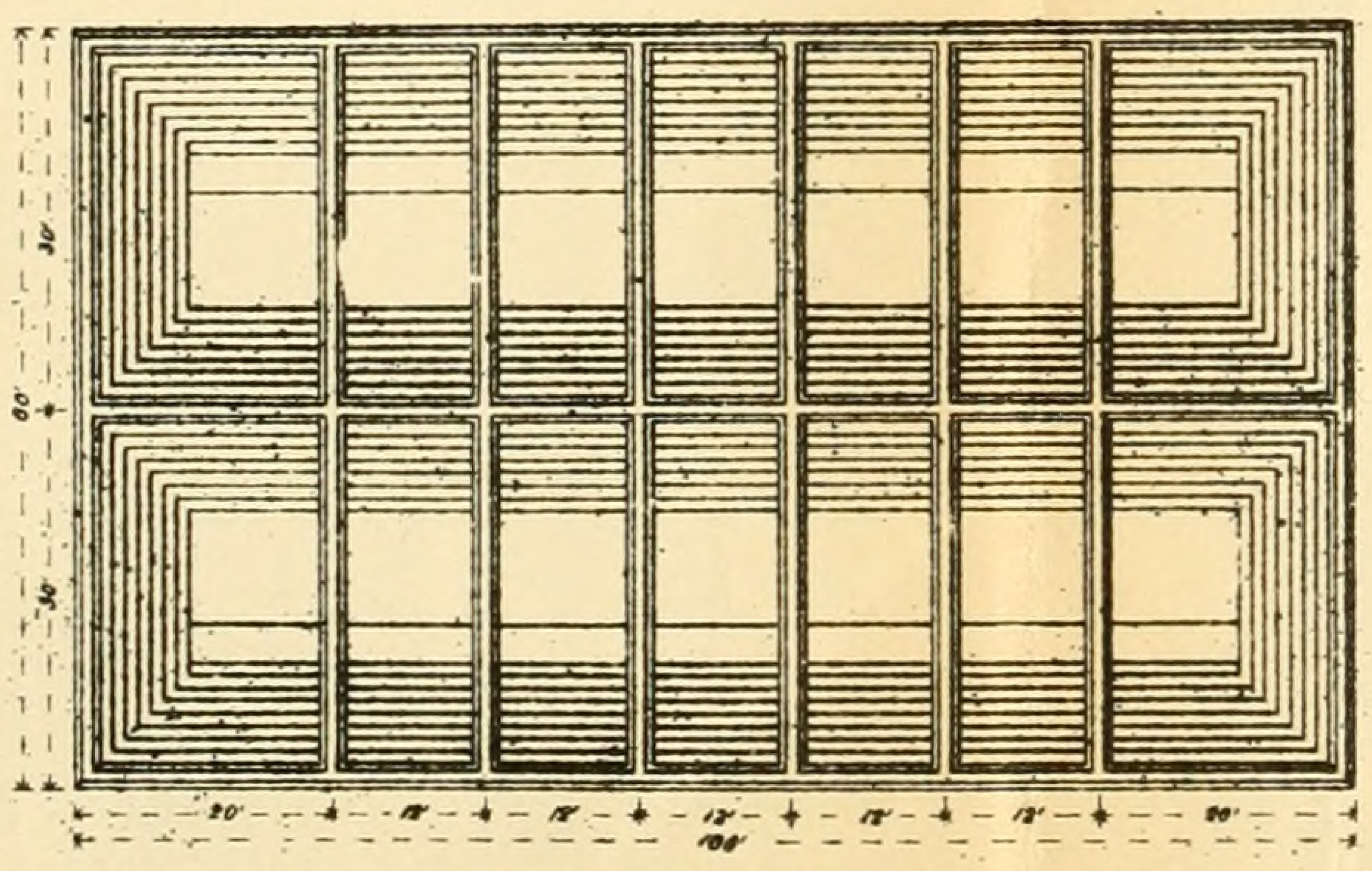
Side Elevation, Floating Caisson.



Plan of Top. Section on a.b.



Plan, Floating Caisson.



Plan of Bottom.

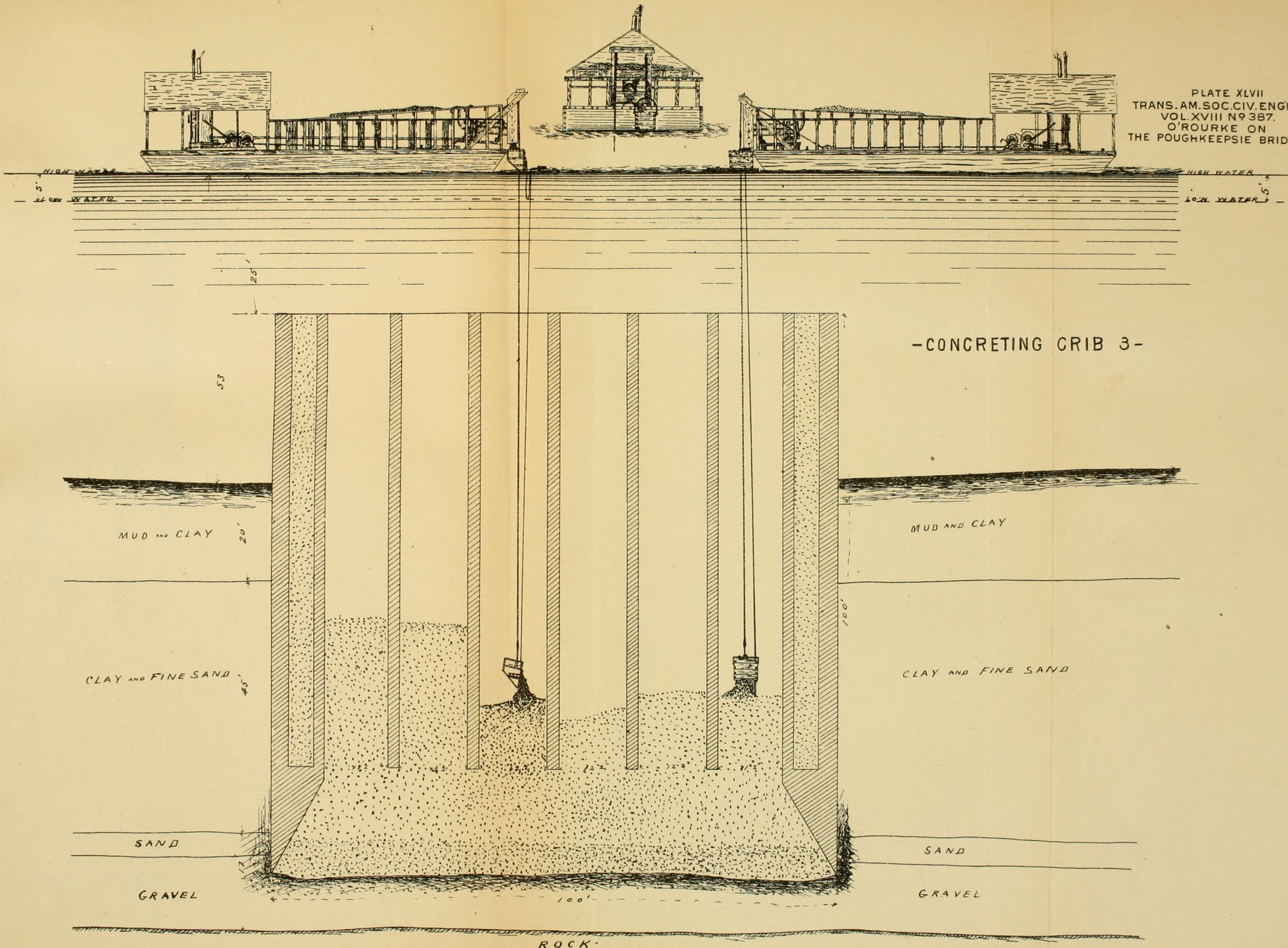
used for erecting the cantilever bridge across the Niagara River. They are composed of two trusses, 118 feet long, of which the chords and vertical posts are of wood, and the ties and splice-plates of iron. These are supported on a very heavy floor, extending from the rear end to within 50 feet of the other end, and are carried on twelve wheels, arranged in groups of one, two and three, respectively. Jack-screws, bearing on the front floor beam, relieve the wheels during the erection of a panel, and heavy hooks, under strong tension, clamp each end to the floor beams.

The 212-foot spans suspended from the ends of the cantilever arms are designed to be erected from the ends of the latter, and connected when they meet at the center. Stiff bottom chord, except in the middle three panels, enables each panel, when finished, to support the traveler during the erection of the next beyond. When the travelers meet, the remaining three panels are completed. In connecting the center panel, the top opening should be a little long in order to let the chord section into place, and the bottom one a little short, that the pins may drive easily into the eye-bars. This is insured by adjustment struts between the arms and suspended span, which are shortened in the top chords, and lengthened in the bottom by rollers separated with wedges. They are so arranged, that by drawing them the ends of the top chord approach each other, and those of the bottom chord recede. After the span is connected, the wedges and rollers are removed, and the trusses hang suspended.

The illustrations accompanying this paper are as follows:

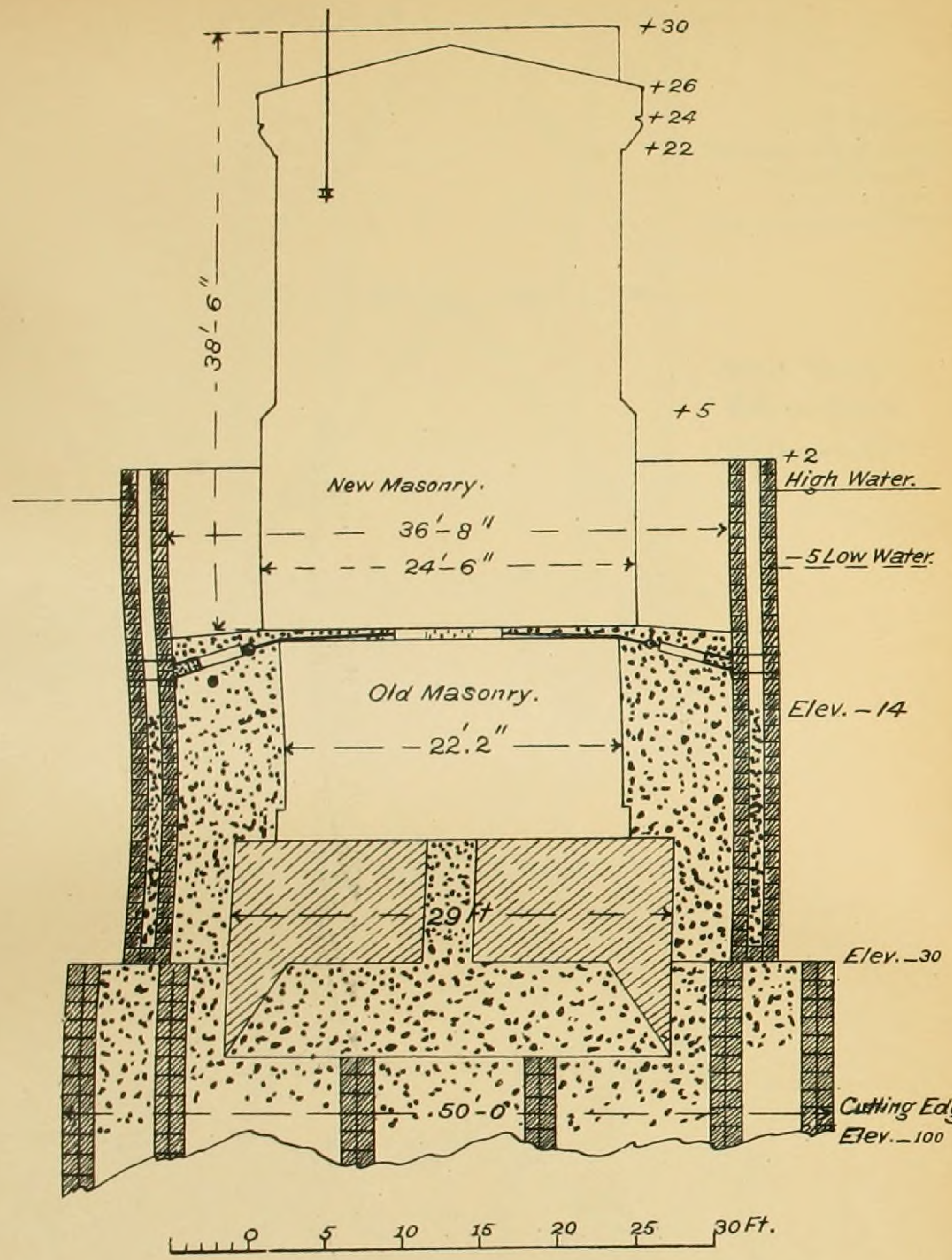
Plate XL,	Page 199.	Photograph of the Finished Structure.
" XLI,	" 202.	The Cantilever Span in Progress of Erection.
" XLII,	" 206.	Comparative Views of the Forth, the Brooklyn, the St. Louis and the Poughkeepsie Bridges.
" XLIII,	" 207.	Cement Testing Machine.
" XLIV,	" 208.	Photograph of Crib.
" XLV,	" 212.	Photograph of the Structure in Progress.
" XLVI,	" 214.	Crib, Grillage, River Pier and Floating Caisson.
" XLVII,	" 216.	Concreting Crib 3.
" XLVIII,	" 216.	Pier 2.
" XLIX,	" 216.	Shore Arm Falsework.
" L,	" 216.	Main Falsework with Traveller. Section of Finished Structure. Method of Splicing Piles.
" LI,	" 216.	Traveller for Erection of Truss Spans.
" LII,	" 216.	Traveller for Erection of Cantilever Arms.
" LIII,	" 216.	Twenty-Ton Derrick.
" LIV,	" 216.	Cross Section of Viaduct.
" LV,	" 216.	General Plan of Floor System.
" LVI,	" 216.	Triangulation and Topography.
" LVII,	" 216.	Anchors. Method of Launching Anchors. Crib Anchored in Position.
" LVIII,	" 216.	Method of Anchoring Cribs.
" LIX,	" 216.	General Profile of Bridge.

PLATE XLVII
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

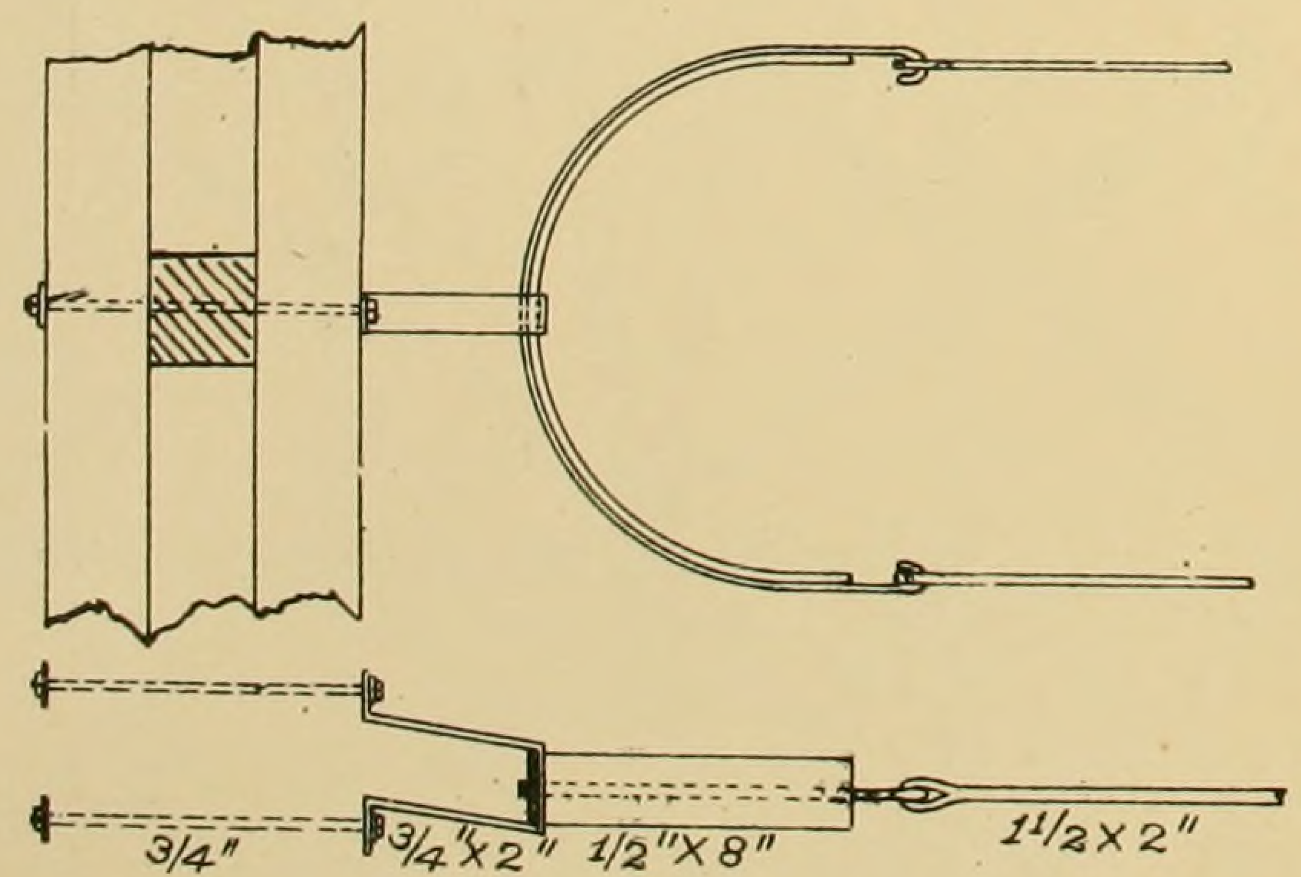


-CONCRETING CRIB 3-

PLATE XLVIII
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII No. 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.



PIER 2 POUGHKEEPSIE BRIDGE



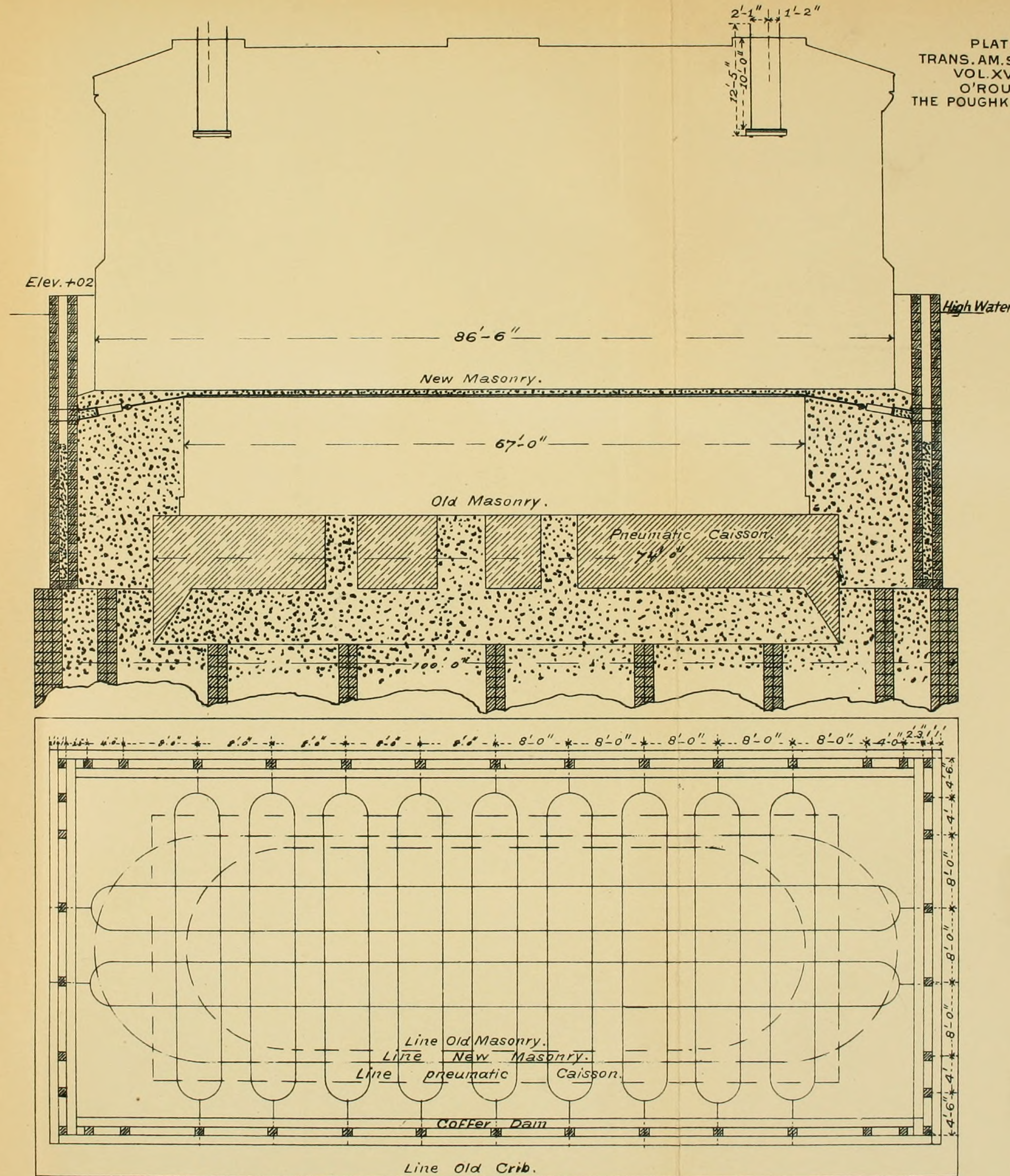
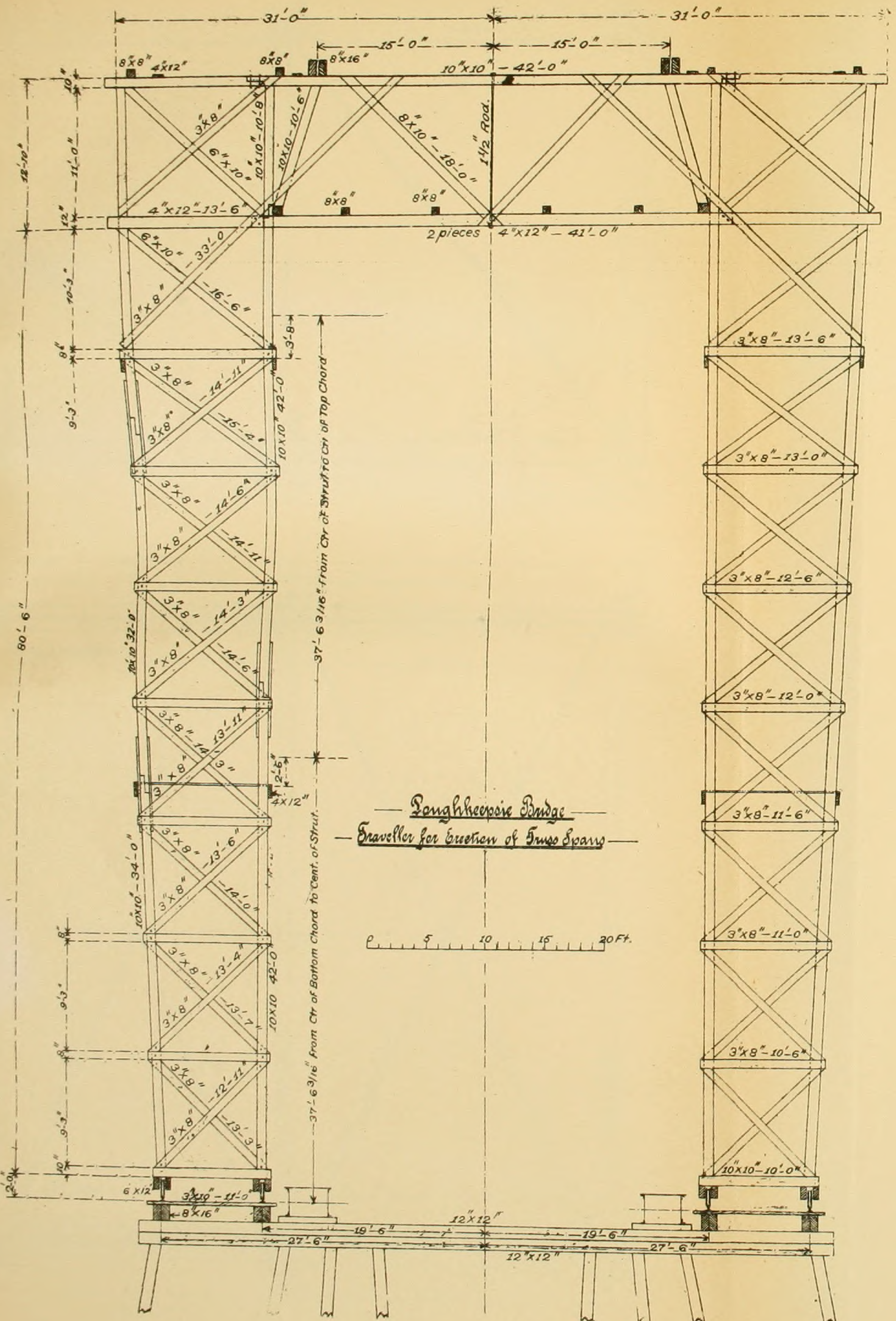


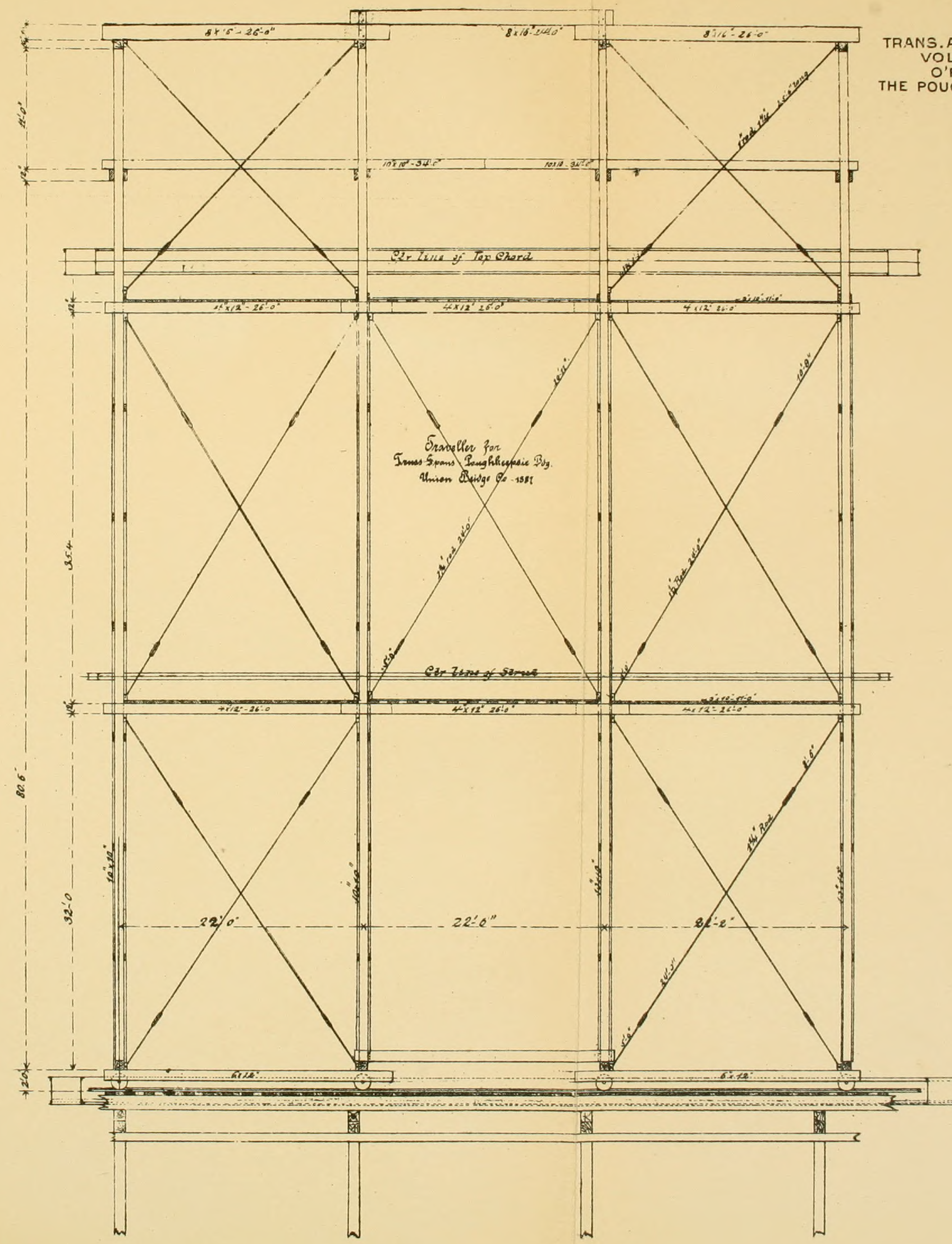
PLATE XLIX
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

Cross Section
Shore Arm
Falsework.

PLATE L
TRANS. AM. SOC. CIV. ENG'NS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

PLATE L'
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.





Side Elevation.
Half Bottom Plan
Half Top Plan.
2 Rods 1½" 52800#
2 Rods 1¼" 37200#
2 Rods 1⅝" 61600#
2 Rods 1⅝" 52800#
2 Rods 1⅝" 61600#
1 Rod 1⅛" 20250#
2-8½"×16"
2-7"×15"
2-6"×12"×22'0"
15 tons cap. each side.
10 tons cap. each side.
5 tons cap. each side.
Centre line of Chord.
Jack Screw.
Clamp.
C of Track & of Derrick.
17'0"
Channel 12"×65#×16'
118' 5⅛"

Twenty Ton Derrick

used in raising Materials to Top of Falsework.

Poughkeepsie Bridge

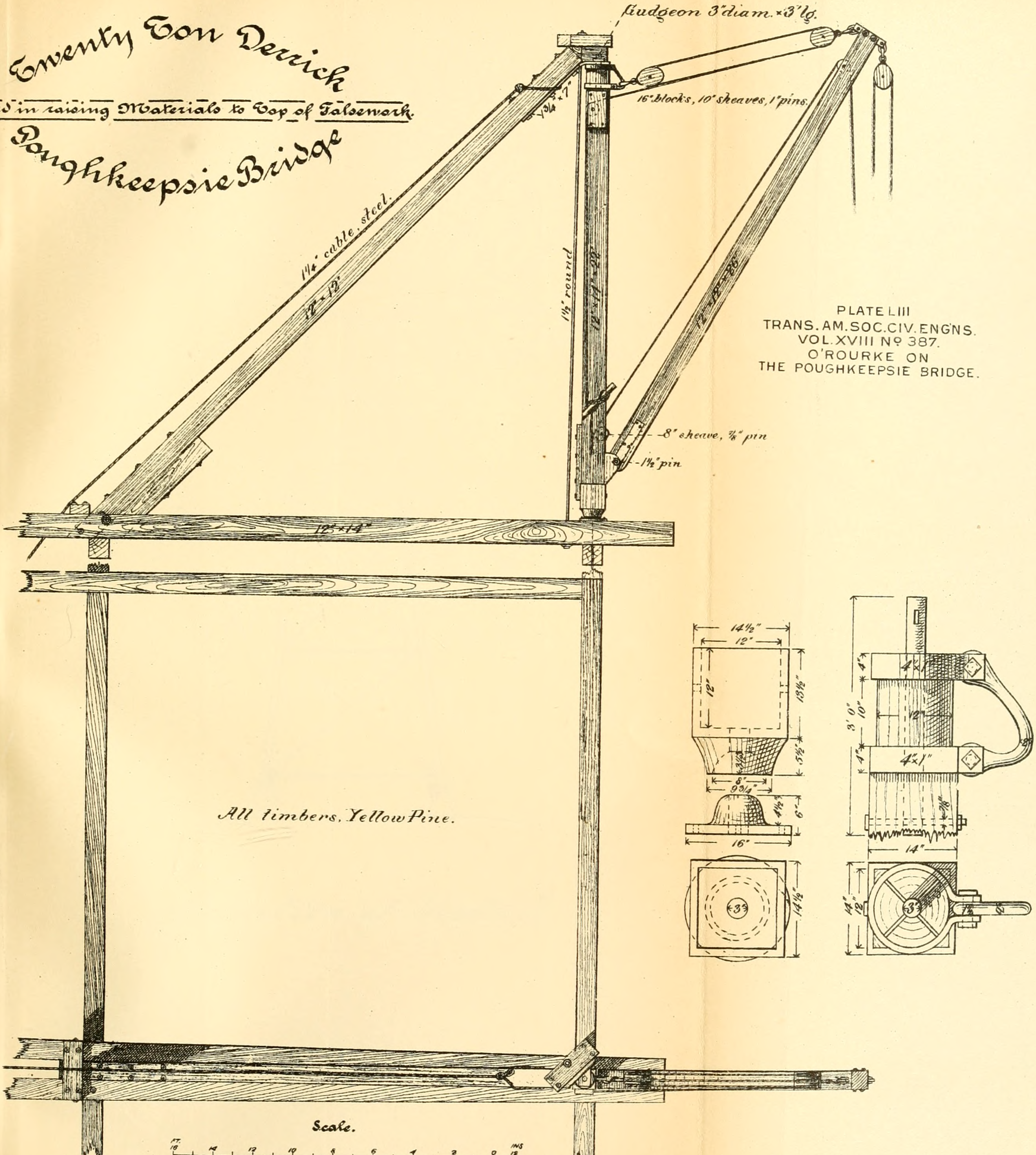
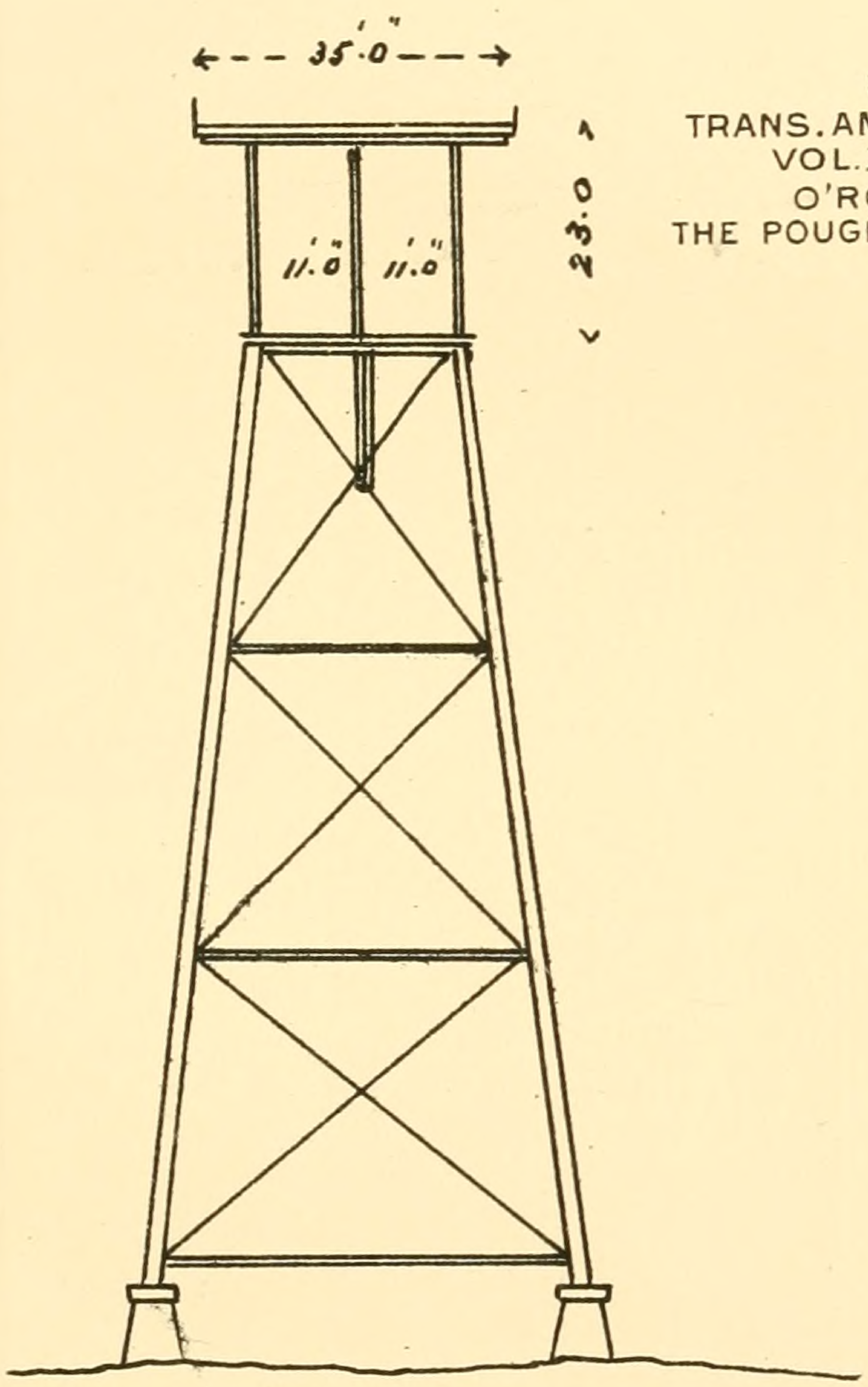


PLATE LIII
TRANS. AM. SOC. CIV. ENG'NS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

PLATE LIV
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII No. 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.



Cross-section of Viaduct

PLATE LV
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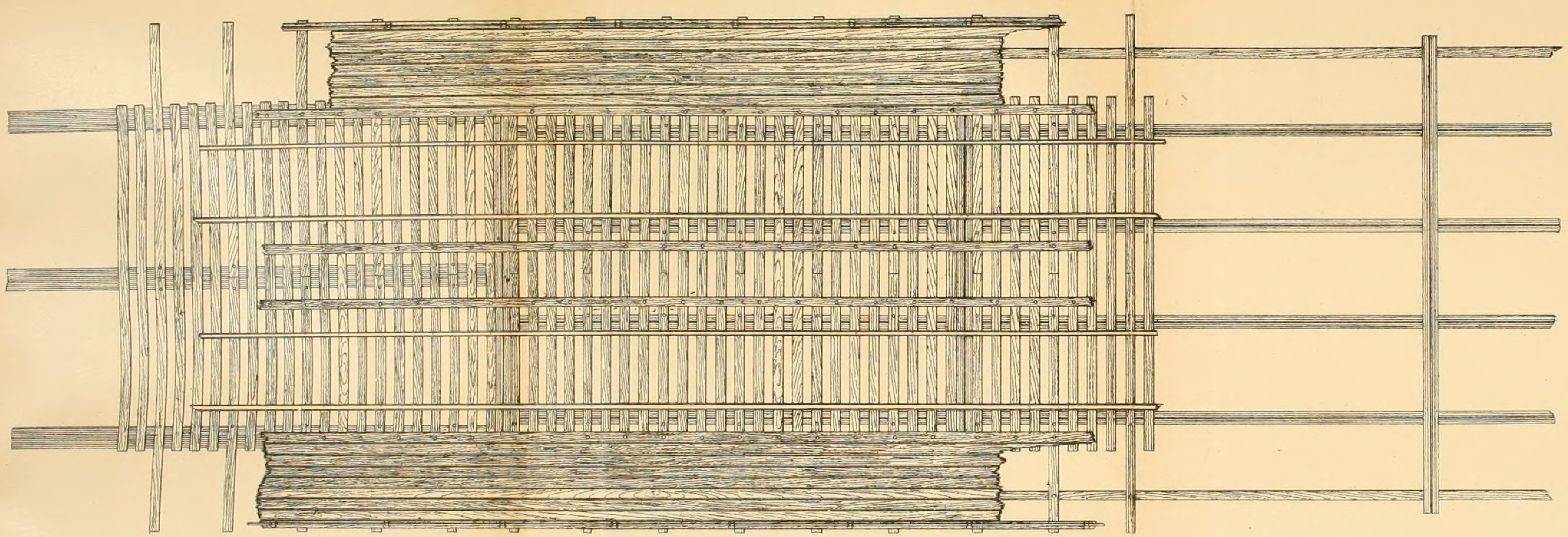
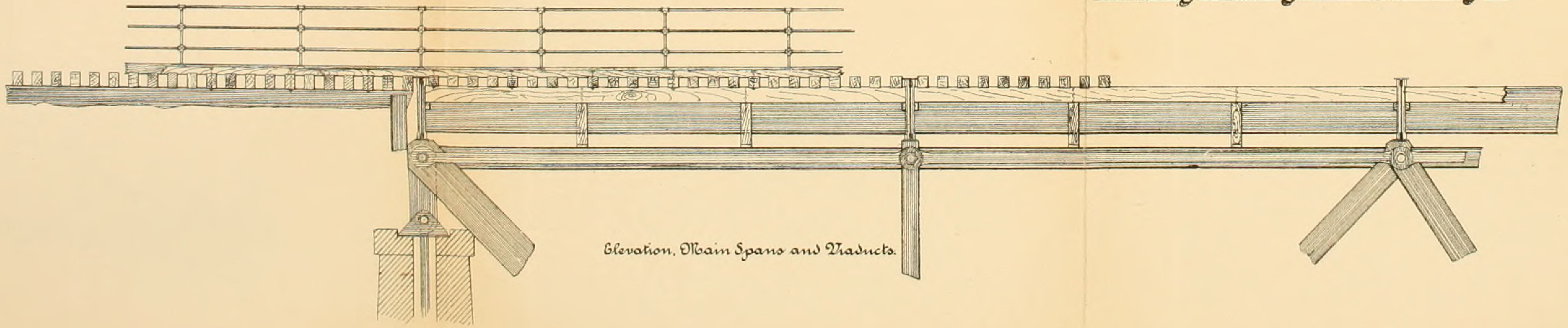
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

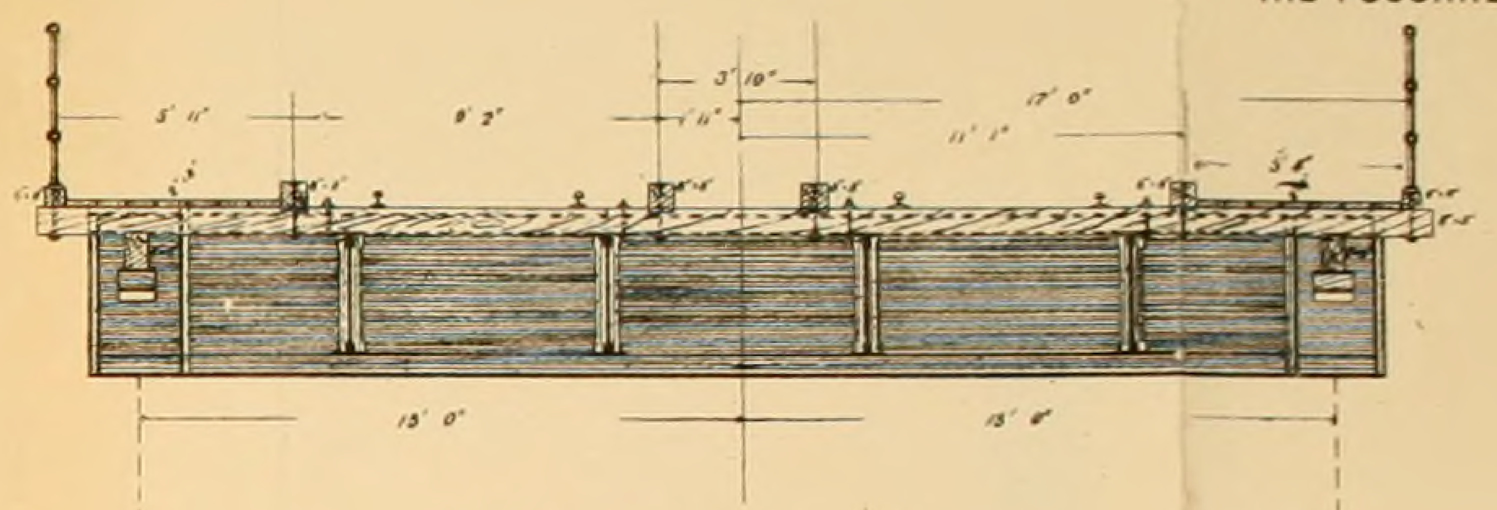
General Plan of Floor System
Poughkeepsie Bridge.



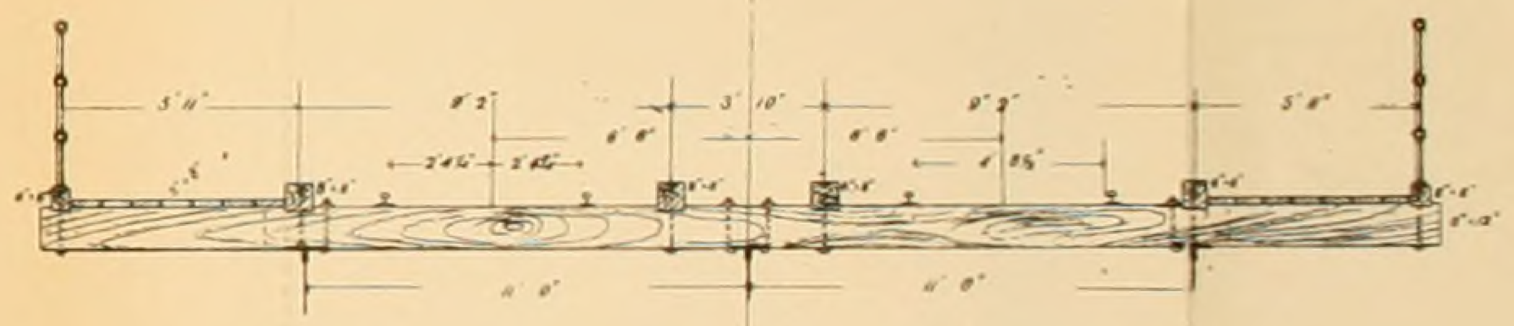
Plan, Main Spans and Viaducts.



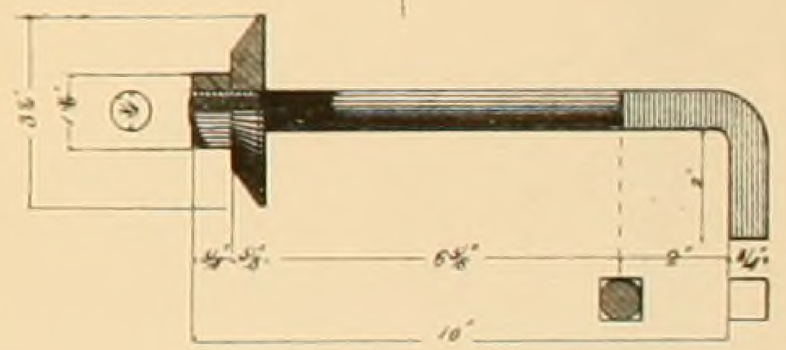
Elevation, Main Spans and Viaducts.



Cross Section, Main Spans.



Cross Section, Viaducts.



Hook Bolt, Scale 4"=1'.

Bill of Material.

Iron: Location	No.	Description	Size	Weight	Remarks	Timber: Description	Pieces	Length	Section	Ft. B.M.	Remarks
Main Spans	4750	Guard Rail Bolts	3/4" × 16" under head @ 2.55	12100	1 cast & 1 stamp washer. Head under.	Stringer Posts	392	3' 0"	8" × 8"	6272	
Viaducts	2800	- - -	3/4" × 17" - - - 2.68	7500	2 stamp washers - -	Stringers	148	32' 0"	8" × 12"	37888	size to 11½"
-	2800	- - -	3/4" × 19½" - - - 3.00	8400	1 cast, 1 stamp washer - -	-	42	30' 0"	-	10080	- - -
Main Spans	1180	Stringer -	3/4" × 21" - - - 3.18	3750	1 cast washer. Head driven flush with tie.	-	4	20' 0"	-	640	- - -
- -	1180	Hand Rail -	3/4" × 14" - - - 2.31	2700	1 cast, 1 stamp washer. Head under.	-	8	16' 0"	-	1024	- - -
Viaducts	1380	- - -	3/4" × 18" - - - 2.70	3750	do.	Ties	2070	24' 0"	-	397440	- - [illegible] girder
Main Spans	2400	Hook -	10" - 2.00	4800	3/4", 8" from end, cut 3/4", 1 cast washer	-	1380	17' 6"	-	193200	- - - -
Viaducts	2800	- -	14" - 2.25	6300	3/4", 12" - - - - -	-	1768	24' 0"	8" × 8"	226304	- - 7½"
Main Spans	400	Drift -	3/4" × 20" - 2.50	1000	For Stringer Posts	-	1180	17' 6"	-	110133	- - -
	16000	Stamp Washers	3/4" bolts - -	16000		Guard Rail	28300 lin. ft.	16' to 24'	-	152000	- - -
	17000	Cast -	- - - 0.33	5700		Footing Rail	640	22' 0"	6" × 6"	42240	- - 3½"
		30 d. Nails		3000		Plank	6000	16' 0"	3" × 8"	128000	
Weight of Head & Nut			0.33	75000		Total for Bridge				1305221	Yellow Pine.


PLATE LVI
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.
MAP SHOWING
TRIANGULATION AND TOPOGRAPHY
OF THE
POUGHKEEPSIE BRIDGE
UNION BRIDGE CO.
POUGHKEEPSIE
ULSTER COUNTY
HIGHWAY TO MILTON
1
2
3
4
5

PLATE LVII
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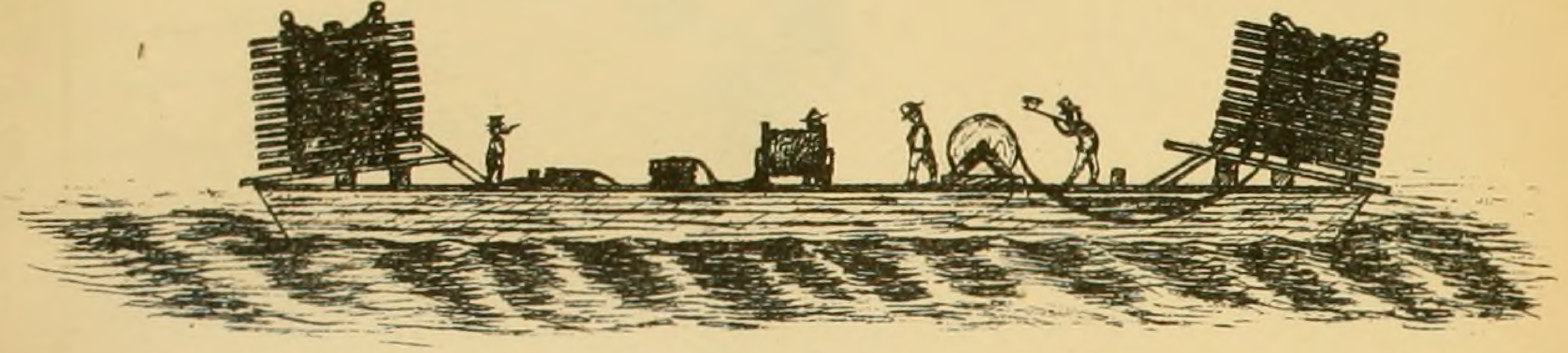
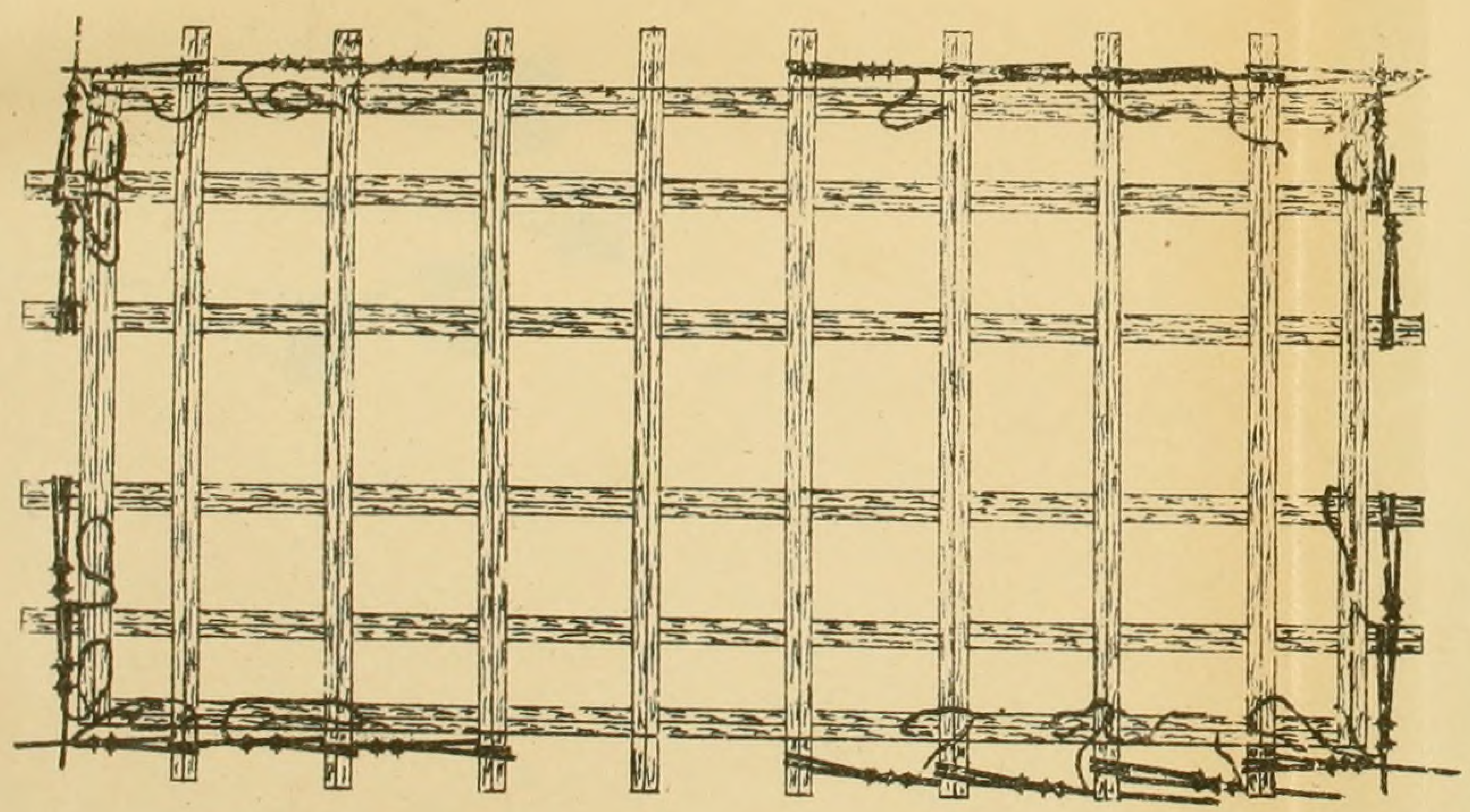
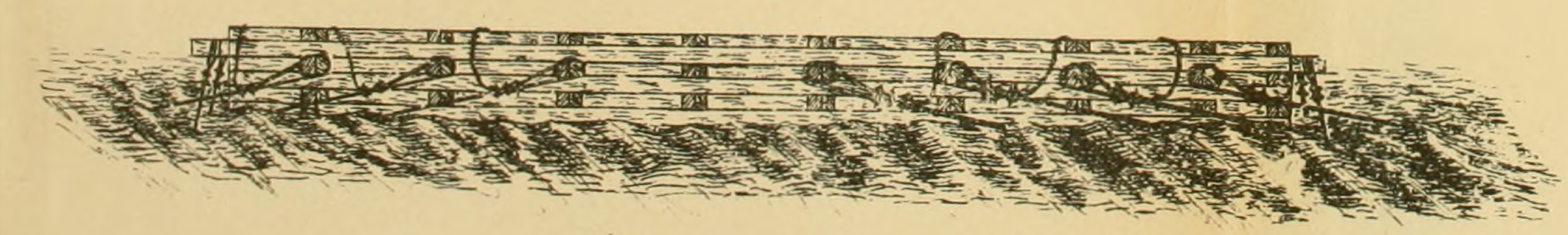
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

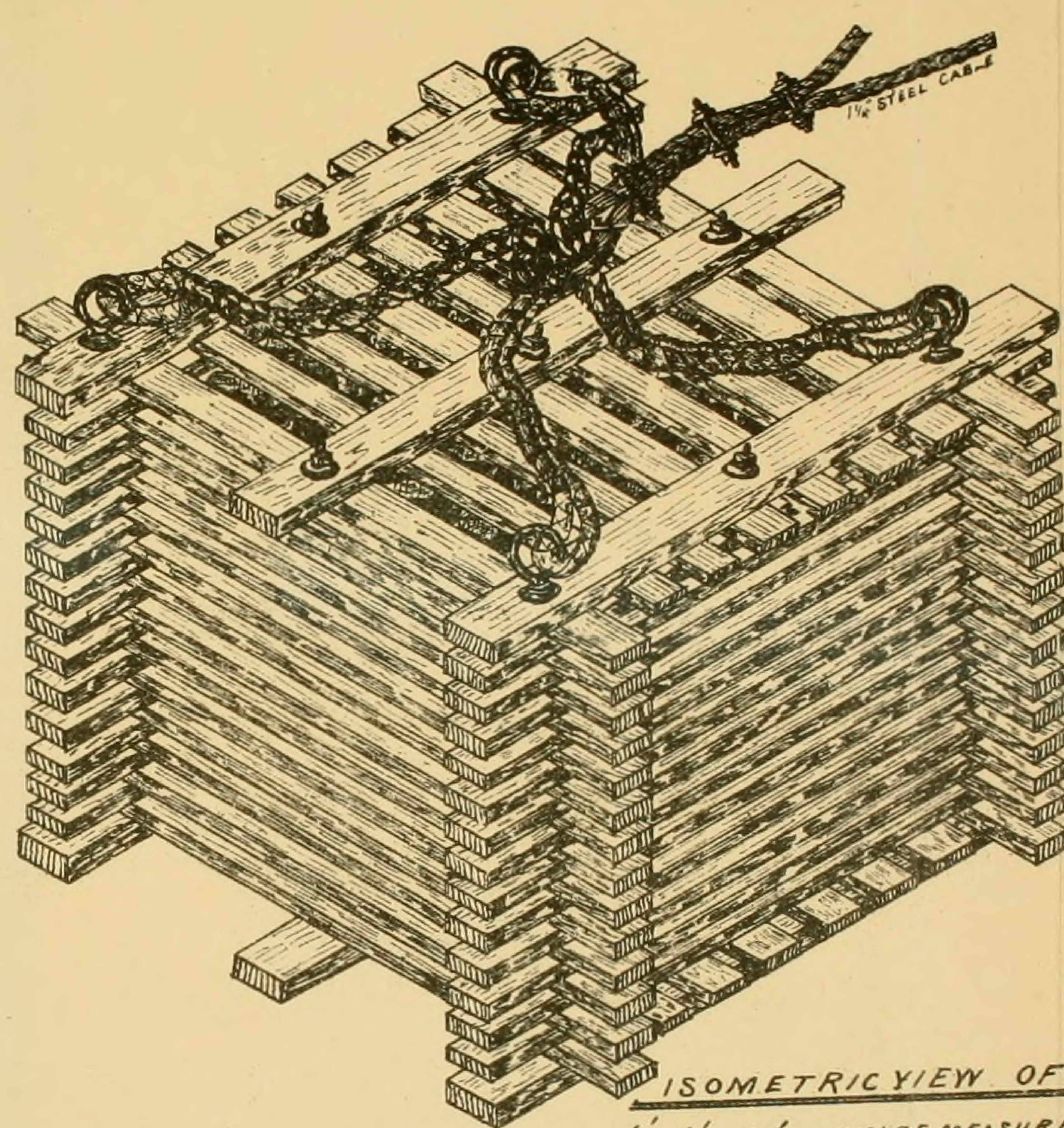


METHOD OF LAUNCHING ANCHORS





CRIB, ANCHORED IN POSITION

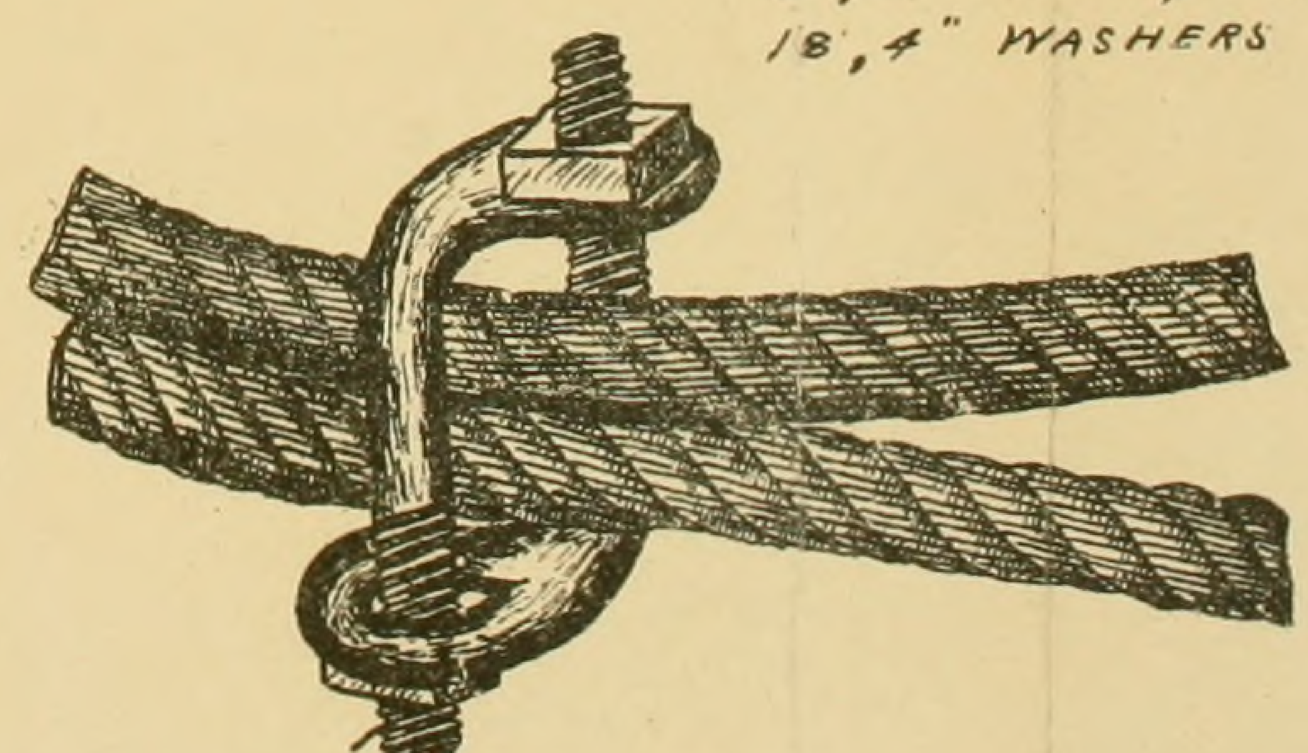


ISOMETRIC VIEW OF CHINEESE ANCHOR

6'x6'x7' INSIDE MEASUREMENT   LOADED WITH BROKEN STONE

BILL OF MATERIAL

52 HEMLOCK STRIPS 3"x6"x11'
6 " " 4x9"x11'
12 " " 3x4x10'
4, IRON RODS ⅞" DIA. 7'5" BTW. WASHERS & EYE AT ONE END
5, " " ¾" " 7'5 " "
18, 4" WASHERS



STYLE OF CLIPS USED

PLATE LVIII
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VOL. XVIII. Nº 387
TRA O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

GENERAL PLAN OF

N OF POUGHKEEPSIE BRIDGE

PLATE LIX
TRANS. AM. SOC. CIV. ENGRS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.