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AMERICAN SOCIETY OF CIVIL ENGINEERS
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PAPERS AND DISCUSSIONS

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RECONSTRUCTION OF THE NORFOLK AND WESTERN RAILWAY COMPANY'S BRIDGE OVER THE OHIO RIVER AT KENOVA, WEST VIRGINIA.

By William G. Grove,* Esq., and Henry Taylor,
Assoc. M. Am. Soc. C. E.

To be Presented February 17th, 1915.

Synopsis.

The purpose of this paper is to set forth in a general way, by using a specific case, the difficulties that engineers must surmount when it becomes necessary to replace an existing structure, which has become inadequate for the demands of modern service, with another structure capable of meeting present and future conditions.

In this instance, the problem consisted of replacing a single-track, five-span bridge, 1 800 ft. long and 100 ft. above water level, with a double-track bridge, on the same piers, without interruption either to railway traffic or river navigation.

The methods used in the reconstruction are described as well as the design of the new structure. The paper is divided into eight parts, as follows:

History and description of the old bridge;
Erection of the viaduct approach;
Various preliminary schemes for the erection of the river spans;

Note.—These papers are issued before the date set for presentation and discussion. Correspondence is invited from those who cannot be present at the meeting, and may be sent by mail to the Secretary. Discussion, either oral or written, will be published in a subsequent number of *Proceedings*, and, when finally closed, the papers, with discussion in full, will be published in *Transactions*.

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Description of the new spans, with loads and unit stresses used in the design;

Method of remodeling the tops of the present piers;

Description of the pier girders and material tracks;

Method finally adopted and used for the reconstruction of the five river spans;

Arrangement of the material yard.

The writers, as far as possible, have endeavored to make the paper a descriptive one, and hence have omitted all the calculations necessary in the design and in ascertaining the deflections of the several spans. The calculated figures, however, agreed very closely with the distances actually measured in the field.

By the addition of drawings and photographs, it is hoped to show the actual field conditions in a much clearer way than could be done by description. Figs. 46 and 47, showing the flood of March, 1913, tell better than words why the extra precautions were taken during this reconstruction.

By this method of description and illustration, the writers hope to make the paper interesting and instructive to those members of the Society who are not connected with the structural end of engineering, as well as to bridge engineers.

In conclusion, the point to be emphasized is the practicability, from an economic as well as from an engineering standpoint, of safely reconstructing existing structures without serious interruption of traffic.

Introduction.

The original single-track Norfolk and Western Railway bridge across the Ohio at Kenova, W. Va., having become inadequate for the heavy traffic of the road, it was decided in 1909 to replace it with a heavier double-track structure. As this bridge was on the only practical route for the Railway Company's traffic, the problem presented to bridge builders was one of replacing the bridge and at the same time not disturbing the traffic over it, or river navigation. As the tops of the piers were about 100 ft. above the water, and as the construction of new piers would have involved quite a considerable additional expense, the question ultimately resolved

itself into one of replacing the bridge with a new structure on the same piers.

The paper describes the manner in which this reconstruction, by the method of cantilever erection, was accomplished successfully by the American Bridge Company during 1912-1913, without any interference with river navigation and, except for one day, without interruption of railway traffic.

History and Description.

The Town of Kenova is on the south bank of the Ohio River, in West Virginia. It is just opposite the extreme southern part of Ohio, and is separated from that State by the Ohio River, and from Kentucky by the Big Sandy River which empties into the Ohio at this point, hence the derivation of the name: Ken for Kentucky, o for Ohio, and va for Virginia, and it is therefore called the Tri-State City.

At this point the Ohio River flows from east to west. On the north or Ohio shore the bank is very steep and the hills extend almost to the river bank. On the south shore, however, conditions are different. The hills begin to rise about ½ mile back from the river, and Kenova is on the plain between the hills and the river. The tracks of the Baltimore and Ohio Railroad and the Chesapeake and Ohio Railway run parallel to the Ohio River on the south bank. The Norfolk and Western Railway comes directly out of the hills on the south bank and, after passing along a viaduct over the Chesapeake and Ohio and the Baltimore and Ohio lines, crosses the Ohio River at right angles and at an elevation of about 100 ft. above mean water level. Trains cross the bridge at the rate of 72 per day, or about 1 every 20 min., and consist of from 50 to 75 cars each. These trains are made up principally of coal cars, bringing coal from the fields in the mountains of West Virginia and transporting it through Ohio, Indiana, etc.

The old bridge, Fig. 1, completed in 1891, was fabricated by the Edge Moor Bridge Company (now the Edge Moor Plant of the American Bridge Company), and was erected by Messrs. Baird Brothers. It consisted of five single-track, through, pin-connected truss spans, a channel span of 518 ft., flanked on each side by two 298-ft. spans. There was a 2 148-ft., single-track, deck, plate-girder, viaduct approach on the West Virginia side and one 64-ft., single-track, deck, plate-girder span on the Ohio side. The old bridge was designed for

Cooper's E-40 live load. The trusses were made 34 ft. from center to center, with the idea of putting a third truss in the center when it became necessary to double-track the bridge. All the spans were of the sub-panel type. The bottom chord was made up of two lines of eye-bars, 7 ft. 0 in. apart vertically; in the end panels, however, the two lines were brought together so as to connect to the single pin at the shoe. Floor-beams and stringers were placed between the two lines of eye-bars. In the intermediate panels, there were two sets of bottom laterals, one in the plane of the top flange of the floor-beams and the other in that of the bottom flange. In the end panels there was only one set of bottom laterals, which was in the plane of the shoe pins. All the top laterals, bottom laterals, and sway-bracing diagonals were of rods connected to the trusses by pins. A longitudinal strip of timber was placed on top of each line of stringers, and supported the wooden cross-ties, which, in turn, carried the rails.

At both ends of the bridge and viaduct the line had already been double-tracked, and, on account of the very heavy traffic and the increase in the weight of the loads carried, it became necessary to provide double track and, at the same time, increase the strength of the bridge. Various plans were considered, and the one finally adopted retained the same alignment as the old bridge, letting the new viaduct rest on the old footings and the new spans on the old piers.

Erection of Viaduct.

The new viaduct, designed in such a manner that it could be erected without interrupting traffic, was built in 1911. New footings had been placed under the old viaduct columns some years before. They were built on concrete piles, and each was designed to carry the load of a double-track viaduct column. The viaduct approach consisted of sixty-eight spans of 30 ft. 8¼ in., and one span of 61 ft. 4½ in., giving a total length of about 2 148 ft. New columns were provided throughout and new girders for all but twenty spans at the south end. For these twenty spans the old girders taken from the remainder of the viaduct were framed together in pairs, and two were used under each rail. These old girders were in good condition, and this substitution saved the expense of considerable new material. The viaduct runs through the sparsely settled part of the town, and its height varies from 20 ft. at the south end to 50 ft. at the north or river end.

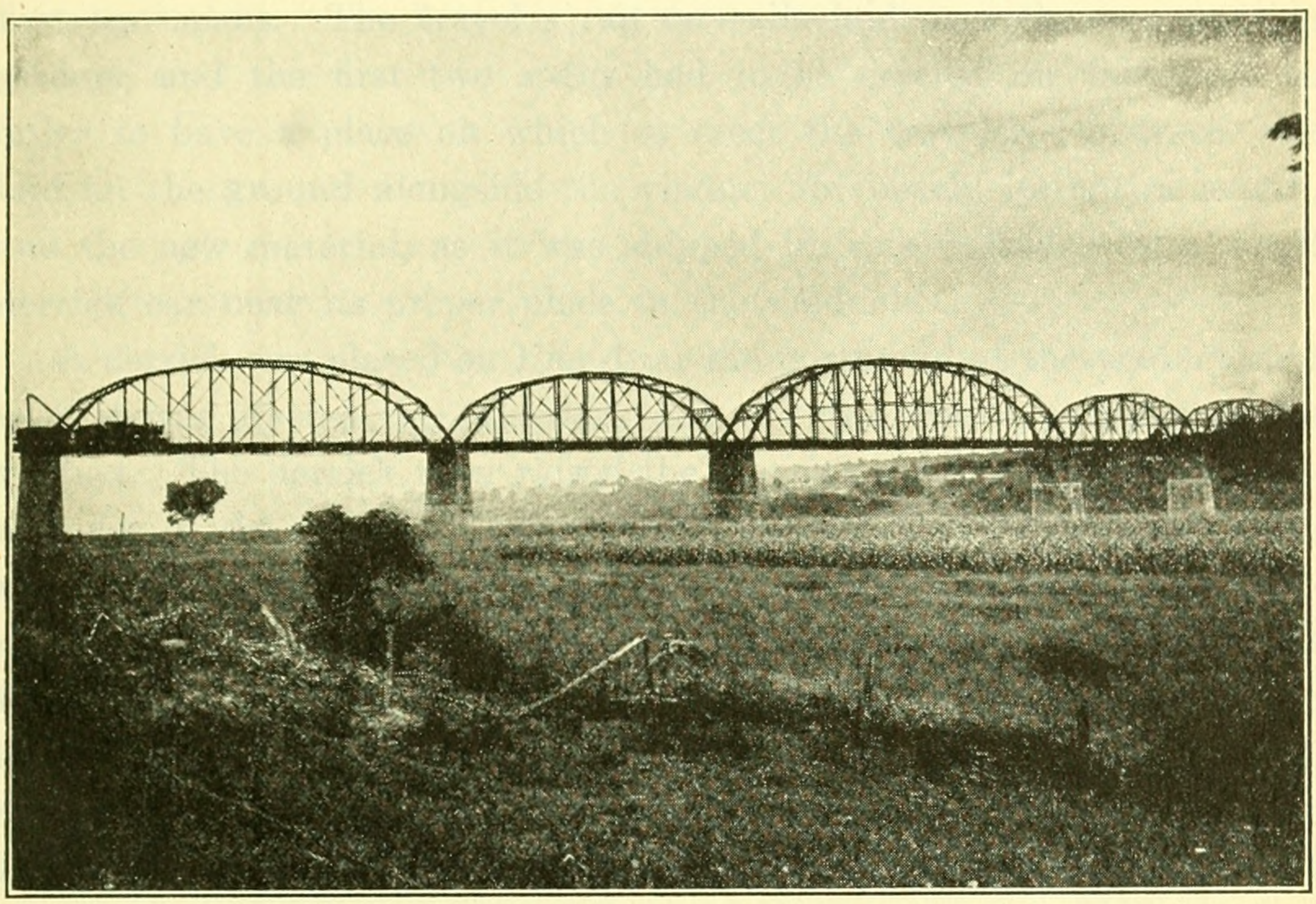


FIG. 1.—THE OLD NORFOLK AND WESTERN RAILWAY BRIDGE AT KENOVA, W. VA.

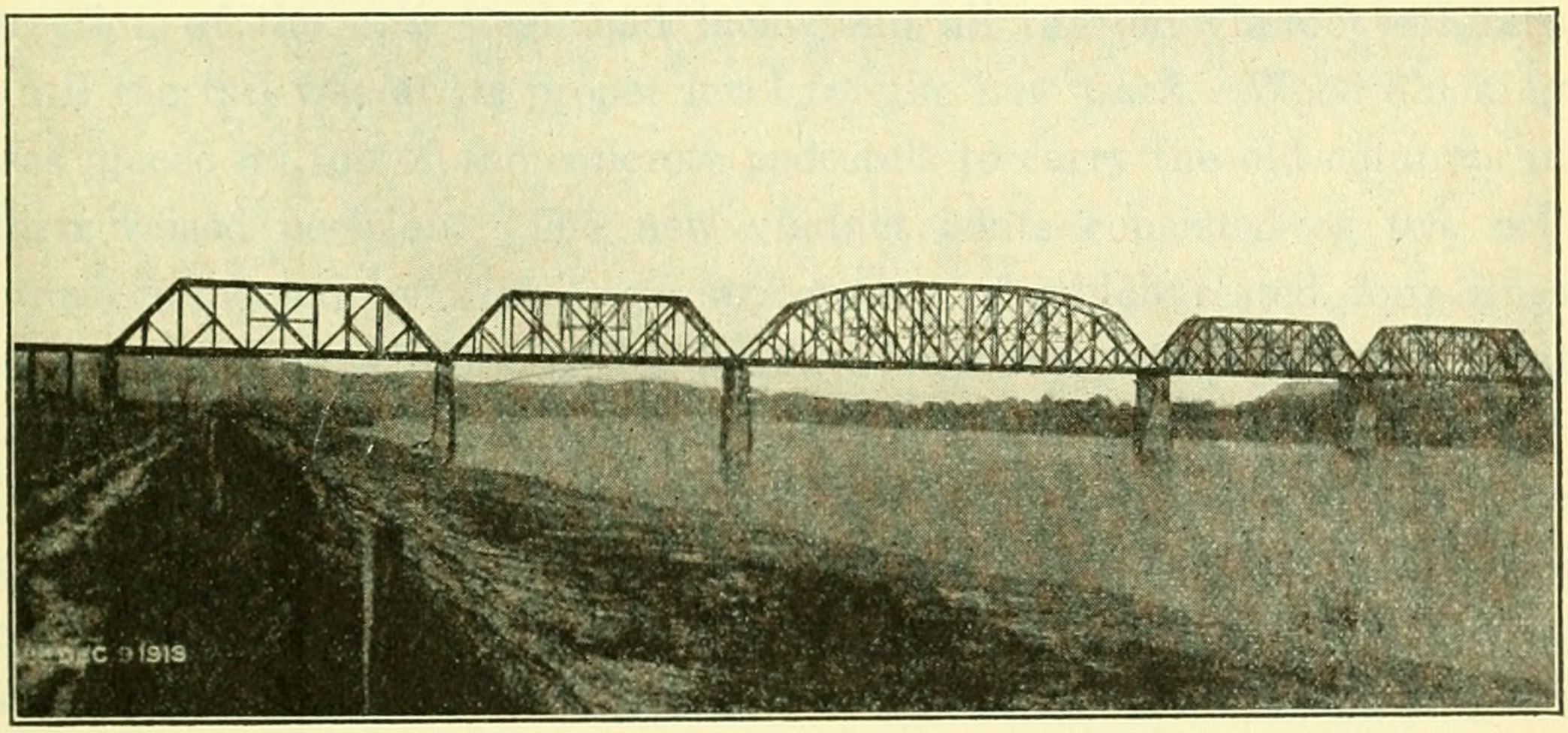


FIG. 2.—THE NEW BRIDGE AT KENOVA, W. VA.

Erection was started at the north end and was carried on without interrupting traffic and without the use of falsework except under the first two spans. The traveler ran on rails laid over the new outside girders, and the first two spans had to be erected on falsework in order to have a place on which to erect the traveler. A track was laid on the ground alongside the viaduct for nearly its entire length, and the new material, as it was shipped in, was unloaded by a small derrick car near its proper place in the viaduct.

A derrick was placed on Pier 1, at the north end of the viaduct, and with it was erected the falsework and the first two new spans of the viaduct. The derrick then raised the traveler used in erecting the remainder of the viaduct. This traveler consisted of two wooden bents resting on wooden sills. The bents were shaped like those of an ordinary wooden gantry traveler, and were braced together. A platform, 21 ft. 6 in. above the rail, carried two hoisting engines which worked the booms on the forward end of the traveler. These booms were of steel, one 80 ft. and the other 65 ft. long. They turned on foot-blocks made fast to the front end of the sills, and each was capable of lifting about 12 tons. As there were no braces between the bents below 21 ft. 6 in. above the rail, trains were run through the traveler without interrupting its work in any way. The old viaduct being single-track, trains were carried on the two inside girders of the new work until the viaduct was completed. As a change of grade was found necessary in the new work, the Railway Company, some time before commencing the erection of the new steel, had jacked up all the old viaduct columns until the rail was at its proper level for the new work. Wood blocking was placed on top of the concrete pedestals to carry the old columns in their raised position. The new viaduct bents consisted of two columns connected by a cross-girder, on top of which rested four lines of longitudinal girders. The bents were connected by longitudinal bracing in alternate openings.

The method of erection (shown by Fig. 3) was as follows: The traveler erected two new bents on blocking level with the top of the concrete pedestals, one alongside each old bent. A temporary wooden strut was bolted to the old bents to brace them, and the old longitudinal bracing was removed. The ends of the old girders over these bents were fastened together and, using both booms of the traveler, the girders were hoisted a few inches, so as to clear the tops of the old

columns. This condition is shown by (1) of Fig. 3. The old bents were then pulled out to one side by lines from the traveler. New bents were pulled into place, and the old girders were slacked down on them, timber blocks on the tops of the columns being used to make up the difference in height of the old and new girders. Trains were then allowed to pass. The new longitudinal bracing was put in between the new bents, and the old bents were cut to pieces. This condition is shown by (2) of Fig. 3. The track was picked up at each end of the old girder span and blocked so as to clear the old

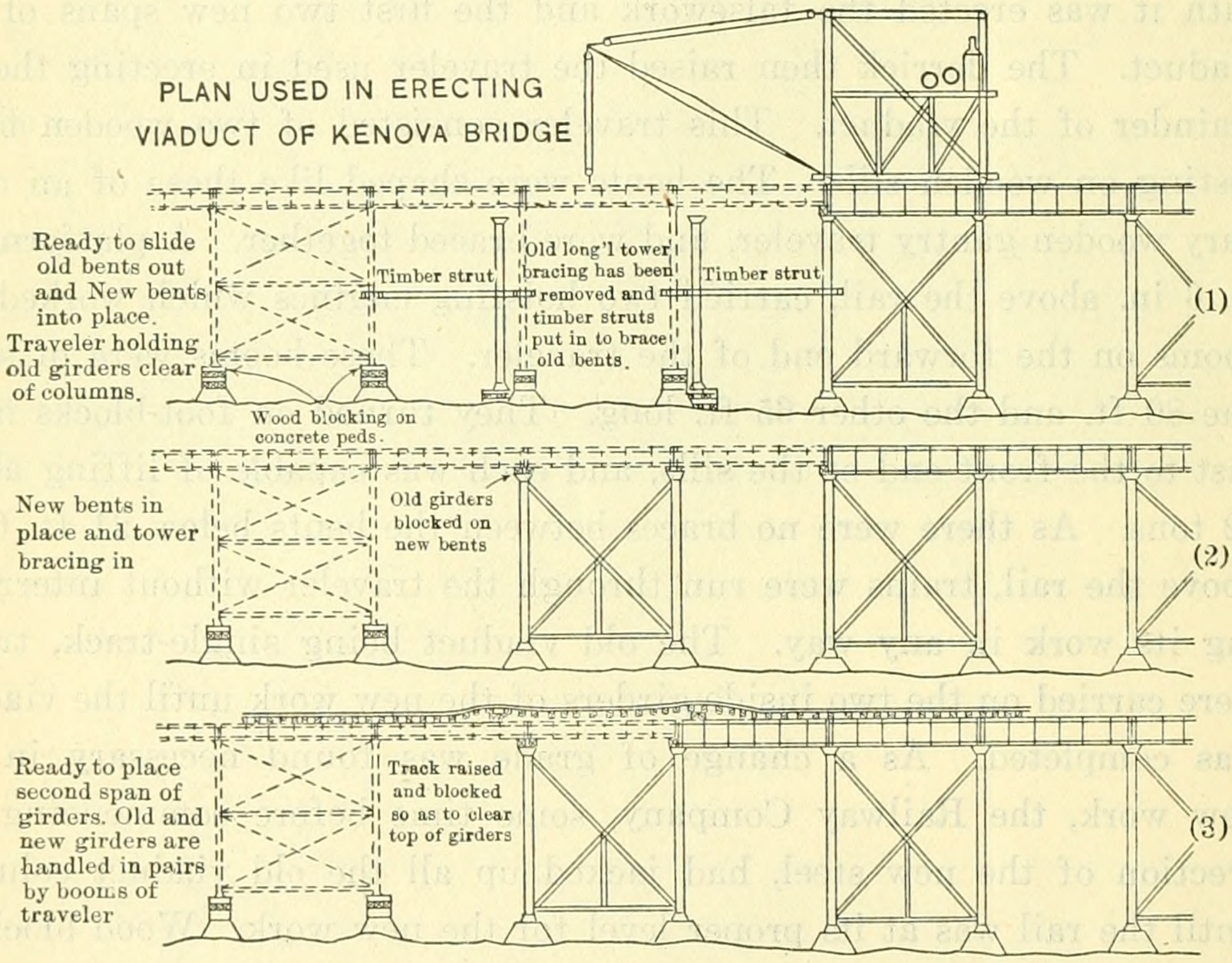


FIG. 3.

girders, the latter then being pulled out from under the track and laid on the ground below. The bracing between the girders was not cut out, so that, while one boom was removing the old girders, the other one hoisted the new girders into place. The new girders were shipped riveted up in pairs with bracing and cross-frames. The track was again picked up, the blocks taken out, the track slacked down, and trains allowed to pass. The second span of the old girders was handled in the same way. This is shown by (3) of Fig. 3. The traveler was then moved ahead two panels, and the operation was repeated.

None of these operations took more than 15 or 20 min., and it was very seldom that trains were held even a few minutes, as work

was not started if a train was seen to be approaching. The rate of progress was two spans, or about 60 ft. per day. The traffic, consisting mostly of coal trains, was very heavy during the reconstruction of the viaduct.

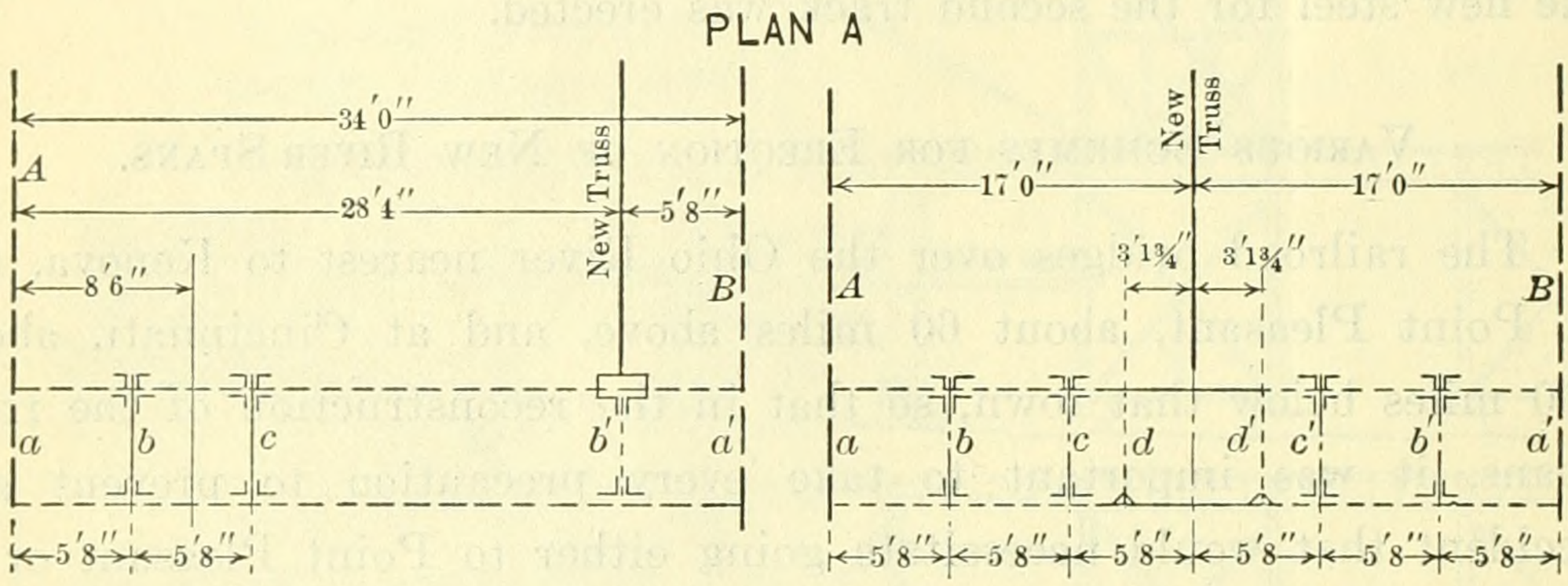
At the south end of the viaduct was the Kenova station, and this portion of the work was erected with a small derrick car, as the traveler would have interfered with the proper handling of passengers and trains. This portion of the old work was already double-tracked, and trains were allowed to run on one track while the derrick car erected the new work on the other. Traffic was then shifted, and the new steel for the second track was erected.

Various Schemes for Erection of New River Spans.

The railroad bridges over the Ohio River nearest to Kenova, are at Point Pleasant, about 60 miles above, and at Cincinnati, about 150 miles below that town, so that in the reconstruction of the river spans, it was important to take every precaution to prevent any accident that would necessitate going either to Point Pleasant or to Cincinnati to cross the river. Another condition which had to be considered was the stage of the Ohio River, the rise during floods amounting to as much as 70 ft. A third condition was the fact that provision had to be made for river navigation during the reconstruction. On account of these conditions and the very heavy traffic, the contract was awarded with the provision that traffic should be maintained at all times, and that no falsework should be used in the river.

Several designs for the river spans were worked up in the New York office of the American Bridge Company. The first design provided for the addition of a third center truss and the reinforcement of the two old outside trusses. New stringers were to be provided, but the old floor-beams were to be cut so as to use their ends and a new central portion which would connect to the new center truss. The floor-beam splice on each side of the new truss was to be designed so as to transmit shear but not moment, and by this means the live load transmitted to the outside trusses could be limited to a definite quantity by the location of the floor-beam splice, and thus not overstress the old trusses. Fig. 4 shows the details of this method.

The second design provided for placing falsework under the old stringers only and disconnecting the latter from the old floor-beams, so that the falsework would carry the old stringers, old track, and live load. New floor-beams were to be suspended from the old ones by rods, and new spans were to be built up around the old ones on brackets attached to the ends of the new floor-beams in suspended position. After the new spans were swung, the old ones were to be blocked up on them and then taken down. Finally, the new floor-beams were to be raised to their final position and new stringers added. Fig. 5 shows the details of this method.

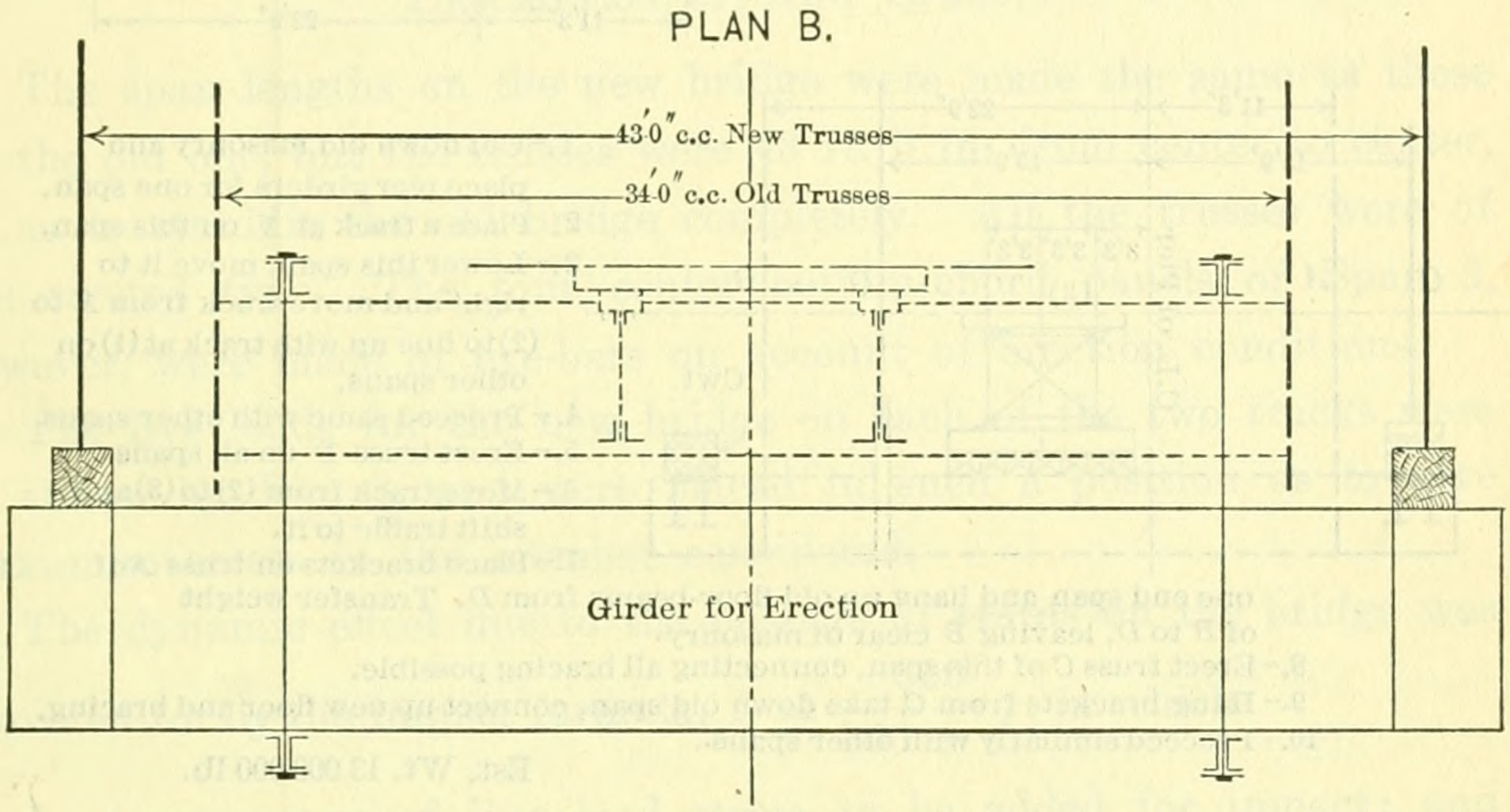


1.-Repair old trusses, rearrange old top laterals and portals to clear new truss when first erected, erect other new bracing.
2.-Erect new stringers at b and c.
3.-Remove old stringers and bolt one line to floor-beams at b'.
4.-Erect new truss at b', swing it and remove old stringers.
5.-Move new truss to center line of bridge, connect it to transverse struts and erect new top laterals and portals.
6.-Block up stringers at any panel point on temporary erection girders hung from old trusses. Saw old floor-beam through at d and d' and remove old center section. Place new center section, connecting it to truss and to old end sections of floor-beam, making efficient shear connections and top flange tension splices, but making butt joints for compression only in the bottom flange.
7.-Add reinforcing plates to floor-beams from c to d and c' to d'.
8.-Erect new stringers at b' and c'.

FIG. 4. Est. Wt. 9 000 000 lb.

The third design eliminated the use of falsework entirely. New stringers were to be placed on top of the old floor-beams and a track was to be laid so that the base of rail would be about 8 ft. 9 in. above the present base of rail and the center line of track about 10 ft. 0 in. from the original center line. Then the masonry piers under one span were to be cut down and the span was to be lowered and moved sidewise 5 ft. 9 in., the temporary track being shifted until it lined up with the track on the other spans. The other spans were then to be treated in the same manner. One new truss was to be erected in its permanent position on all spans and the truss swung; then the tempo-

rary track was to be shifted to its permanent location near the new truss. Brackets were to be attached to the ends of the old floor-beams, and one end of the latter was to be hung from the new truss just swung, so that the adjacent old truss would be clear of the masonry. The other new truss was then to be erected on the brackets in its permanent location and swung. The other ends of the old floor-beams were to be hung from the second new truss and the old spans taken down. Finally the new floor-beams and stringers were to be placed. Fig. 6 shows the details of this method.



1. Cut down old piers and place new pier girders.

2. Support old stringers on falsework, cutting them loose from floor-beams, and carry traffic on falsework during erection of new trusses.

3. Erect new trusses outside of old trusses, as shown, connecting up bracing where possible.

4. Hang erection girders from new trusses and take down old span, connecting up new floor and bracing throughout.

Est. Wt. 16 000 000 lb.

FIG. 5.

Each design had certain objectionable features. The first gave a patched-up bridge. The second gave a new bridge, but required falsework under all the spans. The third design provided for a new bridge and eliminated the falsework, but the erection programme was very complicated, requiring the lowering and sliding of the old spans and considerable shifting of the track.

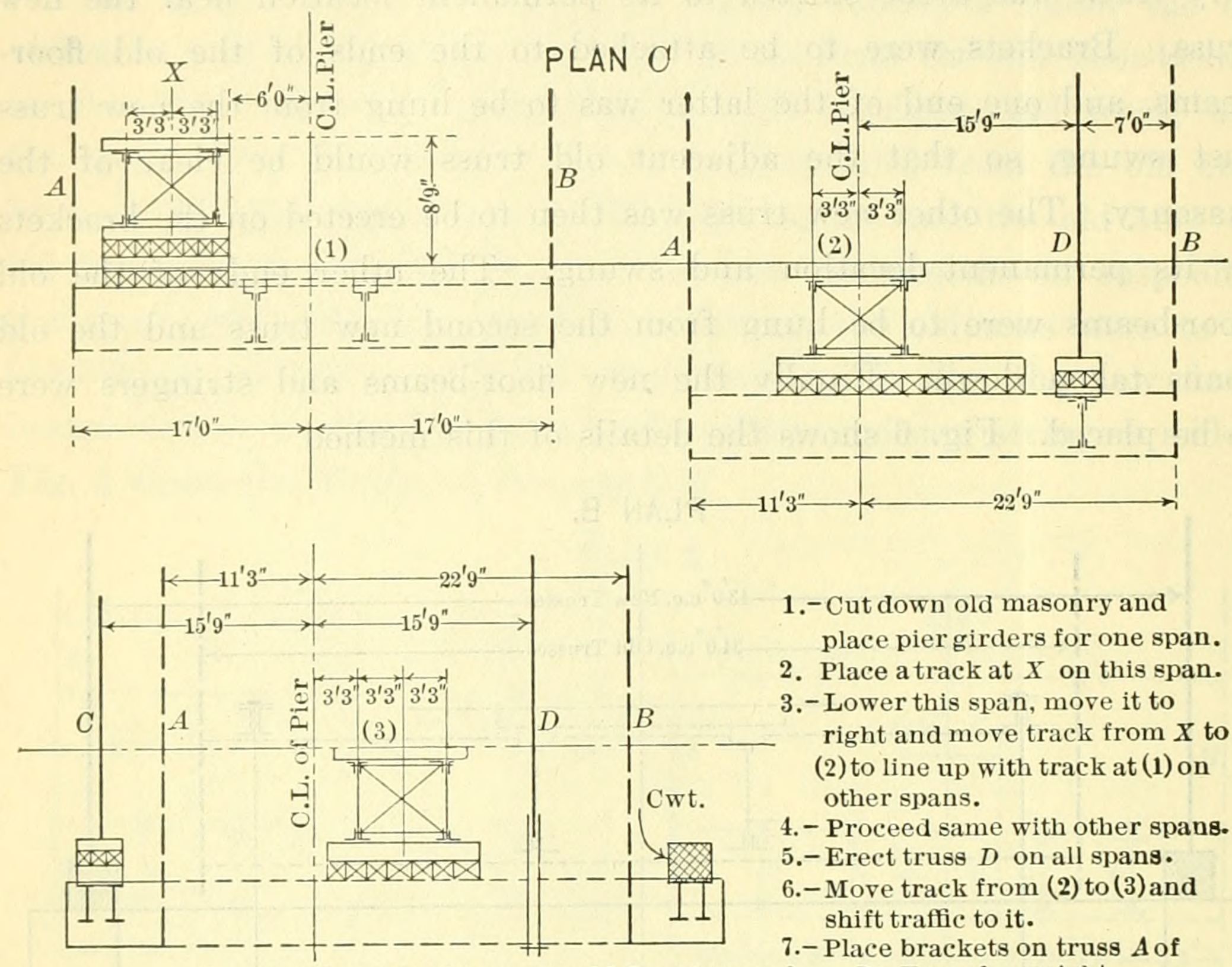

PLAN C
X
6′0″
C.L.Pier
3′3″ 3′3″
8′9″
A
B
(1)
17′0″
17′0″
C.L.Pier
15′9″
7′0″
3′3″ 3′3″
(2)
D
11′3″
22′9″
11′3″
22′9″
15′9″
15′9″
C
A
C.L. of Pier
3′3″ 3′3″ 3′3″
(3)
D
B
Cwt.
1.- Cut down old masonry and place pier girders for one span.
2. Place a track at X on this span.
3.- Lower this span, move it to right and move track from X to (2) to line up with track at (1) on other spans.
4.- Proceed same with other spans.
5.- Erect truss D on all spans.
6.- Move track from (2) to (3) and shift traffic to it.
7.- Place brackets on truss A of one end span and hang up old floor-beams from D. Transfer weight of B to D, leaving B clear of masonry.
8.- Erect truss C of this span, connecting all bracing possible.
9.- Hang brackets from C, take down old span, connect up new floor and bracing.
10.- Proceed similarly with other spans.
Est. Wt. 13 000 000 lb.

FIG. 6.

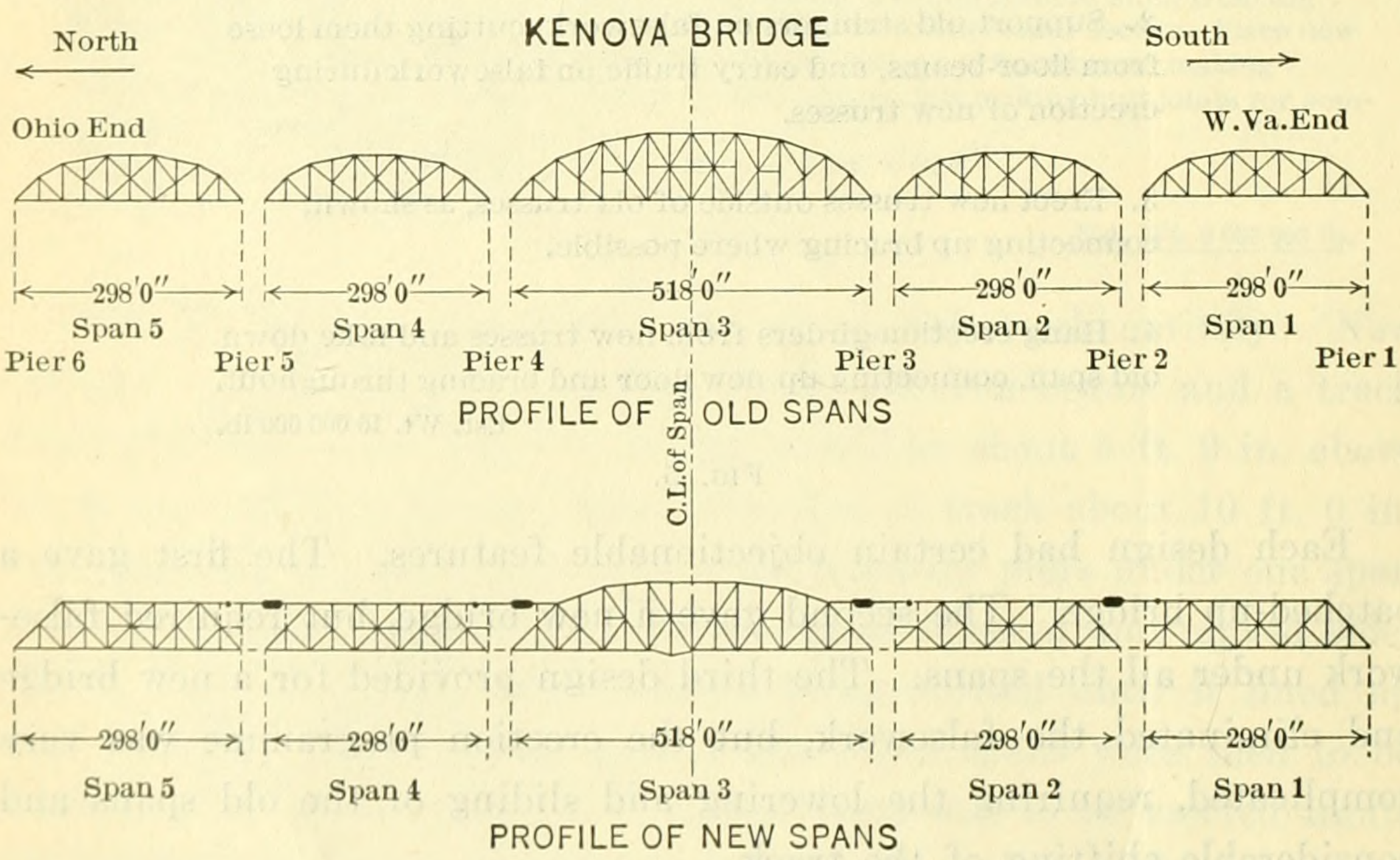

KENOVA BRIDGE
North
South
Ohio End
W.Va.End
298′0″
298′0″
518′0″
298′0″
298′0″
Span 5
Span 4
Span 3
Span 2
Span 1
Pier 6
Pier 5
Pier 4
Pier 3
Pier 2
Pier 1
PROFILE OF OLD SPANS
C.L.of Span
298′0″
298′0″
518′0″
298′0″
298′0″
Span 5
Span 4
Span 3
Span 2
Span 1
PROFILE OF NEW SPANS

FIG. 7.

These objectionable features led to the adoption of the final design which, in brief, was as follows (Fig. 7): Spans 1 and 5 were to be erected according to the method of the second design. Then Spans 2 and 4 were to be erected around these old spans by cantilevering out from Spans 1 and 5, respectively. Span 3 was then to be erected around the old span by cantilevering each end out from Spans 2 and 4, and joining the two halves of Span 3 in the center. Finally, the old spans were to be blocked up on the new ones and removed.

Description of New Spans.

The span lengths on the new bridge were made the same as those on the old one, but the trusses were 43 ft. 0 in. from center to center, so as to straddle the old bridge completely. All the trusses were of the riveted type. The four center bottom-chord panels of Span 3, however, were made of eye-bars on account of erection conditions.

The live loads for the new bridge on each of the two tracks were as shown by Fig. 8, and were placed in such a position as to give maximum stress in the member considered.

The dynamic effect due to the passage of trains on the bridge was provided for by the impact formula, $I = \frac{300}{300 + L}$, in which

I = percentage of live load stress to be added for impact; and
L = length of loaded track producing the live load stress.

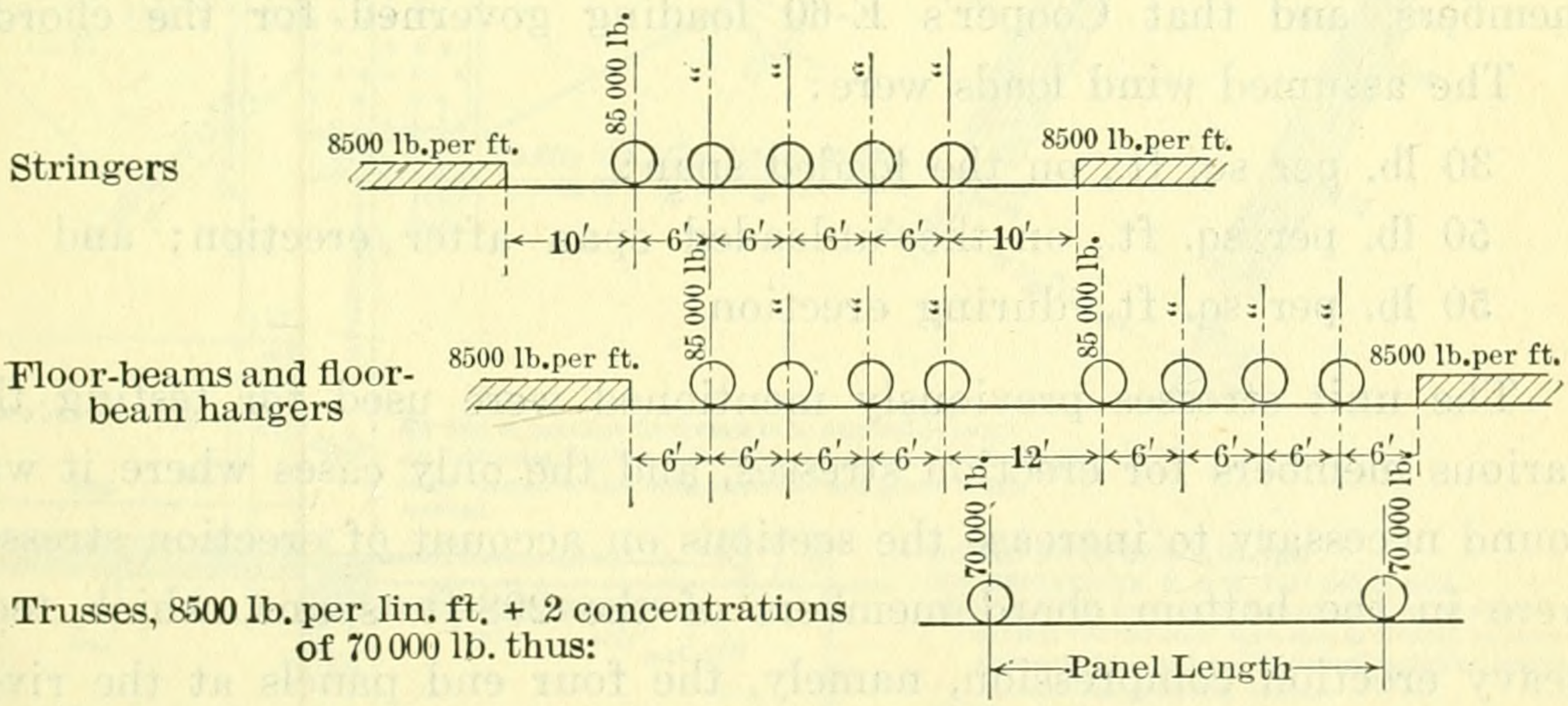


Fig. 8.

The structural steel for the new bridge had an ultimate tensile strength of from 62 000 to 70 000 lb. per sq. in., and the rivet steel an ultimate tensile strength of from 47 000 to 55 000 lb. per sq. in.

The allowable unit stresses were as follows:

Tension, 20 000 lb. per sq. in. (including dead, live, and impact stresses);

Tension, 24 000 lb. per sq. in. (including dead, live, impact, and wind and secondary stresses);

Tension in hangers, 16 000 lb. per sq. in.;

Compression, $\left(20\,000 - 100\,\frac{l}{r}\right)$ lb. per sq. in.;

Extreme fiber stress on pins, 30 000 lb. per sq. in.;

Shear on shop rivets and pins, 15 000 lb. per sq. in.;

Shear on air-driven field rivets, 14 000 lb. per sq. in.;

Shear on hand-driven field rivets, 12 000 lb. per sq. in.;

Shear on plate-girder webs, 12 000 lb. per sq. in.;

Bearing on shop rivets and pins, 30 000 lb. per sq. in.;

Bearing on air-driven field rivets, 28 000 lb. per sq. in.;

Bearing on hand-driven field rivets, 24 000 lb. per sq. in.;

Bearing on masonry, 600 lb. per sq. in.

After the bridge had been designed according to these loads and unit stresses, it was tested for Cooper's E-60 live load on each track, using the American Railway Engineering and Maintenance of Way Association Specifications for 1910, and the design was modified accordingly where the latter conditions required the larger sections. It was generally found that the first condition governed for the web members, and that Cooper's E-60 loading governed for the chords.

The assumed wind loads were:

30 lb. per sq. ft., on the loaded span;

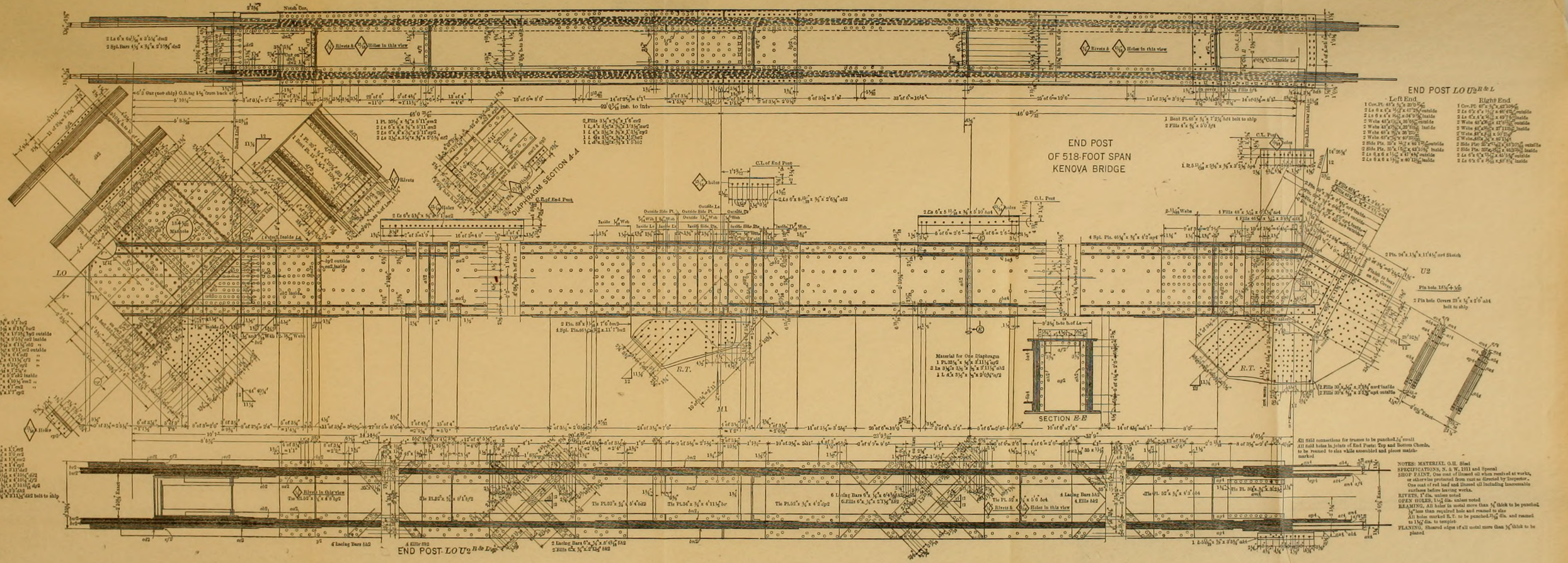
50 lb. per sq. ft., on the unloaded span after erection; and

50 lb. per sq. ft., during erection.

The unit stresses previously mentioned were used for testing the various members for erection stresses, and the only cases where it was found necessary to increase the sections on account of erection stresses were in the bottom chord members of the 298-ft. spans, which took heavy erection compression, namely, the four end panels at the river end of Spans 1 and 5 and the four end panels at both ends of Spans 2 and 4.

The rails on the new bridge are 100 lb. per yd. on the north-bound and 85 lb. per yd. on the south-bound tracks. The new ties are 8 by

PLATE I.
PAPERS, AM. SOC. C. E.
JANUARY, 1915.
GROVE AND TAYLOR
ON RECONSTRUCTION OF KENOVA BRIDGE.



All field connections for trusses to be punched 1/16" small
All field holes in joints of End Posts: Top and Bottom Chords, to be reamed to size while assembled and pieces match-marked

NOTES: MATERIAL, O.H. Steel
SPECIFICATIONS, N. & W. 1911 and Special
SHOP PAINT, One coat of linseed oil when received at works, or otherwise protected from rust as directed by Inspector. One coat of red lead and linseed oil including inaccessible surfaces before leaving works.
RIVETS, 1" dia. unless noted
OPEN HOLES, 1 1/16" dia. unless noted
REAMING, All holes in metal more than 3/8" thick to be punched 1/16" less than required hole and reamed to size
All holes marked R.T. to be punched 1 3/16" dia. and reamed to 1 1/16" dia. to templet
PLANING, Sheared edges of all metal more than 3/8" thick to be planed

10 in., notched to 9½ in. Each track was assumed to weigh 450 lb. per lin. ft. The assumed total dead loads per linear foot of bridge were 9 400 lb. for Spans 1, 2, 4, and 5, and 12 950 lb. for Span 3; and the actual total dead loads per linear foot of bridge were 9 380 lb. for Spans 1 and 5, 9 510 lb. for Spans 2 and 4, and 12 340 lb. for Span 3. All rivets are ⅞ in. in diameter, except those in the trusses of Span 3, where 1-in. rivets are used. Fig. 9 is a diagram of the 298-ft. spans and Table 1 is the stress sheet. Fig. 10 is a diagram of the 518-ft. span and Table 2 is the stress sheet.

Special attention should be called to the fact that the trusses of the 518-ft. span are the largest riveted trusses ever built for a simple truss span.

Plate I shows the details of the end post for the 518-ft. span. Fig. 11 shows a typical floor-beam of this span.

Remodeling the Tops of the Piers.

The length of the two piers under Span 3 was 46 ft. 0 in. under copings, and of the other four 43 ft. 0 in. As the new trusses were made 43 ft. 0 in. from center to center, so that they would clear the old spans, the shoe bearings of the new trusses came directly over the ends of the piers. It was necessary, therefore, to place distributing girders under the new trusses in order to transfer the reaction of these trusses in toward the center of each pier, and hence the piers had to be cut down to receive these pier girders. Two devices were used in order to reduce this pier cutting to a minimum. The rockers on the truss spans were made 36 in. deep, and narrow enough to be placed inside the bottom chord. Fig. 12 shows the position of the rockers of Span 3. Second, the pier girders consisted of three separate girders connected by diaphragms, and the cast-steel pedestals under the girders were made with ribs extending up between the girder sections and were connected to them by pins. In this way the pier cutting was reduced by about 6 ft., and it was only necessary to remove five courses of masonry, including the coping stones.

Fig. 13 shows the remodeled top of Pier 3. To form a neat finish to the tops of the piers after they were cut down, and also to give a strong bond, the Railway Company put a reinforced concrete coping around the three masonry courses immediately under the new steel. After it was determined just how many courses were to be removed,

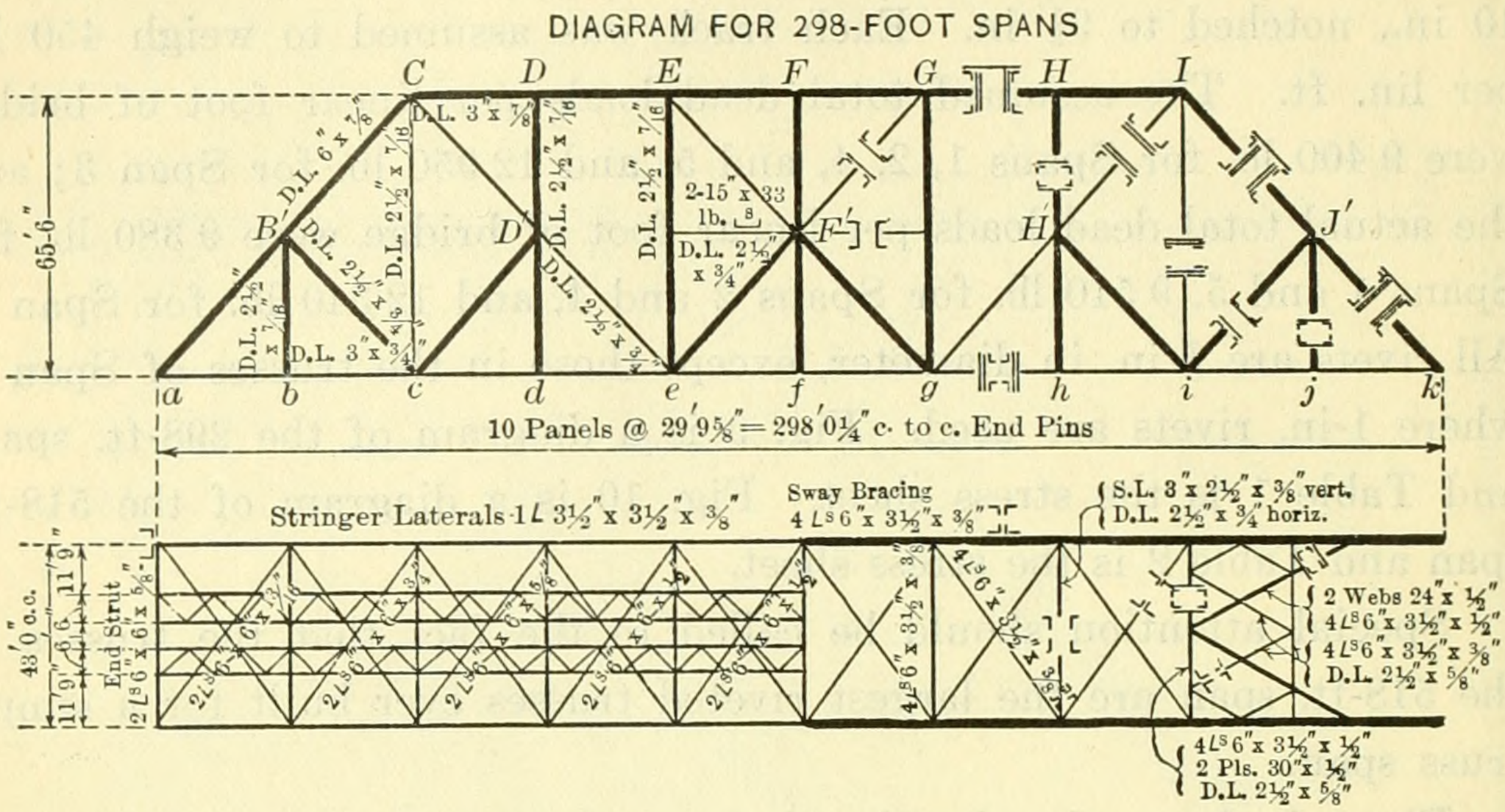


FIG. 9.

STRESSES, ETC., IN 298-FOOT SPANS.

End Reaction on Pier.	End Reaction on Span.		Dead Load, in Pounds per Linear Foot.	
D = 797 000 lb.	D = 690 000 lb.	D = 690 000 lb.	Trusses 6 550	C. S. Pedestal 3 ft. 8 in. by 8 ft. 0 in.
L_1 = 1 404 000 "	L_1 = 1 260 000 "	L_2 = 939 000 "	Floor 1 950	100 lin. ft. of 36-in. rockers.
I_1 = 468 000 "	I_1 = 420 000 "	I_2 = 313 000 "	Track 900	
2 669 000 lb.	2 370 000 lb.	1 942 000 lb.	Total 9 400	
at 600 = 4 448 sq. in.				

Pier Girders.

Shear.	*Moment.*
D = 715 000 lb.	D = 42 740 000 ft-lb.
L = 1 260 000 "	L = 75 600 000 " "
I = 420 000 "	I = 25 200 000 " "
2 395 000 lb.	143 540 000 ft-lb.
at 12 000 = 199.6 sq. in.	at 20 000 = 7 177 sq. in.

Web. 3 Pls. 46 × ⅝ = 86.3
6 Fills. 34 × 15/16 = 165.8
6 R. Pls. 44 × ⅝ = 165.0
417.1 sq. in.

Top Flange. 6 Ls. 6 × 6 × 15/16 = 54.5g. = 44.7n.
12 Covers 15 × 11/16 = 123.8g. = 90.8n.
178.3g. = 135.5n.

Bottom Flange. 6 Ls. 6 × 6 × 13/16 = 54.5 sq. in.
9 Cov. 13 × ¾ = 87.8 " "
142.3 sq. in.

Floor-Beams.

Shear.	*Moment.*
D = 43 400 lb.	D = 7 047 000 ft-lb.
L = 343 000 "	L = 61 700 000 " "
I = 246 000 "	I = 44 300 000 " "
632 400 lb.	113 047 000 ft-lb.
at 12 000 = 52 sq. in.	at 82.5 = 1 370 000
	at 20 000 = 68.5 sq. in.

Web. 82 × 11/16 = 56.4 sq. in.
⅛ web = 7.0 " "
2 Ls. 6 × 6 × ¾ = 16.9g. = 13.9 sq. in. n.
5 Cov. Pls. 16 × 11/16 = 55.0g. = 46.0 " " n.
68.9 sq. in. n.

Stringers.

Shear.	*Moment.*
D = 6 700 lb.	D = 599 000 ft-lb.
L = 127 000 "	L = 9 800 000 " "
I = 115 400 "	I = 8 920 000 " "
249 100 lb.	19 319 000 ft-lb.
at 12 000 = 20.8 sq. in.	at 65.8 = 294 000
	at 20 000 = 14.7 sq. in.

Web. 69 × ½ = 34.5 sq. in.
⅛ web = 4.3 " "
2 Ls. 6 × 6 × ½ = 11.5g. = 10.5 " " n.
14.5 sq. in.

10 Int. stiffr. 4 × 3½ × ⅜ crimp.

TABLE 1.—STRESS SHEET FOR 298-FOOT SPANS.

Member.	D.	L_1.	I_1.	$D + L_1 + I_1$.	L_2.	I_2.	$D \times L_2 \times I_2$.	W_1.	Sections for Spans 2 and 4.		
a B'	− 838	− 1 701	− 569	− 3 108	− 1 269	− 428	− 2 532	8 610 000 ± 8.5	1 Cov. Pl. 38 × 13/16, 2 Ls. 6 × 4 × ¾ 4 Webs. 42 × 13/16, 2 Ls. 6 × 6 × ¾ 2 Pls. 29 × ½		227.2
B' C	− 745	− 1 511	− 506	− 2 762	− 1 099	− 368	− 2 212	8 610 000 ± 4.3	1 Cov. Pl. 38 × 13/16, 2 Ls. 6 × 4 × ¾ 4 Webs. 42 × 13/16. 2 Ls. 6 × 6 × ¾		198.2
C D E	− 752	− 1 522	− 510	− 2 784	− 1 082	− 362	− 2 196	± 13 C D ± 32 D E	1 Cov. Pl, 38 × 13/16 = 30.9 2 Ls. 6 × 4 × ¾ = 13.9		
E F G	− 784	− 1 585	− 531	− 2 900	− 1 195	− 400	− 2 379	± 43	2 Ls. 6 × 6 × ¾ = 16.9 4 Webs 42 × 11/16 = 115.5	177.2	
a b c	+ 564	+ 1 145	+ 383	+ 2 092	+ 854	+ 286	+ 1 704	± 41 a b ± 118 b c	4 Pls. 48 × ¾ = 144.0 g. = 126.0 n.		
c d e	+ 564	+ 1 164	+ 390	+ 2 118	+ 856	+ 287	+ 1 707	± 169 c d ± 206 d e	4 Ls. 6 × 6 × ¾ = 33.8 g. = 27.8 n. 133.8 n.		
e f g	+ 784	+ 1 585	+ 531	+ 2 900	+ 1 195	+ 400	+ 2 379	± 224			
C D'	+ 373	+ 874	+ 399	+ 1 646	+ 646	+ 295	+ 1 314	.....	4 Pls. 30 × ⅝ = 75.0 g. = 65.0 n.		
D' e	+ 280	+ 789 − 219	+ 360 − 137	+ 1 429 − 169	+ 605 − 168	+ 276 − 105	+ 1 161 − 86	....	4 Ls. 4 × 4 × ⅝ = 18.4 g. = 15.9 n. 80.9 n.		
E F'	+ 47	+ 281 − 185	+ 141 − 103	+ 469 − 257	+ 217 − 145	+ 109 − 81	+ 373 − 195	....	2 Pls, 22 × ⅝ = 27.5 g. = 22.5 n. 4 Ls. 4 × 4 × ⅝ = 18.4 g. = 15.9 n. 38.4 n.		
F' g	− 47	+ 185 − 281	+ 103 − 141	+ 257 − 469	+ 145 − 217	+ 81 − 109	+ 195 − 373	....			
C c	+ 227	+ 634	+ 354	+ 1 215	+ 452	+ 324	+ 1 003	.....	4 Pls. 30 × ⅝ = 75.0 g. = 65.0 n. 4 Ls. 4 × 4 × ⅝ = 18.4 g. = 15.9 n.	80.9 n.	
E e	− 83	+ 137 − 208	+ 76 − 104	+ 158 − 395	+ 107 − 161	+ 60 − 81	+ 112 − 325	....	2 Pls. 26 × ½ = 26.0 4 Ls. 4 × 4 × ½ = 15.0	41.0	
Sub-Hanger	+ 89	+ 343	+ 246	+ 678	+ 258	+ 185	+ 532	.....	2 Pls. 26 × ⅝ = 32.5 g. = 27.5 n. 4 Ls. 6 × 4 × 9/16 = 21.2 g. = 19.0 n.	46.5 n.	
Sub-Diagonal	− 93	− 231	− 166	− 490	− 174	− 125	− 392	.....	2 Pls. 20 × 9/16 = 22.5 4 Ls. 4 × 4 × ½ = 15.0	37.5	
Sub-Post	− 48	0	0	− 48	0	0	− 48	.....	2 Pls. 26 × ⅜ = 19.5 4 Ls. 4 × 4 × ⅜ = 11.4	30.9	

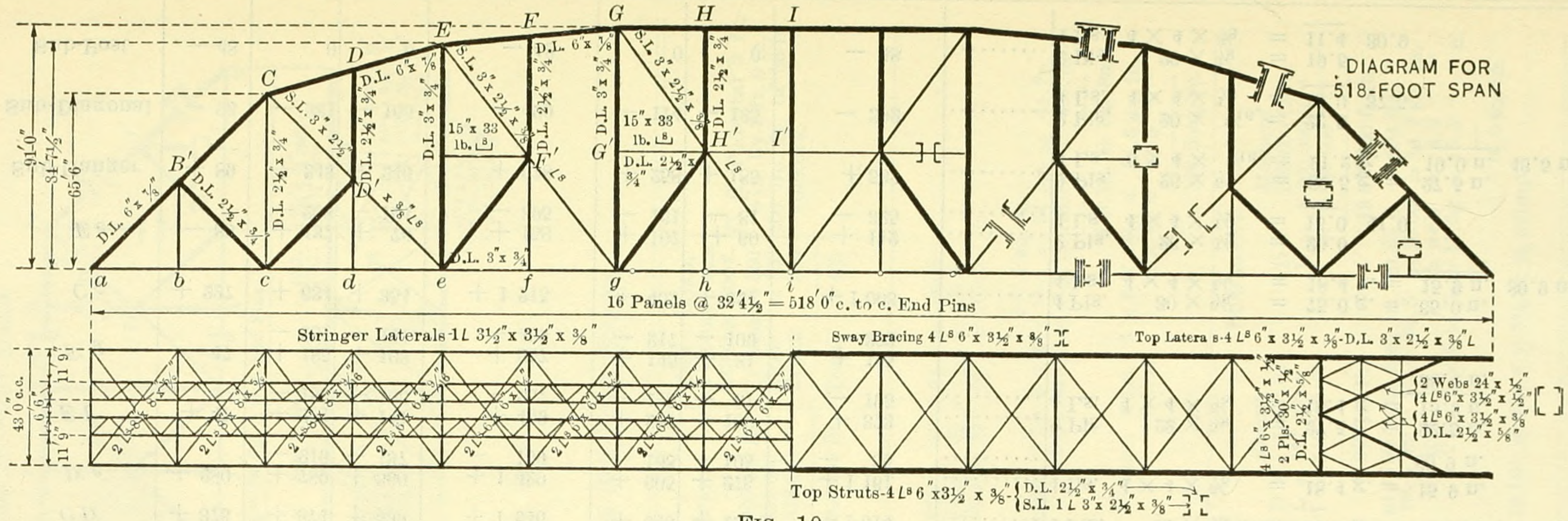


FIG. 10.

STRESSES, ETC., IN 518-FOOT SPAN.

End Reaction on Pier.	End Reaction on Span.		Dead Load, in Pounds Per Linear Foot.		Pier Girder.	
					Shear.	*Moment.*
D = 1 852 000 lb.	D = 1 712 000 lb.	D = 1 712 000 lb.	Trusses 10 050	C. S. Pedestal 6 ft. 0 in. by 9 ft. 0 in. 183 lin. ft. of 36-in. rockers.	D = 1 740 000 lb.	D = 83 600 000 ft-lb.
L = 2 349 000 "	L_1 = 2 190 000 "	L_2 = 1 600 000 "	Floor 2 000		L = 2 190 000 "	L = 105 000 000 " "
I_1 = 529 000 "	I_1 = 493 000 "	I_2 = 368 000 "	Track 900		I = 493 000 "	I = 23 600 000 " "
4 730 000 lb.	4 395 000 lb.	3 680 000 lb.	Total 12 950		4 423 000 lb.	212 200 000 ft-lb.
at 600 = 7 883 sq. in.					at 12 000 = 351.9 sq. in	at 20 000 = 10 610 sq. in.

Floor-Beams.		Stringers.		
Shear.	*Moment.*	*Shear.*	*Moment.*	
D = 47 000 lb.	D = 7 730 000 ft-lb.	D = 8 100 lb.	D = 788 000 ft-lb.	*Web.* 3 Webs. 55 × ⅝ = 103.1 6 Fills. 39 × ⅞ = 204.8 6 Pls. 53 × ⅝ = 198.8 506.7 sq. in.
L = 374 000 "	L = 67 300 000 " "	L = 134 000 "	L = 11 470 000 " "	
I = 261 000 "	I = 47 000 000 " "	I = 120 900 "	I = 10 350 000 " "	
682 000 lb.	122 030 000 ft-lb.	263 000 lb.	22 608 000 ft-lb.	
at 12 000 = 56.8 sq. in.	at 82.5 × 20 000 = 74.0 sq. in.	at 12 000 = 21.8 sq. in.	at 65.8 × 20 000 = 17.2 sq. in.	*Top Flange.* 6 Ls. 8 × 8 × ⅞ = 79.4g. = 61.7n. 12 Cov. Pls. 18 × 11/16 = 148.5g. = 111.4n. 173.1n.
Web. = 82 × ¾ = 6.15 sq. in.		*W.* = 69 × ½ = 34.5 sq. in.	⅛ web. = 4.3 sq. in.	*Bottom Flange.* 6 Ls. 8 × 8 × ⅞ = 79.4g. 9 Cov. Pls. 16½ × ¾ = 111.4g. 190.8g.
Flange.	⅛ web. = 7.7	2 Ls. 6 × 6 × ⅝ = 14.2g. = 12.9 sq. in. n.		
2 Ls. 6 × 6 × ¾ = 16.9g. = 13.9n.		Full T 38 ft. B, 34 ft., 29 ft., 25 ft., 19 ft.		
5 Cov. Pls. 16 × ¾ = 60.0g. = 52.5n. 74.1n.				

TABLE 2.—Stress Sheet for 518-Foot Span.

Member.	D_1.	L_1.	I_1.	$D_1 + L_1 + I_1$.	L_2.	I_2.	$D_1 + L_2 + I_2$.	W_1.	Sections.
a B'	− 2 210	− 3 083	− 693	− 5 986	− 2 254	− 518	− 4 982	17 000 000 ± 477	1 Cov. Pl. 48 × ¾ 2 Webs. 48 × ½ 4 Ls. 6 × 4 × 11/16 2 Webs. 48 × 9/16
B' C	− 2 070	− 2 872	− 645	− 5 587	− 2 063	− 476	− 4 609	17 000 000 ± 377	4 Ls. 6 × 6 × 11/16 4 Pls. 35 × 11/16 4 Webs. 48 × 11/16 Total 423 sq. in.
C D E	− 2 000	− 2 793	− 627	− 5 420	− 1 963	− 462	− 4 425	± 170 C D ± 104 D E	1 Cov. Pl. 48 × ¾ 4 Webs. 48 × 11/16 4 Ls 6 × 4 × 11/16 4 Pls. 35 × 11/16 4 Ls. 6 × 6 × 11/16 Total 321 sq. in.
E F G	− 2 240	− 3 118	− 702	− 6 060	− 2 156	− 509	− 4 905	± 35 E F ∓ 4 F G	1 Cov. Pl. 48 × ¾ 4 Webs. 48 × 11/16 4 Ls. 6 × 4 × 11/16 2 Webs. 48 × ⅜ 4 Ls. 6 × 6 × 11/16 4 Pls. 35 × 11/16 357 sq. in.
G H I	− 2 380	− 3 322	− 746	− 6 448	− 2 264	− 535	− 5 179	∓ 33 G H ∓ 46 H I	1 Cov. Pl. 42 × ¾ 4 Webs. 48 × 11/16 4 Ls. 6 × 4 × 11/16 2 Webs. 48 × ½ 4 Ls. 6 × 6 × 11/16 4 Pls. 35 × 11/16 369 sq. in.
a b c	+ 1 550	+ 2 165	+ 487	+ 4 202	+ 1 582	+ 364	+ 3 496	± 286 a b ± 449 b c	4 Ls. 6 × 6 × 13/16 = 36.4 g. = 29.9 n.
c d e	+ 1 550	+ 2 193	+ 492	+ 4 235	+ 1 589	+ 370	+ 3 509	± 597 c d ± 713 d e	4 Webs. 48 × ¾ = 144.0 g. = 126.0 n. 2 Webs. 48 × 13/16 = 78.0 g. = 68.2 n. 224.1 n.
e f g	+ 2 000	+ 2 808	+ 632	+ 5 440	+ 1 957	+ 463	+ 4 420	± 810 e f ± 882 f g	4 Ls. 6 × 6 × 13/16 = 36.4 g. = 29.9 n. 4 Webs. 48 × ¾ = 144.0 g. = 126.0 n. 2 Webs, 48 × 13/16 = 78.0 g. = 68.2 n. 2 Pl. 35 × 13/16 = 56.9 g. = 50.4 n. 274.5 n.
g h i	+ 2 304	+ 3 236	+ 726	+ 6 266	+ 2 220	+ 524	+ 5 048	± 907 g h ± 932 h i	10 bars. 16 × 2 = 320.0
C D'	+ 673	+ 1 128	+ 293	+ 2 094	+ 882	+ 219	+ 1 714	.....	4 Ls. 6 × 6 × ⅝ = 28.4 g. = 23.4 n. 2 Webs. 30 × ½ = 30.0 g. = 26.0 n. 4 Webs. 30 × 9/16 = 67.5 g. = 58.5 n. 107.9 n.

TABLE 2—(*Continued*).

Member.	D_1.	L_1.	I_1.	$D_1 + L_1 + I_1$.	L_2.	I_2.	$D_1 + L_2 + I_2$.	W_1.	Sections.			
D' e	+ 525	+ 1 070	+ 290	+ 1 885	+ 800	+ 217	+ 1 542	.....	4 Ls. 6 × 6 × 5/8	= 28.4 g. =	23.4 n.	
		− 372	− 211	− 233	− 280	− 158	− 88	.....	4 Webs. 30 × 1/2	= 60.0 g. =	52.0 n.	
									2 Webs. 30 × 7/16	= 28.3 g. =	22.8 n.	
											98.2 n.	
E F'	+ 512	+ 1 043	+ 305	+ 1 860	+ 764	+ 230	+ 1 506	.....	4 Ls. 6 × 6 × 5/8	= 28.4 g. =	23.4 n.	
		− 334	− 164	− 157	− 256	− 129	− 43	.....	2 Webs. 30 × 1/2	= 30.0 g. =	26.0 n.	
F' G	+ 380	+ 985	+ 301	+ 1 666	+ 725	+ 223	+ 1 328	.....	4 Webs. 30 × 7/16	= 52.5 g. =	45.5 n.	
		− 467	− 214	− 427	− 362	− 167	− 276					
											94.9 n.	
G H'	+ 257	+ 853	+ 287	+ 1 397	+ 623	+ 216	+ 1 096	.....	4 Ls. 6 × 6 × 5/8	= 28.4 g. =	23.4 n.	
		− 494	− 199	− 522	− 375	− 153	− 359	.....	6 Webs. 30 × 7/16	= 78.8 g. =	68.3 n.	
H' i	+ 128	+ 804	+ 283	+ 1 215	+ 609	+ 216	+ 953				91.7 n.	
		− 621	− 238	− 773	− 475	− 183	− 572					
C c	+ 336	+ 687	+ 369	+ 1 394	+ 494	+ 265	+ 1 095	.....	4 Ls. 4 × 4 × 5/8	= 18.4 g. =	15.9 n.	
									4 Webs. 30 × 3/4	= 90.0 g. =	78.0 n.	
E e	− 142	− 553	− 167	− 862	− 421	− 128	− 691				93.9 n.	
		+ 494	+ 239	+ 638	+ 370	+ 183	+ 458	.....	4 Ls. 6 × 6 × 3/4	= 33.8		
G g	− 70	− 553	− 183	− 786	− 452	− 159	− 681	.....	2 Webs. 30 × 13/16	= 48.8		
		+ 563	+ 222	+ 739	+ 419	+ 171	+ 543					
										82.6		
I i	− 82	.....	.....	− 82	.....	.....	.....	.....	4 Ls. 4 × 4 × 3/8	= 11.4		
									2 Webs. 30 × 7/16	= 26.3		
										37.7		
Sub-Hanger	+ 127	+ 374	+ 261	+ 762	+ 264	+ 164	+ 555	.....	4 Ls. 6 × 4 × 9/16	= 21.2 g. =	19.0 n.	
									2 Webs. 30 × 5/8	= 37.5 g. =	32.5 n.	51.5 n.
B' C	− 148	− 263	− 184	− 595	− 185	− 115	− 448	.....	4 Ls. 4 × 4 × 5/8	= 18.4		
C D'									2 Webs. 22 × 5/8	= 27.5	45.9	
F' e	− 132	− 236	− 165	− 533	− 166	− 103	− 401	.....	do.			
H' g	− 128	− 230	− 160	− 518	− 162	− 101	− 391	.....	do.			
D D'	− 82	.....	.....	.....	.....	.....	.....	.....	4 Ls. 4 × 4 × 3/8	= 11.4		
F F'-H H'									2 Webs. 30 × 7/16	= 26.3	37.7	

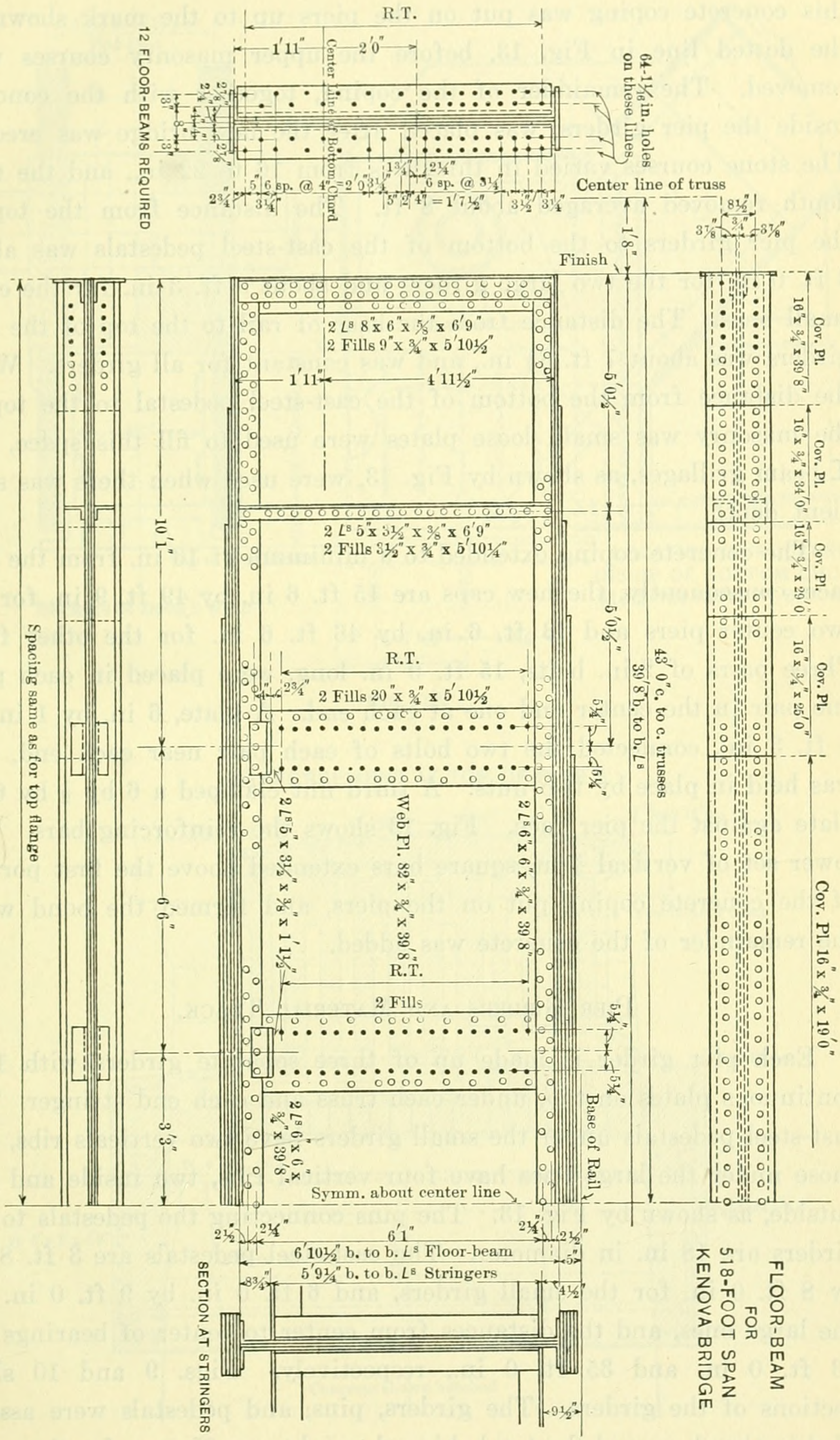

FLOOR-BEAM
FOR
518-FOOT SPAN
KENOVA BRIDGE
12 FLOOR-BEAMS REQUIRED
Spacing same as for top flange
SECTION AT STRINGERS
R.T.
Center Line of Bottom Chord
64-1 1/16 in. holes on these lines
Center line of truss
Finish
2 Ls 8" x 6" x 5/8" x 6' 9"
2 Fills 9" x 3/4" x 5' 10 1/2"
2 Ls 5" x 3 1/2" x 3/8" x 6' 9"
2 Fills 3 1/2" x 3/4" x 5' 10 1/4"
2 Fills 20" x 3/4" x 5' 10 1/2"
2 Ls 5" x 3 1/2" x 3/8" x 1' 1 1/2"
Web Pl. 82" x 3/4" x 39' 8"
2 Ls 6" x 6" x 3/4" x 39' 8"
2 Fills
2 Ls 6" x 6" x 3/4" x 39' 8"
Symm. about center line
Base of Rail
43' 0" c. to c. trusses
39' 8" b. to b. Ls
Cov. Pl. 16" x 3/4" x 39' 8"
Cov. Pl. 16" x 3/4" x 34' 0"
Cov. Pl. 16" x 3/4" x 29' 0"
Cov. Pl. 16" x 3/4" x 25' 0"
Cov. Pl. 16" x 3/4" x 19' 0"
6' 10 1/2" b. to b. Ls Floor-beam
5' 9 1/4" b. to b. Ls Stringers

FIG. 11.

this concrete coping was put on the piers up to the mark shown by the dotted line in Fig. 13, before the upper masonry courses were removed. The remainder of the coping, together with the concrete inside the pier girders, was placed after the new bridge was erected. The stone courses varied in thickness from 16 to 22 in., and the total depth removed averaged about 8 ft. The distance from the top of the pier girders to the bottom of the cast-steel pedestals was about 6 ft. 0 in. for the two large girders and about 5 ft. 3 in. for the eight small ones. The distance from the base of rail to the top of the pier girders was about 7 ft. 8½ in., and was constant for all girders. When the distance from the bottom of the cast-steel pedestal to the top of the masonry was small, loose plates were used to fill this space, and I-beam grillages, as shown by Fig. 13, were used when there was sufficient depth.

The concrete coping extended to a minimum of 16 in. from the pier face, consequently, the new caps are 15 ft. 6 in. by 49 ft. 9 in. for the two center piers and 13 ft. 6 in. by 46 ft. 6 in. for the other four. Three pairs of 2-in. bolts, 15 ft. 0 in. long, were placed in each pier, one pair in the center and one at each end. A plate, 6 in. by 1 in. by 4 ft. 3 in., connected the two bolts of each pair near each end, and was held in place by two nuts. A third nut clamped a 6 by ½ by 6-in. plate against the pier face. Fig. 13 shows the reinforcing bars. The lower set of vertical ¾-in. square bars extended above the first portion of the concrete coping put on the piers, and formed the bond when the remainder of the concrete was added.

Pier Girders and Material Track.

Each pier girder is made up of three separate girders with 1-in. continuous plates on top, under each truss and each end stringer. The cast-steel pedestals under the small girders have two verticals ribs, and those under the large ones have four vertical ribs, two inside and two outside, as shown by Fig. 13. The pins connecting the pedestals to the girders are 18 in. in diameter. The cast-steel pedestals are 3 ft. 8 in. by 8 ft. 0 in. for the small girders, and 6 ft. 0 in. by 9 ft. 0 in. for the large ones, and the distances from center to center of bearings are 33 ft. 0 in. and 35 ft. 0 in., respectively. Figs. 9 and 10 show sections of the girders. The girders, pins, and pedestals were assembled in the shop, and the total shipped weight was 88 tons for the small

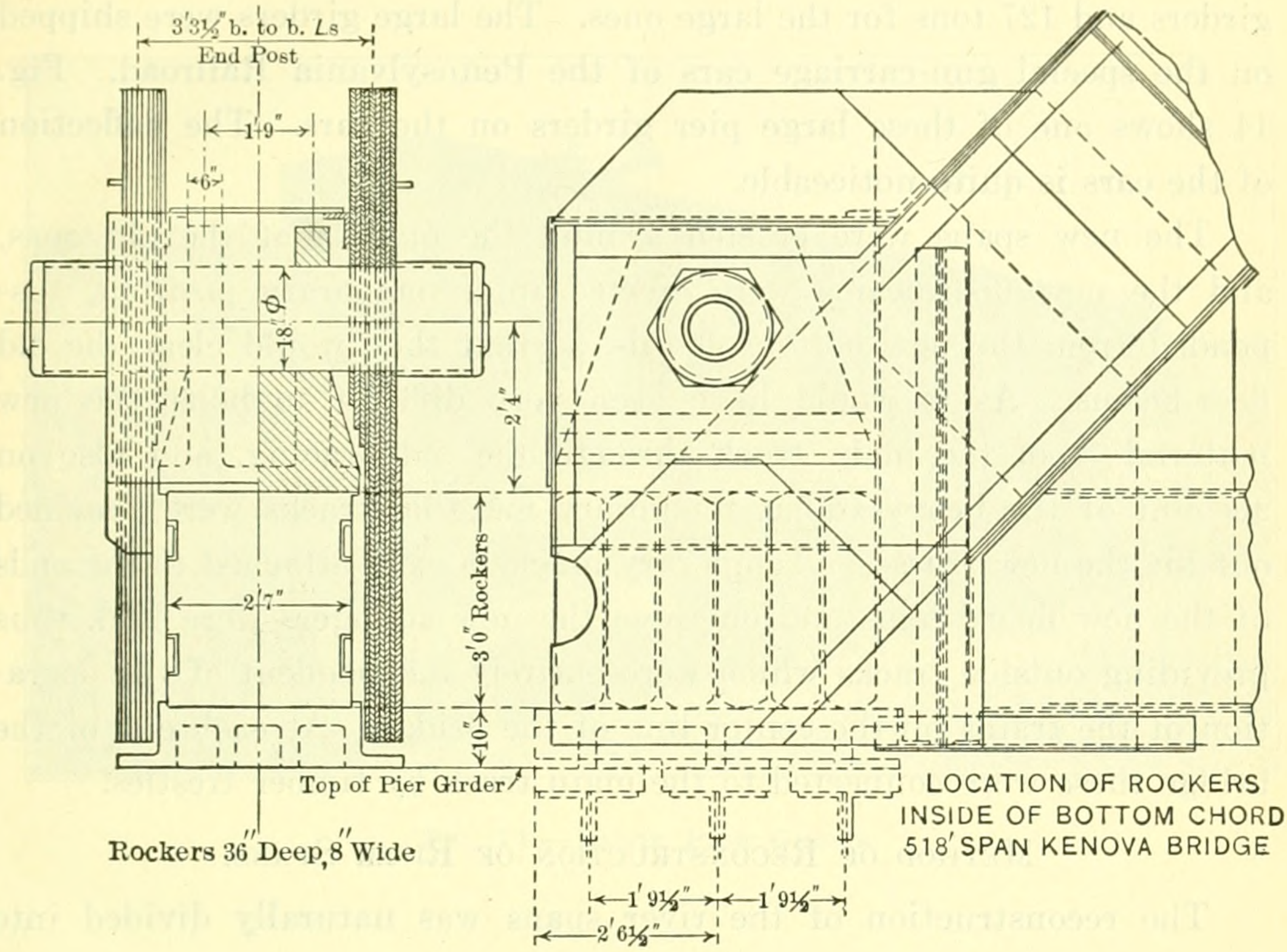

3'3½" b. to b. Ls
End Post
1'9"
6"
18" φ
2'4"
2'7"
3'0" Rockers
10"
Top of Pier Girder
Rockers 36" Deep, 8" Wide
LOCATION OF ROCKERS
INSIDE OF BOTTOM CHORD
518' SPAN KENOVA BRIDGE
1'9½"
1'9½"
2'6½"

FIG. 12.

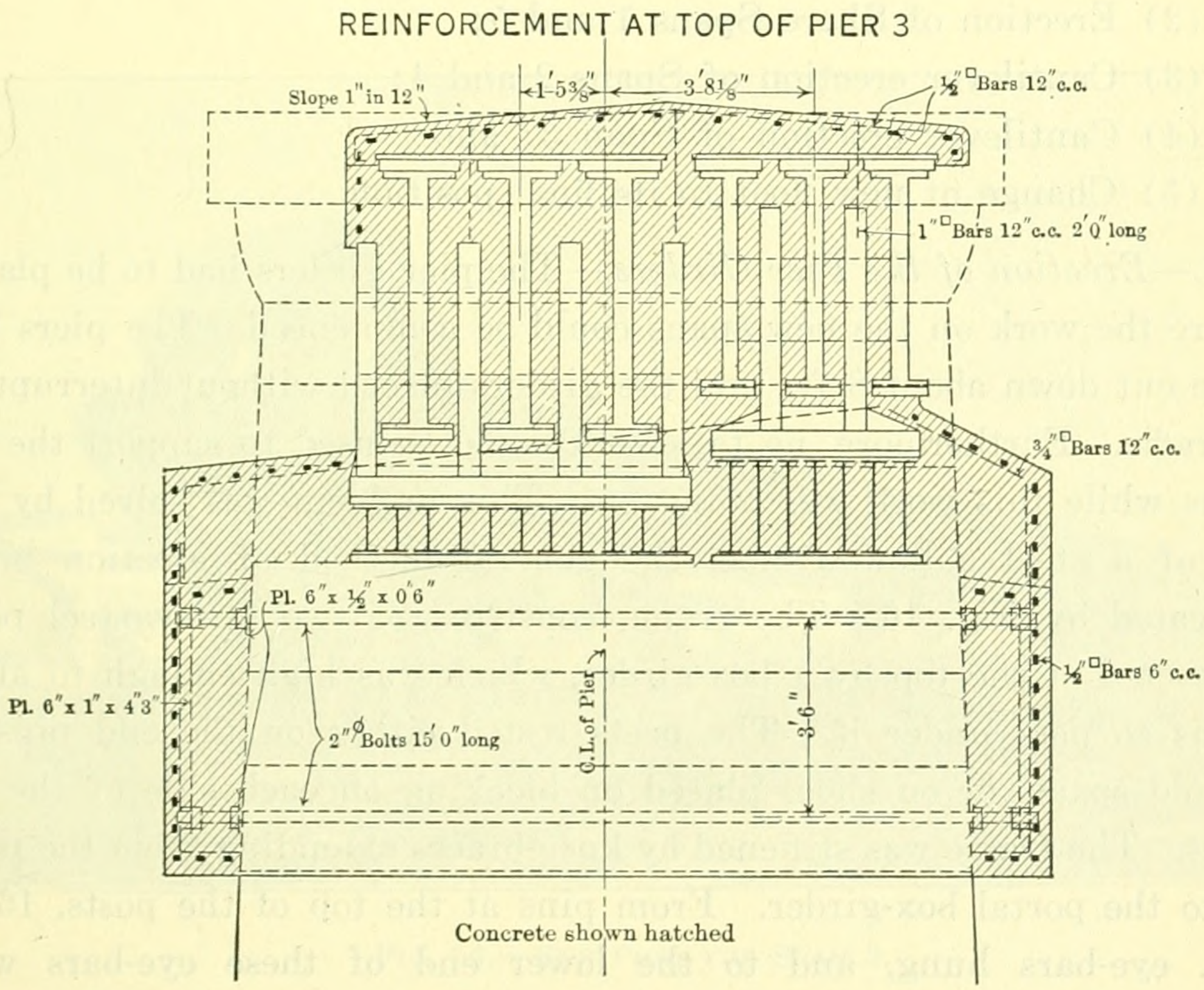

REINFORCEMENT AT TOP OF PIER 3
Slope 1" in 12"
1'5⅜"
3'8⅛"
½" □ Bars 12" c.c.
1" □ Bars 12" c.c. 2'0" long
¾" □ Bars 12" c.c.
Pl. 6" x ½" x 0'6"
½" □ Bars 6" c.c.
Pl. 6" x 1" x 4'3"
2" φ Bolts 15'0" long
℄ of Pier
3'6"
Concrete shown hatched

FIG. 13.

girders and 127 tons for the large ones. The large girders were shipped on the special gun-carriage cars of the Pennsylvania Railroad. Fig. 14 shows one of these large pier girders on the cars. The deflection of the cars is quite noticeable.

The new spans were erected around the outside of the old ones, and the new floor-beams were erected in a temporary position, suspended from the new bottom chords, so that they would clear the old floor-beams. As it would have been very difficult to hoist the new material from the main track through the old bracing, and also on account of the heavy traffic, temporary material tracks were provided outside the new trusses. Temporary brackets were attached to the ends of the new floor-beams and on these the new stringers were laid, thus providing outside tracks which were entirely independent of the operation of the trains on the center line of the bridge. At each end of the bridge these were connected to the main track by timber trestles.

Method of Reconstruction of River Spans.

The reconstruction of the river spans was naturally divided into five separate operations:

(1) Erection of the pier girders;
(2) Erection of Shore Spans 1 and 5;
(3) Cantilever erection of Spans 2 and 4;
(4) Cantilever erection of Span 3; and
(5) Change of new floor to its final position.

1.—Erection of the Pier Girders.—The pier girders had to be placed before the work on the new spans could be commenced. The piers had to be cut down about 8 ft., and the girders placed without interruption of traffic. Furthermore, no falsework could be used to support the old spans while this work was going on. This problem was solved by the use of a steel gallows-frame, the general method of erection being indicated by Fig. 16. The frame consisted of two heavy steel posts connected at the top by a box-girder, which was high enough to allow trains to pass under it. The posts rested either on the end pins of the old spans, or on shoes placed on blocking on each side of the old shoes. The frame was stiffened by knee-braces extending from the posts up to the portal box-girder. From pins at the top of the posts, 16 by 2-in. eye-bars hung, and to the lower end of these eye-bars were fastened links which held the end pins of the span to be supported.

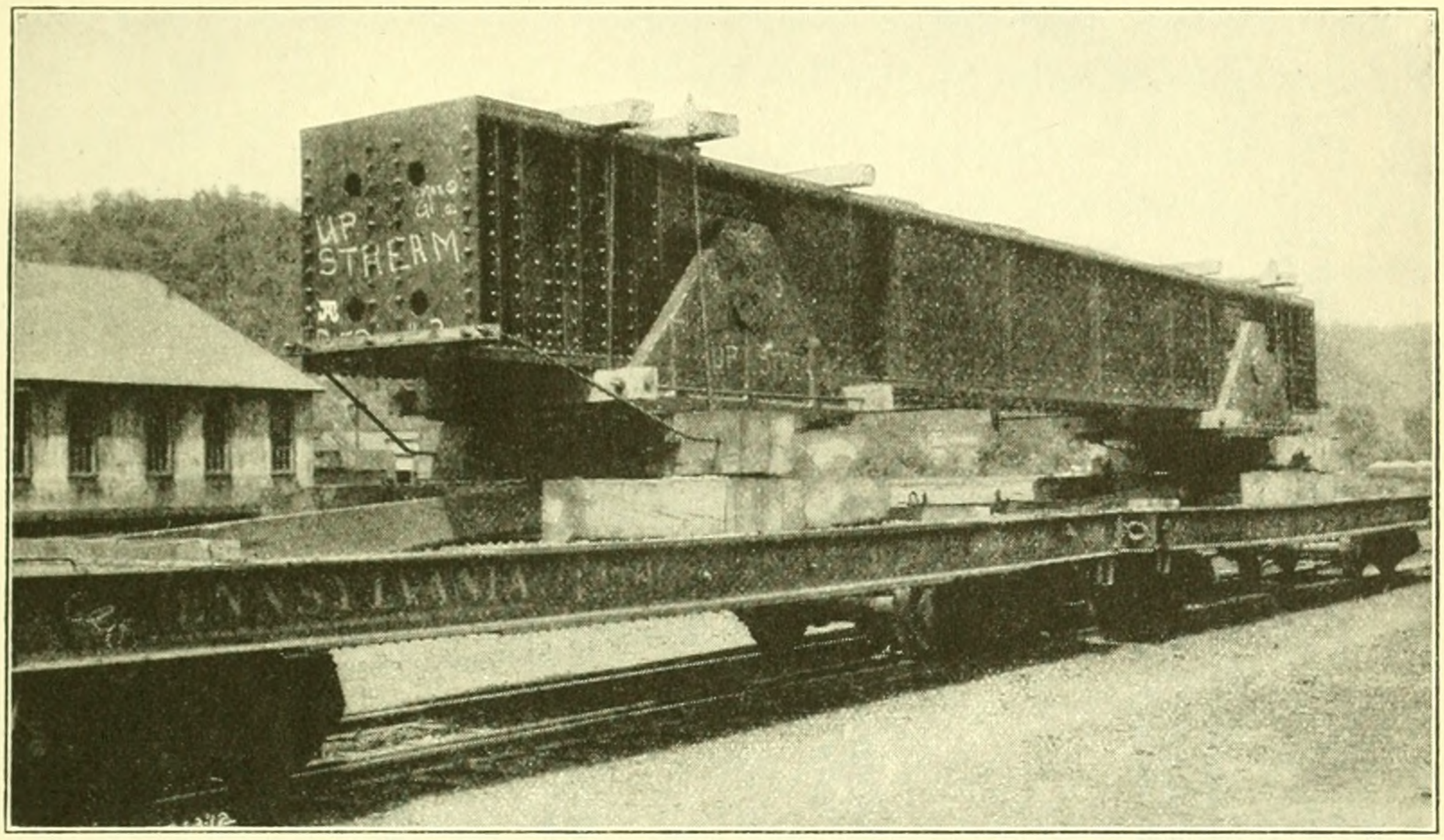


FIG. 14.—LARGE PIER GIRDER.

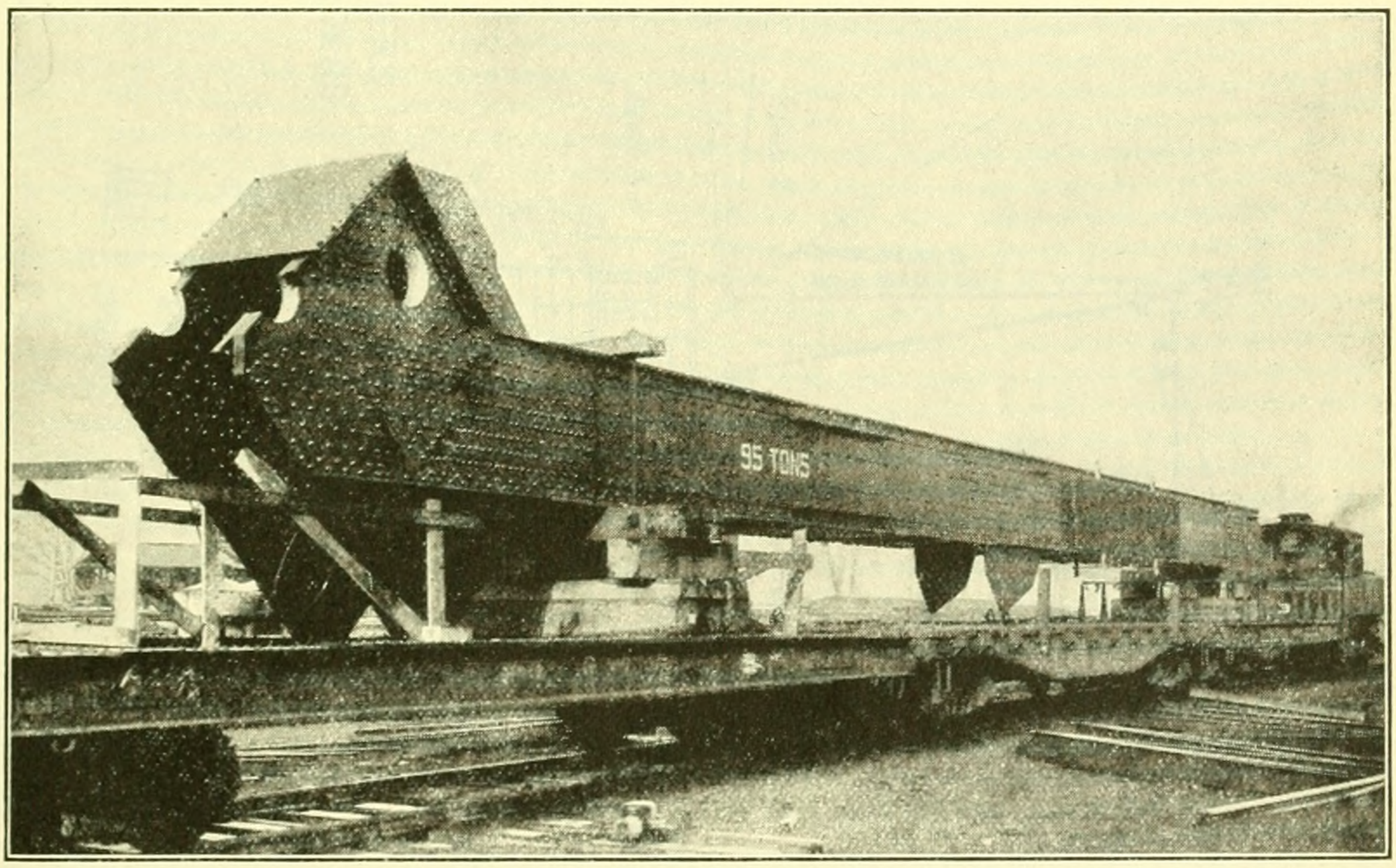


FIG. 15.—END POST FOR SPAN 3.

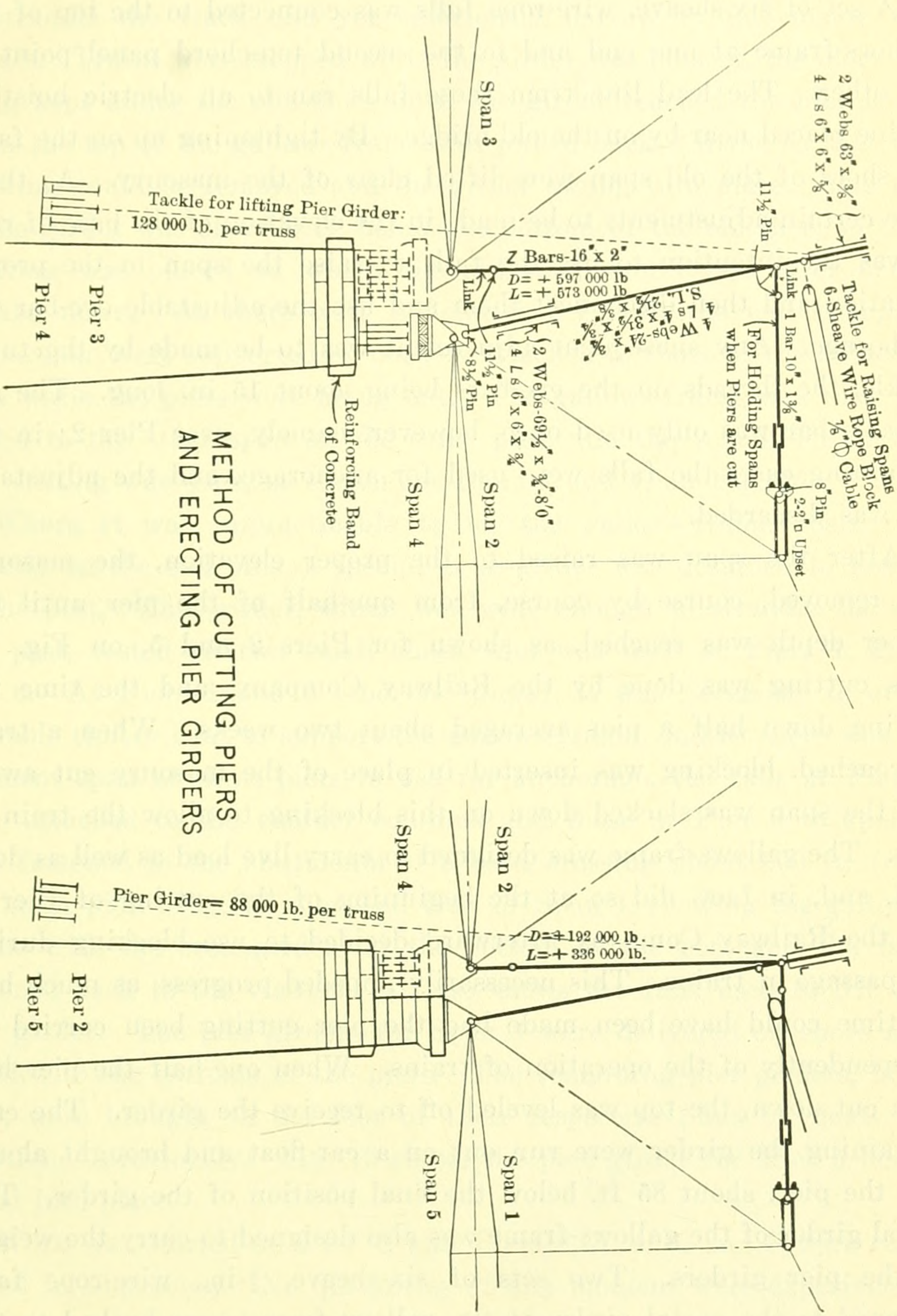

METHOD OF CUTTING PIERS
AND ERECTING PIER GIRDERS
Tackle for lifting Pier Girder:
128 000 lb. per truss
Pier Girder = 88 000 lb. per truss
Pier 4
Pier 3
Pier 5
Pier 2
Span 3
Span 4
Span 2
Span 5
Span 1
Z Bars-16" x 2"
D = + 597 000 lb
L = + 573 000 lb
D = + 192 000 lb.
L = + 336 000 lb.
2 Webs 63" x 3/8"
4 Ls 6" x 6" x 5/8"
11½" Pin
Link
Link 1 Bar 10" x 1⅜"
Tackle for Raising Spans
6-Sheave Wire Rope Block
⅞" Φ Cable
8" Pin
2-2" □ Upset
For Holding Spans
when Piers are cut
4 Webs-24" x ¾"
4 Ls 4" x 3½" x ⅜"
S.L. 2½" x ⅜"
2 Webs-69½" x ¾"-8'0"
4 Ls 6" x 6" x ¾"
11½" Pin
8½" Pin
Reinforcing Band
of Concrete

FIG. 16.

From the pin at the top of the post, a 10 by $1\frac{3}{8}$-in. horizontal adjustable eye-bar extended back to an equalizer which, in turn, connected to the pin at the hip point of the anchor span.

A set of six-sheave, wire-rope falls was connected to the top of the gallows-frame at one end and to the second top-chord panel point at the other. The lead line from these falls ran to an electric hoisting engine placed near-by on the old bridge. By tightening up on the falls, the shoes of the old span were lifted clear of the masonry. As there were certain adjustments to be made in the elevation of the base of rail, it was the intention to use the falls to raise the span to the proper elevation and then disconnect them and use the adjustable eye-bar for anchorage. Any subsequent adjustment was to be made by the turn-buckle, the threads on the eye-bars being about 15 in. long. The adjustable bar was only used once, however, namely, over Pier 2; in the remaining cases the falls were used for anchorage, and the adjustable bar was discarded.

After the span was raised to the proper elevation, the masonry was removed, course by course, from one-half of the pier until the proper depth was reached, as shown for Piers 2 and 5, on Fig. 16. This cutting was done by the Railway Company, and the time for cutting down half a pier averaged about two weeks. When a train approached, blocking was inserted in place of the masonry cut away, and the span was slacked down on this blocking to allow the train to pass. The gallows-frame was designed to carry live load as well as dead load, and, in fact, did so at the beginning of the cutting of Pier 1, but the Railway Company afterward decided to use blocking during the passage of trains. This necessarily impeded progress, as much better time could have been made had the pier cutting been carried on independently of the operation of trains. When one-half the pier had been cut down, the top was leveled off to receive the girder. The cars containing the girder were run out on a car-float and brought alongside the pier, about 85 ft. below the final position of the girder. The portal girder of the gallows-frame was also designed to carry the weight of the pier girders. Two sets of six-sheave, $\frac{3}{4}$-in., wire-rope falls fastened to the portal girder of the gallows-frame were hooked to the pier girder below. Three-sheave, manila-rope falls were attached to the old span and used to keep the girder clear of the masonry as it was hoisted. The manila-rope falls were worked by a derrick car run out

on the bridge and the wire-rope falls by the electric engine used to raise and lower the gallows-frame. This engine had four drums and eight spools. The wire-rope falls were 19 ft. 0 in. apart, wide enough to straddle the track and yet sufficiently narrow to fall inside the trusses. Trains were stopped while the girder was hoisted, the blocking being kept under the old shoes until the girder reached the pier level. Then the top of the gallows-frame was pulled back a little, so that the blocking could be removed and the girder swung into place. The top of the girder was about 2 ft. below the bottom of the old shoe, so that blocking was placed on which the old span would rest after being slacked down. As there were no end floor-beams, the end stringers of one span were supported by pockets attached to those of the adjacent span while the piers were being cut. The gallows-frame was then reversed to the other span on the same pier, and the remainder of the pier cutting was done, as shown for Piers 3 and 4, on Fig. 16.

Where it was impracticable to let the gallows-frame posts rest directly on the end pins, a special cross-girder was designed to fasten to the post. This girder, which was wide enough to straddle the old end post, rested on two small shoes, and was used at Piers 1, 3, 4, and 6. At Piers 1 and 6 (the end piers), it was necessary to erect a double timber bent to support the gallows-frame, and as there was no adjacent span at these piers to use for anchorage, the falls at Pier 1 were attached to the viaduct columns and those at Pier 6 to anchor rods fastened to the abutments of a road crossing about 300 ft. from the latter pier. Fig. 17 is an end view of Span 1, showing the gallows-frame with the cross-girders at the bottom of the post and the falls fastened back to the viaduct. It also shows the falls used to lift the pier girder. The pier girders for Span 1 were delivered on shore and skidded to the bottoms of the piers. The remaining pier girders, however, were brought to the foot of their respective piers on floats, as mentioned previously. Fig. 19 shows the pier girder for Pier 5 being lifted into place.

Work was started on Pier 1, and Piers 2, 3, 4, 6, and 5 were completed in succession. No difficulties of any moment were experienced, except that it proved a more difficult job than was expected to take down the gallows-frame from one pier and erect it on another. This was due partly to the old spans being in the way and partly to having to work between trains.

2.—Erection of Shore Spans 1 and 5.—After the pier girders were placed under Span 1, the erection of the new work on this span was started. It was originally intended to erect Spans 1 and 5 simultaneously, then Spans 2 and 4, and finally Span 3, the two erection gangs working independently of each other. As the piers for Span 1 were ready for the new steel long before those for Span 5, it was impossible to carry out this part of the programme. Fig. 21 shows the general method of erection of Spans 1 and 5.

Falsework was erected beneath the span, as shown by Fig. 21, and the new floor-beams were brought out and hung from the old ones by 3-in. rods. As these floor-beams were erected, they were blocked temporarily on falsework so as not to put too much load on the old span while it was carrying traffic. Pony bents were erected on each side of the new floor-beams, and the old stringers were blocked up on these bents. The rivets connecting the old stringers to the old floor-beams were cut out, letting the falsework carry the live load, track, and stringers. The hanger rods holding up the new floor-beams were then screwed up until the latter showed the right amount of camber, which had been determined previously. The conditions governing this will be given later.

I-beams were placed on the top chord in the two center panels and blocked up at the panel points so as not to allow any bending in the top chord from the weight of the traveler. The track was laid on these I-beams and the small traveler was erected, a 6-ton ginny-wink being used. This traveler consisted of a 30 by 34-ft. frame, with one 16-in. steel wheel at each corner and one in the center of each sill; 12 by 12-in. posts were placed at each corner and braced together. A lifting beam, composed of two 24-in., 100-lb. I-beams connected by diaphragms, was put at each end of the traveler on top of the posts. One 50-ft. boom was placed at each end of the traveler, resting on a foot-block in the center of the cross-sill. A four-drum, eight-spool, 100-h.p., electric engine was placed on the floor of the traveler, which floor consisted of seven 15-in., 42-lb. I-beams resting on the traveler sills. After the traveler was erected, it put in the remainder of the falsework on top of the span.

The new stringers were erected on the brackets on the ends of the floor-beams, and temporary tracks were laid on these stringers throughout the entire length of the span, thus providing means for bringing the

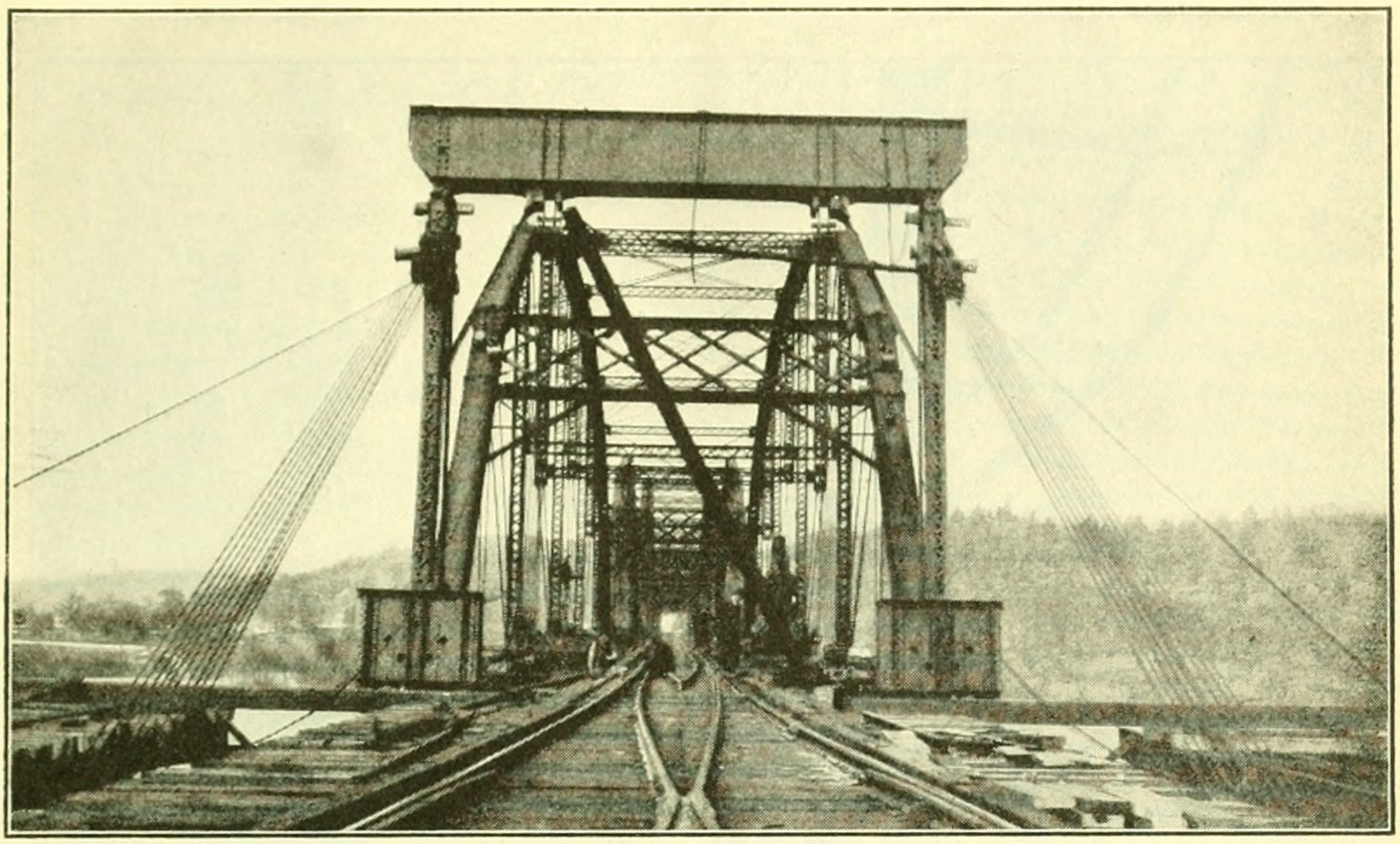


FIG. 17.—GALLOWS FRAME AT PIER 1.

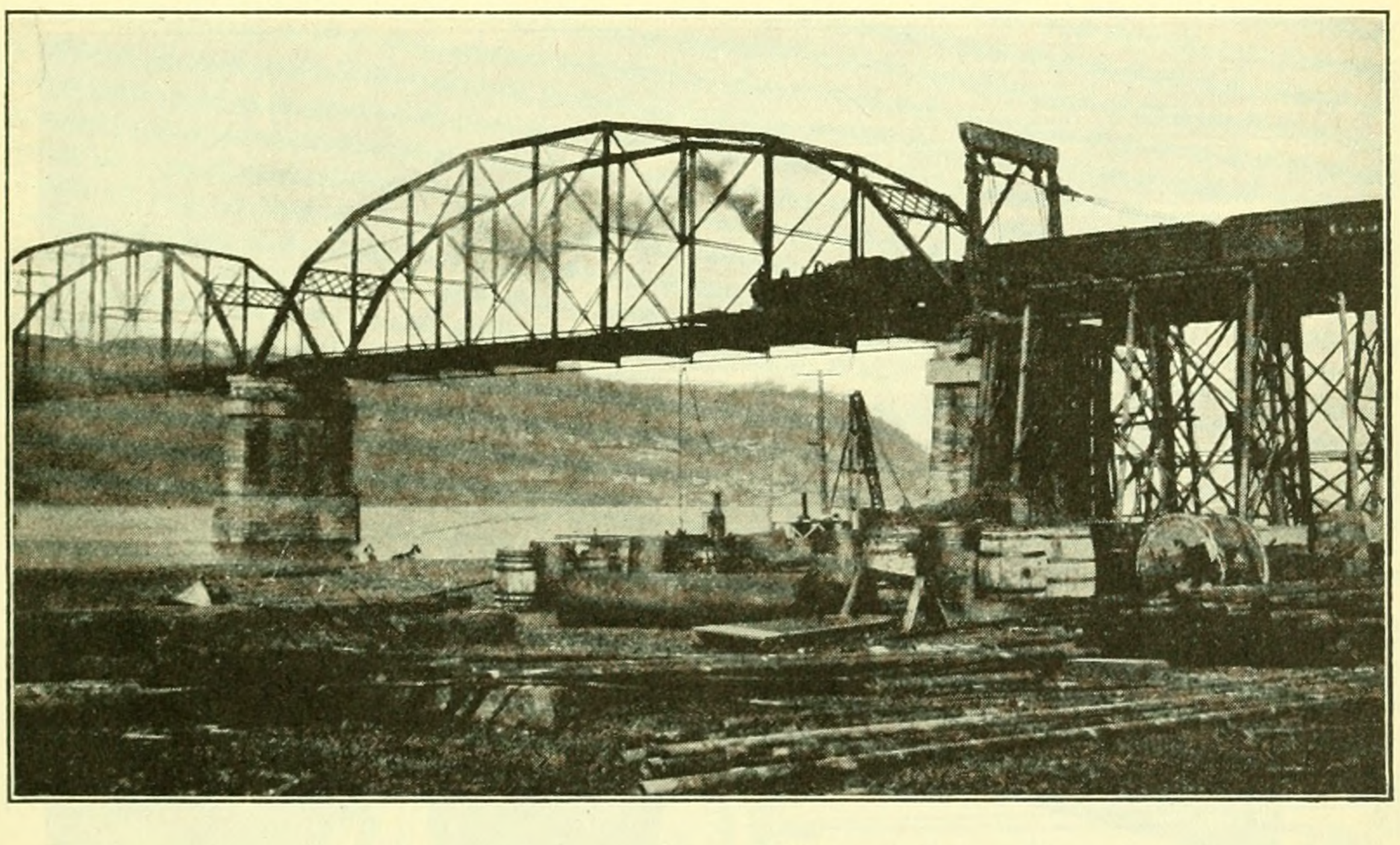


FIG. 18.—GALLOWS FRAME HOLDING SPAN 1.

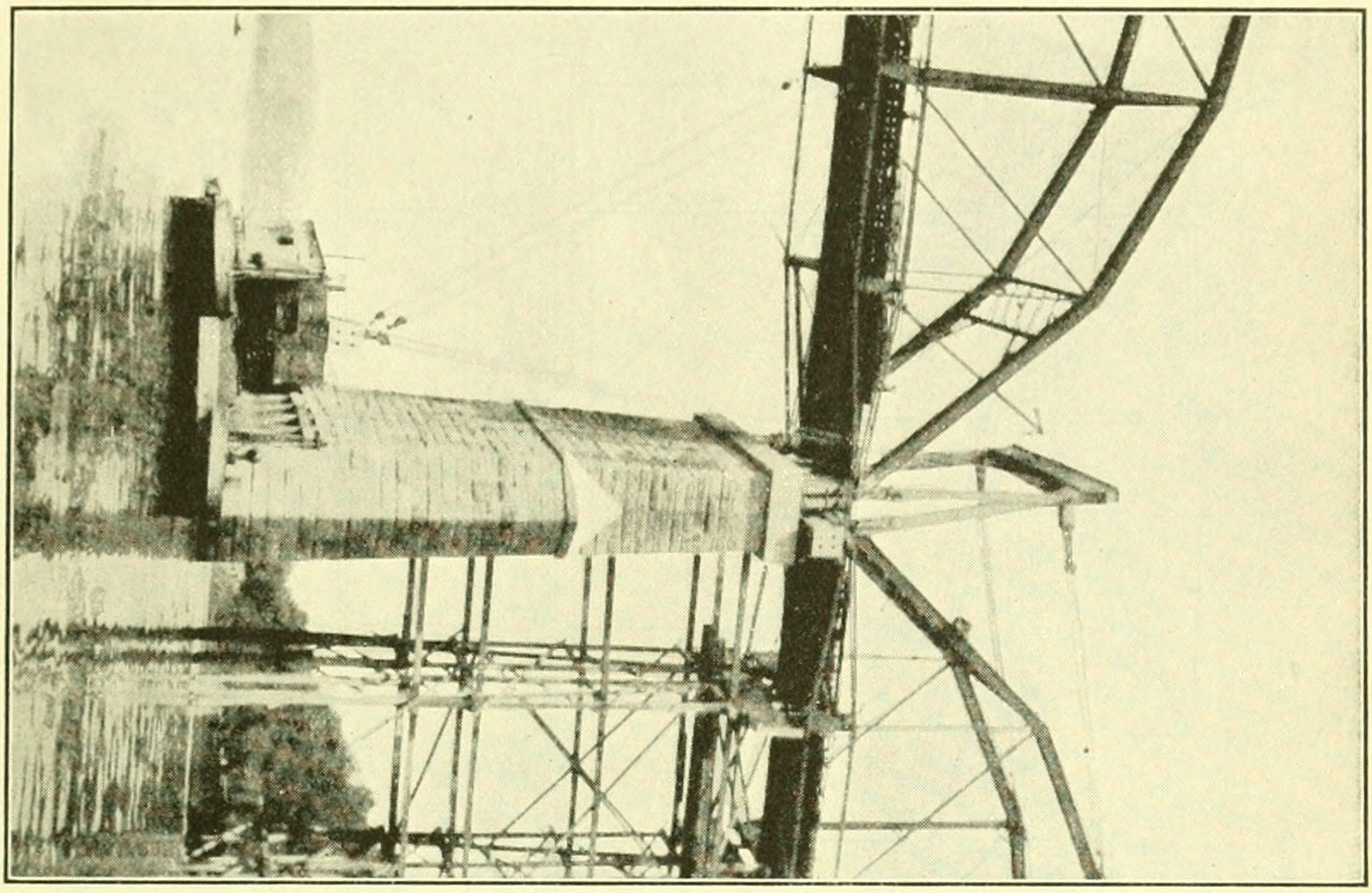


FIG. 19.—PIER GIRDER BEING LIFTED FROM BARGE.

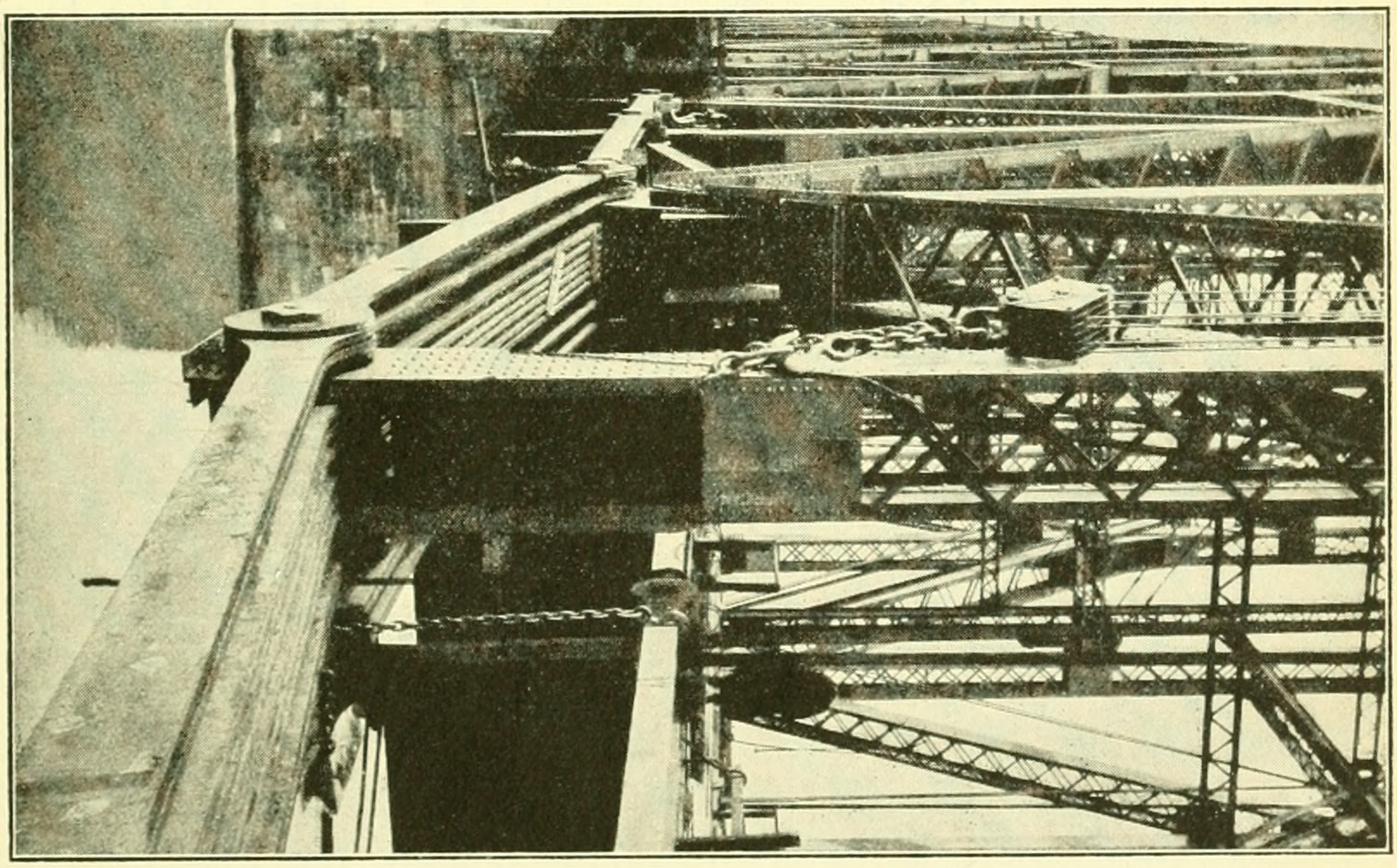


FIG. 20.—PANEL POINT *j* BEFORE CLOSING.

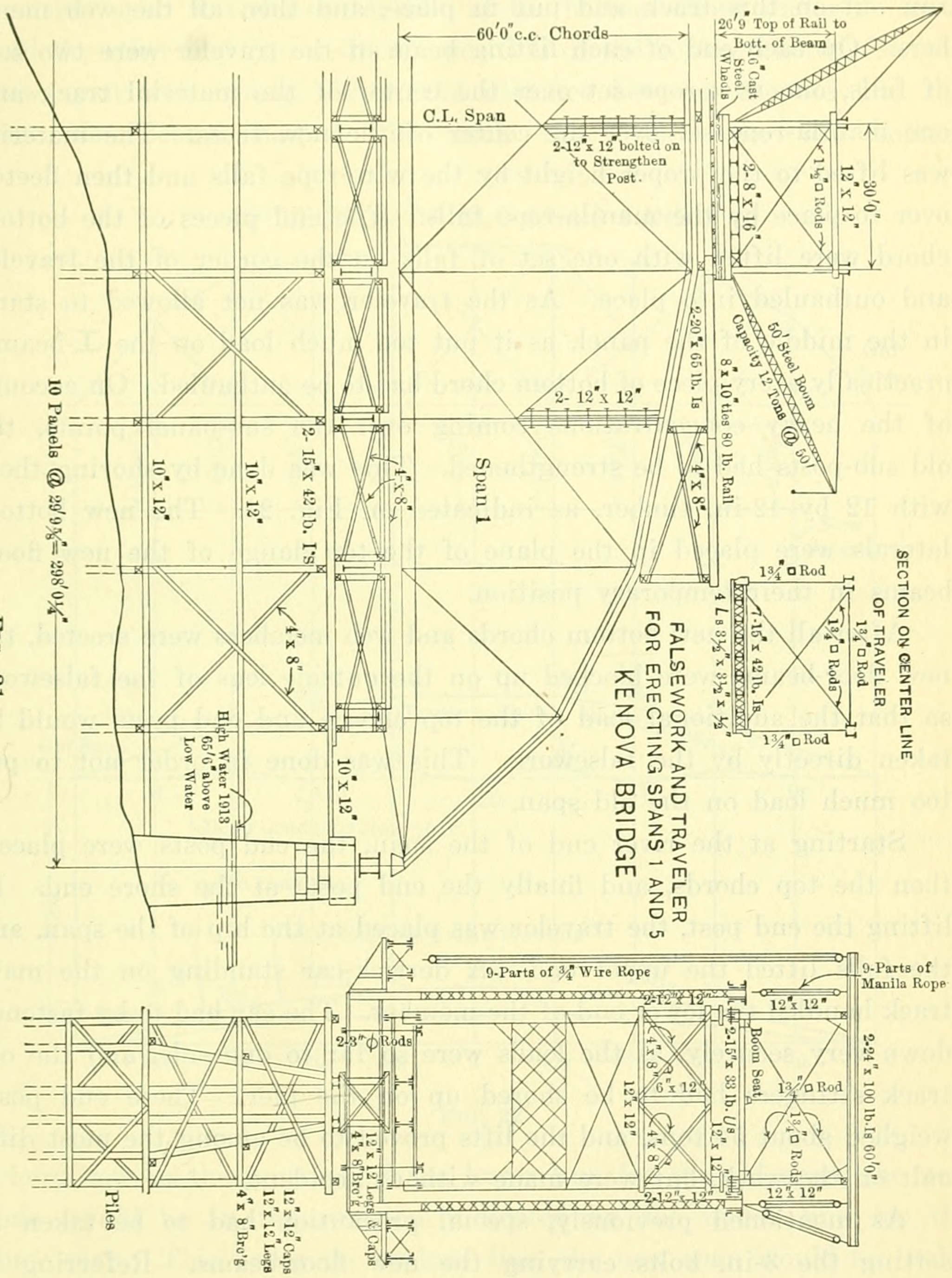

60'0" c.c. Chords
26'9" Top of Rail to Bott. of Beam
16" Cast Steel Wheels
C.L. Span
2-12"x 12" bolted on to Strengthen Post.
2-8"x 16"
1½"□ Rods
12"x 12"
30'0"
2-20"x 65 lb. Is
50' Steel Boom Capacity 12 Tons @ 50'
8"x 10" ties 80 lb. Rail
2-12"x 12"
4"x 8"
Span 1
2-15"x 42 lb. I's
10"x 12"
10"x 12"
4"x 8"
4"x 8"
10"x 12"
High Water 1913 65'6" above Low Water
10 Panels @ 29'9⅝" = 298'0¼"
SECTION ON CENTER LINE OF TRAVELER
1¾"□ Rod
1¾"□ Rods
1¾"□ Rod
7-15"x 42 lb. Is
4 Ls 3½"x 3½"x ½"
1¾"□ Rod
FALSEWORK AND TRAVELER FOR ERECTING SPANS 1 AND 5 KENOVA BRIDGE
9-Parts of ¾" Wire Rope
9-Parts of Manila Rope
2-12"x 12"
12"x 12"
2-3" ϕ Rods
4"x 8"
6"x 12"
12"x 12"
2-15"x 33 lb. Us
Boom Seat
1¾"□ Rod
1¾"□ Rods
2-24"x 100 lb. Is 60'0"
4"x 8"
12"x 12"
2-12"x 12"
12"x 12"
Piles
12"x 12" Caps
12"x 12" Legs
4"x 8" Bro'g
12"x 12" Legs & Caps
4"x 8" Bro'g

FIG. 21.

new material out to its proper place in the bridge entirely independent of the main track. Run-offs from these material tracks connected with the viaduct about 100 ft. from Pier 1. All the bottom chords were run out on this track and put in place, and then all the web members. On each end of each lifting beam of the traveler were two sets of falls, one wire-rope set over the center of the material track and one manila-rope set over the center of the new truss. The material was lifted to the proper height by the wire-rope falls and then fleeted over to place by the manila-rope falls. The end pieces of the bottom chord were lifted with one set of falls on the corner of the traveler and outhauled into place. As the traveler was not allowed to stand in the middle of the panel, as it put too much load on the I-beams, practically every piece of bottom chord had to be outhauled. On account of the heavy concentrations coming over the sub-panel points, the old sub-posts had to be strengthened. This was done by shoring them with 12 by 12-in. timber, as indicated on Fig. 21. The new bottom laterals were placed in the plane of the top flange of the new floor-beams in their temporary position.

After all the new bottom chords and web members were erected, the new floor-beams were blocked up on the outside legs of the falsework so that the additional load of the top chords and end posts would be taken directly by the falsework. This was done in order not to put too much load on the old span.

Starting at the river end of the span, the end posts were placed, then the top chords, and finally the end posts at the shore end. In lifting the end post, the traveler was placed at the hip of the span, and the falls lifted the upper end. A derrick-car standing on the main track handled the lower end of the member. The car had to be fastened down very securely, as the loads were so far to one side, and the old track stringers had to be shored up on the pier. These end posts weighed about 54 tons, and the lifts proved to be among the most difficult on the work, but were made without accident.

As mentioned previously, special precaution had to be taken in setting the 3-in. bolts carrying the new floor-beams. Referring to Fig. 22, the theoretical center line of the bottom chord of the new span was 1 ft. $10\frac{7}{8}$ in. below that of the old span, making the theoretical distance between the old and new floor-beams 2 ft. 11 in. At the bottom of Fig. 22, the upper line for the old span represents the posi-

tion of the center line of the bottom chord after the stringers had been disconnected. The other line represents the position of the bottom chord when the old span carried the new one. The upper line for the new span was the center line of the bottom chord under no load, and the other line represents the position of the bottom chord after the new span was swung. Now, the distance between the old and the new floor-beams had to be such that when the old bottom

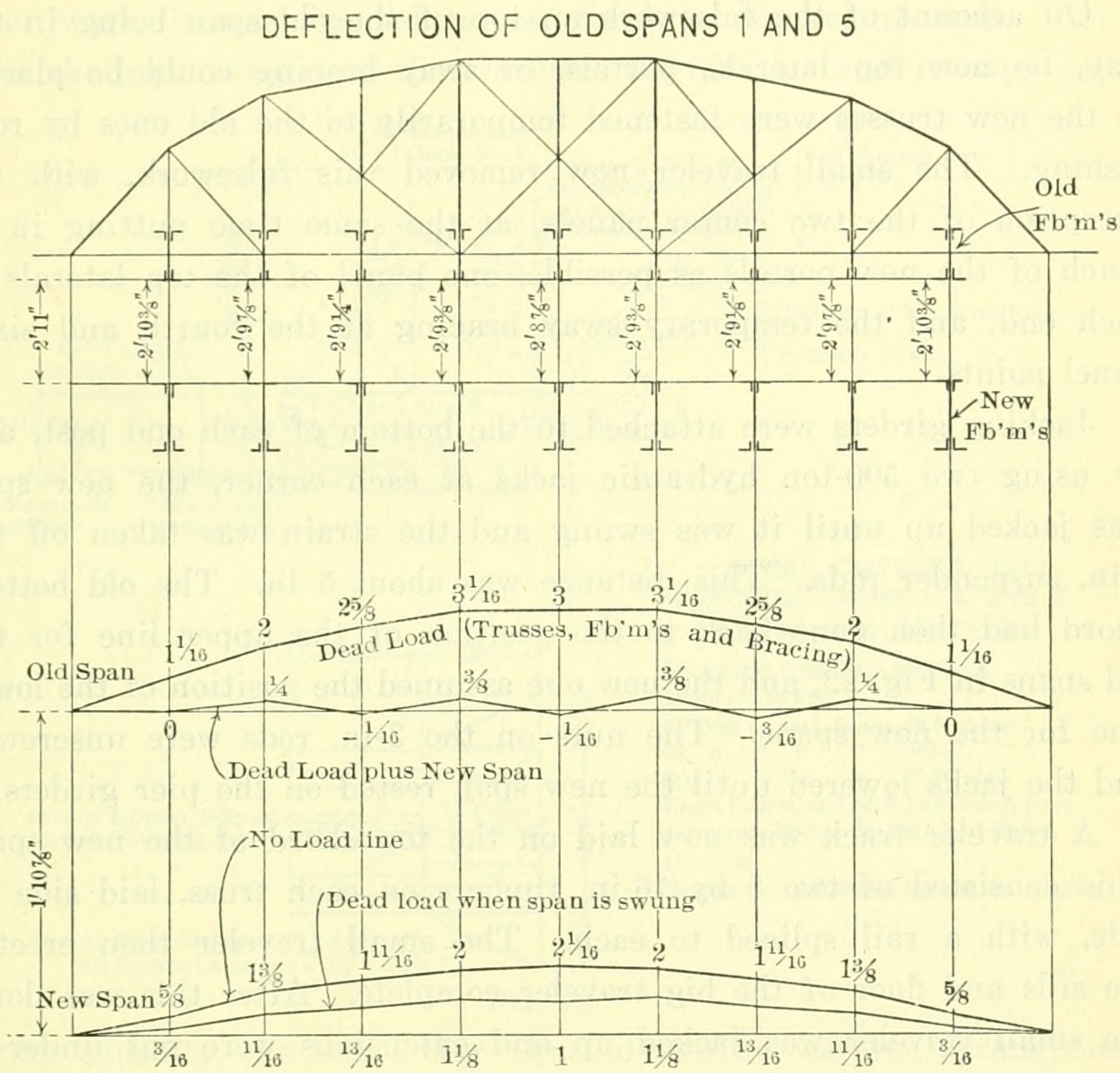


FIG. 22.

chord was in the position of the lower line for the old span, the new one would be in the position indicated by the upper line for the new span. This being the no-load line, the new span would be under zero stress and, consequently, all the truss connections could be easily made. The figures for placing the new floor-beams are given in Fig. 22. These figures were increased to allow for the settling of the wood blocking under the shoes of the old span.

The total actual deflection in the center of the span at the time the new floor-beams were blocked up on the outside legs of the falsework was about 2½ in. below the dead-load camber, or ½ in. below a horizontal line drawn from center to center of the end pins. Wedges had to be provided between the pony bents and old stringers so that the latter could be raised and lowered with the movements of the span, otherwise the old floor-beams would bear on the tops of the stringers and put more load on the falsework.

On account of the falsework on top of the old span being in the way, no new top laterals, portals, or sway bracing could be placed, so the new trusses were fastened temporarily to the old ones by rope lashing. The small traveler now removed this falsework, with the exception of the two center panels, at the same time putting in as much of the new portals as possible, one panel of the top laterals at each end, and the temporary sway bracing at the fourth and sixth panel points.

Jacking girders were attached to the bottom of each end post, and by using two 500-ton hydraulic jacks at each corner, the new span was jacked up until it was swung and the strain was taken off the 3-in. suspender rods. This distance was about 5 in. The old bottom chord had then gone back to the position of the upper line for the old spans in Fig. 22, and the new one assumed the position of the lower line for the new spans. The nuts on the 3-in. rods were unscrewed and the jacks lowered until the new span rested on the pier girders.

A traveler track was now laid on the top chord of the new span. This consisted of two 8 by 16-in. timbers on each truss, laid side by side, with a rail spliced to each. The small traveler then erected the sills and floor of the big traveler complete. After this was done, the small traveler was jacked up and extensions were put under it so that it could run on the track laid on the new top chord. The remainder of the falsework was removed from the top of the old span, and the remaining new top laterals and struts were placed. The old stringers were then reconnected to the old floor-beams by bolts, thus letting the old span again carry the live load. The small traveler placed a 12-ton, steel derrick with a 65-ft. boom on the deck of the large traveler. This derrick raised the remainder of the large traveler and was then taken down by the small traveler. The electric engine, which up to this time had been on the small traveler, was transferred

to the large traveler, and a 2-drum, 4-spool, steam engine was placed on the small traveler to do what little hoisting remained for this traveler. The large steel traveler was then rigged up complete. Fig. 23 shows sections of this traveler. The masts, booms, stiff legs, and cast-steel foot-blocks were standard parts of a 65-ton derrick, the remainder had been made especially for this bridge. The traveler could have been made somewhat lighter if it had been designed throughout for this bridge, but as the 65-ton derricks would be needed later for other work, it was decided to use them at Kenova as well. Aside from the great weight of the traveler (423 000 lb.) and its very great

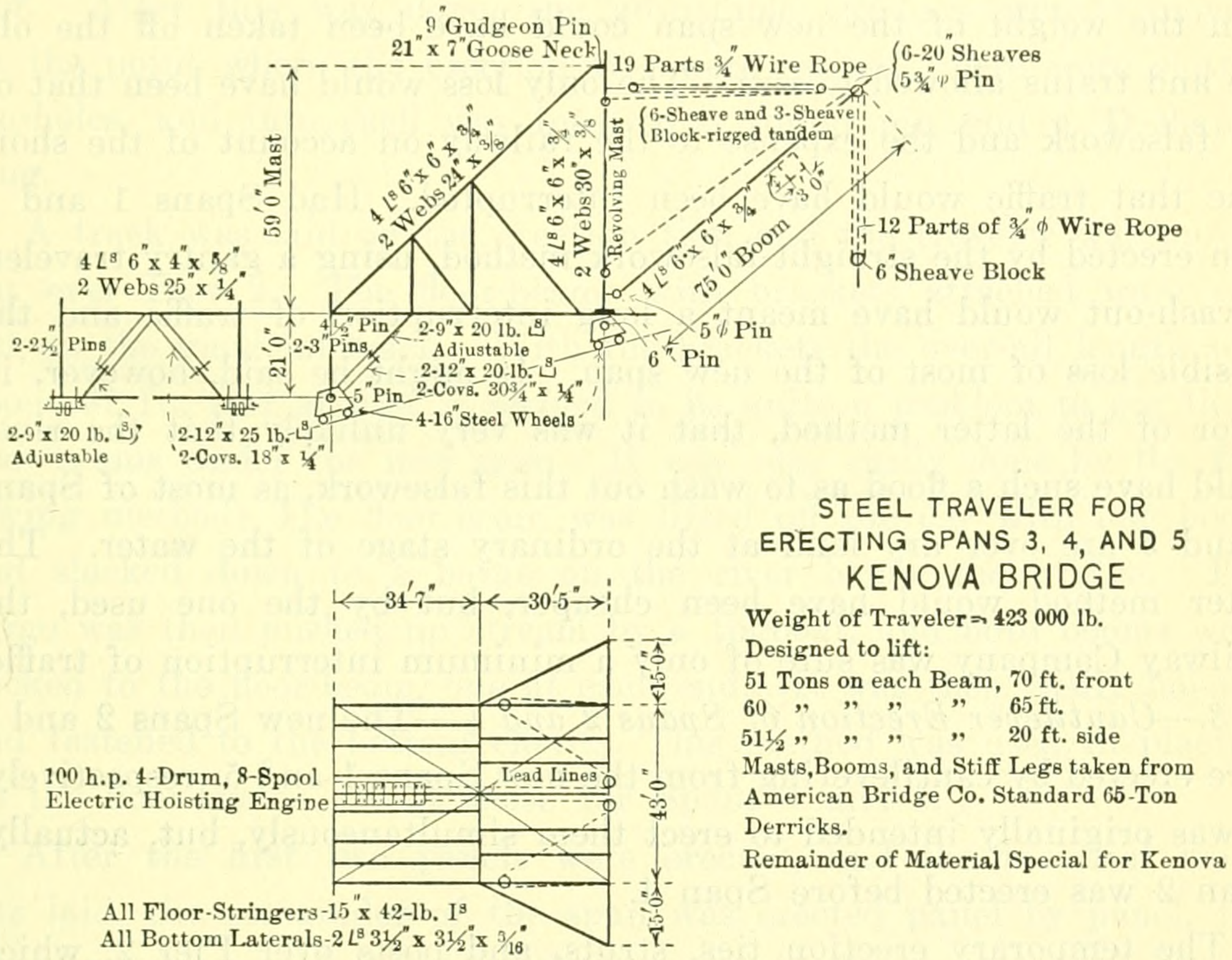


FIG. 23.

lifting capacity, the only other unusual feature was the arrangement for keeping the revolving mast plumb when working on the inclined top chords of Span 3. This was taken care of by a long leg in the back and telescoping braces. In order to raise the rear end of the traveler, the booms were hooked to the old span ahead. At the proper height, pins were driven in the back legs and telescoping braces. To work satisfactorily, a traveler or derrick with revolving masts should have these masts plumb.

The work of removing the falsework under the span was commenced, and the 15-in. I-beams, on which the pony bents had rested,

were placed on top of the new floor-beams. The old span was blocked up on these I-beams, and the old trusses and bracing were removed, using both travelers. The old floor system was not removed at this time, but was allowed to remain blocked up on the I-beams until all the new spans were erected. Span 5 was erected in the same way, but it was not started until some time after Span 1 had been put in place.

If there had been a flood in the river after the erection of the new trusses had been commenced, and this flood should have taken out the falsework, traffic would have been interrupted only for the length of time necessary to complete the erection of the new span, for then the weight of the new span could have been taken off the old one and trains allowed to run. The only loss would have been that of the falsework and the expense to the railway on account of the short time that traffic would have been interrupted. Had Spans 1 and 5 been erected by the straight-falsework method, using a gantry traveler, a wash-out would have meant a long interruption of traffic and the possible loss of most of the new span. It might be said, however, in favor of the latter method, that it was very unlikely that the river could have such a flood as to wash out this falsework, as most of Spans 1 and 5 are over dry land at the ordinary stage of the water. The latter method would have been cheaper, but by the one used, the Railway Company was sure of only a minimum interruption of traffic.

3.—Cantilever Erection of Spans 2 and 4.—The new Spans 2 and 4 were erected by cantilevering from the new Spans 1 and 5, respectively. It was originally intended to erect them simultaneously, but, actually, Span 2 was erected before Span 4.

The temporary erection ties, struts, and posts over Pier 2, which would connect the new Spans 1 and 2, shown by dotted lines in Fig. 7, were erected by the large traveler. The distance between the two hip points of adjacent spans was about 125 ft., and the ties were supported at each panel point by vertical posts. The total section in each tie was 225 sq. in., and, as the large traveler had to cross them, the ties were made deep enough to be good for this load in bending. The direct tension in each tie was about 4 000 000 lb. Span 1 acted as the anchor arm, and, for additional counterweight, 286 000 lb. of rails were placed on its shore end and the small traveler was run as far back toward the shore on this span as possible to serve also as a counterweight.

After the erection ties were in position, the end posts for Span 2, each weighing about 54 tons, were brought out on the material track and hoisted into place, one boom being used for each post. The shoes of these posts were put in in the material yard. The hitch for lifting them was placed so that they hung in the correct position after being hoisted clear of the push-cars. Temporary adjustable eye-bars, which fastened to the center of the end post and to the top of the erection post over Pier 2, were now connected up and held the end post until the remainder of the erection ties, the first piece of the bottom chord, and the first two panels of the web members, were put in by the traveler. After this was done, the adjustable eye-bars were removed. At the point where the erection ties were spliced, there were slotted pin-holes, and into each was inserted a round pin and a **D**-shaped plug.

A track was laid on the erection ties, and the traveler was moved out over Pier 2. The floor-beams with brackets attached were run out on the material track. With the brackets the over-all length was about 67 ft., and at first it seemed to be quite a problem to get these floor-beams under the new span. It was very easily done by the following method: The floor-beam was lifted off the car with one boom and slacked down to a barge on the river below the bridge. The barge was then pushed up stream by a tugboat, and both booms were hooked to the floor-beam, one at each end. It was then easily hoisted and fastened to the bottom chord. This method was used in placing all the floor-beams except those for Spans 1 and 5.

After the first two panels were erected, and the material track was laid, the remainder of the span was erected panel by panel, the large traveler creeping out on the top chord. As much as possible of the new bracing was placed at this time. The erection tie was shortened $7\frac{1}{4}$ in. in order to be sure that the river end of Span 2 would clear the pier girder; this clearance was about 3 in. A typical cross-section of Span 2, during and after erection, is shown at the right of Fig. 24.

Jacks were then placed under jacking girders attached to the shore end of Span 1 and the river end of Span 2, and both travelers were run over Pier 2 so as to put as little load as possible on the jacks. The jacks were pumped and the ends of the spans raised until the stresses in the trusses were reversed and there was zero stress in the

erection ties. At this time each span was acting as a simple span, and the D-shaped plugs previously mentioned were knocked out of the slotted holes. Each slot was so long that, after the spans were lowered, the erection ties could still be used for the travelers to cross from one span to the other. The total jacking was about 25 in., Span 1 being jacked 16 in. and Span 2, 9 in. This latter span could not be jacked any more on account of fouling old Span 2. During this jacking, the track was broken and the traffic interrupted, but the whole operation, from the time the track was broken until it was reconnected, did not take more than 2 hours. The spans were then lowered on the pier girders.

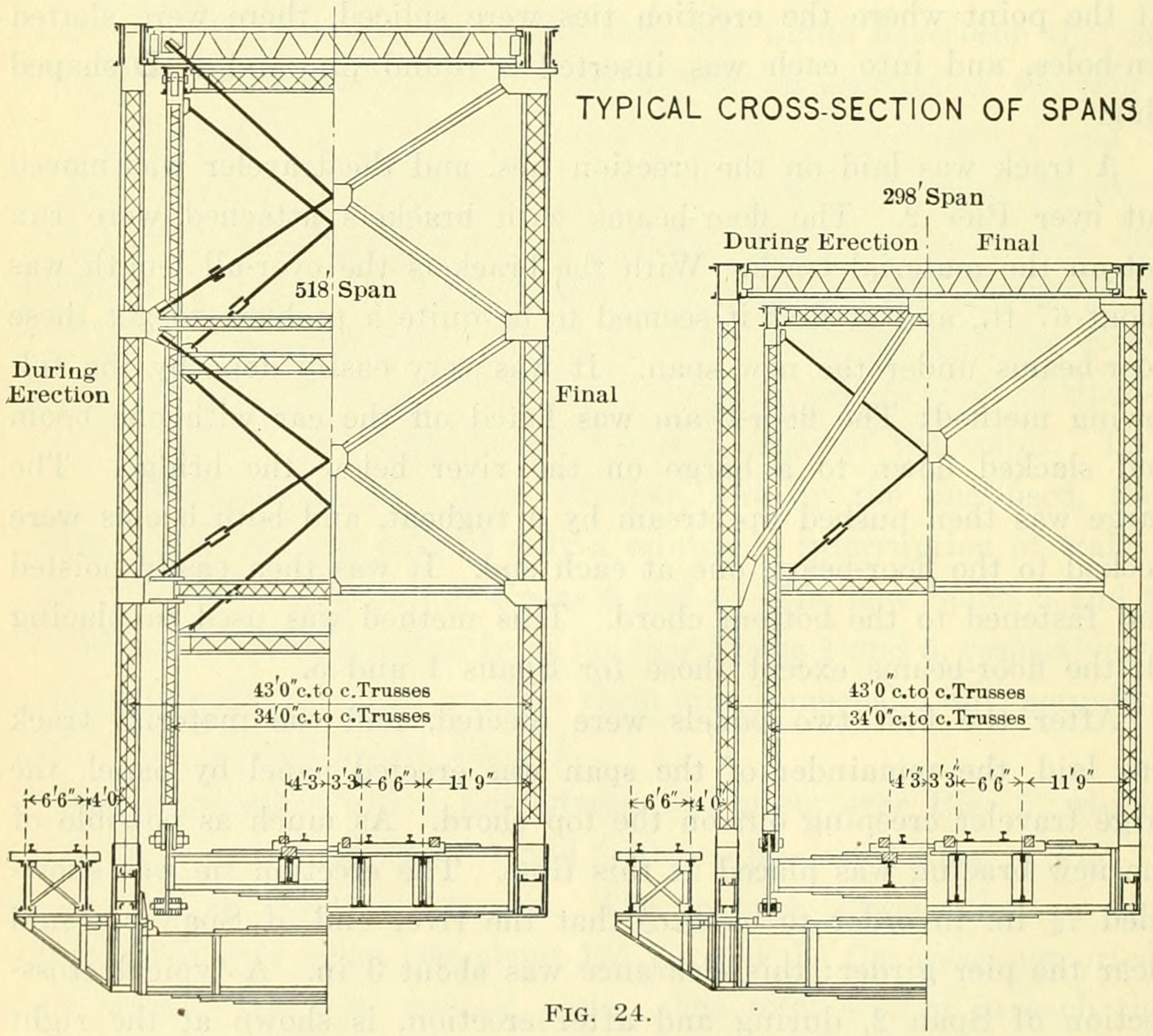


FIG. 24.

I-beams were placed on top of the new floor-beams of Span 2, and on these old Span 2 was blocked up, and then the trusses and bracing were taken down. These trusses were allowed to remain on new Span 2 so as to be used as a counterweight when the span acted as the anchor span during the erection of new Span 3. The method of erecting Span 4 was similar to that used for Span 2.

4.—Cantilever Erection of Span 3.—The small traveler crossed the erection ties to Span 2, removing the ties as it crossed. These ties were designed so that many of the pieces could be used again between Spans 2 and 3, and such as could be used were erected in position over Pier 3 by the large traveler. (See dotted lines in Fig. 7.) The small traveler was placed as near as possible to the shore end of Span 2 to serve as a counterweight, and an additional counterweight was provided by the rails which had previously been used on Span 1.

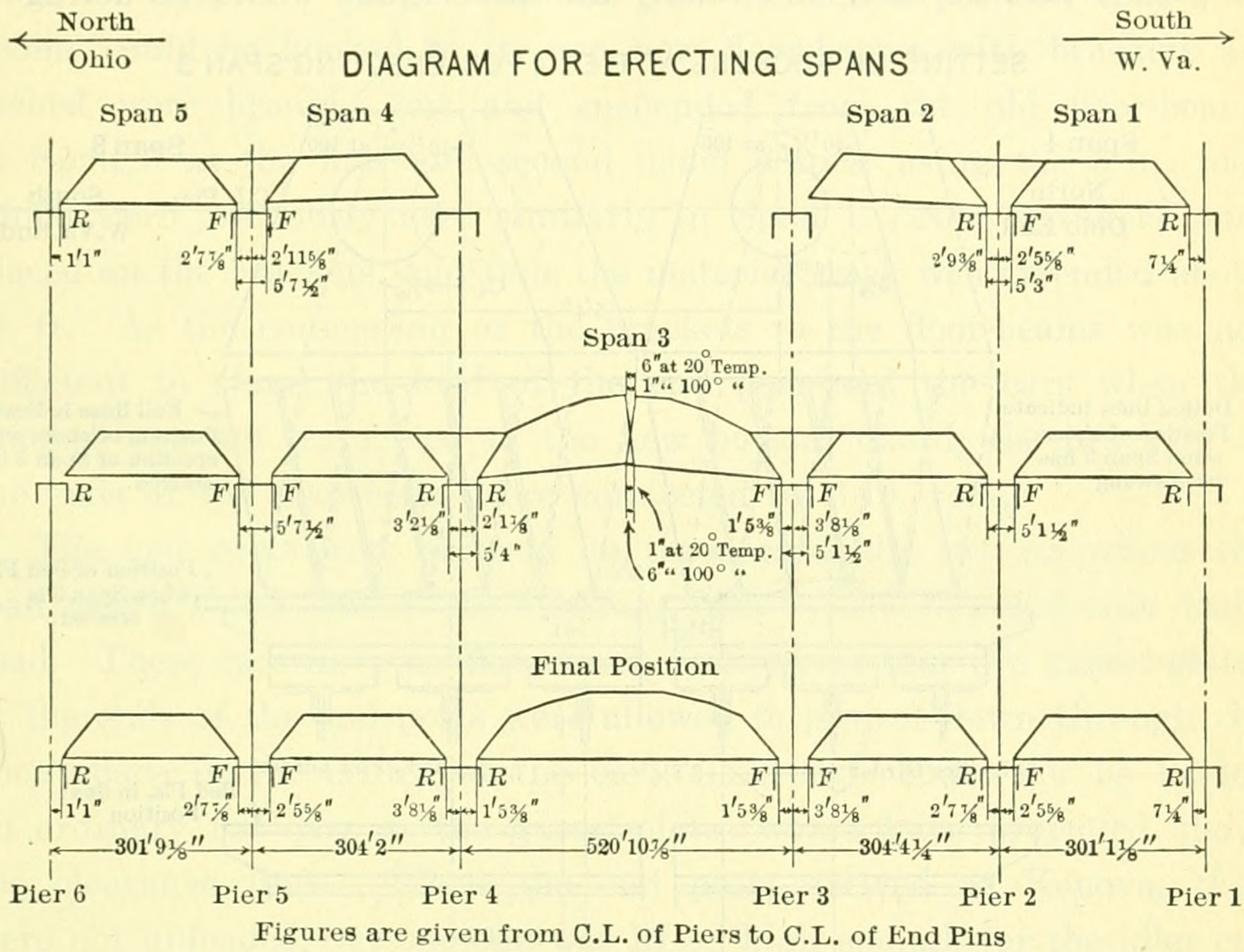


FIG. 25.

Span 3 was erected by cantilevering each half from new Spans 2 and 4, and then joining the two halves in the center. This is shown on Fig. 25. The south end of Span 3 was fixed and the north end on rockers. The adjacent or south end of Span 4 was also on rockers, so that there were two rocker ends over Pier 4. The purpose of this will appear later. The joint in Span 3 was made at the center of the top chord, but at the sub-panel point next to the center in the bottom chord (see Fig. 7) the four center panels of the bottom chord were made of eye-bars. As the bottom chords shortened under erection compression, and as there would be still more contraction in cold weather, new Span 4 had been erected 6 in. south of its final position.

That was done so as to be sure that at a temperature of 20° there would be a minimum lap of 1 in. Furthermore, to insure a minimum gap of 1 in. in the top chord at 100°, the erection ties were shortened 9¼ in. over Piers 3 and 4. In order to close Span 3, the shore ends of Spans 2 and 4 were to be jacked until the top chords of Span 3 touched, closing the gap. Then, as jacking continued, the bottom chord would straighten out by the longitudinal movement of Span 4 and the north half of Span 3. On further jacking, the stresses would reverse, and finally all three spans would be acting as

SETTING OF ROCKERS AT PIER 4 FOR ERECTING SPAN 3

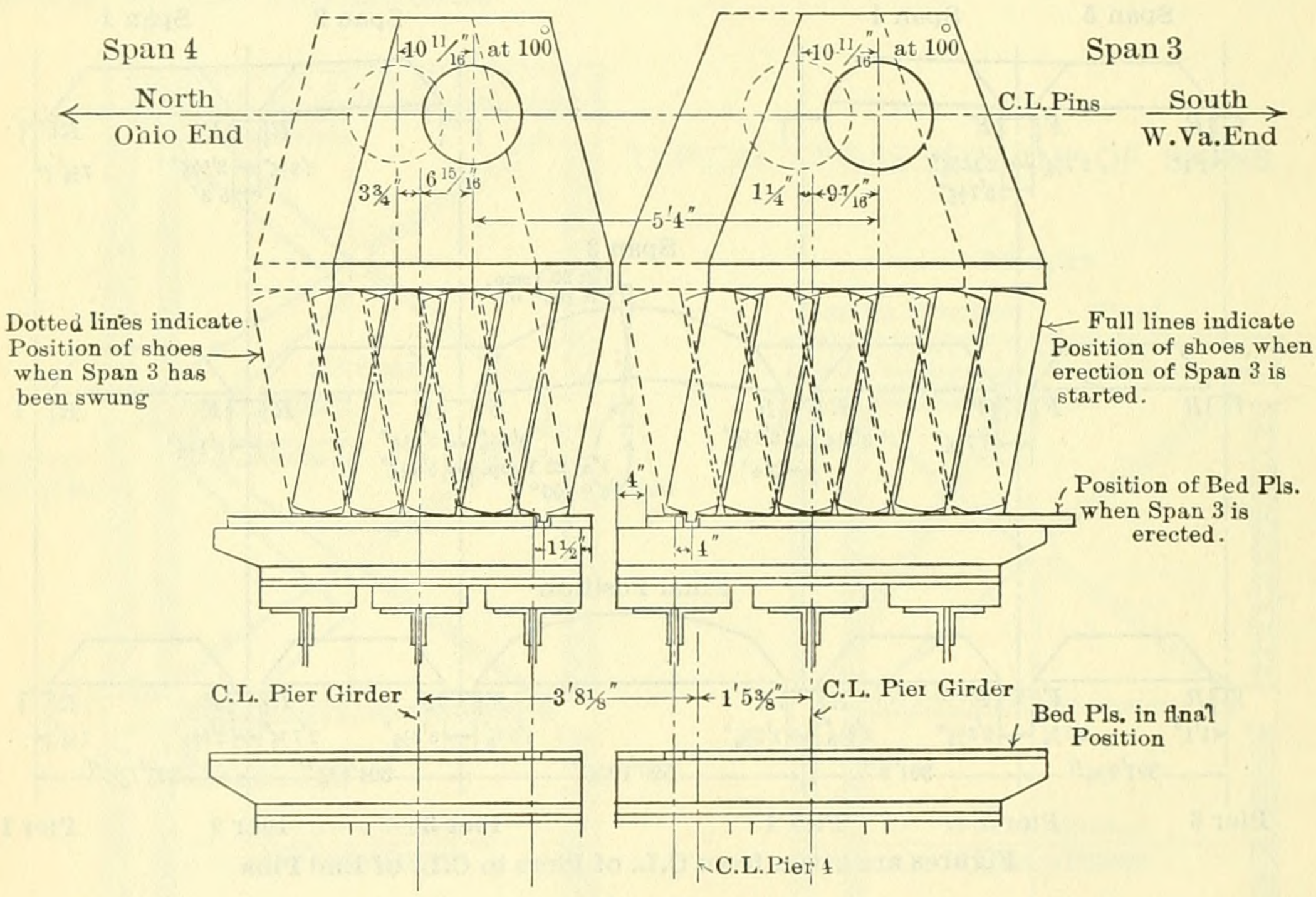


FIG. 26.

simple spans and Span 4 would have moved back to its final position. The rockers on Pier 4 were adjusted by sliding plates so that the inclination south before jacking would about equal the inclination north after Span 3 was closed. Fig. 26 shows the setting of the rockers over Pier 4.

After the erection ties were placed, the end post for Span 3 was brought out. This end post was about 105 ft. long and weighed 95 tons by itself, or about 105 tons when the shoe and pin were attached. It is shown in Fig. 15. As the capacity of each boom was only 65 tons, these posts had to be handled with both booms of the traveler. This was done by a balance beam hooked to the post at such a point

that, when the end post was lifted clear of the cars, it hung at the proper inclination. The balance beam served to distribute the load equally between the two booms. In order to place the end posts, the traveler had to stand directly over Pier 3, and, as the material track extended only as far as the pier, the booms could not reach the balance beam unless some provision was made for extending the material track farther out. Also, it was practically impossible to run the end post out on the main track and hoist it between the portals of old Span 3 and new Span 2. To get the end post in such a position that both booms could be hooked to it, two new floor-beams with brackets attached were brought out and suspended from the old floor-beams of Span 3 at the first and second panel points, using the 3-in. rods which were previously used similarly in Span 1. New stringers were placed on the brackets, and thus the material track was extended about 65 ft. As the connection of the brackets to the floor-beams was not sufficient to stand the load of the end post and the cars when the bracket was not connected to the new bottom chord, the brackets at the ends of the floor-beam were connected by 3-in. rods.

The end posts were shipped on three cars, the two on which the load rested being special gun-carriage cars of the Pennsylvania Railroad. These cars have no floor in the center, so that the gusset-plates at the ends of the end posts were allowed to project down through the open space in the center of the car. The posts could not be loaded on ordinary flat cars as the gusset-plates would have projected above the clearance lines. When the end posts arrived at Kenova, they were not unloaded, but one end was lifted high enough for the idler car to be taken out. The end car was then put back, but in such a position that the center of gravity of the end posts was as near as possible to the forward end of the car. The posts were brought out on the material track and placed by the traveler without any trouble. Temporary adjustable eye-bars, similar to those used during the erection of the end post for Span 2, were used.

After the first two panels of Span 3 were erected the other panels up to the center were erected by methods similar to those used for Span 2. The left side of Fig. 24 shows a typical cross-section of Span 3, during and after erection. In this case, however, the traveler had to climb the curved top chord. To pull the traveler up the inclined top chord of the new span, two sets of six-sheave, wire-rope falls were

used, fastened to the top of old Span 3. Also, two sets of four-sheave, manila-rope falls were put on, to catch the traveler in case anything gave away. After the traveler was pulled up to its proper place, the brackets were fastened to the top chord behind the front shoes. The falls were then slacked off, and the brackets prevented the traveler from running down the incline.

Attention has been called to the fact that the erection ties were shortened $7\frac{1}{4}$ and $9\frac{1}{4}$ in. over Piers 2 and 3, respectively, for certain purposes. There was another feature to be considered, which necessitated this shortening being kept to a minimum. The actual eleva-

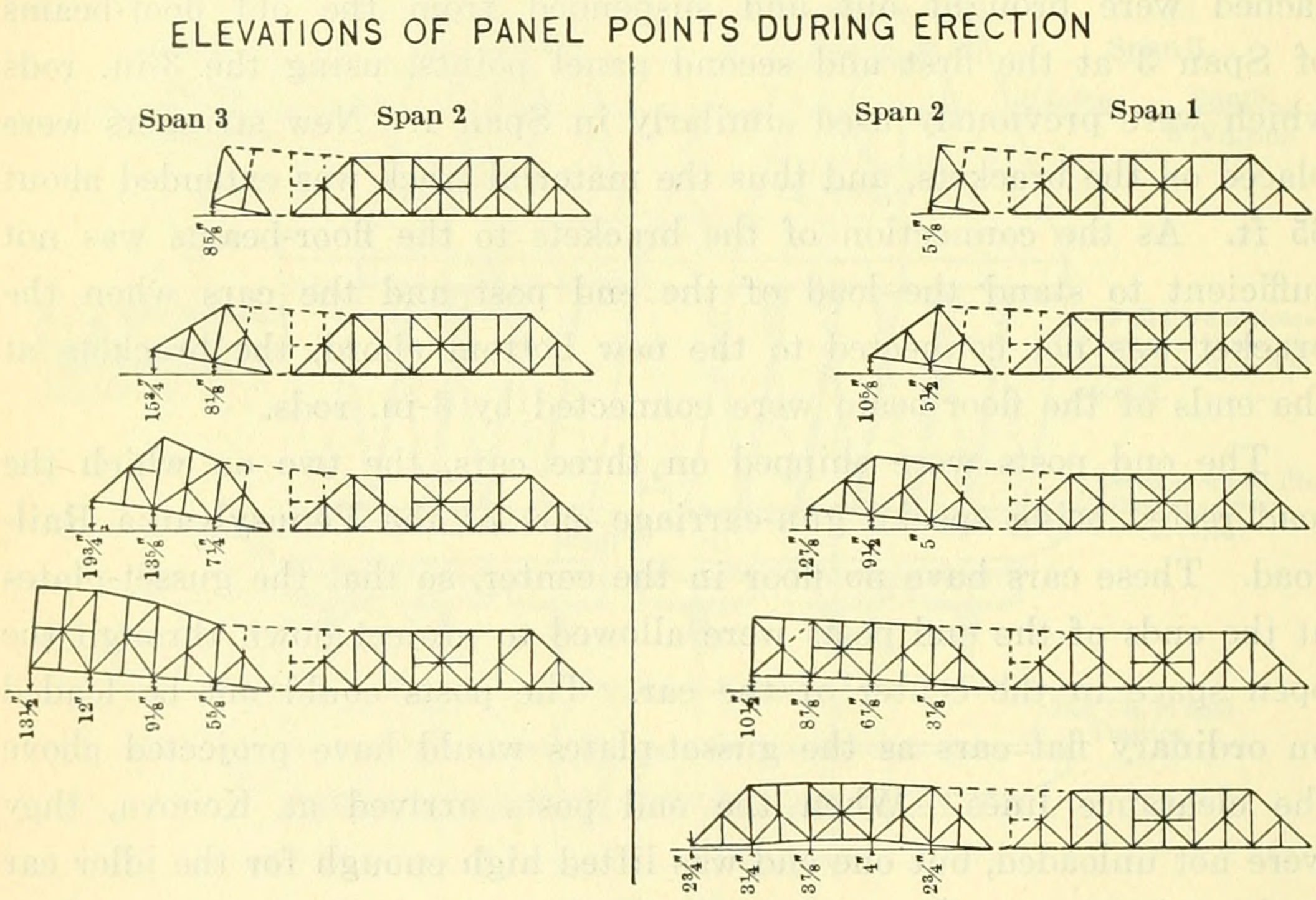


FIG. 27.

tions of the intermediate bottom-chord panel points of the cantilever spans were greater at the time the floor-beams were placed than after the span was erected prior to being swung. Thus, in Fig. 27, the sixth panel point of Span 2 was $12\frac{7}{8}$ in. above the horizontal when the floor-beam was placed, and only $3\frac{7}{8}$ in. just before the span was swung. Also, the sixth panel point of Span 3 was $19\frac{3}{4}$ in. above the horizontal when the floor-beam was placed, and only 12 in. just before the span was closed. The old Spans 2, 3, and 4, were carrying traffic during this period, therefore it was necessary to drop the new floor-beams sufficiently to clear the old spans. At the same time, it was

not advisable to go down too far, as the bottom lateral system in temporary position was in the plane of the top of the new floor-beams, and hence below the new bottom chords.

To determine as nearly as possible the actual deflections of the old spans under traffic, a set of levels was taken on the bottom-chord panel points of all five old spans, first under dead load and

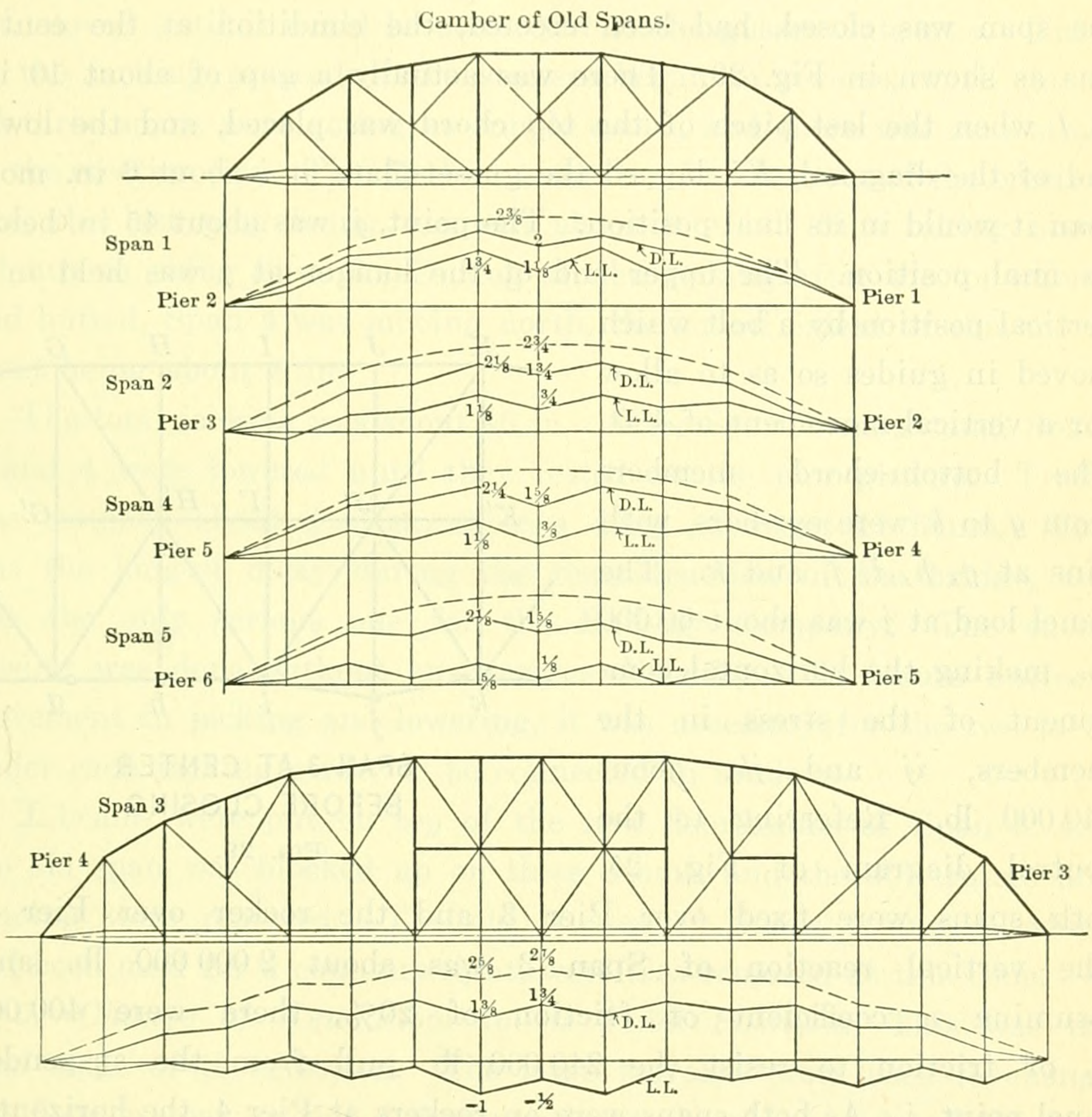
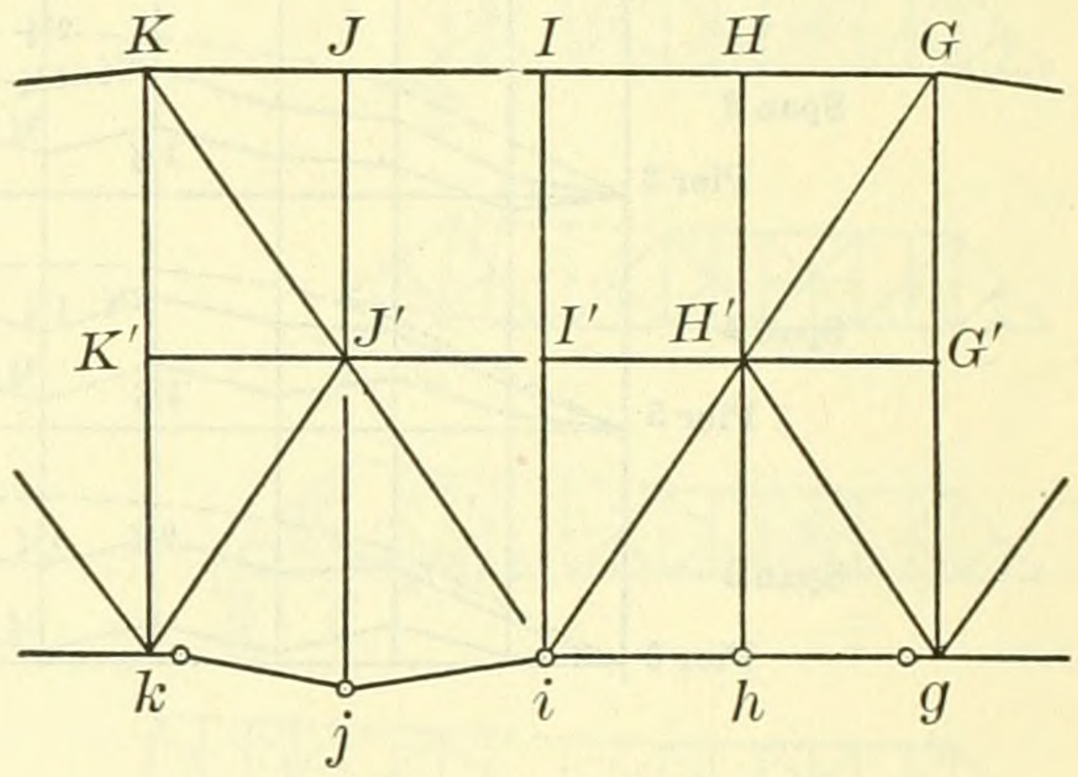


FIG. 28.

second under an actual live load, a train being stopped on the bridge for the purpose. The results of these tests are plotted in Fig. 28. The dotted lines represent the theoretical dead-load line, the upper full lines are the actual dead-load lines, and the lower full lines are the positions of the bottom chords under dead and live loads. It will be seen from Fig. 28 that although the bottom chord of the 298-ft. spans did not go below the horizontal under live load, the

518-ft. span near the center went down as much as 1 in. As a matter of precaution, therefore, the floor-beams near the center of the 518-ft. span were dropped from 4 to 8 in. more than had been intended originally. It was not necessary to place the three center floor-beams of Span 3 until after the new span was swung, as there was no material track in the four center panels of this span.

When all the trusses and bracing which could be placed before the span was closed, had been erected, the condition at the center was as shown in Fig. 29. There was actually a gap of about 10 in. at *I* when the last piece of the top chord was placed, and the lower end of the diagonal, *Ki,* lapped the gusset-plate at *i* about 6 in. more than it would in its final position. The point, *j,* was about 45 in. below its final position. The upper end of the hanger at *j* was held in a vertical position by a bolt which moved in guides so as to allow for a vertical movement of 4 ft. The bottom-chord members from *g* to *k* were eye-bars, with pins at *g, h, i, j,* and *k.* The panel load at *j* was about 60 000 lb., making the horizontal component of the stress in the members, *ij* and *jk,* about 240 000 lb. Referring to the central diagram of Fig. 25,



SPAN 3 AT CENTER BEFORE CLOSING

FIG. 29.

both spans were fixed over Pier 3 and the rocker over Pier 4. The vertical reaction of Span 3 was about 2 000 000 lb. and, assuming a coefficient of friction of 20%, there were 400 000 lb. of friction to resist the 240 000 lb. pull from the suspended panel point, *j.* As both spans were on rockers at Pier 4, the horizontal pull at this pier had to be transferred to the fixed end of Span 4 over Pier 5. Here, the reaction was comparatively small, so that, in order to prevent Span 4 from moving, under the action of this horizontal force, it was necessary to fasten the anchor end of Span 4. Fig. 20 shows the drop in the bottom-chord eye-bars at *j* immediately before closing Span 3.

When everything was ready to close Span 3, traffic was interrupted at about 7 o'clock one morning and the track was broken. Jacks

were placed under jacking girders attached to the trusses at the shore ends of Spans 2 and 4 over Piers 2 and 5. As Span 4 had to move longitudinally about 6 in., the jacks under this span were placed on a carriage on rollers. These jacks were then pumped out. The top chords came together at *I*, then, as jacking was continued, the bottom chord straightened out, the hanger at *j* moved up until connection could be made at the top of the hanger, and the member, *Ki*, moved until it could be connected to the gusset-plate at *i*. Then, as the jacking proceeded, the stresses began to reverse, until finally all three spans were acting as simple spans, and there was zero stress in the erection ties. The D-plugs were then knocked out of the erection ties, the last plug being removed about 2 P. M., thus taking about 7 hours to swing Span 3. During all the jacking after the top chords had butted, Span 4 was moving north, the actual extent of this movement being about 8 in.

The total jacking was about 46 in. After Span 3 was swung, Spans 2 and 4 were lowered until they rested on the pier girders. Traffic was resumed about 6 P. M., after a delay of about 11 hours. This was the longest delay during the reconstruction of the bridge, and was the only serious one for the Railway Company. The entire closing was done without any serious difficulty. To insure uniform movement in jacking and lowering, it was necessary for the two jacks under each jacking girder to be connected in tandem.

I-beams were put on top of the new floor-beams of Span 3, and the old span was blocked up on these beams, and the old trusses and bracing were removed. The old trusses of Spans 2 and 4, which had been used for a counterweight, were also removed at this time.

5.—Change of New Floor to its Final Position.—This was the final stage of the erection. The large travelers were used to change the floor system, except a few panels at the shore ends of Spans 1 and 5, which could not be reached by the booms.

It had been planned to start simultaneously at each end of Span 3 and work toward the center, and, as traffic had to be stopped while a panel of floor was being changed, it was desired to change a panel with each traveler whenever an interval of time could be given. The wooden deck of the north traveler caught fire from the sparks of a train beneath, and as it was discovered late at night, the fire could not be put out quickly, and damaged the electric hoisting engine

so badly that two steam engines had to be substituted for it. This delayed the north traveler about 2 weeks, and made it impossible to start both travelers on the floor at the same time. The south traveler had changed the floor of the south half of Span 3 before the north traveler was repaired. From this time forward, however, when an interval was given to change the floor, each traveler would change a panel. On account of the heavy traffic, it was seldom that there was a chance to change more than one panel a day, and on some days no interval at all could be given. After the floors of Spans 2, 3, and 4 were changed, the erection ties over Piers 3 and 4 were taken down and re-erected over Piers 2 and 5. The travelers were then run back on Spans 1 and 5, and the floors changed with the travelers, except the five panels at the shore ends, which were changed by falls hooked to the new trusses.

The method used in changing a panel of floor was as follows: If the ends of the old stringers, in any panel of the span in which the change was to be made, did not clear the cover-plate of the new floor-beam by about 2 in., the old floor system was jacked on end until this condition was accomplished.

Two of the new stringers used in the material track were transferred to the inside of the trusses and hung from the truss by chains. The rivets connecting the old stringers to the old floor-beams were cut out and replaced by bolts, and those connecting the old stringer laterals to the stringers were cut out and replaced by one bolt in each connection. As many of the bolts fastening the new floor-beams to the hanger plates and the hanger plates to the bottom chord were removed as thought safe. Permanent lateral plates were fastened to the bottom of the new floor-beam, and the temporary lateral plates and angles on top of it were removed. The laterals at this point were supported by rope lashing attached to the bottom chord. A piece of rope lashing was run under all the ties in the panel to be changed. All this was done before the interval was given for the change.

As soon as the last train passed, rails were disconnected at each side of the panel, and this section was hauled on end to clear the panel. A line from the traveler was made fast to each end of the rope lashing under the old ties, and when the strain was taken on this line by the hoisting engine, all the ties in the panel were dumped

into the river below. These ties were in such bad shape that it did not pay to save them. Stringer laterals were removed, and the stringers were picked up with the booms of the traveler and outhauled back on the portion of the floor already changed, and piled at each side of the track.

A set of rope falls made fast to the sway bracing was now hooked to the old stringers in the next panel ahead, in order to hold them up after the old floor-beam was removed. As there was no convenient place to put the old floor-beam, it was hoisted up and hung by chains

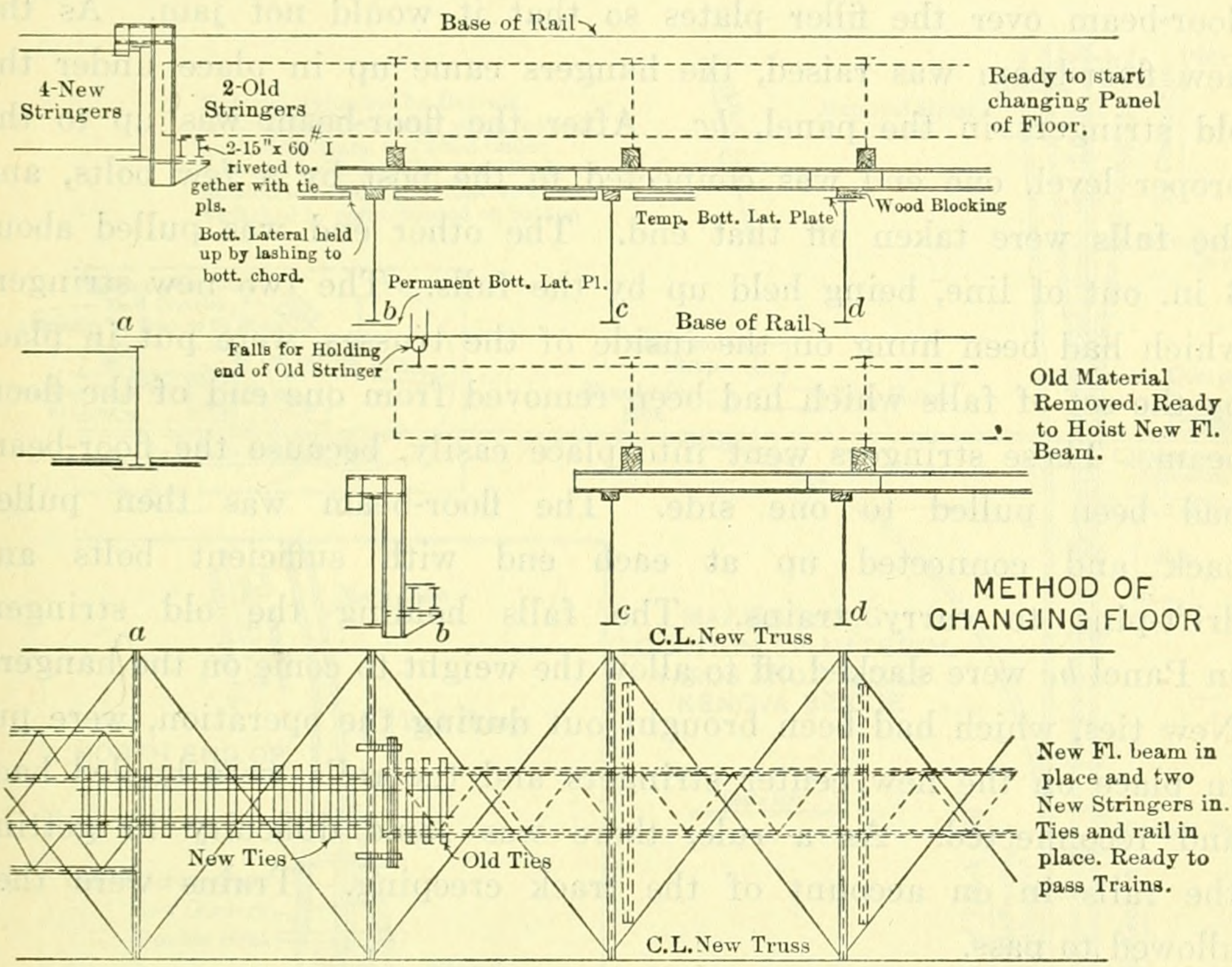


FIG. 30.

from the top of the span. On account of working inside the new trusses, it was hard to dispose of the old material taken out, as the new top bracing was in the way of the falls. I-beams in Panel *bc* (Fig. 30) were pulled back on end into Panel *cd*. The hangers were removed from Floor-beam *a* and put on Floor-beam *b* while in its suspended position. Falls from the traveler booms were then fastened to the ends of the new floor-beam to take the strain, and the remainder of the bolts connecting the floor-beam to the hanger plates and the hanger plates to the bottom chord were removed. The hanger plates were pulled out from between the floor-beam and the bottom chord

and the permanent filler plates were put in. These fillers extended above the top of the floor-beam in its final position, and were held in place by two bolts at the top of each plate.

Jacks, which had been placed between the new bottom chords ahead of the panel to be changed, were now worked, and the trusses were spread apart a little. The bottom laterals at this point had also been disconnected to allow the trusses to spread. The falls from the traveler boom were tightened, and the floor-beam, *b*, was hoisted to its permanent position. Men with connecting bars guided the floor-beam over the filler plates so that it would not jam. As the new floor-beam was raised, the hangers came up in place under the old stringers in the panel, *bc*. After the floor-beam was up to the proper level, one end was connected to the post by a few bolts, and the falls were taken off that end. The other end was pulled about 3 in. out of line, being held up by the falls. The two new stringers which had been hung on the inside of the trusses, were put in place by the set of falls which had been removed from one end of the floor-beam. These stringers went into place easily, because the floor-beam had been pulled to one side. The floor-beam was then pulled back and connected up at each end with sufficient bolts and drift-pins to carry trains. The falls holding the old stringers in Panel *bc* were slacked off to allow the weight to come on the hangers. New ties, which had been brought out during the operation, were put in place on the new center stringers and the rails were hauled back and reconnected. As a rule, there was some difficulty in getting the rails in on account of the track creeping. Trains were then allowed to pass.

The other two stringers were taken from the material track and put in place in the panel, and the stringer laterals put in. It was difficult to get these stringers in because the fit was so close between their ends and the floor-beams. The bottom laterals were connected up to the lateral plates. The old material taken out during the operation was loaded on cars, and preparations were started for the change of the next panel. The average time that traffic was blocked during this operation was about 1½ hours, the minimum time being 55 min. It took a total of 7 weeks to change the whole floor, but this would have been cut down to 5 weeks, if the north traveler had not been delayed on account of the fire.

After the whole floor had been changed, ties were laid on the up-stream line of stringers, these ties being fitted in between those already laid on the center stringers. Track was laid, and the traffic was turned over to the up-stream track. The ties in the center were taken out and put on the down-stream line of stringers, enough extra ties being added to obtain the correct spacing. The center track was then thrown over, making a double track.

A 30-ton, steel derrick with an 80-ft. boom was erected on Span 1 and removed the two south travelers; then it was erected on Span 5 and removed the two north travelers.

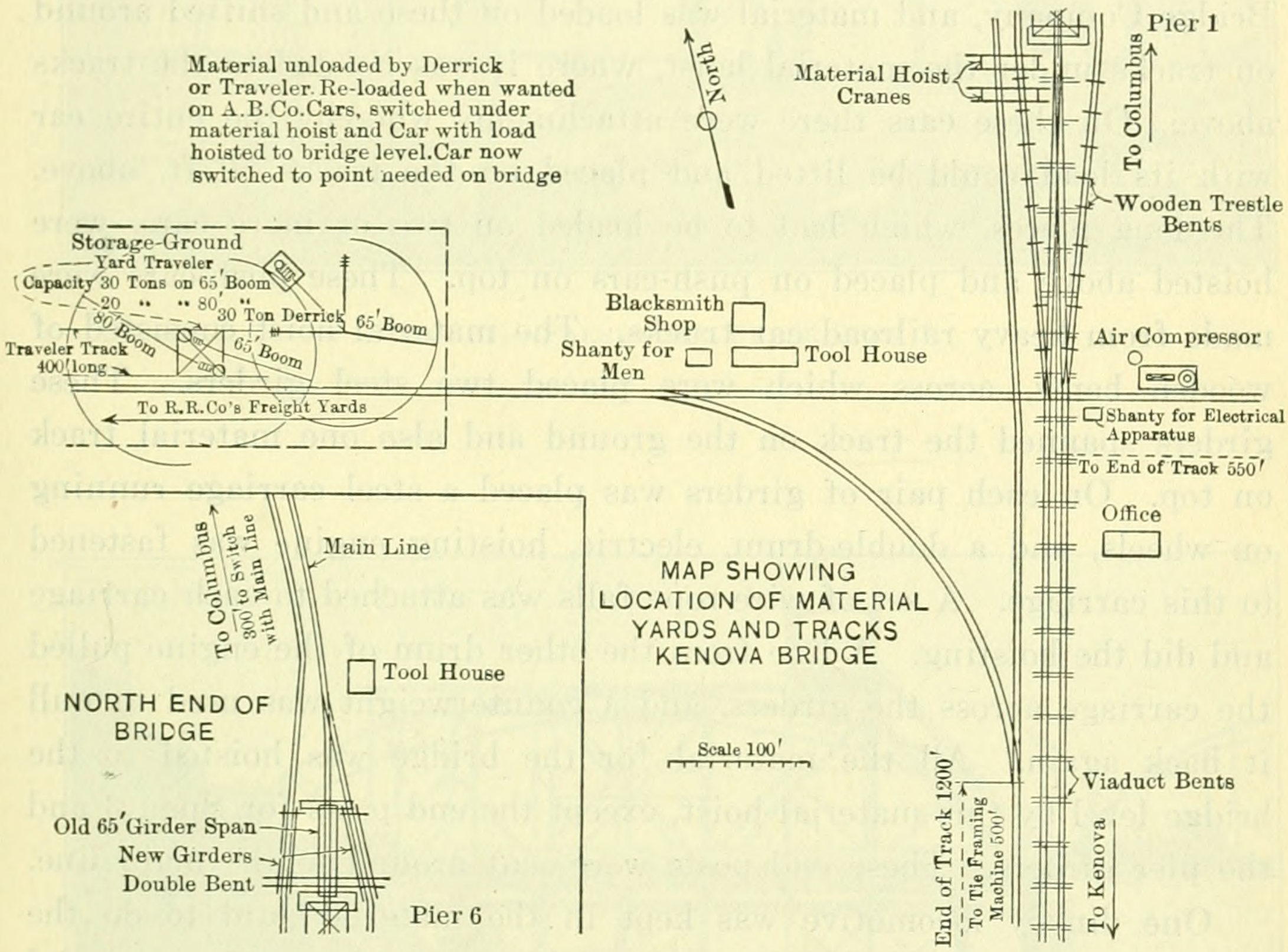


FIG. 31.

ARRANGEMENT OF MATERIAL YARD, TRACKS, ETC.

The layout of the yard, material hoist, and tracks is shown in Fig. 31. The yard was located down stream at the Kenova end of the bridge. It was equipped with one 30-ton derrick with a 65-ft. boom, the derrick being worked by an 85-h.p. steam engine. In addition to the derrick there was a steel traveler with an **A**-frame at each end having a 60-ft. boom on one end and an 80-ft. boom on the other. These booms were good for 30 and 20 tons, respectively. A track

for the traveler was laid on the ground, and this traveler handled all the lighter material. The chords for the 298-ft. spans were unloaded by the derrick; the 518-ft. span chords, each of which weighed more than 40 tons, were unloaded by using the derrick at one end and the traveler at the other. This traveler had previously been used in the erection of the Queen and Crescent Bridge at High Bridge, Ky. It was worked with two, 35-h.p., steam engines placed on its deck. The pier girders were unloaded by skidding them off cars and letting them rest on blocking.

There were seven flat cars on the job belonging to the American Bridge Company, and material was loaded on these and shifted around on tracks under the material hoist, where it was hoisted to the tracks above. On these cars there were attachments whereby the entire car with its load could be lifted and placed on the tracks 50 ft. above. The long pieces, which had to be loaded on two or more cars, were hoisted above and placed on push-cars on top. These push-cars were made from heavy railroad car trucks. The material hoist consisted of wooden bents, across which were placed two steel girders. These girders spanned the track on the ground and also one material track on top. On each pair of girders was placed a steel carriage running on wheels, and a double-drum, electric, hoisting engine was fastened to this carriage. A set of wire-rope falls was attached to each carriage and did the hoisting. A line from the other drum of the engine pulled the carriage across the girders, and a counterweight was used to pull it back again. All the material for the bridge was hoisted to the bridge level by this material hoist, except the end posts for Span 3 and the pier girders. These end posts were sent around to the main line.

One dinkey locomotive was kept in the material yard to do the shifting, and a lighter one was used on the bridge. The material tracks on the bridge had to be connected at each end with the main line. At the south end, this was done by a timber trestle; at the north end, the new 65-ft., deck, plate-girder span was used. A 30-ton, all-steel derrick-car with a 50-ft. boom, was kept on the job to move the gallows-frame from pier to pier and to handle the bottom of the end posts of Spans 1 and 5. After this work was completed, the derrick-car was sent away. A small wooden derrick-car of about 10 tons capacity was also kept on the site to handle light material, timber, etc.

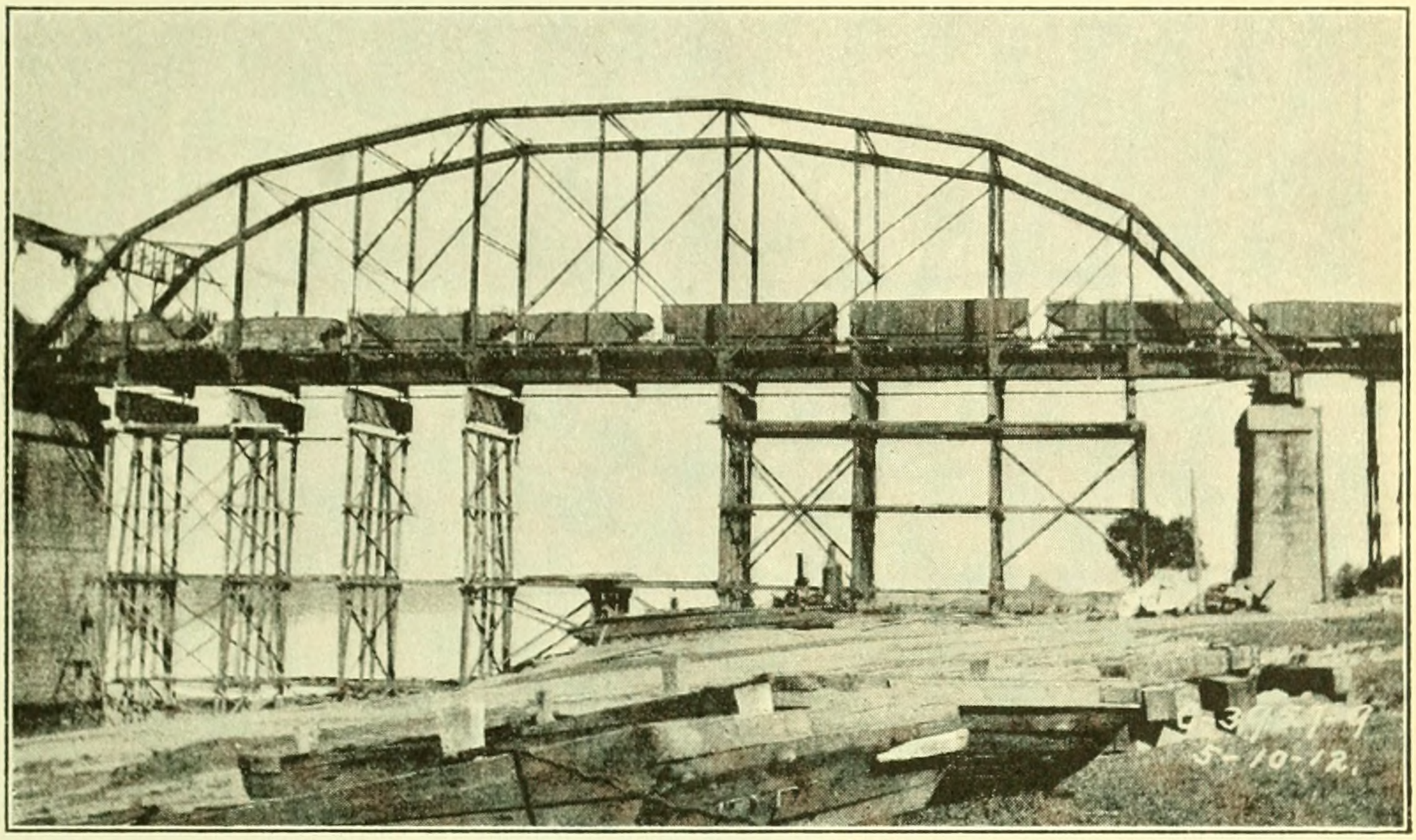


FIG. 32.—FALSEWORK UNDER SPAN 1.

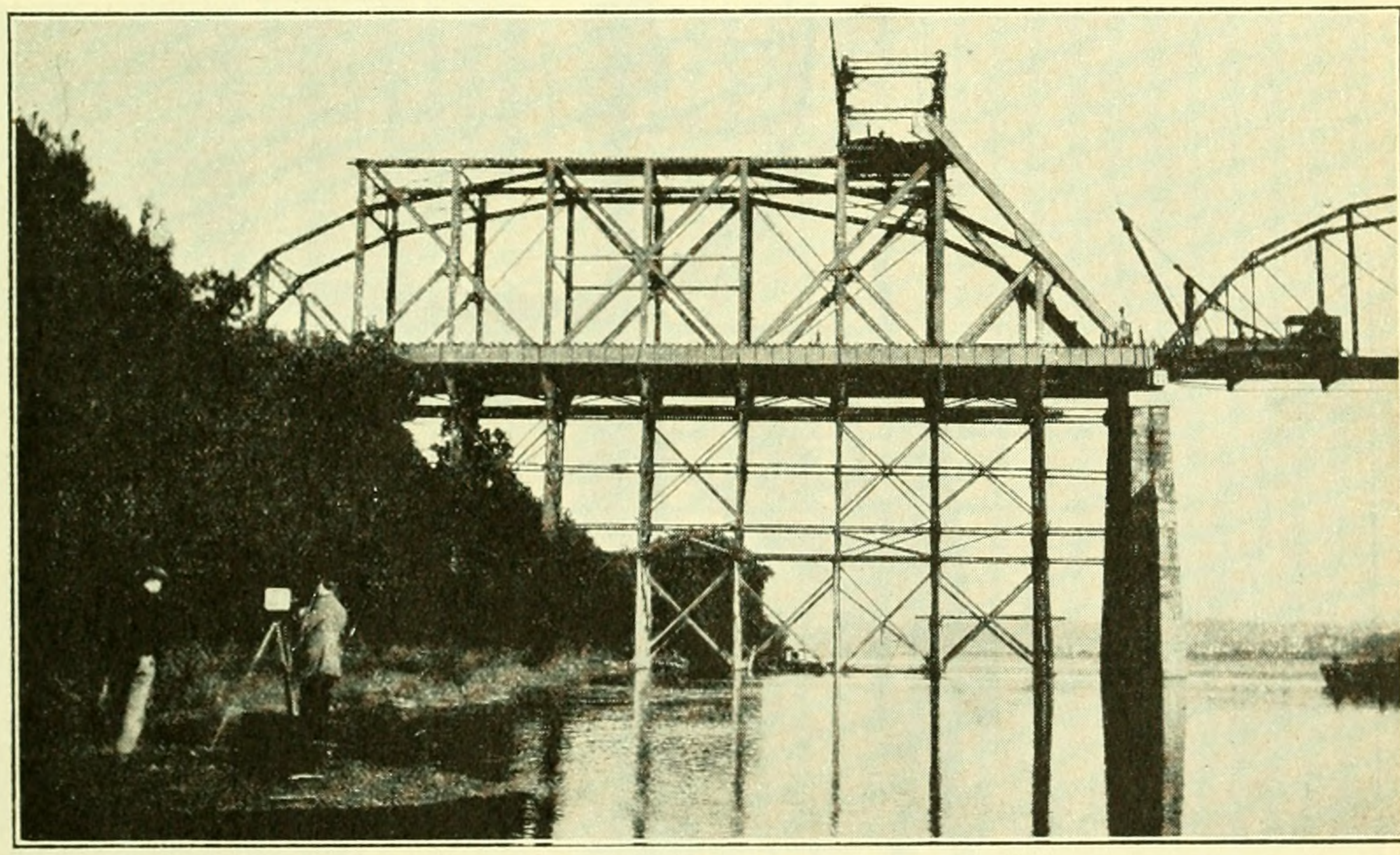


FIG. 33.—PLACING END POST OF SPAN 1.

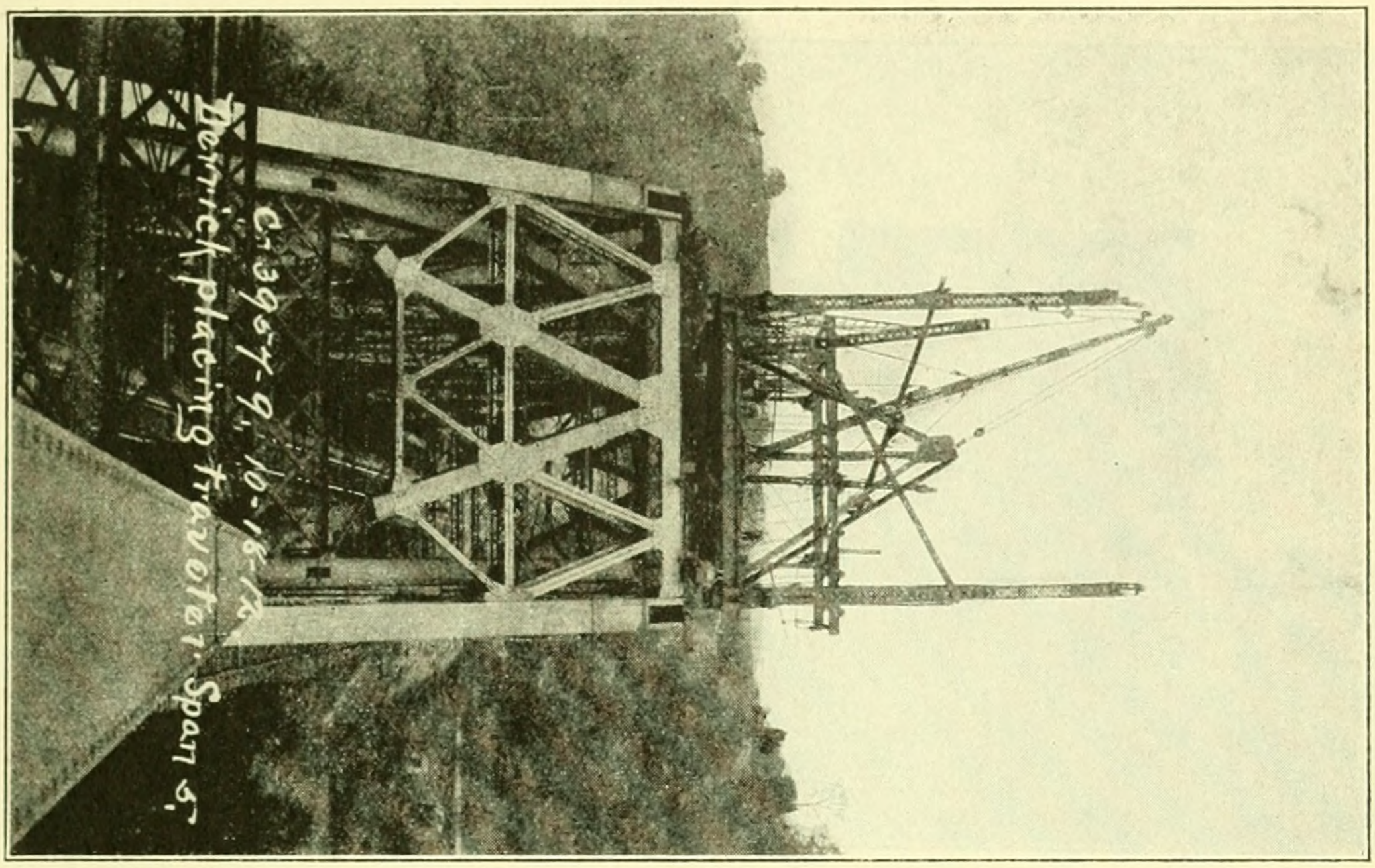


FIG. 34.—PORTALS OF OLD AND NEW SPANS 1.

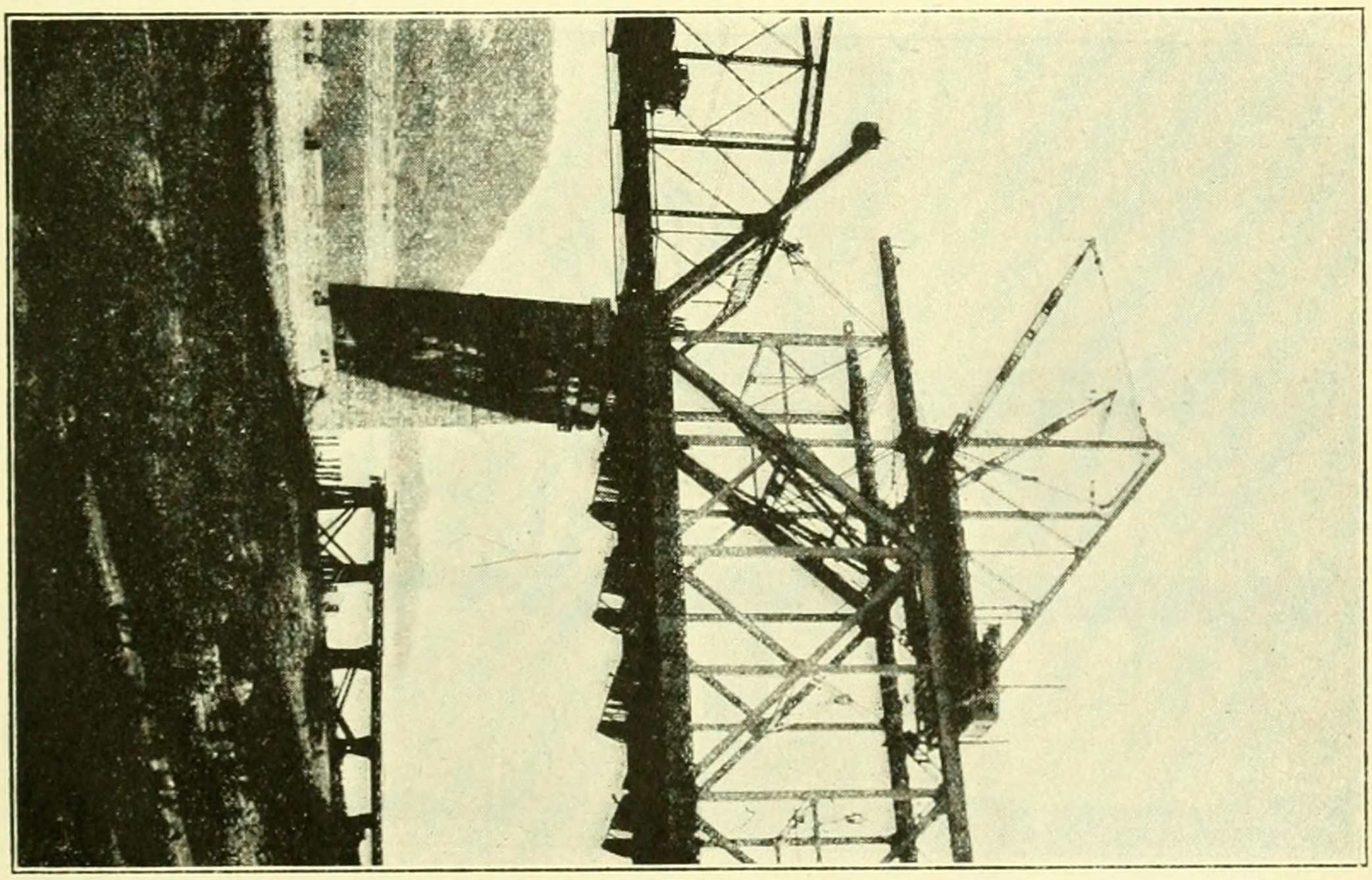


FIG. 35.—PLACING SHORE END POST OF SPAN 2.

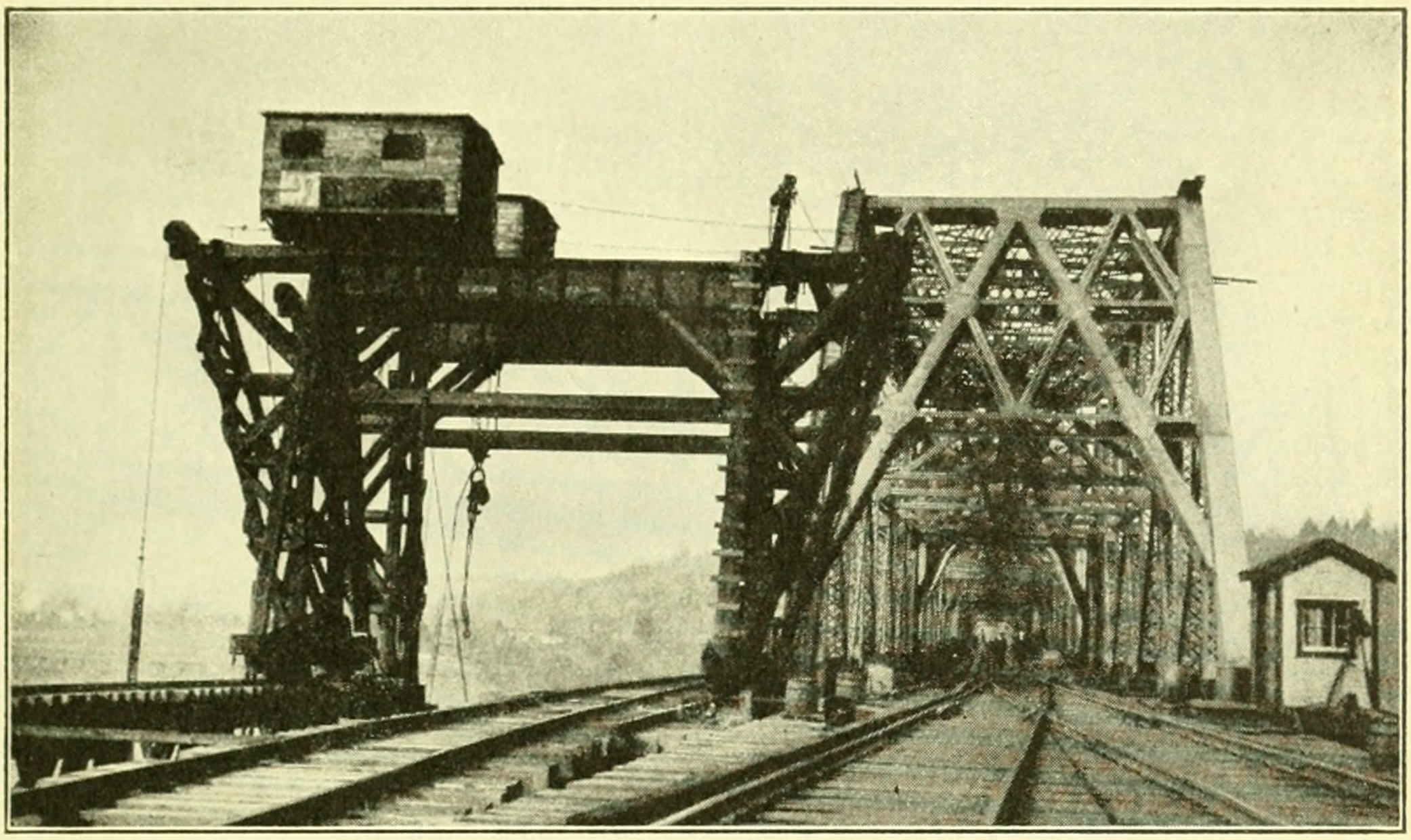


FIG. 36.—MATERIAL HOIST, AND NEW PORTAL.

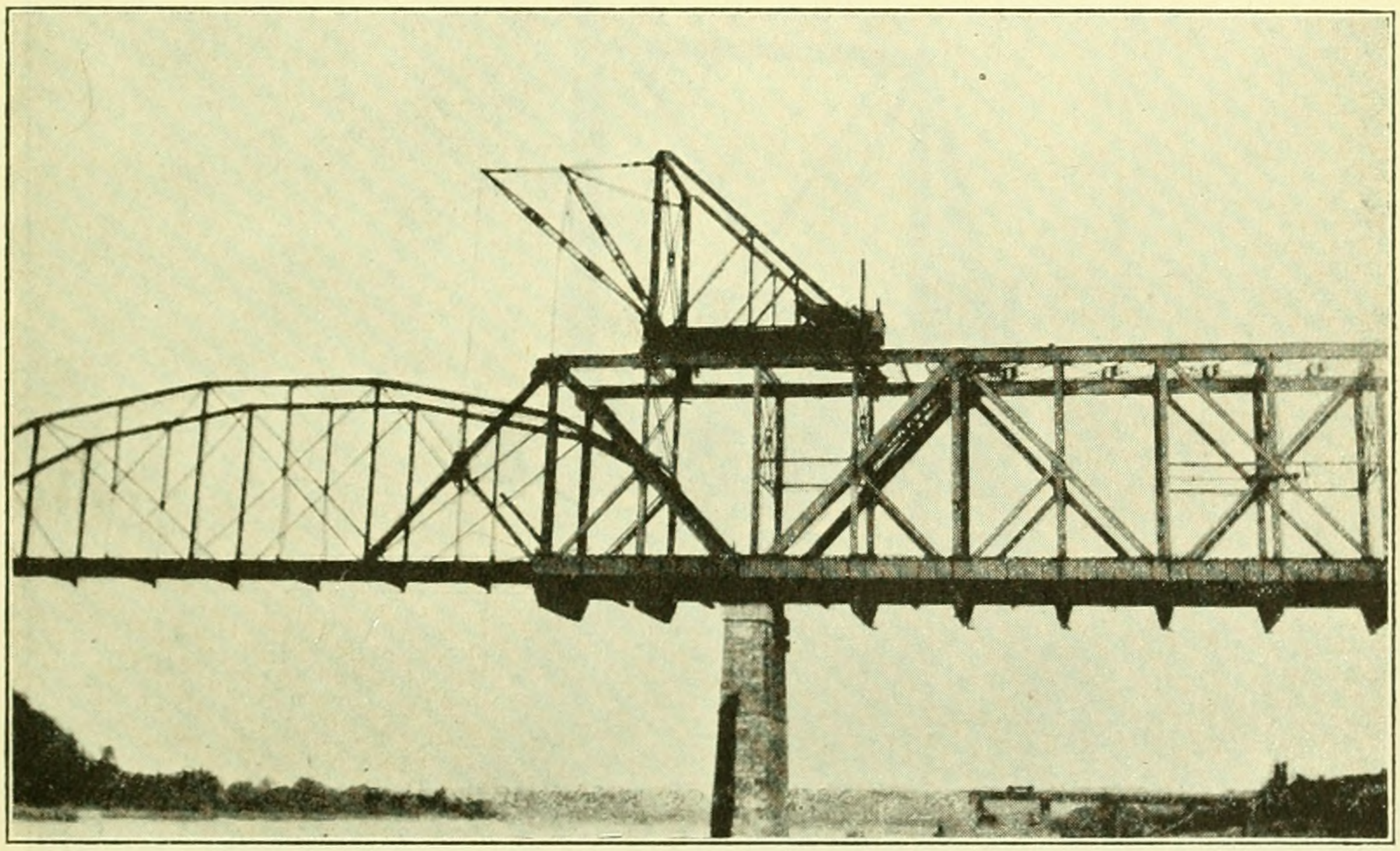


FIG. 37.—PLACING DIAGONAL OF SPAN 2.

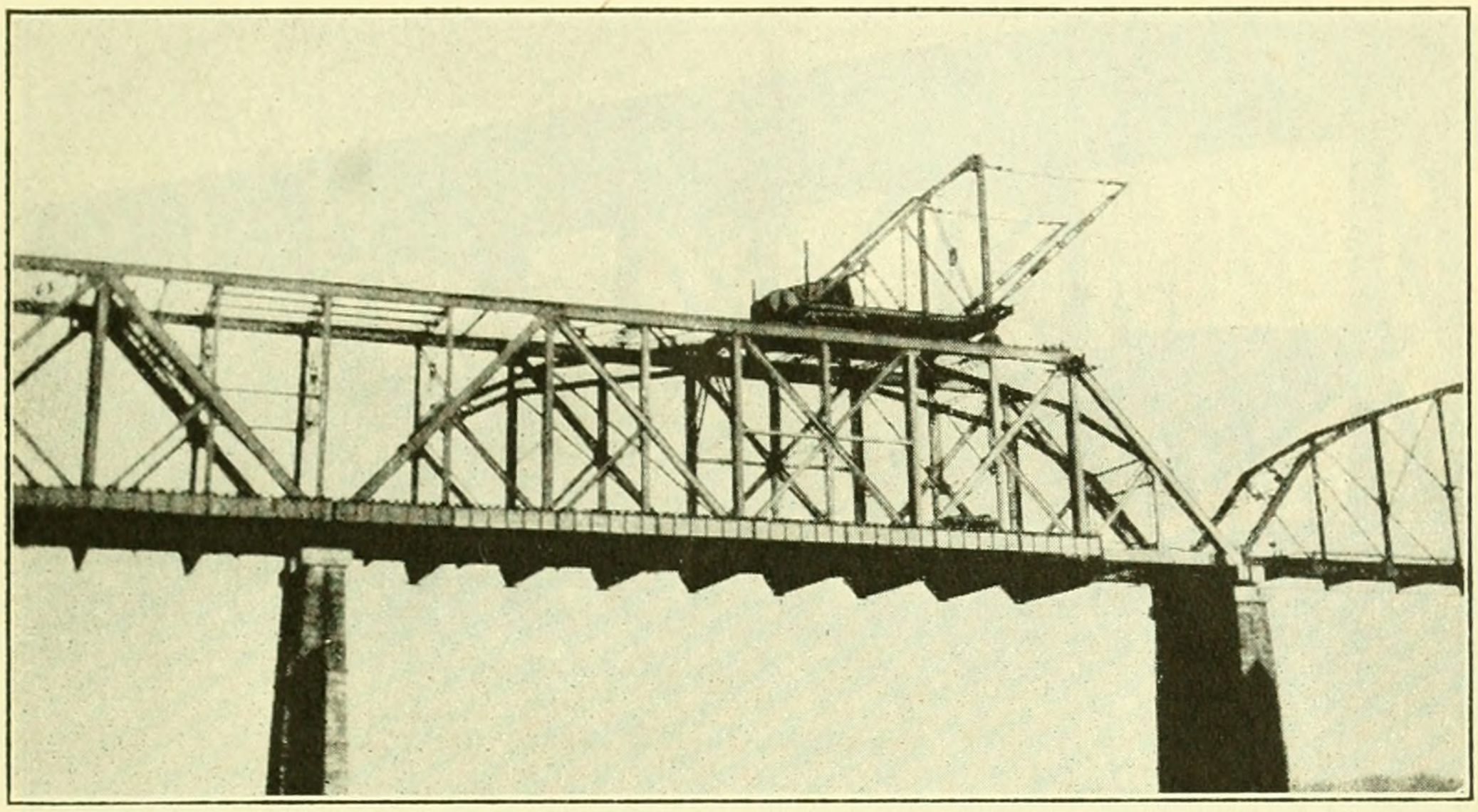


FIG. 38.—PLACING RIVER END POST OF SPAN 2.

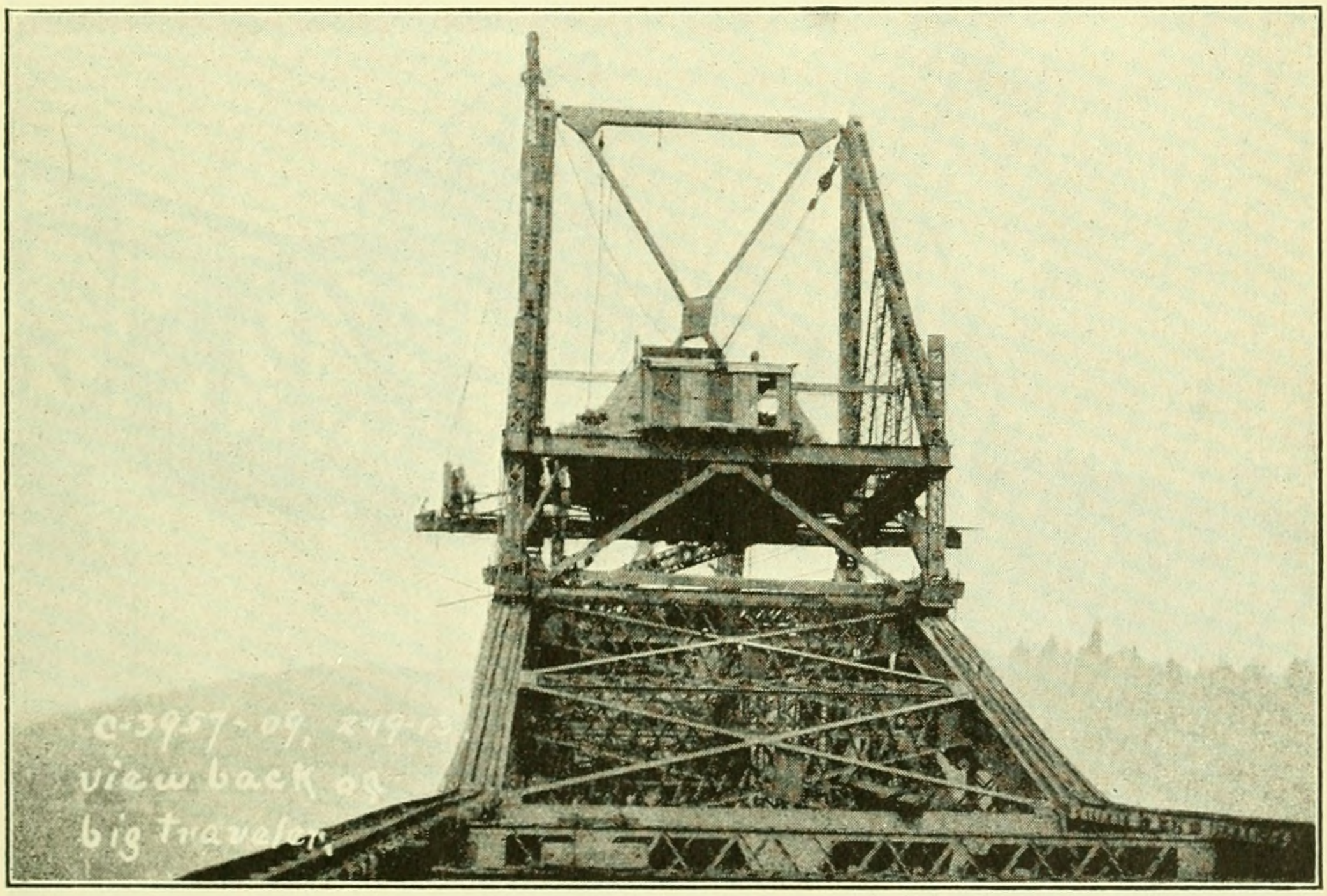


FIG. 39.—LARGE TRAVELER CLIMBING SPAN 3.

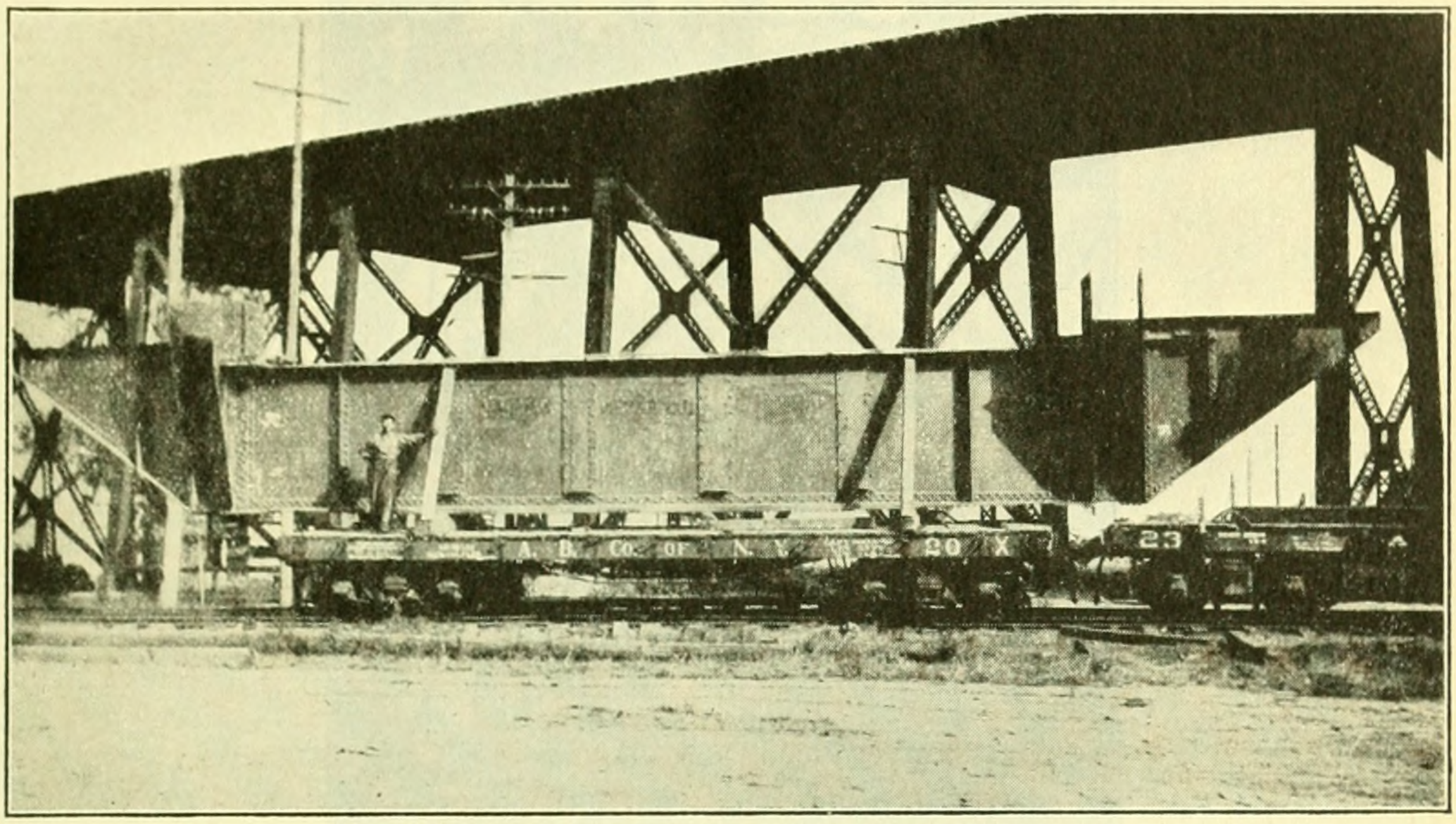


FIG. 40.—NEW FLOOR-BEAM AND TEMPORARY BRACKETS.

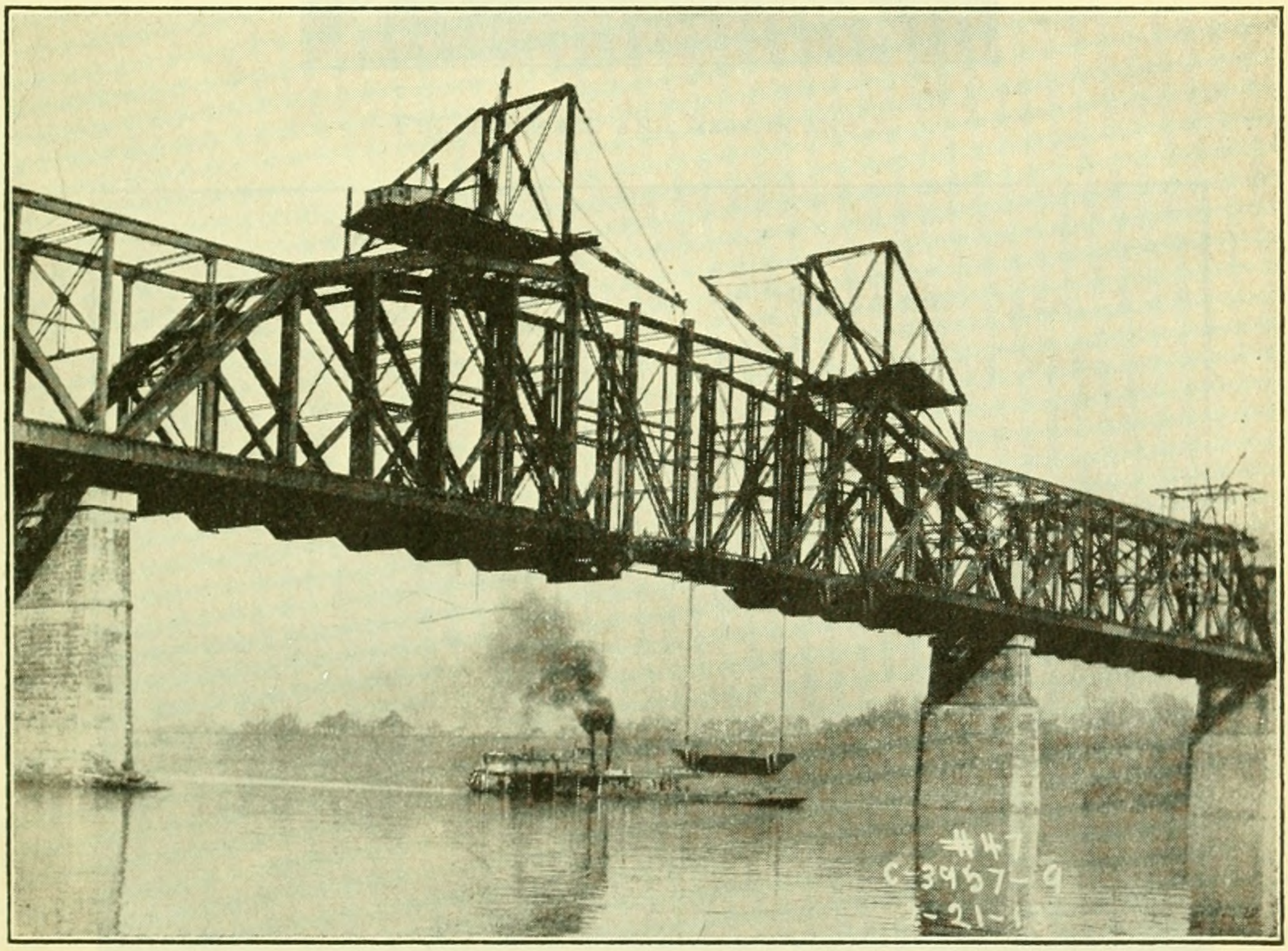


FIG. 41.—LIFTING NEW FLOOR-BEAMS INTO PLACE.

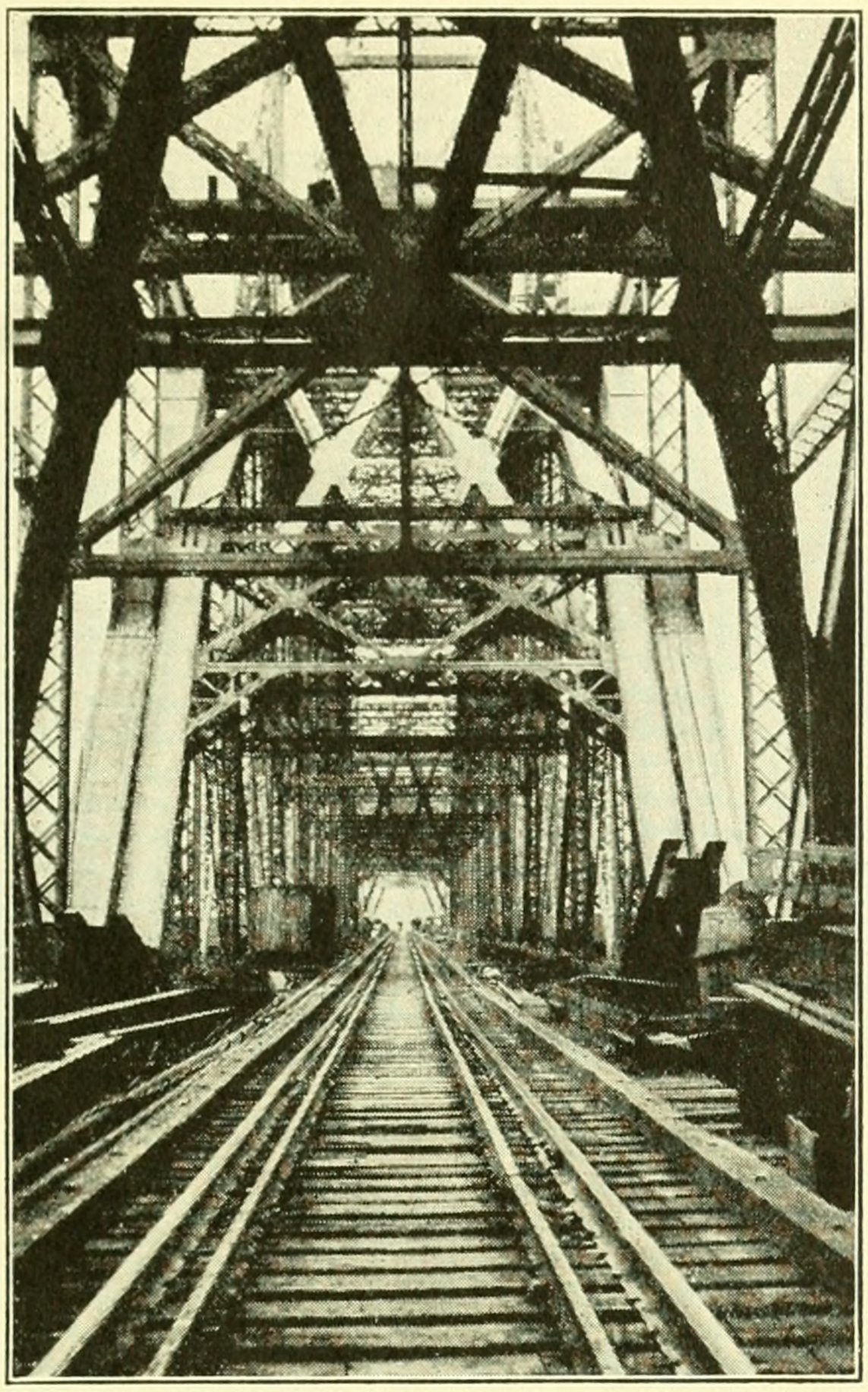


FIG. 42.—OLD AND NEW SPANS 3.

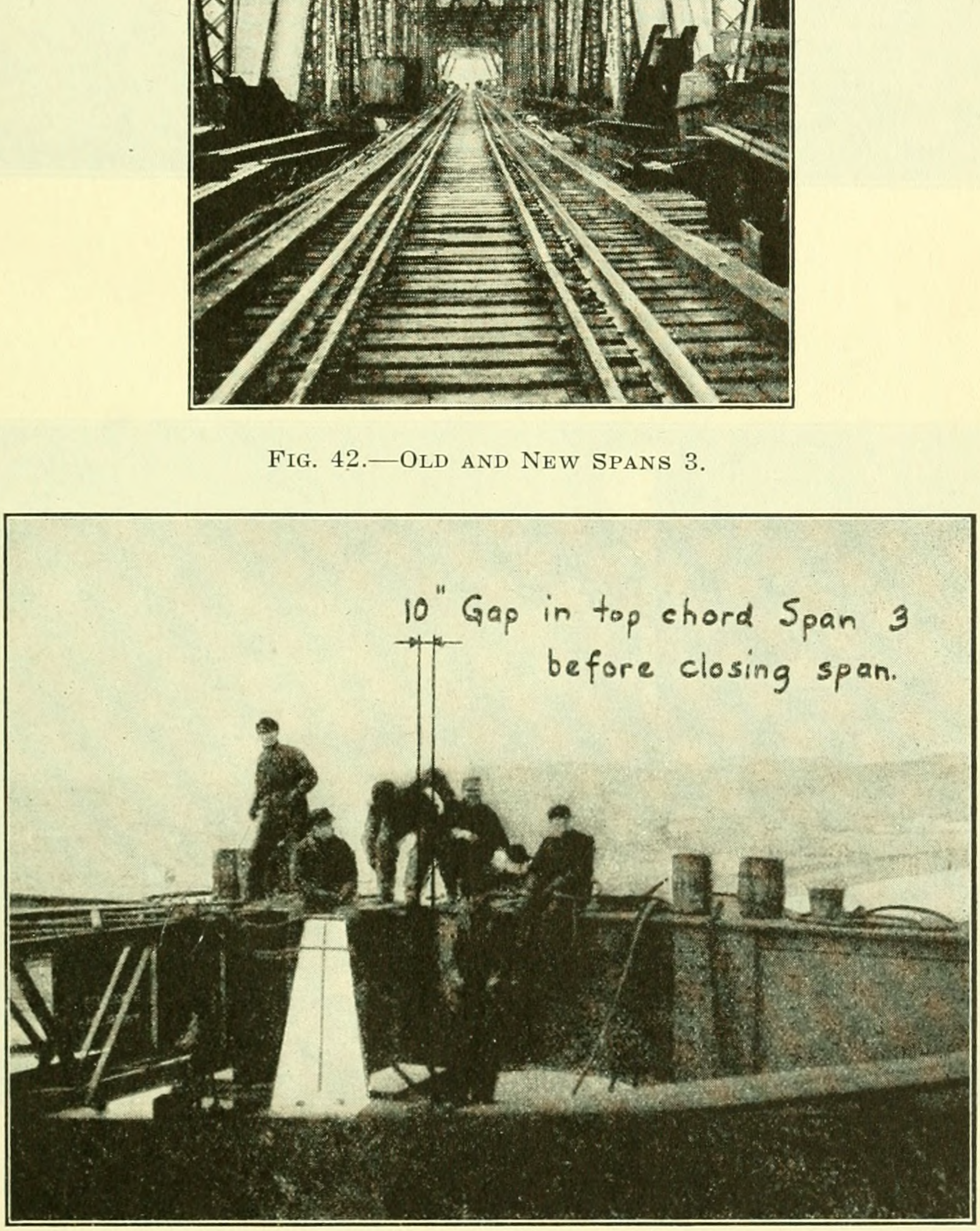


FIG. 43.—GAP AT TOP CHORD, SPAN 3.

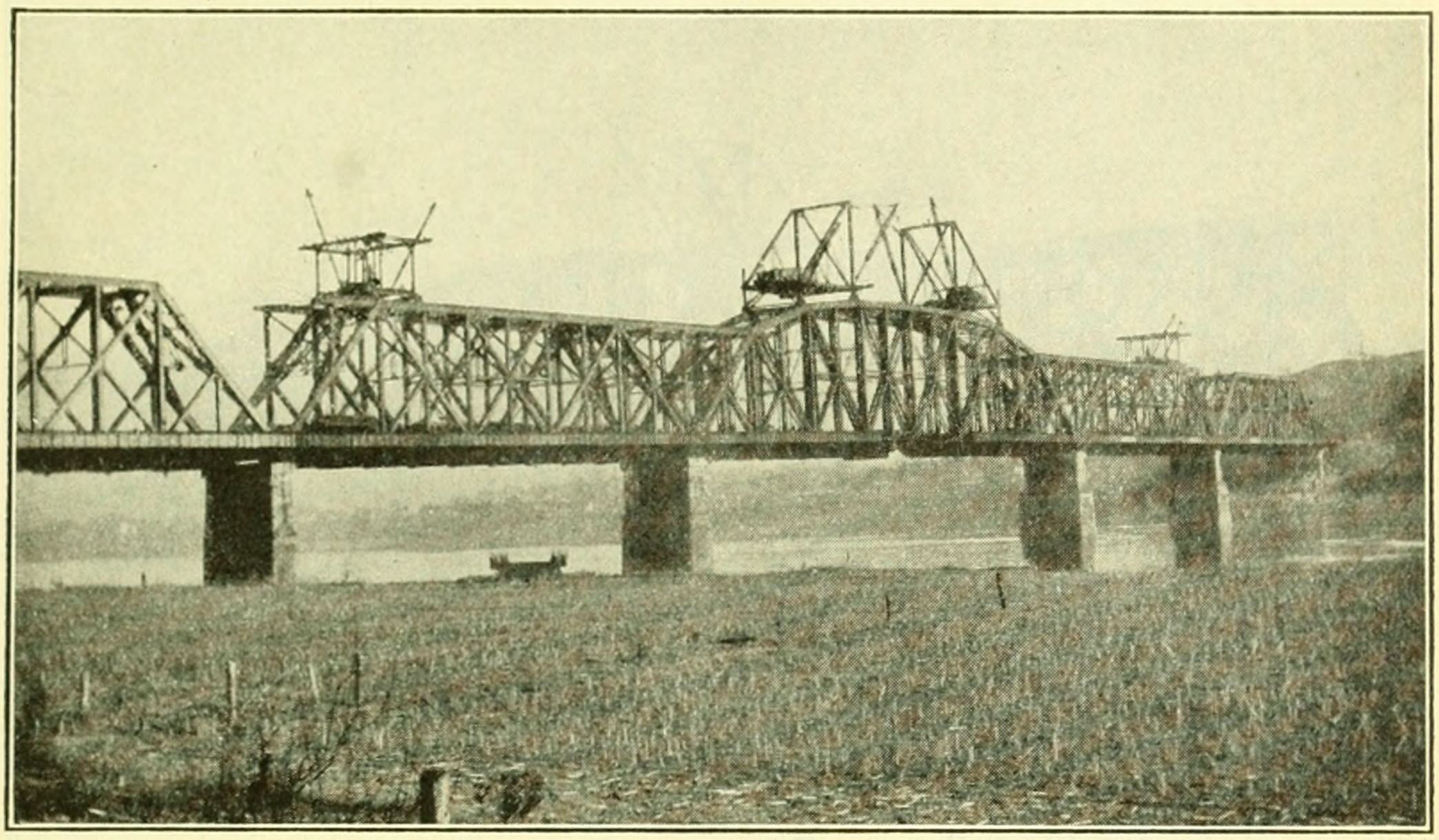


FIG. 44.—SPAN 3, BEFORE CLOSING.

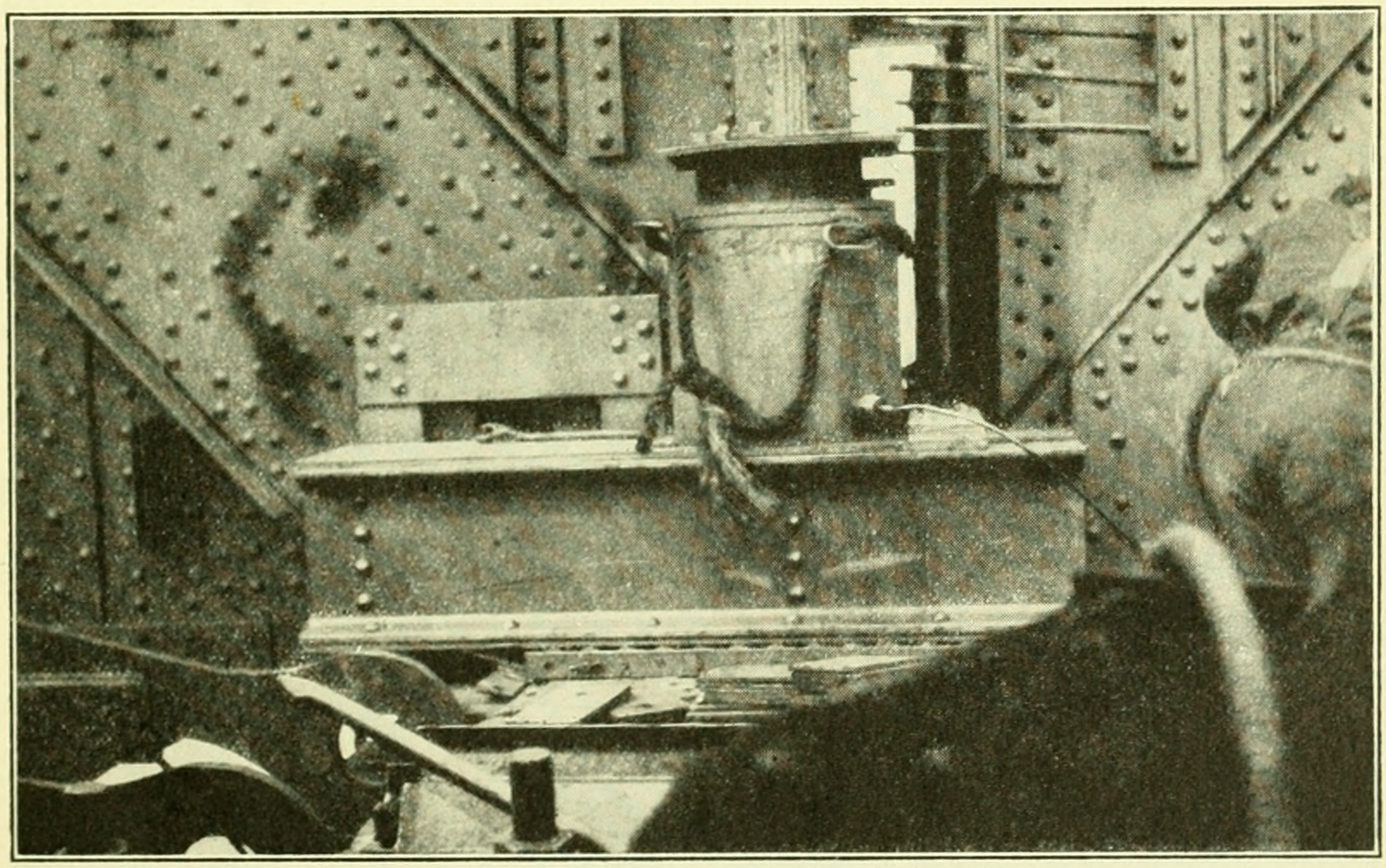


FIG. 45.—JACK, ON ROLLERS, PIER 5.

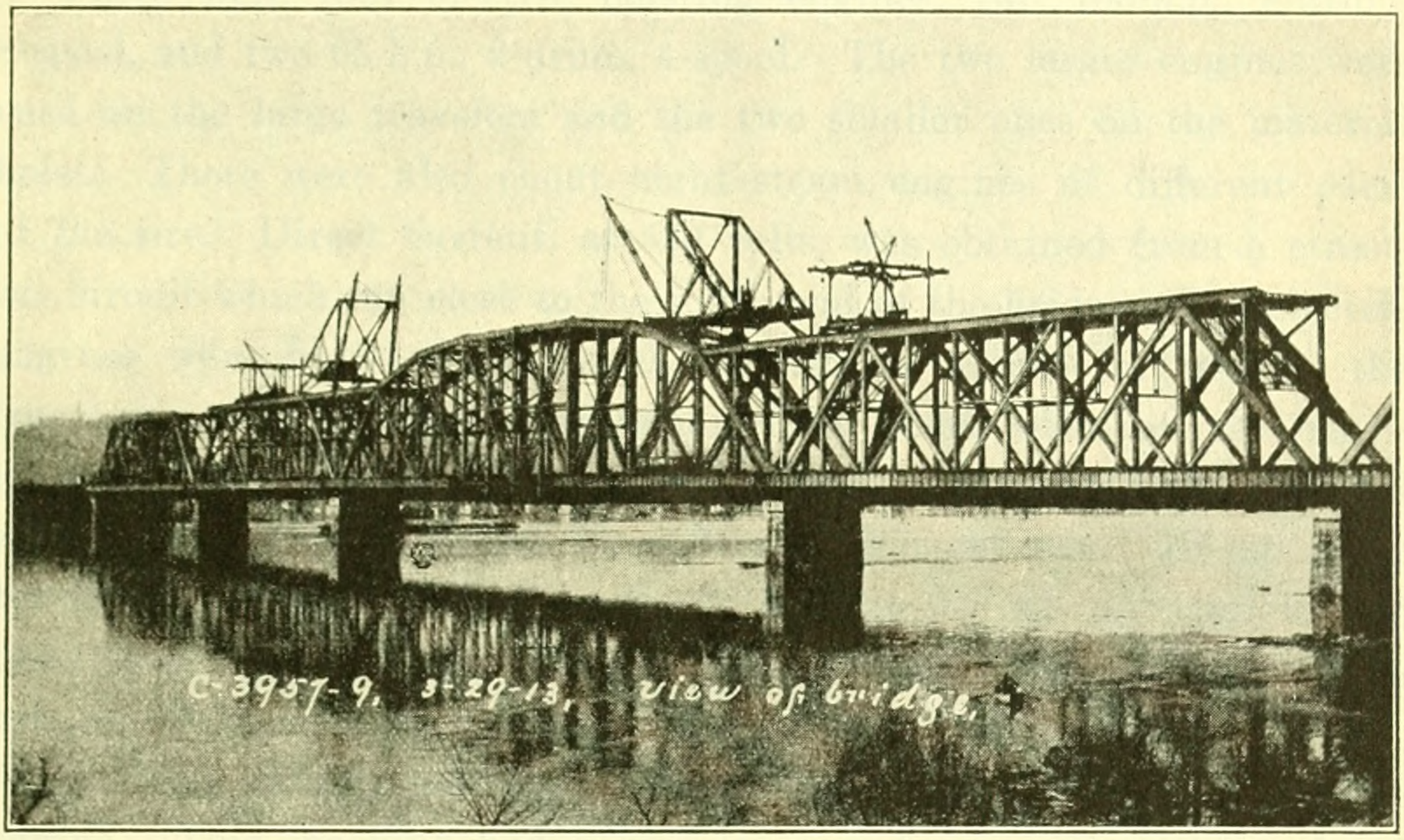


FIG. 46.—KENOVA BRIDGE, AT TIME OF HIGH WATER.

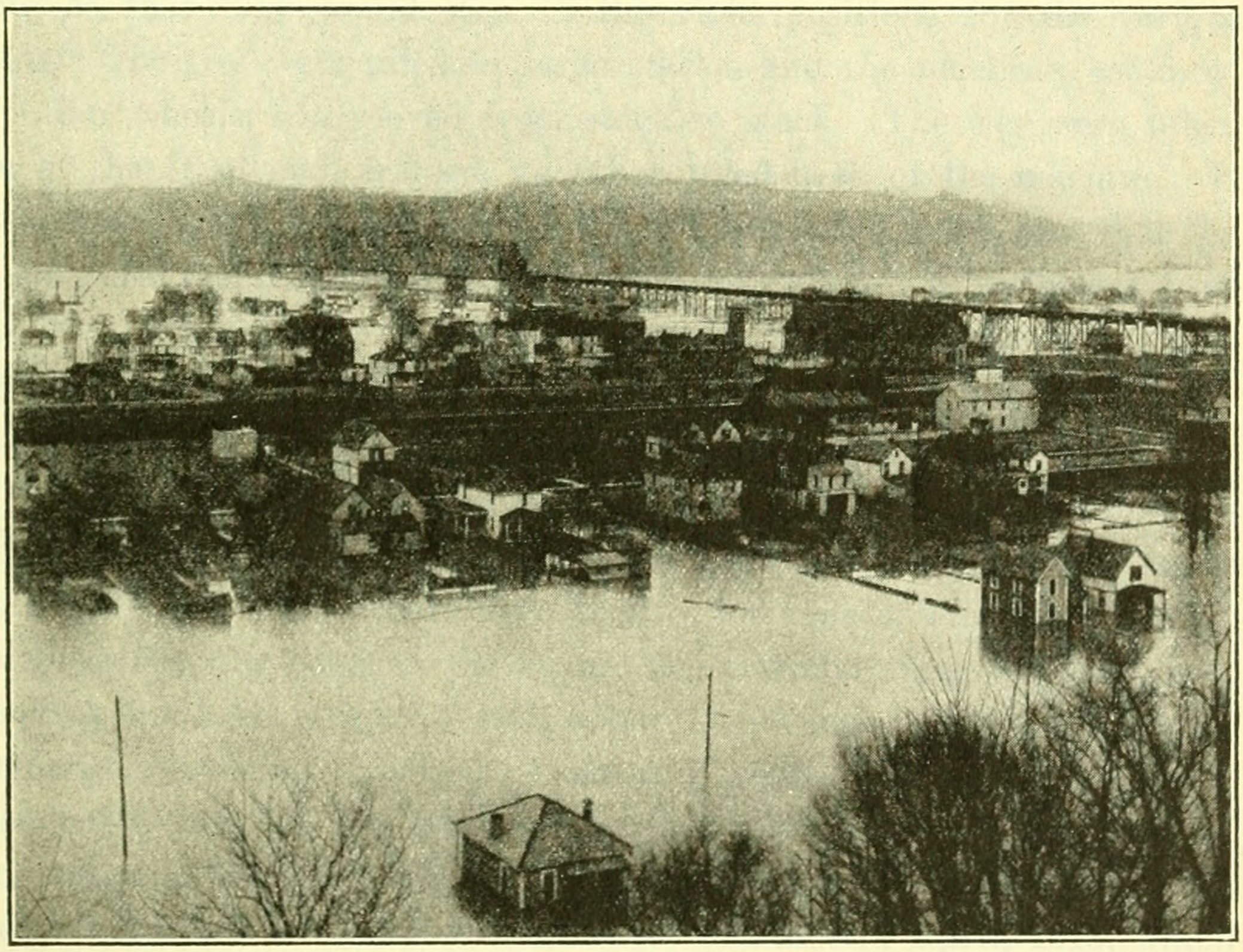
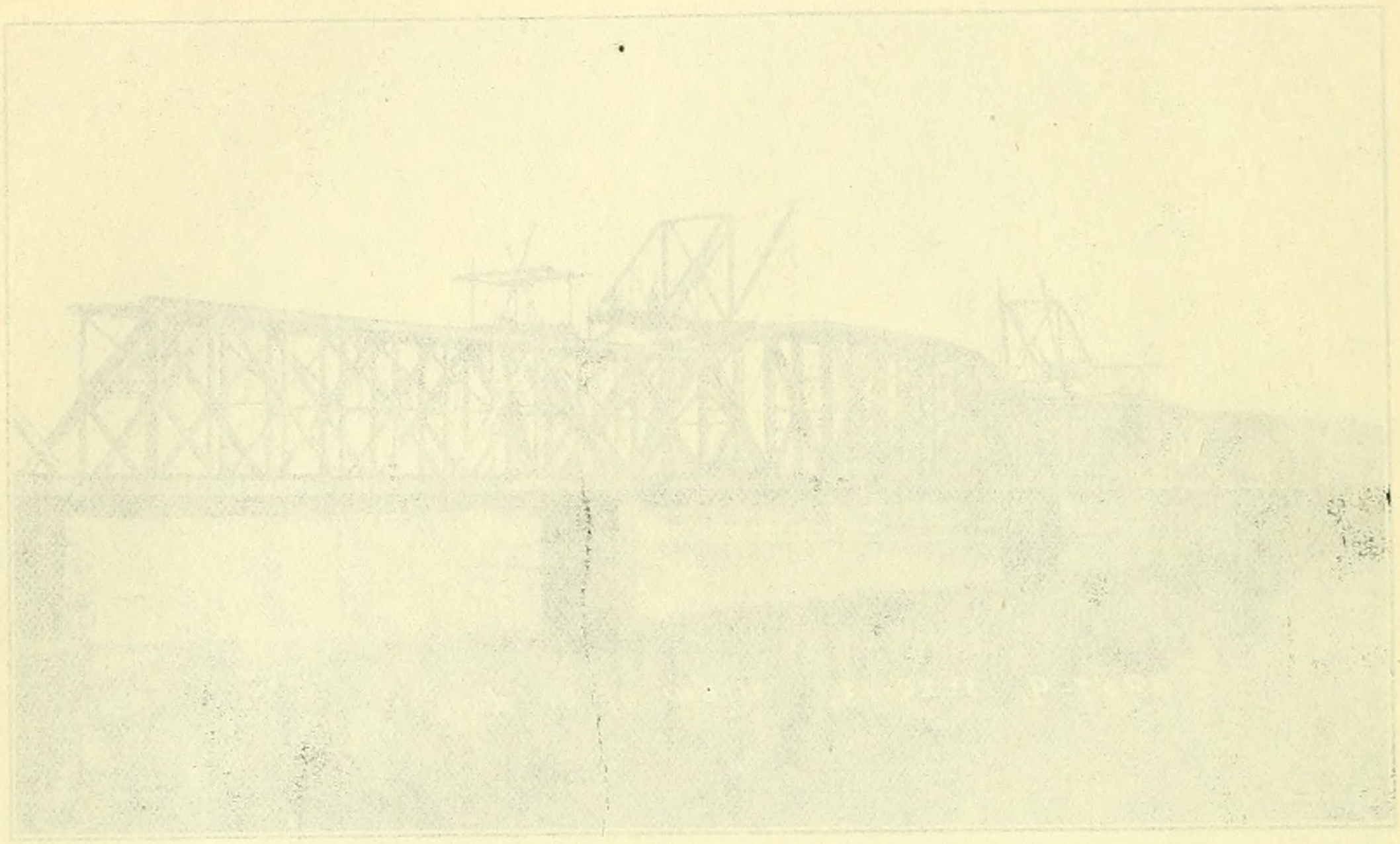


FIG. 47.—KENOVA, W. VA., DURING FLOOD.



There were four electric hoisting engines, two 100-h.p., 4-drum, 8-spool, and two 65-h.p., 2-drum, 4-spool. The two larger engines were used on the large travelers and the two smaller ones on the material hoist. There were also about eight steam engines at different parts of the site. Direct current, at 550 volts, was obtained from a street-car circuit which ran close to the south end of the bridge. The electric engines were found to be much superior to steam for use on the travelers, as there was no vibration from them when on the cantilever arm, the power was always there, and the trouble with coal and water was avoided. Rivets were driven by compressed air at about 100-lb. pressure furnished by a 12 by 12½ by 14-in., straight-line compressor with a capacity of 285 cu. ft. of free air per minute. This compressor was on the ground at the south end of the bridge.

The ties were framed by a tie-dapping machine run by a gasoline engine. This machine had a circular saw for squaring the ends of the ties, and on another shaft there were a number of small coarse-toothed saws to cut the dap. These saws were adjustable, so that a dap of any width could be cut, and there were levers to control the ties so that they would stop in the right positions for the various cuts. The ties were piled in large stacks, and the machine, mounted on four wheels, was moved from stack to stack. The ties were taken in at the front end, framed, and then piled back of the machine. It was found that by this method the framing cost much less than by hand. In removing the old spans, the oxy-acetylene torch was used to burn through the members, and this facilitated the work to a considerable degree.

Conclusion.

The new bridge is shown in Fig. 2. The weight of the approach viaduct is about 2 200 tons, and the weight of the finished river spans is about 9 600 tons. There were about 1 300 tons of erection material, such as the ties between the spans, the material track brackets, etc., making the total weight of steel about 13 100 tons. The entire reconstruction, covering a period of about 2 years, was carried on independently, first, of the heavy traffic over the bridge; and second, of the stage of the Ohio River. There were several floods during this period, the last being the great flood of March and April, 1913, which occurred about a month after the new Span 3 was swung. The water level rose about 65 ft., and the river practically covered the

Town of Kenova, but no damage was done which interfered with the railway traffic.

The general method of the reconstruction of this bridge was proposed by C. G. E. Larsson, M. Am. Soc. C. E., of the American Bridge Company. It was worked up by F. P. Witmer, M. Am. Soc. C. E., now Structural Engineer of the Brooklyn Rapid Transit Company and Mr. William G. Grove, Engineers on designs, under the direction of C. W. Bryan, M. Am. Soc. C. E., Chief Engineer, and Mr. Larsson, Assistant Chief Engineer, of the American Bridge Company. The steelwork was fabricated at the Ambridge Plant. The erection was under the direction of Mr. J. B. Gemberling, Division Erection Manager. The work in the field was in charge of Mr. D. Burns, Foreman, and Henry Taylor, Assoc. M. Am. Soc. C. E., was the Field Engineer. For the Norfolk and Western Railway, the work was under the supervision of C. S. Churchill, M. Am. Soc. C. E., formerly Chief Engineer, and C. C. Wentworth, M. Am. Soc. C. E., Assistant Engineer. J. E. Crawford, M. Am. Soc. C. E., now Chief Engineer, was in charge of the alterations to the masonry piers and the checking of the steel superstructure, and F. P. Turner, Assoc. M. Am. Soc. C. E., now Bridge Engineer, was the Engineer in the field.