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TRANSACTIONS

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THE ST. CROIX RIVER BRIDGE.*

By C. A. P. TURNER, M. AM. Soc. C. E.

The Wisconsin Central Railroad, now leased by the Soo Line, and forming the Chicago Division of that road, is being rapidly improved in order to offer to the traveling public service second to none between the Twin Cities and Chicago. The shortening of the line and the reduction of the grades by a number of changes in location are almost completed.

One of the most marked improvements is in that portion of the line near the St. Croix River, 7 miles above Stillwater, Minn. This new cut-off crosses the river at an elevation of 180 ft. above mean water level, and presents some novel and interesting engineering features. The bridge structure is 2 600 ft. in length. The river bed at this point is 1 800 ft. wide, between high sandstone bluffs, but the full width is overflowed only at high water. The material forming the bottom seems to be fairly uniform throughout, consisting of fine sand and silt, easily eroded, and extending down from 100 to 120 ft. to bed-rock.

The piers of the old bridge, $\frac{3}{4}$ mile below the new, are of masonry resting on wooden piles, cut off and capped with timber in the old-fashioned style. They seem to have been gradually shifting down stream, and to have moved from 6 to 8 in. from their original position at the top, as determined by observations from year to year.

One of the holes drilled to bed-rock, in the line of the new bridge, developed a flowing well, delivering, by Artesian pressure, a 2-in. stream of clear spring water 12 ft. above the river level.

* Presented at the meeting of December 6th, 1911.

With such conditions to meet, the problem of economic and satisfactory foundations required as careful consideration as that of the superstructure.

Selection of Type and Design.—When foundations are inexpensive, no type of structure has been evolved which is less in cost than the tower and girder trestle, and a design using 100-ft. girders between bents and 40-ft. girders over towers was examined, and this, in turn, was compared with trestle approaches and five 350-ft. arch spans, both in reinforced concrete and in structural steel.

The reinforced concrete design required more expensive foundations, and, for a single-track bridge, offered insufficient economy in the superstructure to offset such expense.

The superstructure of the trestle design could be built for nearly \$60 000 less than the arch design. Rip-rap for piers, on the other hand, would cost \$10 000 more for the trestle, due to the increased number of piers; piles would have cost \$25 000 more, and concrete \$60 000, leaving a net saving for the longer spans of approximately \$35 000.

A design intermediate in cost was submitted by the McClintic-Marshall Construction Company, using 200-ft. lattice girders between towers.

A further advantage possessed by the structure of longer span is the longer and wider piers and the decreased probability that they might be weakened by erosion. The box-girder top chords give a width of floor of 12 ft. from out to out, and 6 ft. 2 in. between flanges, which is more satisfactory than the floor of the ordinary girder bridge.

Foundations.—The trestle foundations and end abutments rest on sand rock. The four intermediate piers rest on piles, as at their location it is from 100 to 125 ft. to bed-rock.

The piles are of Norway pine, from 70 to 85 ft. in length. The penetration ranged from 50 to 80 ft. No grillage was used, the piles projecting about 4 ft. into the concrete mass of the pier. There are 110 piles in each pier. Most of them were driven by a steam hammer, and the time of driving ranged from 25 to 40 min. per pile. The penetration at the start was about 2 in. per blow, and, under the last blows of the hammer, it ranged from nothing to $\frac{1}{4}$ in.

The concrete for the piers was mixed on top of the bluff, on both the east and west sides, and was distributed as follows: A light timber

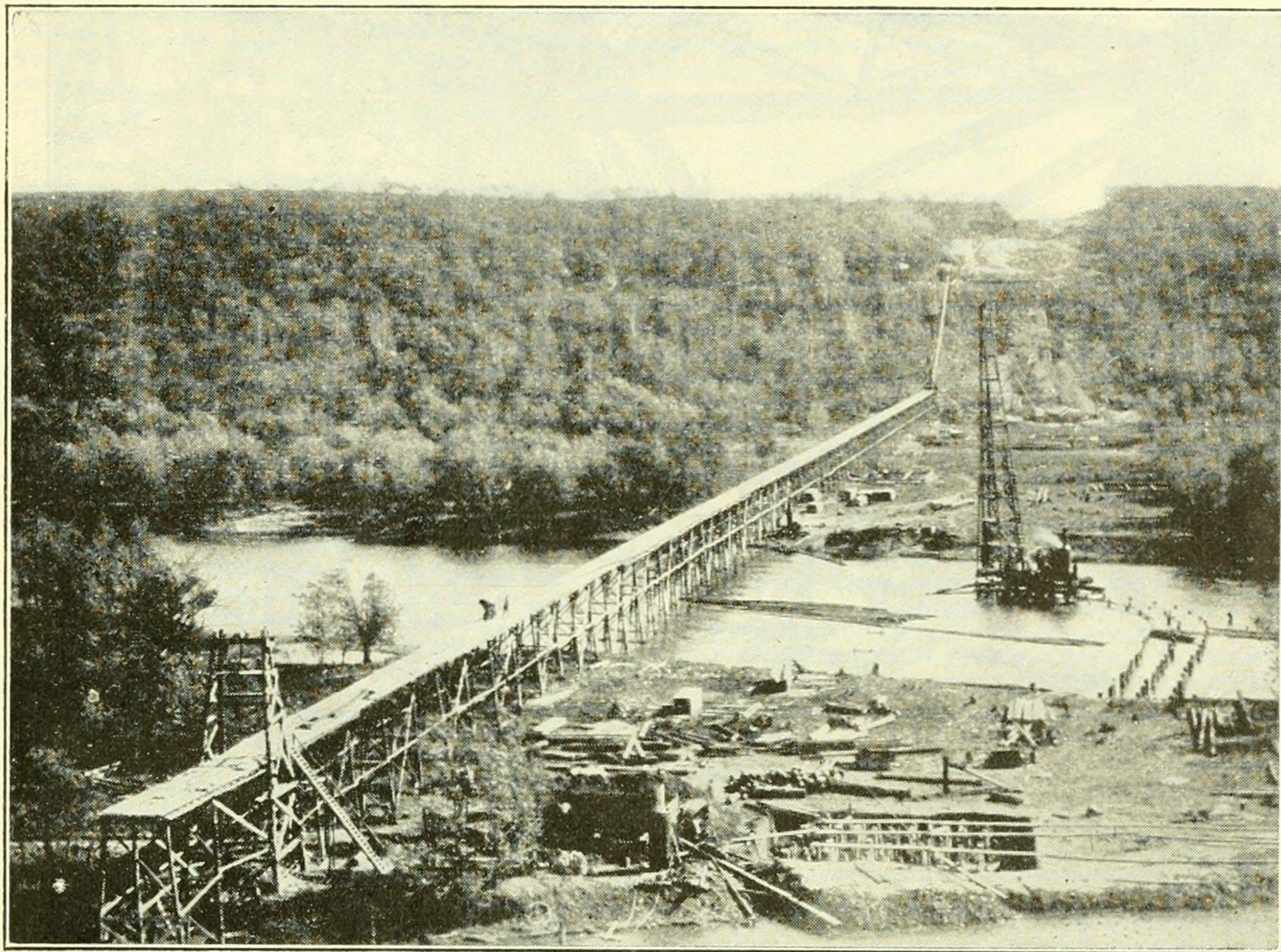


FIG. 1.—PILE-DRIVER, AND TRESTLE FOR HANDLING CONCRETE.

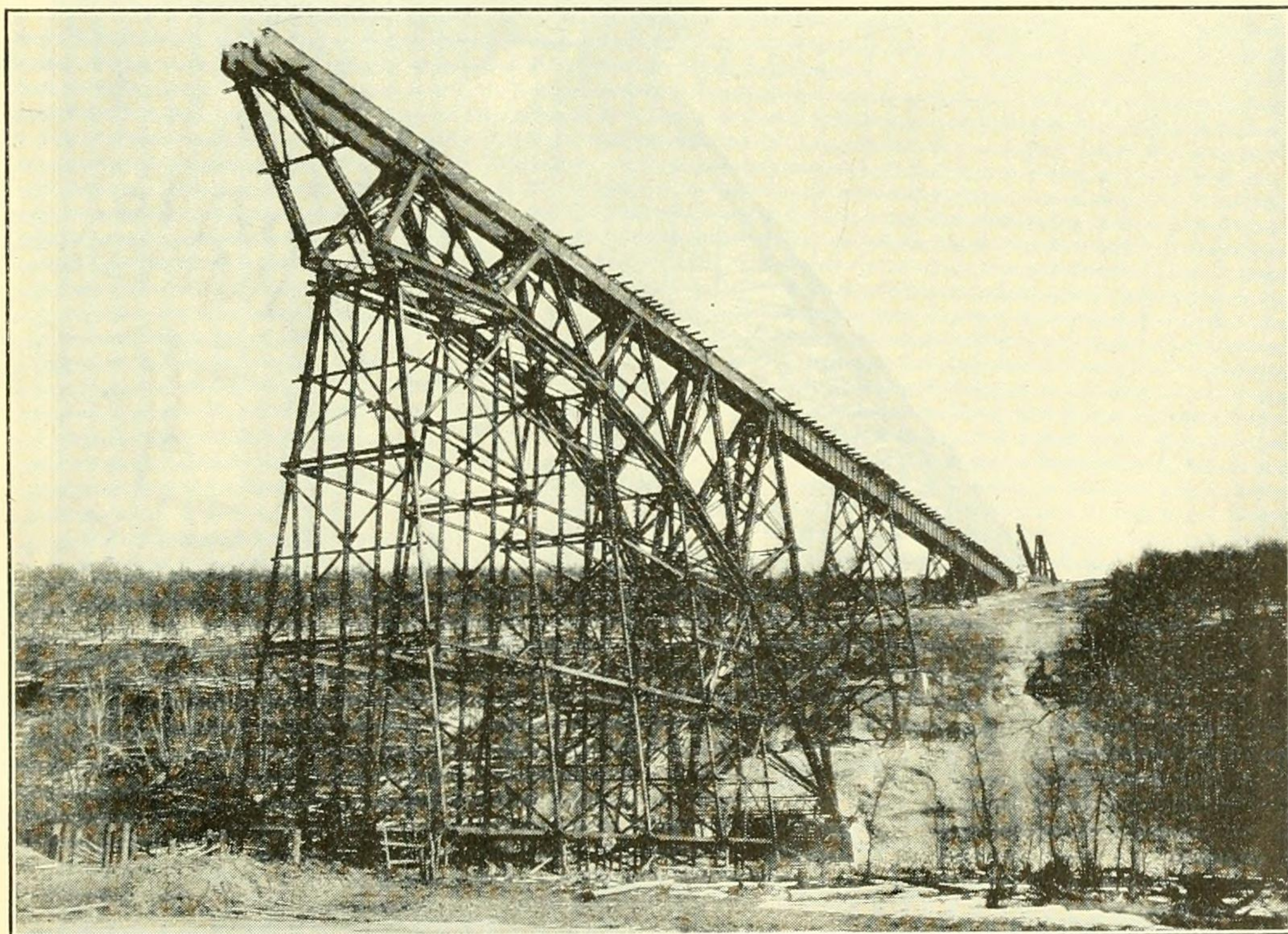


FIG. 2.—ERECTION OF EAST ARCH, ST. CROIX RIVER BRIDGE.

FIG. 3.—ERECTOR OF WEST ARCH, ST. CROIX RIVER BRIDGE.

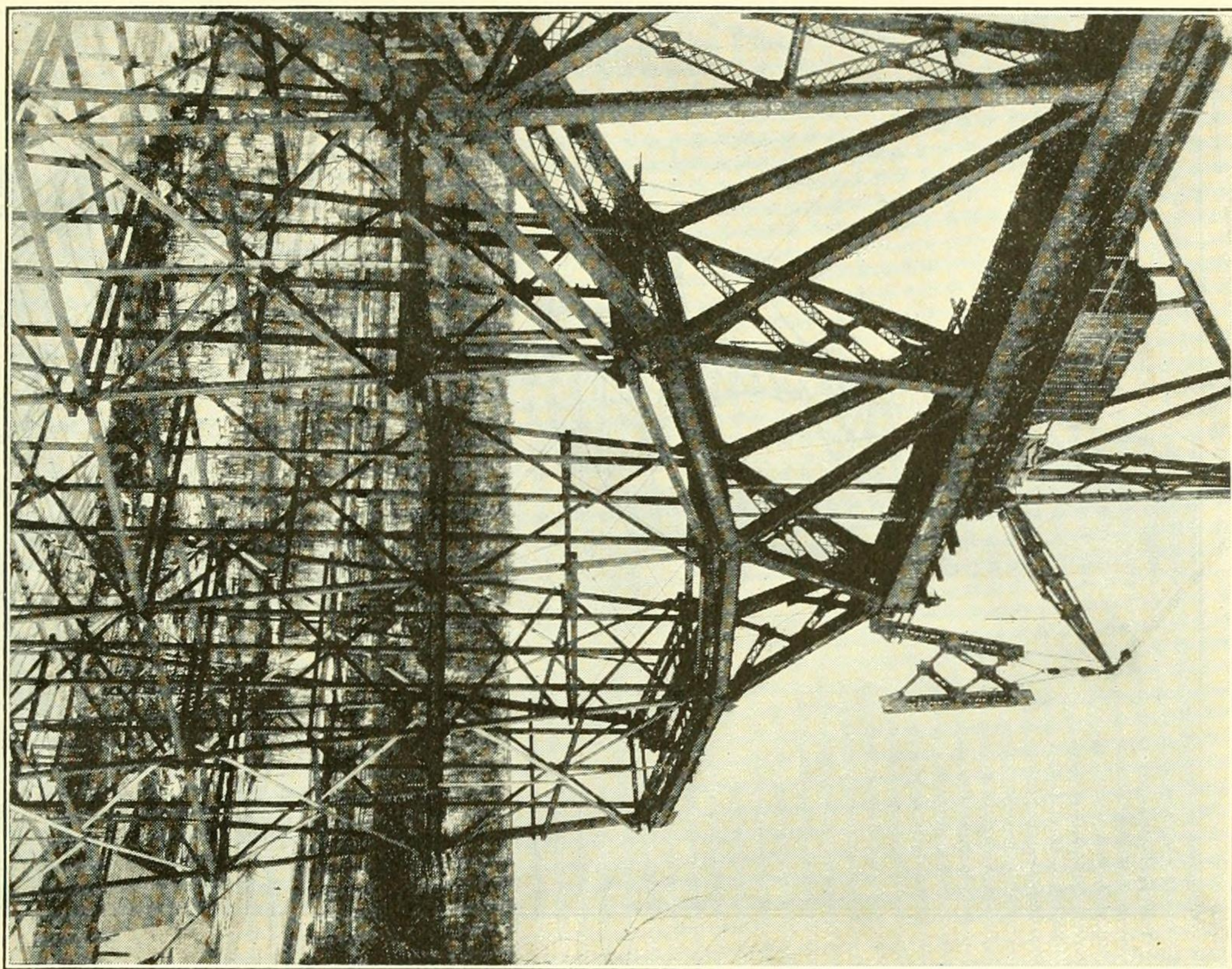


FIG. 4.—ERECTOR OF CENTER ARCH WITHOUT FALSEWORK, AND THE HALF FALSEWORK USED FOR TWO ADJACENT SPANS.

FIG. 4.—ERECTOR OF HALF OF SECOND ARCH AS A CANTILEVER.

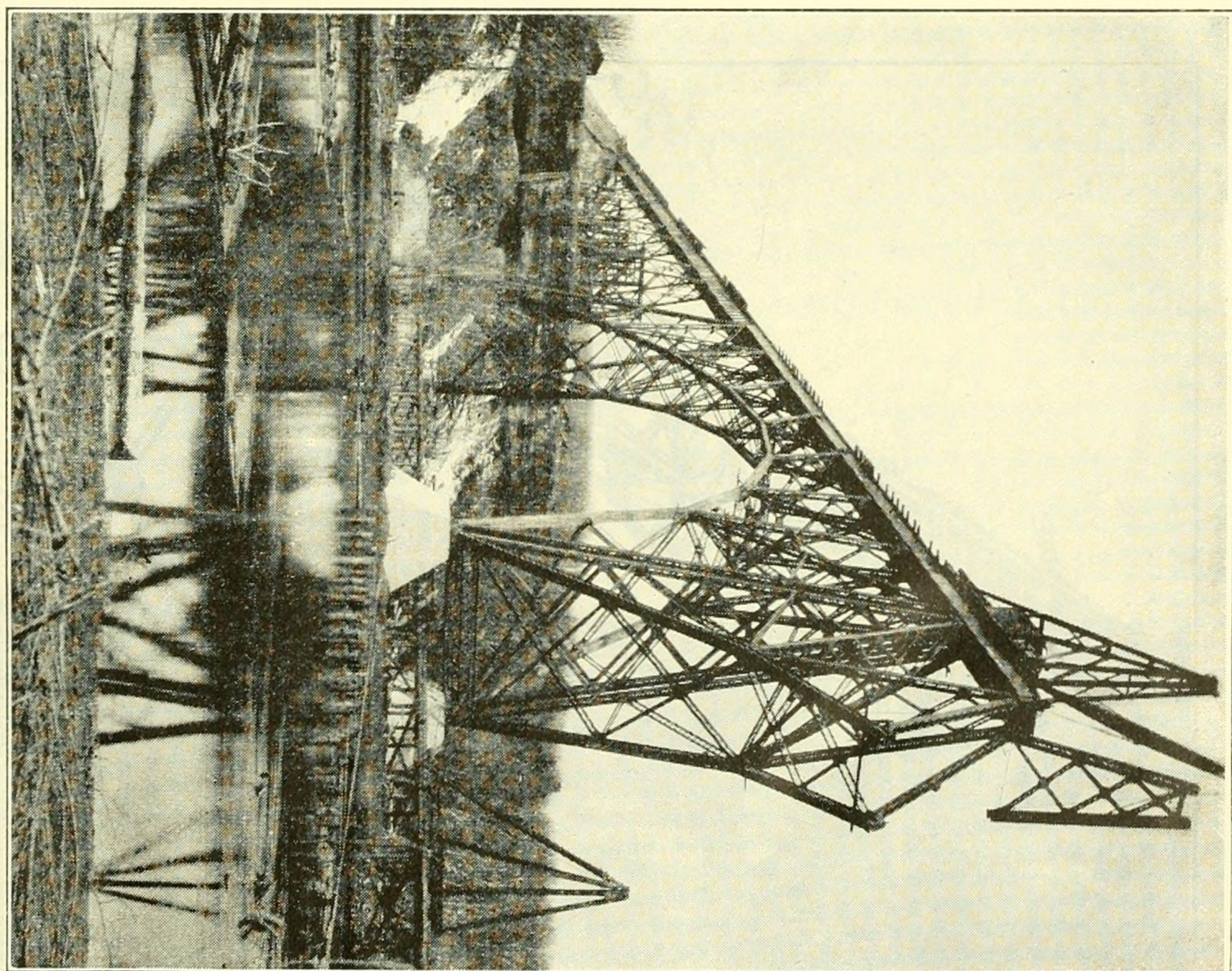


FIG. 5.—THE CLOSURE OF THE CENTER SPAN.

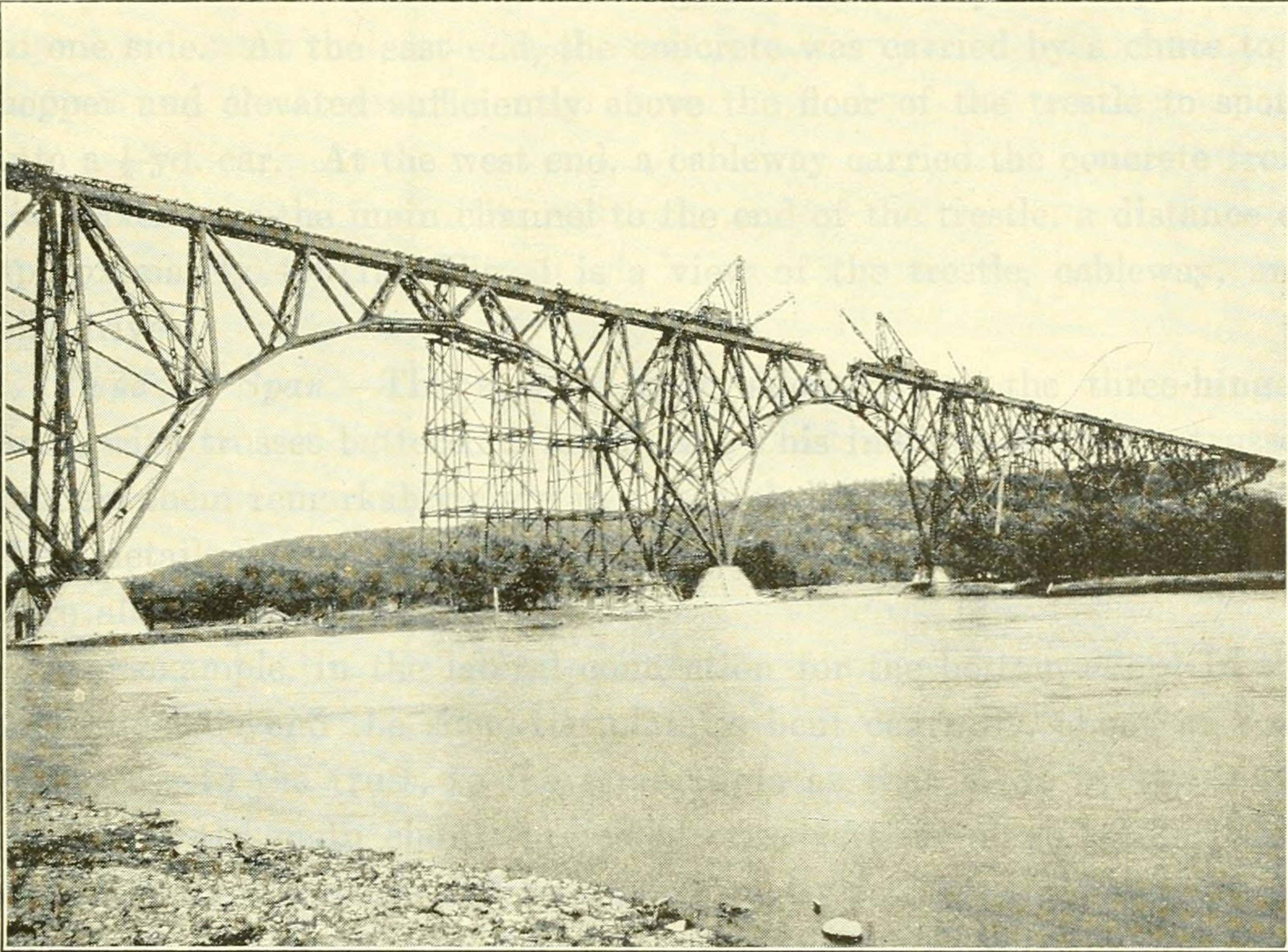


FIG. 5.—ERECTION OF CENTER ARCH WITHOUT FALSEWORK, AND THE HALF FALSEWORK USED FOR TWO ADJACENT SPANS.

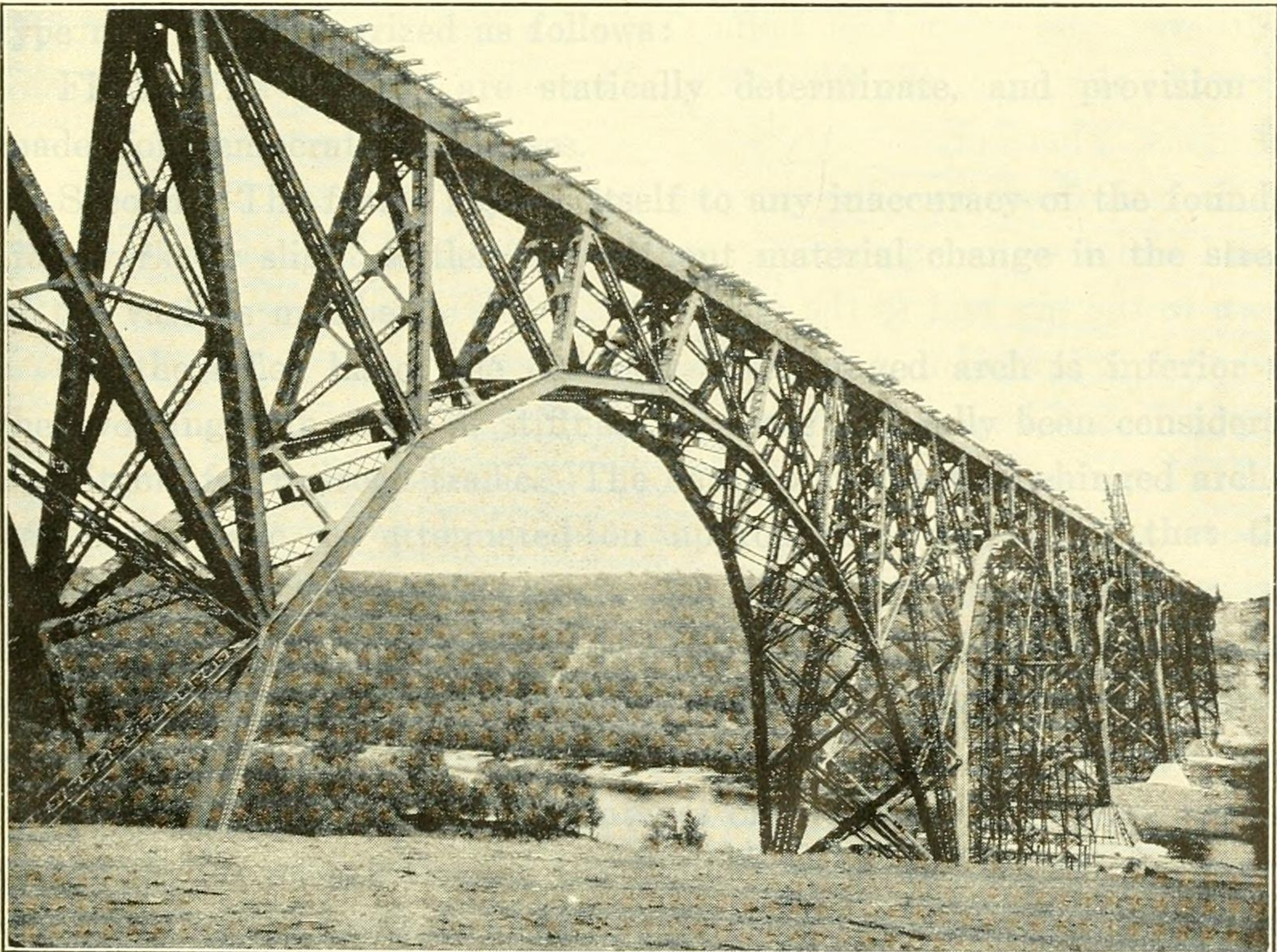


FIG. 6.—THE CLOSURE OF THE CENTER SPAN.

trestle was constructed about 6 ft. higher than the top of the piers, and to one side. At the east end, the concrete was carried by a chute to a hopper and elevated sufficiently above the floor of the trestle to spout into a $\frac{1}{2}$ -yd. car. At the west end, a cableway carried the concrete from the mixer over the main channel to the end of the trestle, a distance of approximately 400 ft. Fig. 1 is a view of the trestle, cableway, and pile-driver.

Type of Span.—The type of span adopted was the three-hinged arch, with trusses battered 2 in. in 12. This inclination of the trusses renders them remarkably rigid in a lateral direction, and involves some skew details in the connections. Then, by a simple expedient, these were all reduced to simple bends.

For example, in the lateral connection for the bottom chord in the first panel beyond the shoe, the plate is bent centrally, about an axis transverse to the truss, to the same angle as that made by the intersection of the main chords projected on a vertical plane, while longitudinally there are two different bevel angles to meet the flange of the chords of different inclination. Slotting the plate, on the line of the transverse bend, to its intersection with the lines of longitudinal bend, leaves them simple bends, in place of die forgings.

The advantage of the three-hinged over the two-hinged or restrained type may be summarized as follows:

First.—The stresses are statically determinate, and provision is made for temperature stresses.

Second.—The frame adjusts itself to any inaccuracy of the foundation work, or slight settlement, without material change in the stress of the various members.

On the other hand, the ordinary three-hinged arch is inferior to the two-hinged in point of stiffness, and has generally been considered unsuitable for railroad traffic. The depth of many three-hinged arches has been made so attenuated on approaching the crown that the complaint concerning this type in that form is well founded.

In the design of the St. Croix River Bridge, the depth of the crown is 25 ft. and the rise is 124 ft., so that the truss has ample depth throughout.

In order to combine the advantages of two-hinged and three-hinged arches, as far as practicable, the connection of the central top chord was made in the form of a friction joint of five plates, two of bronze

and three of steel, giving six friction surfaces. As soon as the live load comes on the central chord, these joints lock by friction as firmly as though riveted, and the frame then deports itself as a two-hinged arch.

This feature of the design, together with the inclination of the truss, renders the structure one of the most rigid in existence.

Erection.—The bridge was erected from both ends toward the center. The equipment consisted of four derrick cars, a lighter one at each end being used for unloading and sorting the material and bringing it to the end of the bridge, where it was handled by the heavier cars.

The end arches, throughout, were erected on falsework, which was placed by the derrick cars as the work was built out.

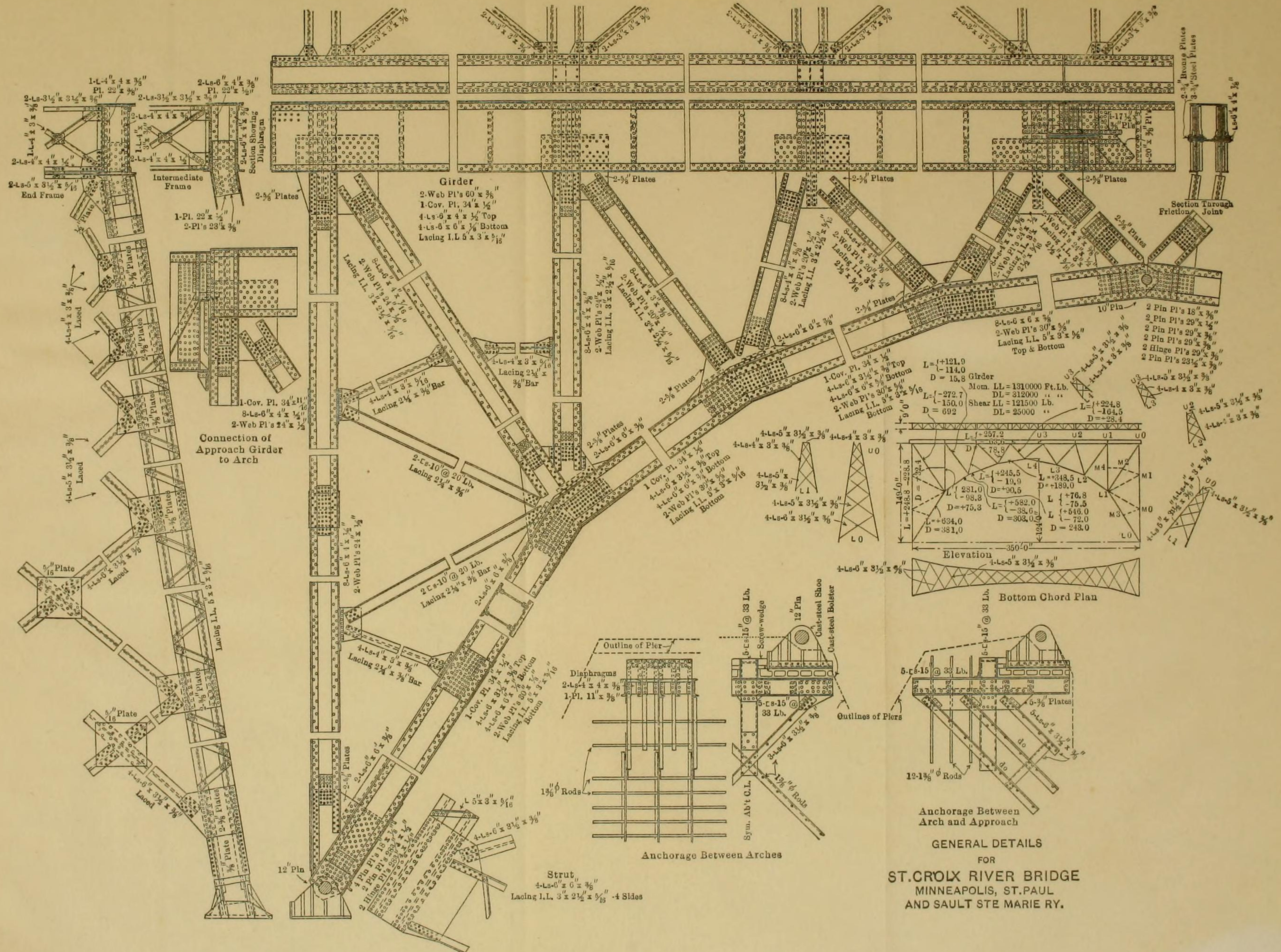
The most difficult part was the erection of the first panel of the end arches. On the east side, a falsework bent was put up, supporting the 100-ft. girder; and, on the west side, the end vertical of the arch was supported on a cob-pile of timber until the end bottom chord could be placed and the connection at the shoe made.

Fig. 2 shows half of the extreme eastern arch. Fig. 3 shows half of the west arch on falsework and the method of placing the frames. Fig. 4 shows the erection of half of the second arch as a cantilever, the other half being built on falsework. Figs. 5 and 6 show the closing of the fifth arch. This arch was erected without any falsework whatever.

Special Features.—In erecting past the center top chord, it was found simplest to support the center top chords from a timber bent down to the pin and to the outer end outside of the line of the chord, and slide it inward to position laterally after the succeeding chord and diagonals had been erected in place.

In building out the end arches, the compression of the timber falsework allowed the members to drop slightly below grade. The jacking up was done by taking advantage of the temperature changes between morning and noon. At about sunrise the shoe at the skewback was wedged out; then, as the temperature increased, the expansion of the steel would raise the span from the falsework, and shim wedges would be driven home; then, as the temperature dropped, $\frac{1}{2}$ or $\frac{3}{4}$ in. could be gained at the shoe.

As shown by Fig. 6, the skewback was arranged as follows: A cast-



steel shoe was given a horizontal bearing on a bolster frame built into the concrete. This frame was arranged with a projecting vertical center member, against which the vertical end of the shoe could thrust. Steel blocking was provided between the vertical impost member and the end of the shoe, calculating for a clearance of about 9 in. Screw-wedges were provided for the adjustment of the span, so that this distance could be increased, to raise the crown of the arch, or decreased, if found to be above grade when erected.

In closing the first arches, erected wholly on falsework, this clearance proved none too great to get the shoe in place, and the scheme of jacking by temperature changes enabled the erectors to force it out so that the wedges could be entered.

The adoption of inclined trusses, with bent plate connections to the top chords, leaving the chord in a vertical position, is a somewhat unusual feature in bridge design.

The broad and exceptionally rigid floor system secured in the 50-ft. panels of the structure would seemingly warrant its adoption, from the economic standpoint, in deck bridges where the depth is not sufficient for arch construction. The elimination of floor-beams, floor-beam connections, and the combination of stringers and chords in one member, with ample width of floor, will generally result in a material saving of metal.

The structure was designed for Cooper's *E-55* loading. Plate I gives a general idea of the details.

The work was executed under the direction of Mr. Thomas Greene, Chief Engineer of the Minneapolis, St. Paul and Sault Ste. Marie Railway, the writer acting as Consulting Bridge Engineer. The Kelly-Atkinson Construction Company was the contractor for the erection of the work, and the American Bridge Company furnished the steelwork. The concrete work was executed by the Railroad Company. The pile-driving was done by George W. Oakes and Company, of St. Paul, Minn.

Since this paper was prepared the writer has passed over the St. Croix Bridge several times in the cab of a heavy locomotive, and, from that point of observation, the bridge seemed to be the most rigid he had ever crossed.