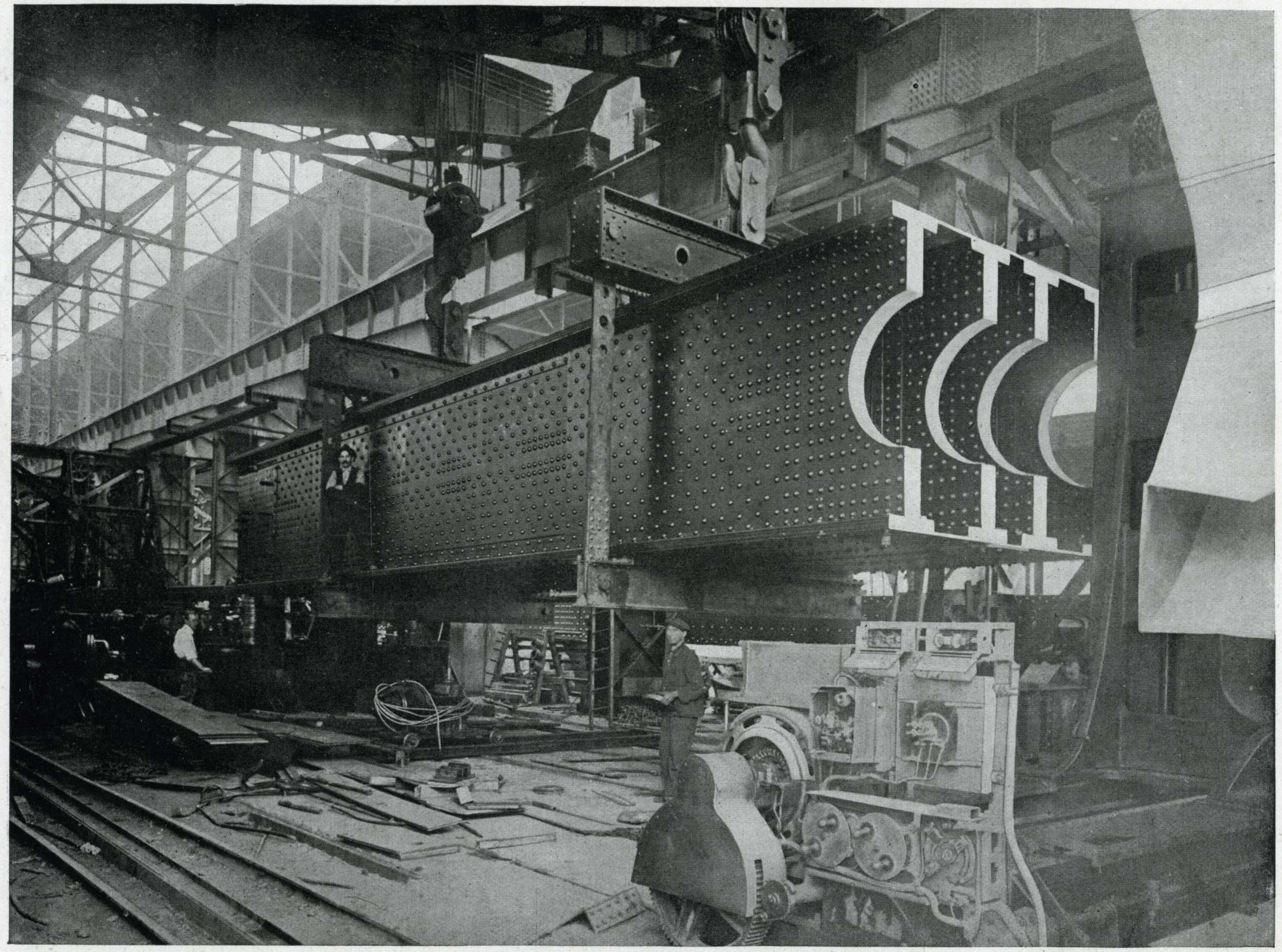
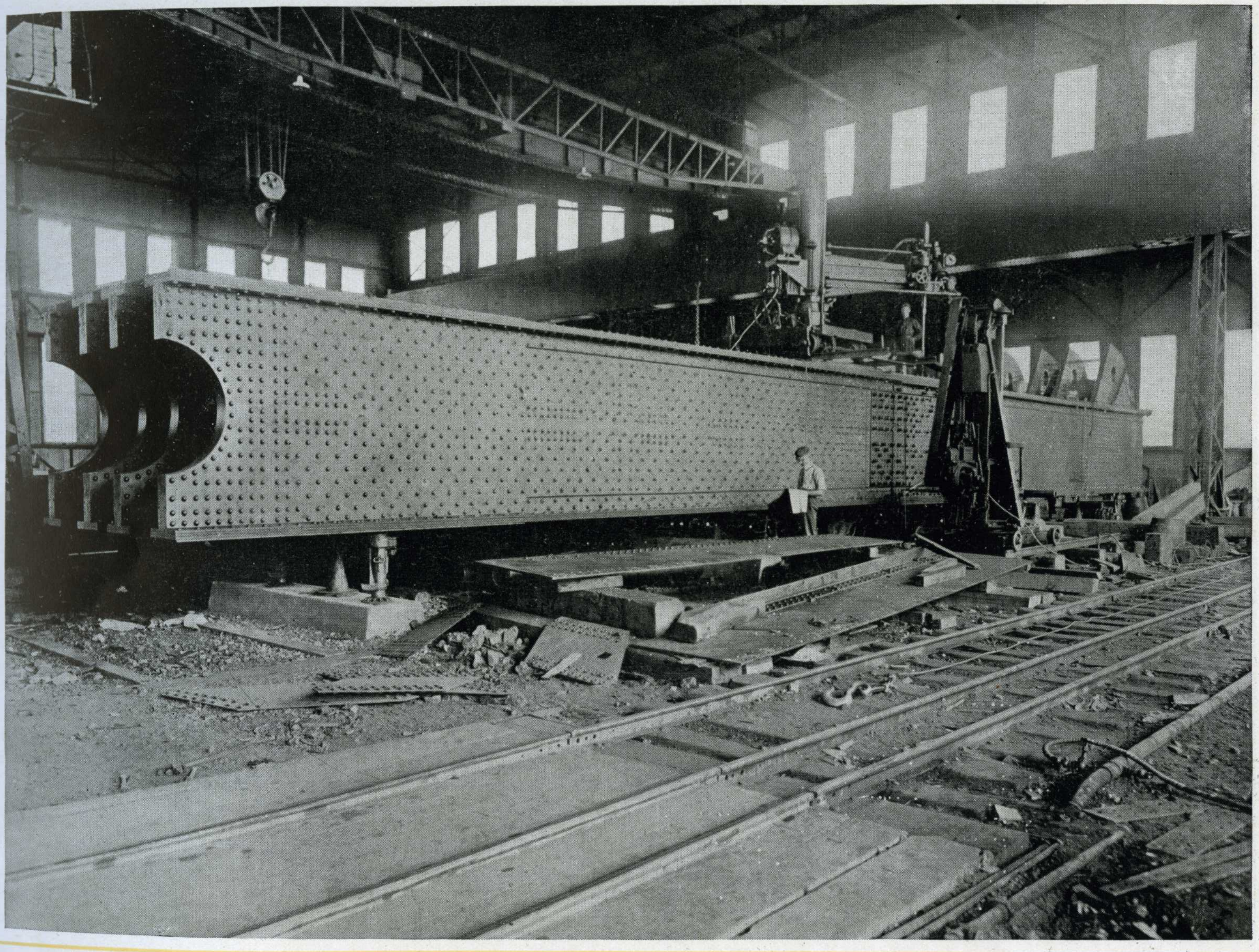
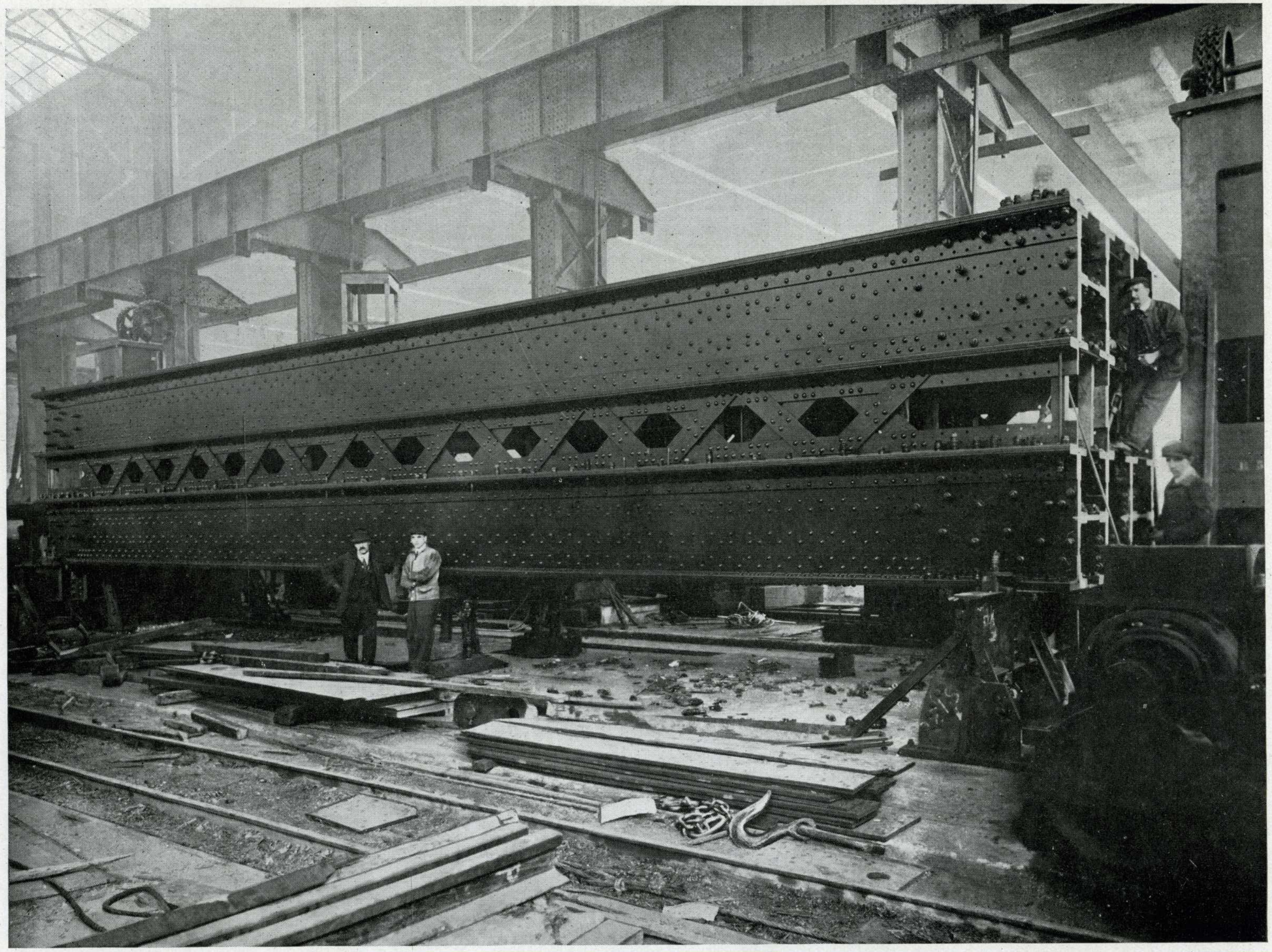


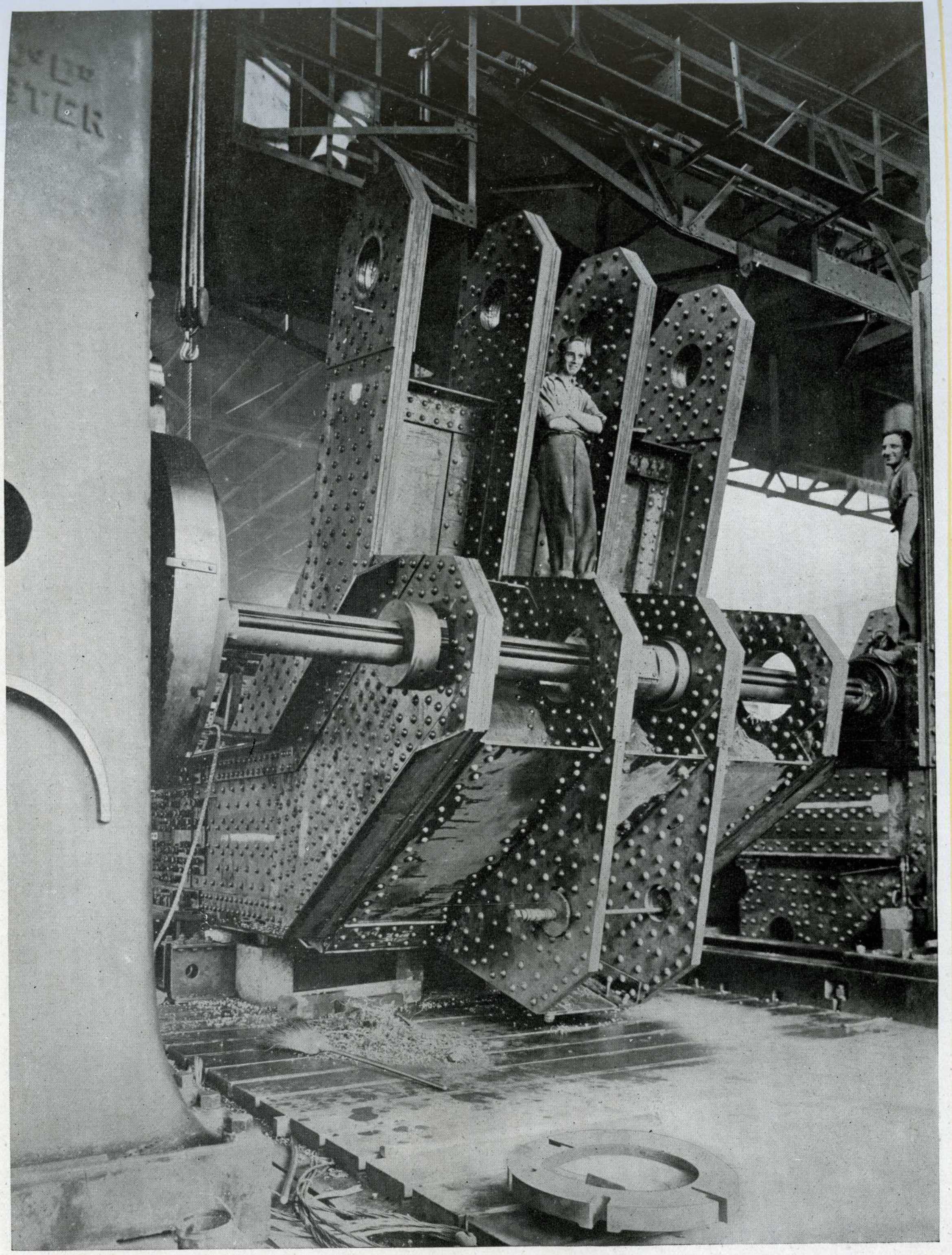
11—An end section of the bottom chord being removed from the vertical planing machine



12—Pier panel of the bottom chord assembled for drilling the splice connection holes



13—Sections of the centre pier post assembled and set for planing



14—The end section of the bottom chord being bored used as far as practicable for the deck of this falsework, as may be seen by referring to Plates 16 and 18. Steel falsework was also used to support the anchor arm trusses during erection and until the river arms were completed.

A large quantity of steel was required for this temporary work—about 8,000 tons in all having been provided. This was distributed approximately as follows:

Inner falsework	1,500	tons
Outside falsework for both sides of the River	950	"
Travellers	1,400	"
Erection struts, temporary bars, supporting platform, storage yard cranes, runways, etc.	4,150	"

The shops were completed and manufacturing steel in 1912 in time to carry out the programme of erection laid down for the completion of the work.

The general programme of erection was as follows:

The storage yards, camp and field equipment, with the exception of the travellers, were completed early in the season of 1913 and the North approach spans were erected on falsework with locomotive cranes before the close of that season. The erection of the North traveller was also started in 1913 in order that it might be ready to erect the anchor arm early in the season of 1914. The traveller was erected on the shore and moved out over the approach spans to the anchor pier from which point it set its own falsework as it proceeded; the 90-foot swinging booms being used for this purpose. The outer falsework to carry the anchor arm trusses, although independent of the inner falsework, was set at the same time while the traveller was proceeding out. As soon as the main pier was reached the grillages and main shoes were set.

After the shoes were set the lower chords of the anchor arm were started at the shoes and erected towards the anchor pier, the traveller being moved back for this purpose as the chords were erected. The lower chords of the anchor arm at every panel point rested on shoes of a rocker type which capped the outside staging columns and the level of the falsework was adjustable in order that the chords might be kept in a perfectly straight line until all the joints had been fully rivetted. After this had been accomplished the elevation of the falsework was adjusted until the chords reached the position calculated to give the truss the necessary camber to make the chords straight when under full load. The traveller was again taken back to the main pier and erected the lower triangles of the "K" system as it was moved back towards the anchor pier. These triangles are shown on Plates 24 and 25. When the traveller reached the anchor pier the inclined end posts and the anchor bars were put in place. It was then moved towards the main pier, erecting the upper triangles, the upper chord and the sway bracing as it was moved outwards.

A difficulty here was overcome in a rather novel manner. Calculations had shown that with the lower chord in its cambered position the web members and upper chord could not be connected without forcing some of the members out of line or altering the elevations of the lower chord to make these connections. It was found, however, that a small elongation of the pin holes in the tension members would permit the connections to be made without trouble. After experiments had been made to determine that the elongation of the pin holes would not in any way weaken these members, this expedient was adopted, and no trouble was experienced in making all connections. A further result of these experiments was the decision to make a slight elongation of all pin holes in tension members, allowing the largest pins to be easily and quickly driven with a 400 lb. ram.

By the end of the season of 1914 the North anchor arm was completely erected with the exception of two upper triangles at the South end, as shown on Plate 26, and the work was left in this condition throughout the following Winter. The tide rising about 5 feet above the falsework foundations, it was necessary to sheathe the bottoms of the bents and the bracing to protect the falsework against ice. Work was resumed on 15th March, 1915, and the North anchor arm was completed, including the main pier posts, on 8th June, 1915. When these posts were erected the framing for camber caused the tops to be 15 inches out of the vertical. The erection of the cantilever arm was at once proceeded with and the traveller was moved over the first sub-panel point, C.M. 15, on June 24th, 1915.

In erecting the cantilever arm the design of the truss made each panel self-supporting as the work was projected out and it would have been possible to erect it without any temporary supporting members, but it was convenient to place the lower members first to avoid interference of the heavy hoisting tackles with members already set in place. The lower chords were spliced half way between panel points and were carried by a platform suspended by temporary eyebars and shifted from panel to panel as the work proceeded. This platform is shown on Plates 31, 32 and 34. It was equipped with two sets of four 100- and 60-ton jacks, the 60-ton set under the mid-panel splices and the 100-ton set near the end of the section to lift the lower chord to the required position for making connection to the vertical suspender. This platform greatly facilitated the erection and the alignment of the chords when making the splices as well as the subsequent matching of the pin holes to make the permanent web connection.

After setting the platform the first half panel of the lower chord was placed on it and the half panel of the compression diagonal was erected and supported by the sub-tension diagonal. The floor beam for this half panel was then placed and the traveller moved out with its front trucks over it. When the traveller was in this position its rear posts were clear of the main vertical post behind it, allowing the permanent sway bracing to be put in place. The outer half panel of the lower chord was then placed and lined up and the rivetting of the splice proceeded while the material above it was being erected. The upper half of the compression diagonal with its sway bracing, followed and was lined up and spliced before completing the triangle. The long tension diagonals were spliced on the floor of the bridge alongside the traveller, erected and connected in one piece. The vertical tension member was next placed and the pins connecting it to the bottom chord driven; the pins connecting it to the middle detail were not driven until later in order to avoid overloading the temporary top chord. The vertical compression member and the eye bar top chord were then placed and the pin connecting this section of chord to the section in the adjacent panel driven. The load carried by the temporary top chord was then transferred to the eye bars by slackening the two 100 ton jacks shown on plate 40. To make the panel self-sustaining it was then only necessary to drive the pins connecting the tension vertical to the middle detail. The double web floor beam was then placed and the floor completed to this floor beam, after which the traveller was advanced and the erection of the next panel commenced.

This procedure was followed, with only slight modifications, for all the panels from the main pier to the panel point 4. Panel 2-4 being short it was possible to erect it completely with the front legs of the traveller at panel 4. Panel 0-2 was erected with the front of the traveller at 2.

It was, therefore, not necessary to advance the traveller beyond this point.

When the truss system of the North anchor arm was completed and the traveller supported over the main pier, the floor beams were connected to the trusses, thus releasing the falsework bents put in to carry the traveller and floor system.

The falsework was then moved over to the South side for the erection of the South anchor arm. Meantime the South traveller had been erected. The erection of the South anchor arm falsework was started 20th May, 1915, and completed 3rd July, 1915. The South anchor arm itself was completely erected, including the vertical posts over the main pier, 3rd December, 1915, and the North cantilever was also completed that season.

The condition of the work at the end of the season of 1915 is shown on Plate 45. It may be noted that the load on the outer falsework carrying the North anchor arm was not fully relieved until the cantilever arm was erected and it was necessary to duplicate this falsework for the South anchor arm.

The design of the bridge was based on floating the suspended span into position and no provision was made for the stresses imposed and extra material that would be required if it were erected by cantilevering. There was so much risk attendant on attempting to float the span at the level it would occupy in the bridge that this plan was never seriously considered although strongly advocated by some after the accident in 1916.

The plan adopted was to erect the span at as low a level as practicable, float it to position and hoist it in place. The best site available for erecting the span was at Sillery Cove, about 3½ miles below the bridge site where excellent conditions existed. The railway connecting with the material yard, at this point was about the level required on the span; there was a good level rock bottom dry at Spring tides, making it easy to prepare the foundations for the steel falsework and for the pontoons. The site was also well protected from navigation risks by shallows, but over which there was sufficient water at high tides to float the pontoons loaded with the span. Steel bents were placed for each panel point of the span and it was erected by the lower part of the traveller that had been used on the North arm; the four booms being all that was required for the purpose, the upper trusses and travelling cranes were omitted.

The method of erection did not differ from that usually followed in a span of this character.

Heavy steel towers were placed under the four corners and after the bridge was completely assembled, with the exception of the permanent floor system, it was swung on these end supports and the other falsework removed. See Plate 49.

The span was erected at such a height that pontoons could be floated under it at high tide and allowed to rest with the receding tide on foundations prepared for them at a height that would permit the blocking and steel grillage girders for distributing the load on the pontoons to be placed under the trusses. See Plate 50.

The pontoons, really scows, six in number, each 165 feet long, 32 feet wide and 11 feet 6 inches deep, were built with heavy steel frames and steel plate girder bulkheads calculated to support the heavy concentrated load to which they were actually subjected and for possible bad conditions of weather. The wooden planking was considered to be only a skin to keep out the water and not as adding strength to the framework. Each of the scows had six valves in the bottom operated from the deck, which were left open to allow the tide to flow in and out while the scows rested on their foundations at Sillery and only closed when it was desired to float the scow.

For the operation of floating the span it was necessary to choose a tide sufficiently low to permit the scows to be drained clear of water at low tide and with sufficient rise to float the scows with 8 feet 2 inches of draft about two hours before the high tide, as it was necessary to traverse the distance to the bridge site on the flood tide and desirable to be in position before the current actually changed—the tide commencing to fall about an hour before the change of current. This condition of tide only obtained for a few days at the period of Spring tides. The span was controlled on its way from Sillery to the Bridge by five tugs on the down-stream side, one of 1,000 H.P. and four of 500 H.P., while two smaller tugs were used on the up-stream side to assist in placing the span transversely to the current. Other powerful tugs were held in reserve in case of a change of wind or the inability of the tugs attached to hold the span against the tidal current which runs at this point about six and one-half miles per hour, but the span was very easily controlled by the tugs attached and the extra tugs were not used.

Plates 55, 56, 57, 58 and 59 show the operation of moving the span out from its supports at Sillery and controlling it to its position at the bridge.

Heavy cantilever mooring frames, each calculated to carry a transverse load of 300,000 lbs. at the lower end, were hinged at the top to the ends of the cantilevers. To avoid risk of fouling the span while being manoeuvred into position these frames were drawn back by means of two nine part 7-8-inch diameter wire rope tackles, which had originally been the main hoists on the traveller, the lines of which were led to electrically operated drums on the floor of the bridge. When approximately in position the span was connected by four $1\frac{1}{4}$-inch plow steel ropes to the frames at each end, which were led diagonally from bollards on the ends of the span through sheaves in the bottom of the mooring frames to nine part $\frac{3}{4}$-inch diameter wire rope tackles operated by electric hoists on the floor of the cantilever. See Plate 59.

After the suspended span was attached by these wire ropes the frames were lowered to the vertical position and the span moored in exact position vertically under its place in the bridge.

The lifting chains were also drawn back to give clearance while the floating span was being placed and were only lowered into vertical position for connecting after the span was moored to the frames.

Provision was made for shifting the mooring tackles as the span was hoisted so that it could be safely anchored at any elevation in the event of a strong wind springing up while it was being hoisted, and recourse was had to this anchorage on the last day before the final connection was made.

Plate 58 shows the mooring frames and lifting chains drawn back and Plates 54 and 60 show the position of these parts after the span was connected and while being hoisted. Plate 54 also shows the lifting chains and their connection to the span.

These chains were spaced 16 feet apart centre to centre at each corner. Each was made up of four 28 x $1\frac{1}{2}$-inch carbon steel links, each link about 28 feet long. The links were bored for pins twelve inch diameter at 6 foot centres through which the lifting pins could be inserted for fastening them to the jacking girders. The links were connected to each other by pins 12 inch diameter 24-foot centres and each placed half way between a pair of the holes spaced 6-foot centres used for connecting to the jacking girders.

It was important that the load should be taken simultaneously on the eight hoisting chains and that the operation of connecting the chains to the lifting girders should not be complicated by having to jack the chains down to follow a dropping tide. The bottom holes in the chains were therefore elongated about 5 feet and when making the connection to the link projecting from the lifting girder the chains were set at an elevation to bring the pins near the top of the slot. The links having the oblong holes were made of Silicon Steel to cover possible increase of stress due to deformation.

Lifting girders, each weighing about 30 tons, on which the suspended span rested while being hoisted, were placed on the corner falsework bents at Sillery before the span was erected and were hung from the ends of the span in position for hoisting while the span was being transferred from Sillery to the site. Shoes were placed between the span and these girders, permitting angular motion both transversely and longitudinally. More extended reference will be made to these when describing the loss of the first span in 1916. At each corner there was placed across the end of the cantilever arm, vertically over the point of intersection, a heavy cross girder, supported on rocker bearings to equalize the load on each pair of chains, from which the jacking girders were suspended at about the level of the cantilever floor. The jacking and lifting girders were deep plate girders connected near each end by double diaphragms between which the hoisting chains passed.

A hydraulic jack was placed outside the hoisting chains at each end on top of these girders and resting on top of the jack plungers were placed lifting girders, practically duplicates of the jacking platform, with corresponding diaphragms, but the suspension bars which were fastened to the jacking platform passed through the lifting girders which were free to slide and were guided on these bars. The diaphragms both in the lifting girders and the suspension platform were each bored with three sets of holes spaced two feet centres vertically. The jacks had a lift of two feet and although the holes in the lifting chains were spaced six feet centres, the arrangement of holes in the diaphragms always enabled the registering of a pin hole in the chain with pin holes in both lifting and platform girder whether the jacks were at the top or bottom of their stroke.

The suspended span in condition for hoisting was estimated to weigh about 5,100 tons; the suspension and lifting appliances added about 440 tons, making a total load of 5,540 tons to be lifted by the jacks. The rams of the jacks were 22 inches in diameter and the working pressure about 4,000 lbs. per square inch. The jacks and the lifting girders were tested under a pressure of 6,000 lbs. per square inch by pinning the jacking platform and the lifting girder together.

Two hydraulic pumps placed at the end of each cantilever operated the jacks. The pumps were driven by compressed air supplied from the power houses on shore. There were separate control valves for each jack at each corner and control valves for each pair of jacks at each end. Multiplying tell-tales were installed to enable the valve operators at the corners to keep the lifting girder exactly horizontal and the valve operator at the centre of the bridge to keep the span itself horizontal. A telephone system was installed through which the lifts at each end of the span were reported to the Officer in general charge and the two ends thus kept at the same height. Four 12-inch diameter counterweighted screw-jacks worked by hand wheels were provided at each corner to follow up the hydraulic jacks and take the load in the event of a packing blowing or any accident to a hydraulic jack, so that it could be removed and repaired.

The operation of lifting was a very simple one: the hoisting chains were pinned to the lifting girder when the jacks were in their lower position. The jacks were then slightly raised to release the strain on the lower pins, and allow them to be withdrawn when the jacks were pumped up until the next pin hole came opposite a hole in the lower diaphragm—a distance of two feet. The lower pins were then inserted again and the load allowed to rest upon them; the upper pins could then be withdrawn and the lifting girder returned to its low position for a repetition of the operation.

All preparations had been made for floating the suspended span before the 1st September, 1916, but it was getting near the end of the series of suitable tides and it was felt that it would be an advantage to drill the engineers and workmen for a few days before actually undertaking the operation. The next suitable tide was on the 11th September and the span was successfully floated into position on that date, connected to the hoisting chains and raised by the jacks until the load was taken off the scows, which floated out with the current leaving the span suspended on the hoisting chains.

Everything had worked as planned up to this point; it was thought all risk in the operation had been successfully overcome and that nothing remained but to jack the span to its final position. The workmen had been on duty since one o'clock in the morning and after the span was raised four lifts at the North end and five lifts at the South end, they were allowed a recess of an hour for breakfast and rest, the span at this time hanging about 30 feet above the water. The hoisting was resumed after recess and just after the first lift had been completed at 10:50 a.m., something failed at the Southwest corner of the span allowing that corner to drop into the water, twisting the bridge until the South end floor beam was almost vertical while the North end of the span still rested on the hoisting girders. The torsion of the bridge caused first the failure of the lateral bracing followed by the failure of the trusses and the Southeast corner was soon pulled off its supports; as the South end sank both corners at the North end were dragged off simultaneously and the whole span disappeared under the water. The successive release of load at the different corners caused violent vibrations in the hoisting chains and the cantilevers.

The opinions of observers differed greatly as to the original point and the sequence of failure, but a photograph was being taken at the moment which shows clearly what occurred. See Plate 62.

The hoisting chains and carrying girders remained in place unbroken as well as the lower portion of the bearing on which the span had rested, and an examination was at once made to ascertain the cause of the accident. The condition of the bearing at the Southwest corner showed that the span had first fallen vertically upon it before kicking the girder backward and allowing the corner of the span to slip off. This led to the conclusion that the failure of the cruciform steel casting forming part of the rocker bearing and shown on Plate 64, was the cause of the accident, probably having split under the upper pin. The castings at the South end of the span had stood the test of carrying the span for about five weeks while on its end supports at Sillery, under much more severe conditions than when it was being hoisted, the load at Sillery having been about 10% greater, due to a heavy temporary floor and subject to the shock of a locomotive crane weighing about 80 tons passing on and off the span. While the cause of the accident was being investigated, a careful examination was being made of the cantilevers to determine if any part of the standing structure had been injured by the severe but unknown stresses to which it had been subjected by the impact of the falling span and by the upward spring and vibrations when the weight of the span was suddenly removed.

A rigid examination of all the connections as well as levels taken on the floor beams showed there had been no injury or change in the cantilevers through the loss of the span. As soon as this had been ascertained it was determined to replace the span and material was ordered to exactly duplicate that which was lost. The point of failure having been located in the cruciform steel casting, this detail was revised to avoid the use of steel castings.

The transverse pins had been used to take care of the angular movement of the truss members at the shoe when the falsework supports were removed, as the span was necessarily erected in a cambered position. This movement was provided for in the new detail by making shallow shoes under the outer ribs of the end post which bore on a confined lead bearing, the bearing on the lead being proportioned to allow the material to flow and adjust itself to the altered conditions of load when the span was swung on its end supports. When the span was floated at Sillery and the load taken off the lead bearings, shim plates under these bearings were removed, which allowed the carrying girder when hoisting to bear against a nickel steel rocker centrally placed under the end post and thus prevent any unequal distribution of load on the two hanging chains at a corner.

Some small changes were also made in the method of operating the follow-up screws and the valve controls of the jacking apparatus, but these were more as a matter of convenience and precaution than of necessity or because the previous arrangements had been found in any way at fault.

Notwithstanding the scarcity of steel at that time, the Carnegie Steel Company, which had supplied all of the rolled material for the bridge, made a special effort and delivered the greater portion of the material for the new span before the end of 1916.

The falsework on which the span was originally built had suffered a good deal from ice shoves during the Winter and the repair of this delayed the commencement of erection in the Spring. Because of the impact of the span falling on the Southwest corner and the extra load imposed by the span rotating around the diagonal line joining the Southeast and the Northwest corners, all of the hoisting rigging at these points was subjected to heavy overloads. It was therefore considered prudent to replace the hoisting chains with new material and to reinforce the hangers and lifting and supporting girders.

The first suitable tide after the new suspended span was ready for floating occurred on Saturday, September 15th, and preparations were made for that day, but unfavorable weather reports and a strong breeze at low tide caused a postponement until Monday, the 17th, when the span was floated at about the same hour as in the previous year. On this occasion everything went smoothly except a slight delay in pinning some of the hoisting chains. Actual hoisting commenced at 9:10 in the morning and the scows floated out at 10:25. After the first few lifts, which were expected to take about 15 minutes each, the men gained confidence and in some cases the cycle was performed in much less time, but as it was not expected to hoist the span in one day, minimum times were set for each operation as a measure of safety and the span was lifted at an average of about four lifts or 8 feet per hour. Each link of the hoisting chains as it came through the jacking girder was taken off by tackles rigged for the purpose and deposited on the platform at the end of the cantilever. Plate 69 shows the last of these links being taken down.

The removal of the links, the adjustment of the mooring tackles, inspection, etc., required nearly as much time as the actual lifting. Twelve lifts were made the first day, twenty-two the second day and twenty-six the third day, when the span was within thirty feet of its final position. At the end of that day the weather was threatening and the span was securely moored. The following morning the wind was blowing about 35 miles per hour, but after releasing the mooring tackles the horizontal displacement of the span was slight and there seemed no risk in proceeding with the hoisting, the mooring tackles being set to a slight stress to prevent swaying.

The permanent suspension bars for carrying the span were in two lengths connected by pins at the centre for convenience in handling the bars themselves, and for facility in making the final connection; the central joint permitting the bars to be deflected to bring the holes in exact position for driving the pins of the final connection. Before hoisting commenced the upper eyebar suspenders were connected to the cantilevers and the lower eyebars were connected to and stayed on the suspended span in a position for entering and passing through the jacking girders, the final connection being made above these girders. The connecting bars are shown on Plates No. 49 and No. 52; the entering of these bars as the span was hoisted on Plate No. 69 and driving the final pin on Plate No. 70.

The suspension bars were entered and backed at 3:10 p.m., the operation of driving the connecting pins was started twenty minutes later, and the span was securely connected at all points at 4 p.m., on the 20th September, 1917. The wind shear connections were put in as soon as possible to make the bridge secure against any conditions.

The floor system of the span was placed by locomotive cranes and one track was rivetted, permitting a train to be taken over the bridge on October 17th. The bridge was handed over to the Operating Department for regular train service on the 3rd December, 1917, the only work remaining to be done being the concrete sidewalks on the suspended span and the painting, which could be carried on while the bridge was in service.

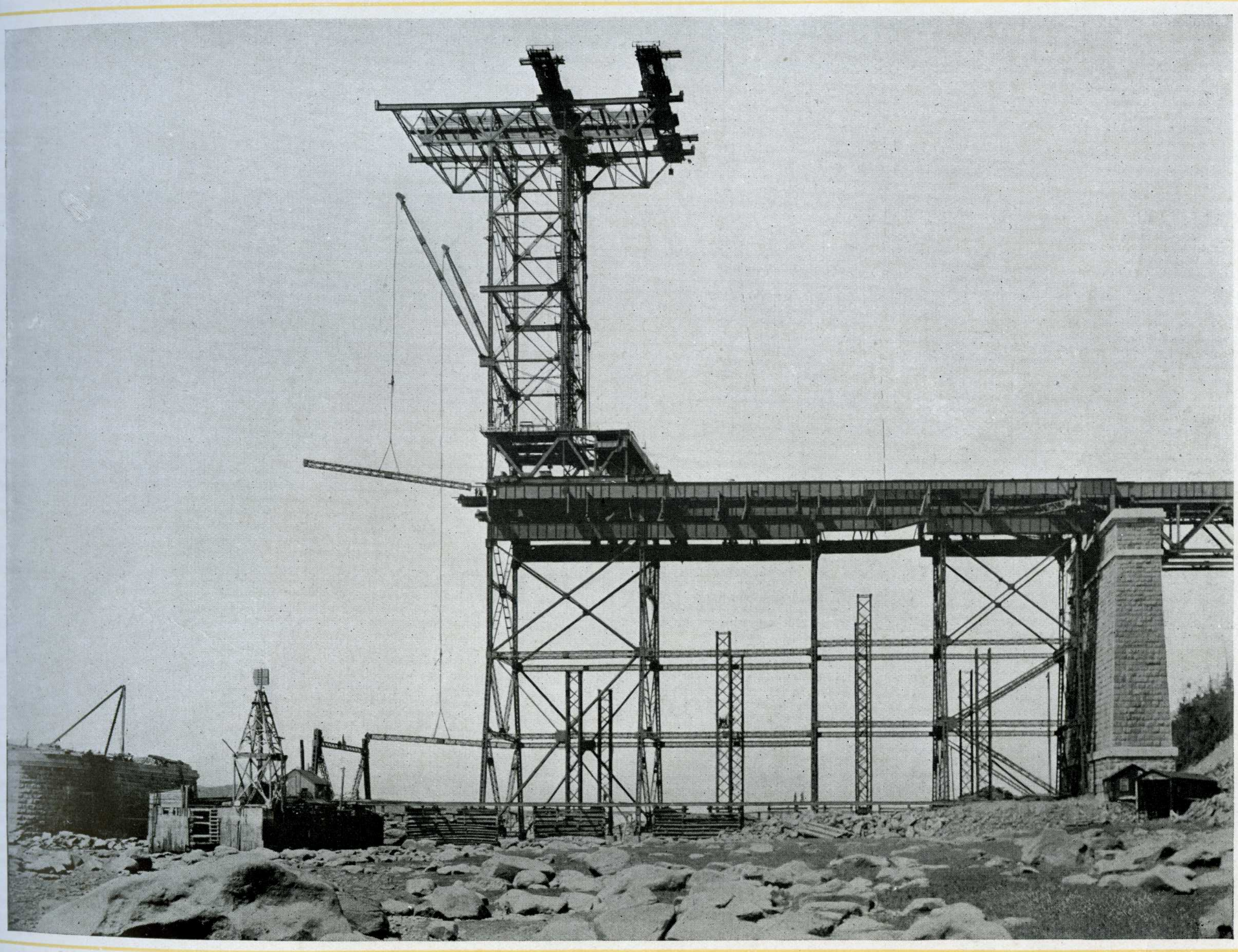
The executive officers of the Company desire to express their appreciation of the faithful and efficient service rendered by the members of its staff. The final success of this great undertaking was due to the efficiency of the organization and the spirit of co-operation between the different departments, all working together to the one end.

They also desire to express their appreciation of the spirit of co-operation and helpfulness of the Board of Supervising Engineers and their staff of inspectors.

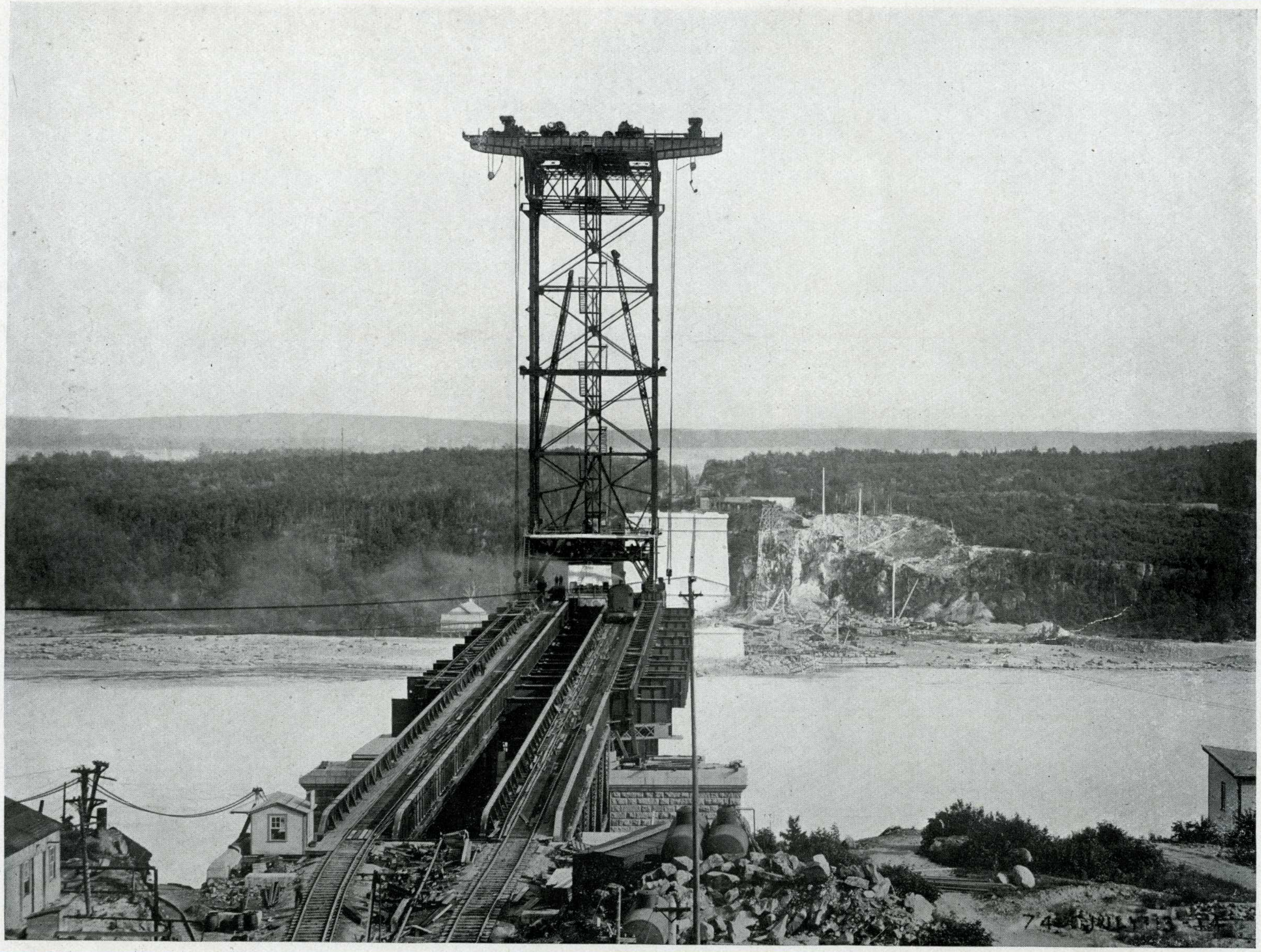
It is a source of great satisfaction to the builders of the bridge to know that the workmanship of the structure shows a degree of perfection believed to have never before been approached. The excellence of the shop work and the exceptional precision in the lengths and fitting of the various members contributed much to the facility with which the bridge was put together in the field, and to the confidence that every part of the structure is performing its calculated duty. This result could only have been reached by the use of the most perfect shop equipment and great care in manufacture. The tool equipment was selected and installed under the supervision of Mr. Walter P. Ladd, who also had full charge of and responsibility for the manufacture of the structure.

Hearty thanks are due to the management of the Carnegie Steel Company for their very prompt delivery of the steel for replacing the suspended span, and also to the Midvale Steel Company for their prompt delivery of pins.

15—The North Shore traveller erected being equipped, also showing the office building and power house to the left

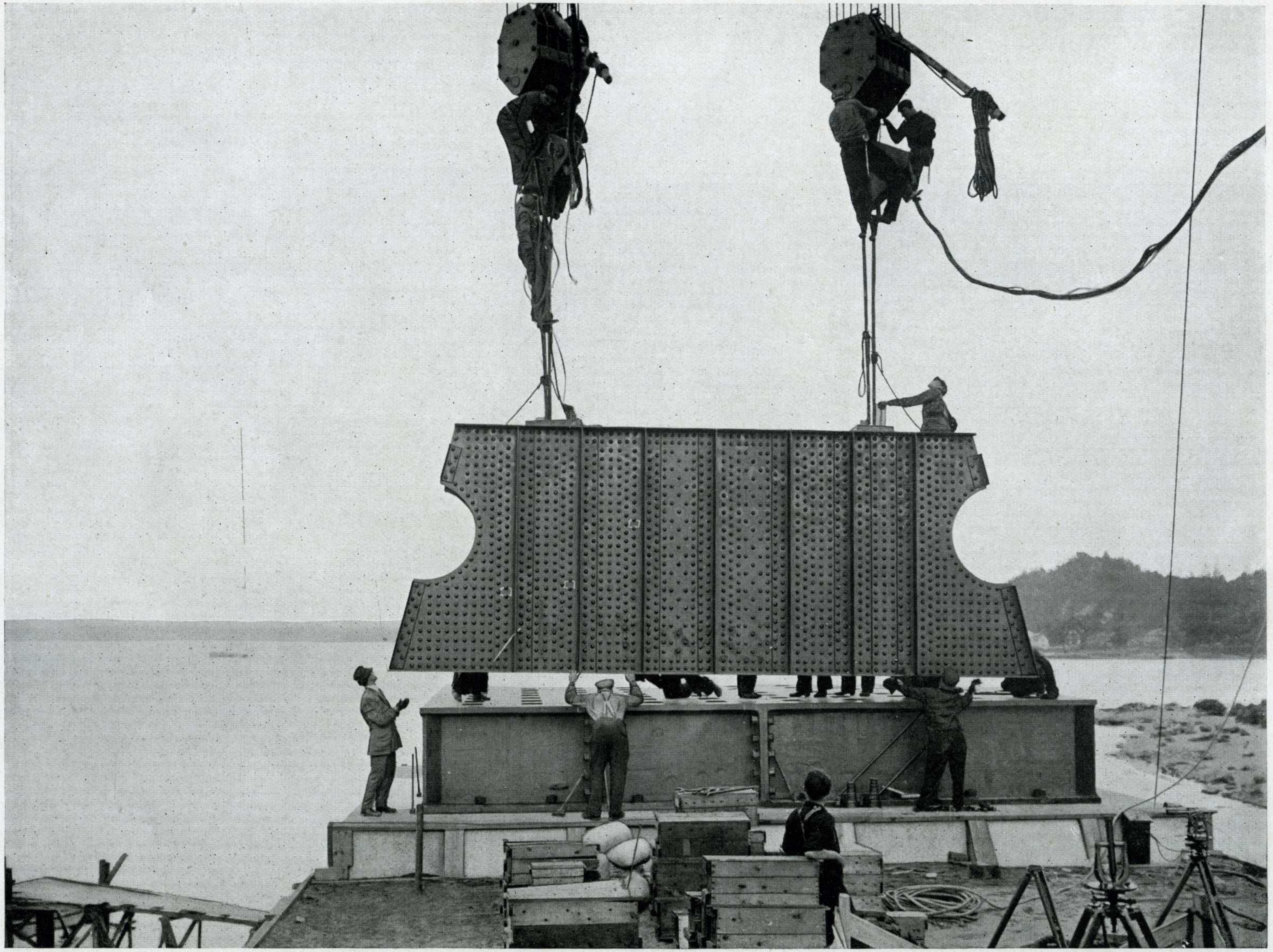


16—The traveller in use setting the falsework for the anchor arm trusses and permanent and temporary floor

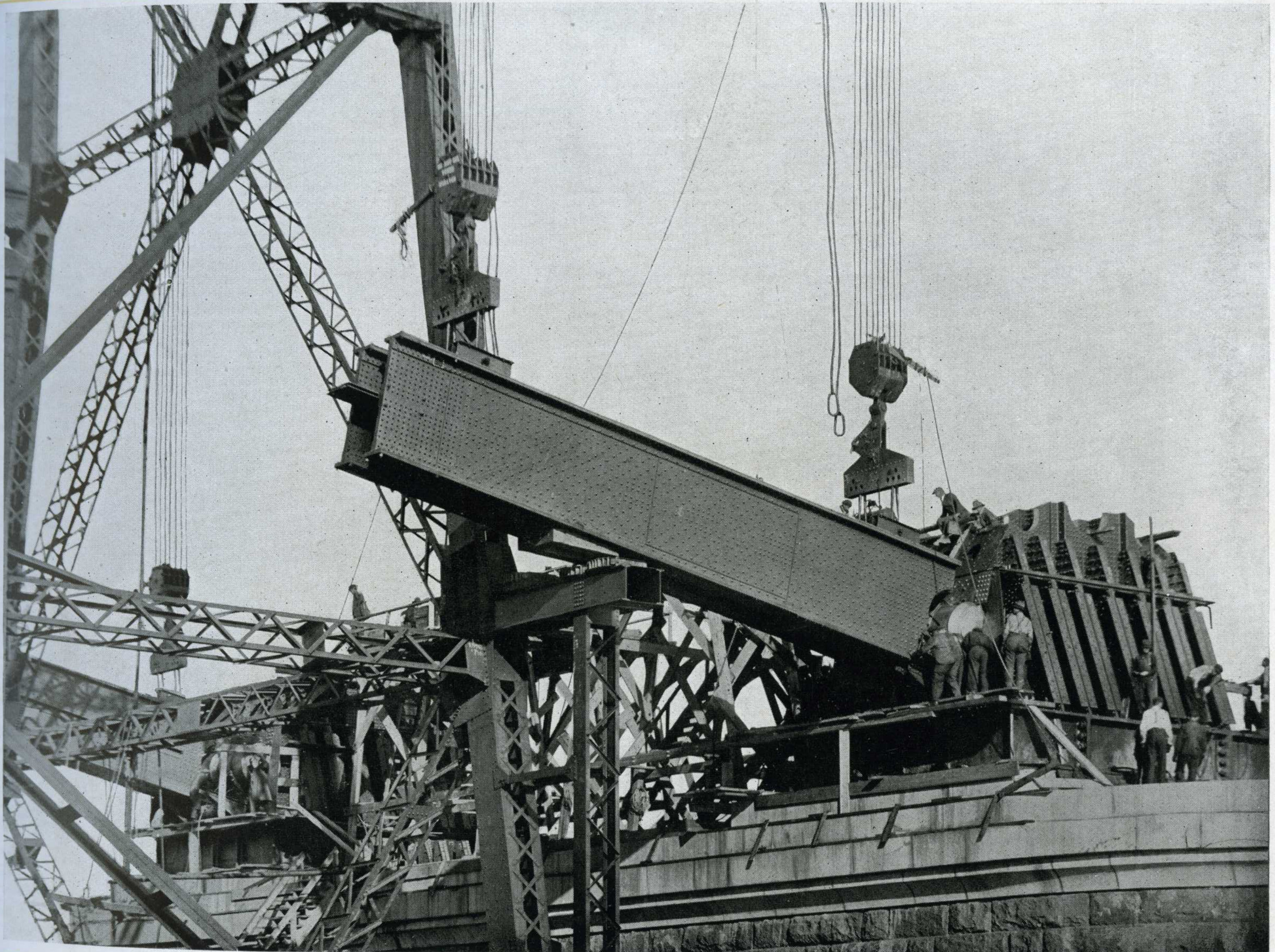


17—End elevation of the traveller at the same position as on plate 16, showing the four tracks on which it was carried and the temporary outside girders to support the outside tracks

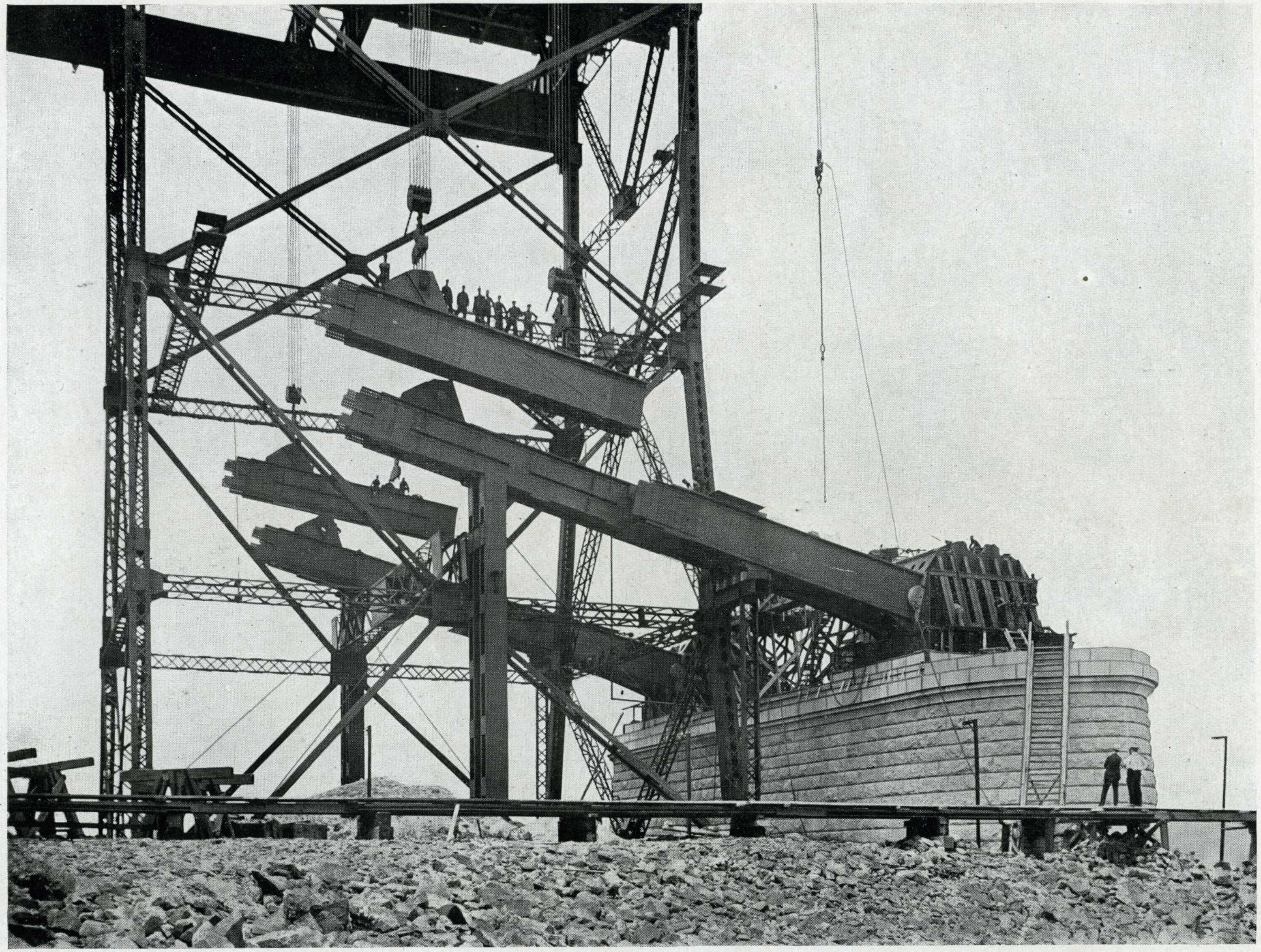
18—Permanent track girders and floor beams supported by the falsework; also shows the bushed pin holes in the end of floor beams



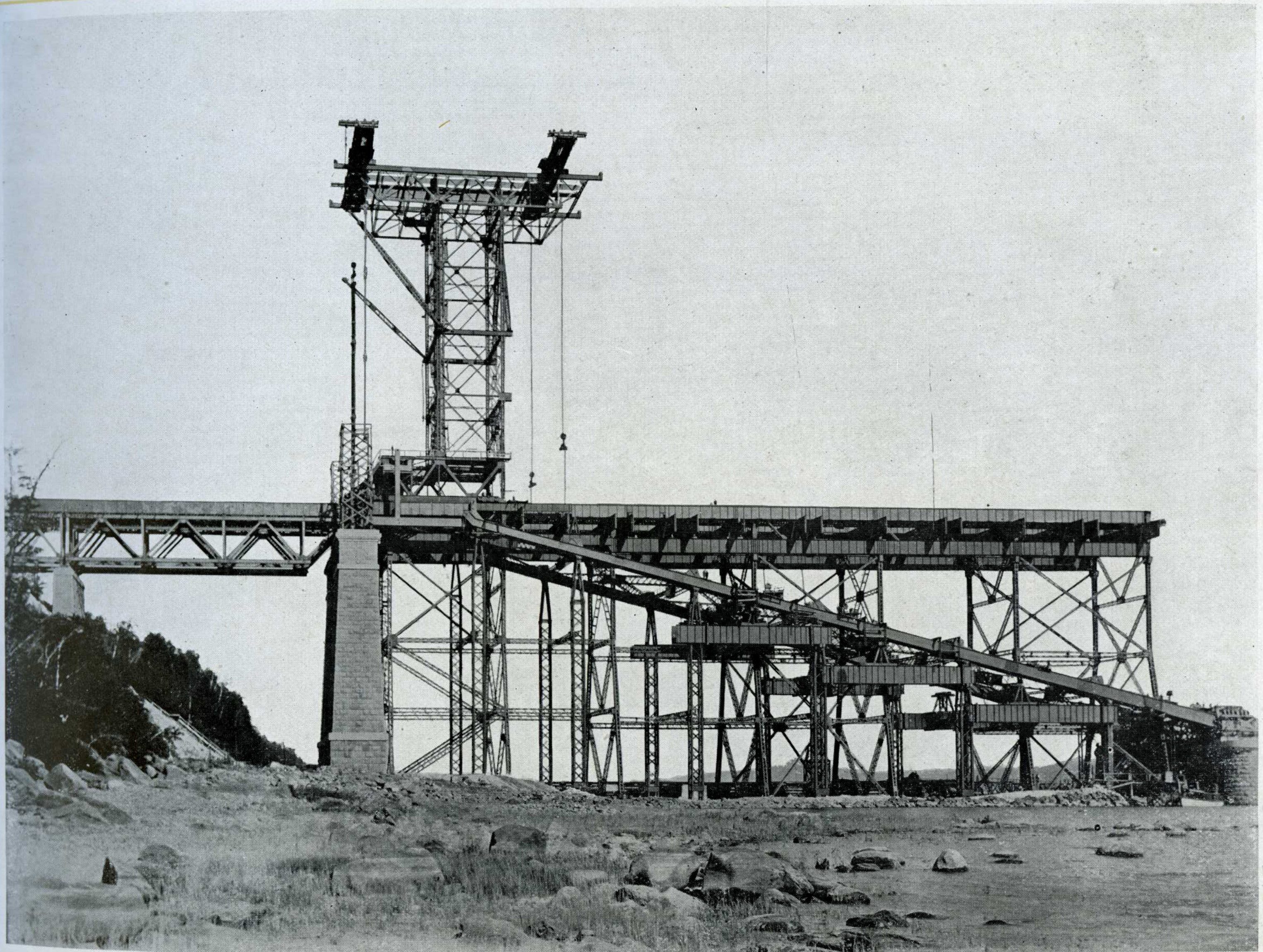
19—The main shoe grillage already set, one rib of the main shoe being placed



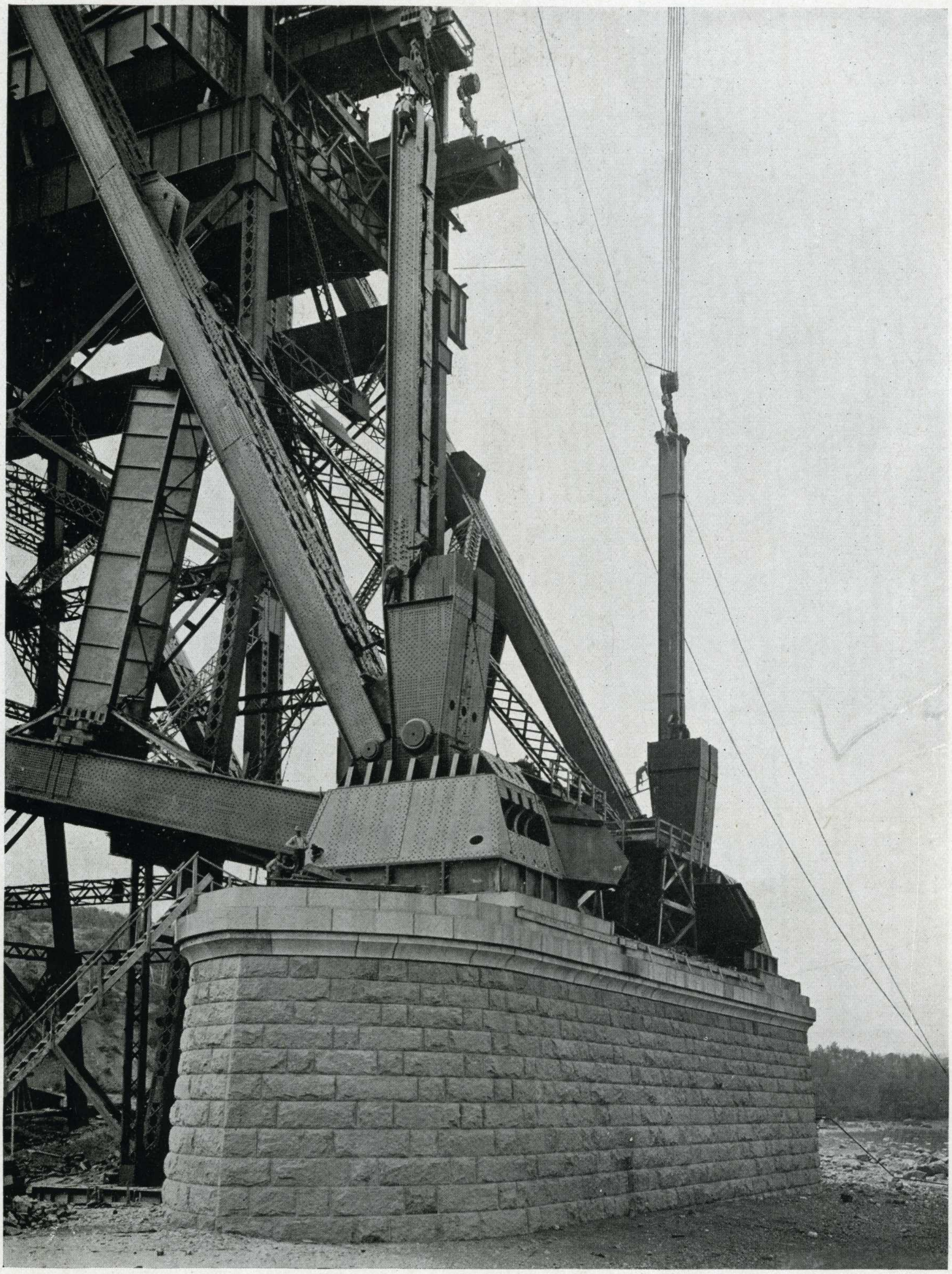
20—The Northwest shoe erected complete except the cover plates over the stiffening ribs. The first section of the lower chord of the anchor arm is being placed



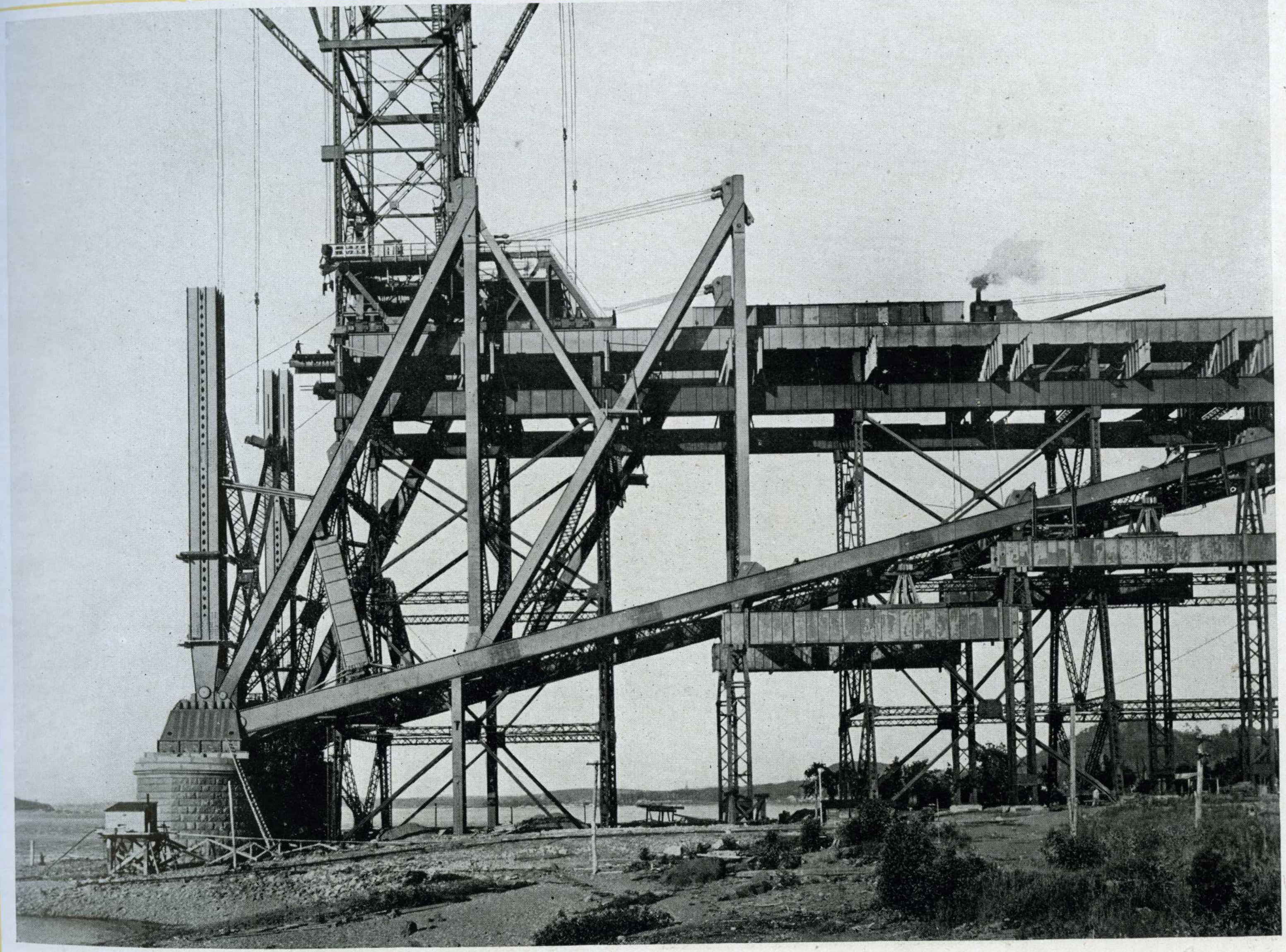
21—Setting the fourth section of the lower chord to complete the first lower chord panel of the anchor arm



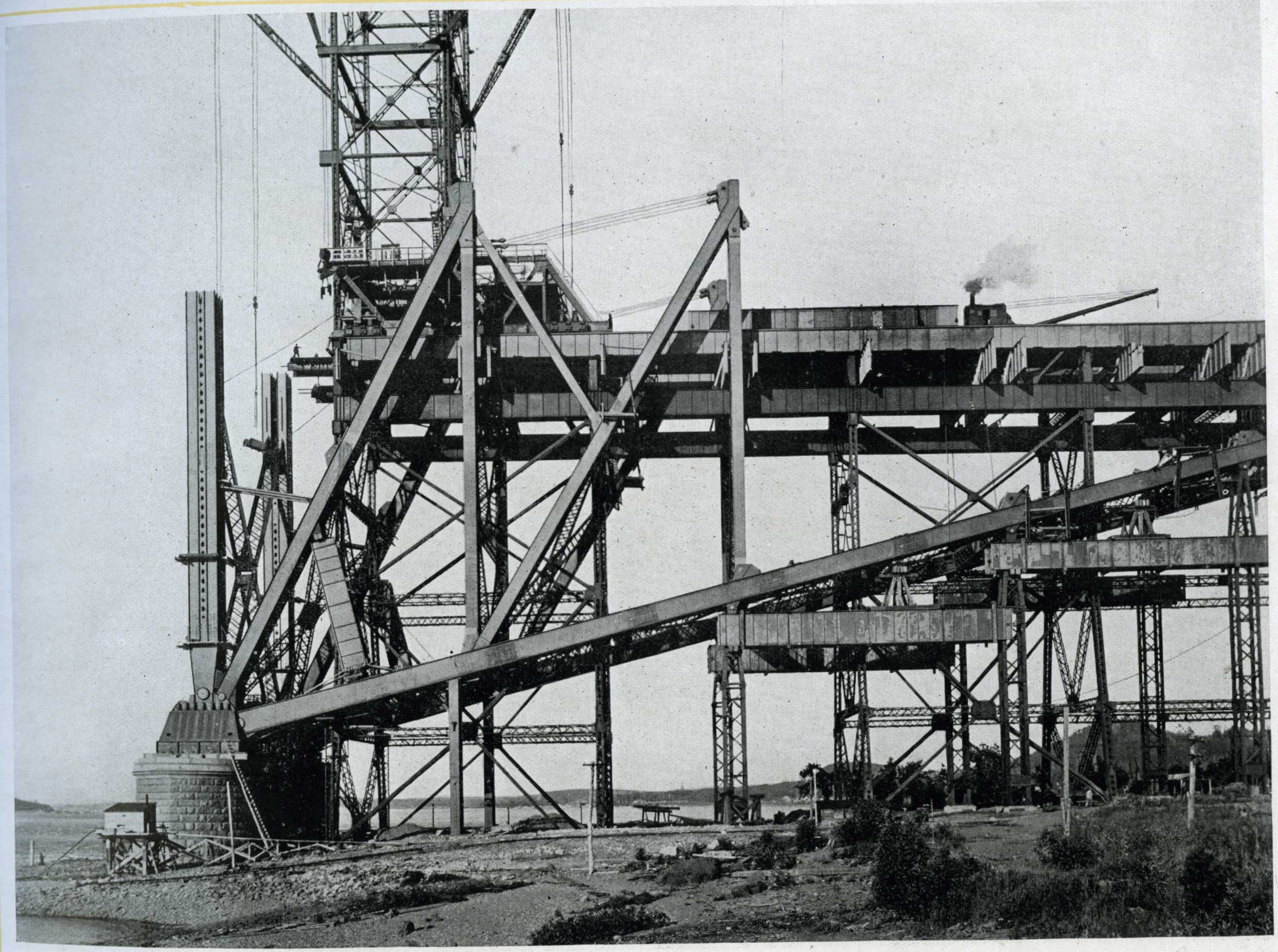
22—The anchor arm lower chord completed. Lowering anchor bars into the wells of the anchor pier



23—Starting the erection of the anchor arm web system



24—Two lower triangles of the web system of the anchor arm erected



24—Two lower triangles of the web system of the anchor arm erected