TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. LV.

DECEMBER, 1905.

Edited by the Secretary, under the direction of the Committee on Publications.

NEW YORK:

PUBLISHED BY THE SOCIETY.

1905.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

Paper No. 1001.

THE RECONSTRUCTION OF THE BALTIMORE AND OHIO RAILROAD BRIDGE OVER THE OHIO RIVER, AT BENWOOD, WEST VIRGINIA.*

By J. E. Greiner, M. Am. Soc. C. E.

With Discussion by O. E. Hovey, M. Am. Soc. C. E.

The Old Bridge.

The original bridge at this place was built under the general authority given by the Act of Congress approved July 14th, 1862. This Act provided that bridges built over the Ohio River above the mouth of the Big Sandy should not have a less elevation than 90 ft. above low-water mark in the channel, nor a less span than 300 ft. over the main channel, the next adjoining span to be not less than 220 ft.

The bridge was composed of 9 Bollman deck spans, 4 deck spans and 2 through spans of Linville and Piper type, as shown on Plate XII, and, in addition thereto, there was an approach on the Ohio side consisting of 43 semi-circular stone arches, with 28 ft. clear span and a total length of approach of 1 490 ft. The length of the iron bridge, from center to center of abutments, is 1 435 ft. 6 in.,

* Presented at the meeting of April 19th, 1905.

PLATE XII.
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and the total length of the entire bridge, including approach, from end to end of masonry, is 3 916 ft. 10 in.

The Bollman spans were built by the Baltimore and Ohio Railroad Company at its Mt. Clare shops, Baltimore. The other spans were built by the Keystone Bridge Company. The first stone was laid in the foundations on May 2d, 1868, and the bridge was opened for traffic on June 21st, 1871.

The structure was designed for a uniform load of about one ton per foot, with the unit strains in use at that time.

Periods of Reconstruction.

The rebuilding of this bridge was not a continuous operation, but was done in sections extending over a number of years, the policy being to replace those spans which were the most expensive to maintain, or which developed weakness under the existing traffic, in the order in which this weakness was made evident. Each section was designed in accordance with the specification in use on the Baltimore and Ohio Railroad at the time the design was made, the result being that the completed new structure is not of uniform strength.

The periods of renewal were as follows:

Year 1893.—Spans 14 and 15, designed for Consolidation engines weighing 107½ tons with tenders; all material, wrought iron; specifications of 1892; Union Bridge Company, builders.

Year 1900.—Spans 1 to 7, inclusive, designed for Consolidation engines weighing 125 tons with tenders; material, soft open-hearth steel; specifications of 1896; builders, Pencoyd Iron Works.

Year 1902.—Spans 8, 9, 10 and 13, designed for Cooper's E-50 engines, followed by a train load of 5 000 lb. per running foot; material, soft open-hearth steel; specifications of 1896; builders, Edgemoor Plant, American Bridge Company.

Year 1904.—Spans 11 and 12, designed for Cooper's E-50 engines; material, open-hearth structural steel; specifications of 1901; builders, Edgemoor Plant, American Bridge Company.

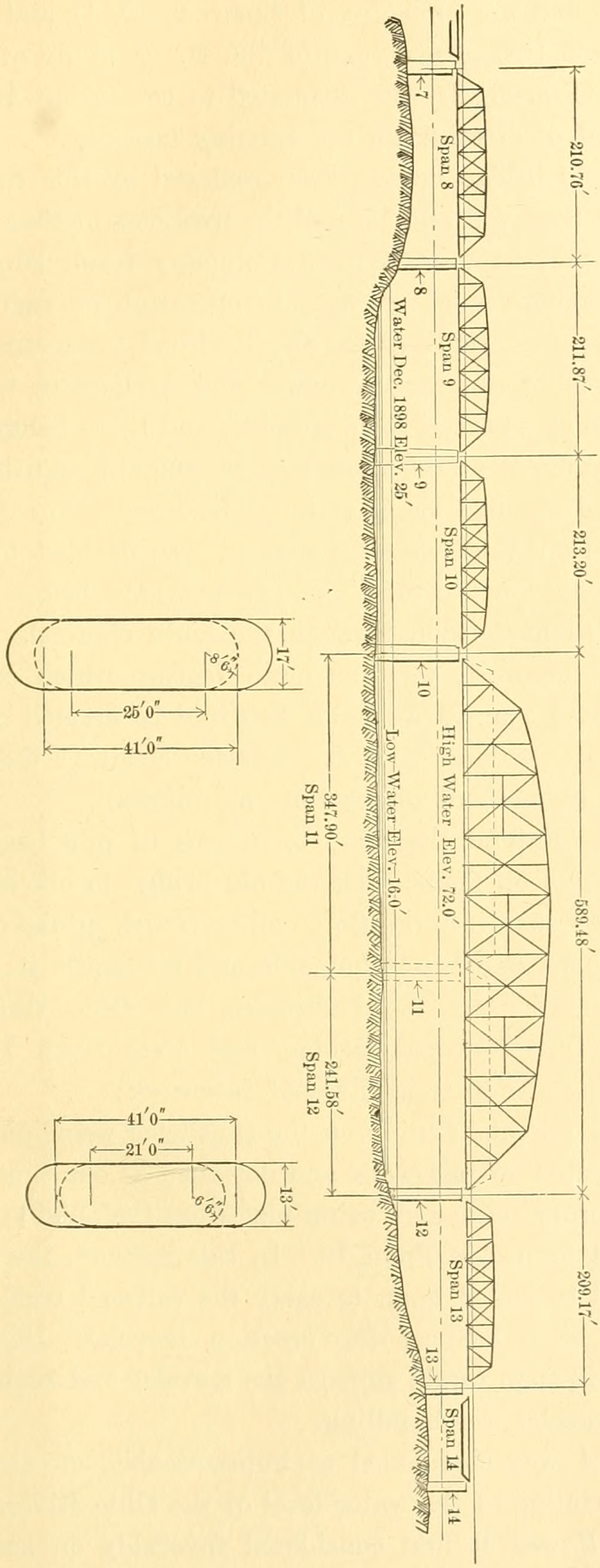
The Design.

The reconstruction of this bridge, except Spans 11 and 12, involved no work of particular interest, either in the design or in the erection, as there was no objection to the use of falsework. Spans 8, 9, 10 and 13 were made through bridges, instead of deck bridges, as the trusses and overhead bracing could be erected before disturbing the old structure, and in case the falsework had been washed out, there would have been the least possible interruption to traffic.

The design of Spans 11 and 12 was controlled by the proposed method of erection, the requirements being that the erection should be carried on without interrupting the railroad traffic or interfering with navigation in the main channel span (Span 11), there being no objection to falsework under Span 12.

The question of widening the channel was fully considered before the final adoption of the design upon which the structure was actually built. The War Department and the river men desired a much larger channel span than existed in the old structure, but there was a still further question as to who should pay for the difference in cost between rebuilding the bridge on the existing masonry and the lengthening out of the span as desired, the Railroad Company claiming under their charter the right to maintain the bridge on the existing masonry. The Railroad Company had obtained a special War Department permit during 1900 for the reconstruction of Spans 8, 9, 10 and 13 on the existing masonry, and, considering this fact, the War Department would probably have been satisfied with the removal of Pier 11 and the replacing of Spans 11 and 12 with one single span of a total length, from center to center of piers, of 589.48 ft., part of which could have been erected on falsework. This would have required extending Piers 10 and 12 and the removal of Pier 11. A study of this plan is shown in Fig. 1. It is estimated that this single span would have cost about $253 500 more than the construction on the existing masonry.

While the War Department would probably have agreed to a span of 589.48 ft., they preferred a span giving at least 700 ft. in the clear of the piers. This would make a length of 730 ft. from center to center of piers. This would have necessitated the removal of three piers, the lengthening out of one pier, the rebuilding



Span 8
Span 9
Span 10
Span 11
Span 12
Span 13
Span 14
210.76′
211.87′
213.20′
589.48′
209.17′
347.90′
241.58′
Water Dec. 1898 Elev. 25′
High Water Elev. 72.0′
Low Water Elev. 16.0′
7
8
9
10
11
12
13
14
17′
8′6″
25′0″
41′0″
41′0″
21′0″
6′6″
13′

Fig. 1.

of one pier, and the replacing of Spans 9, 10, 11 and 12 with one span of 284.55 ft. and one span of 730 ft. A study of this scheme is shown in Fig. 2. It was estimated to cost about $563 000 more than the cost of erecting on the existing masonry.

All the old bridge having been replaced by this time, with the exception of Spans 11 and 12, and the weakness of these spans being such as to prevent the Railroad Company from using the heavy cars and locomotives which were in operation on each side of the bridge, it became necessary for the Railroad Company, in order to get the benefit of their heavy power and equipment, to reconstruct these two spans as speedily as possible, and there being no prospect of the Government or the river men paying the additional cost for the increased channel span, and the Railroad Company not being inclined to bear this extra expense, it was decided to reconstruct these two spans on the existing masonry, care being taken not to interfere with navigation through the main channel. The method of erection, therefore, was the main feature which controlled the design of these spans. As Span 12 could be erected on falsework, this span presented no difficulty, but for Span 11 there were only three apparent methods of erection, as follows:

A.—Extend the piers by means of pile bents, erect the new span on floats, jack the old bridge to one side and float the new span into position, and then pick up the old span with the floats, move it to one side and dismantle it;

B.—Transfer the Baltimore and Ohio traffic over the Wheeling Terminal Bridge, and erect Span 11, using the existing structure in place of falsework;

C.—Erect Span 11 on the cantilever principle, Span 12 to be erected on falsework and designed as one shore arm and a temporary shore arm being placed on the outside of the existing structure in Span 10. In this method, the old Span 11 would be called upon to carry the railroad traffic and at the same time support the erection traveler. Between trains, this old span would support the traveler and such members as the traveler was handling.

Method *A* was abandoned as impracticable, on account of the frequent variation of the water level of the Ohio River.

Method *B* was at first considered favorably on account of the

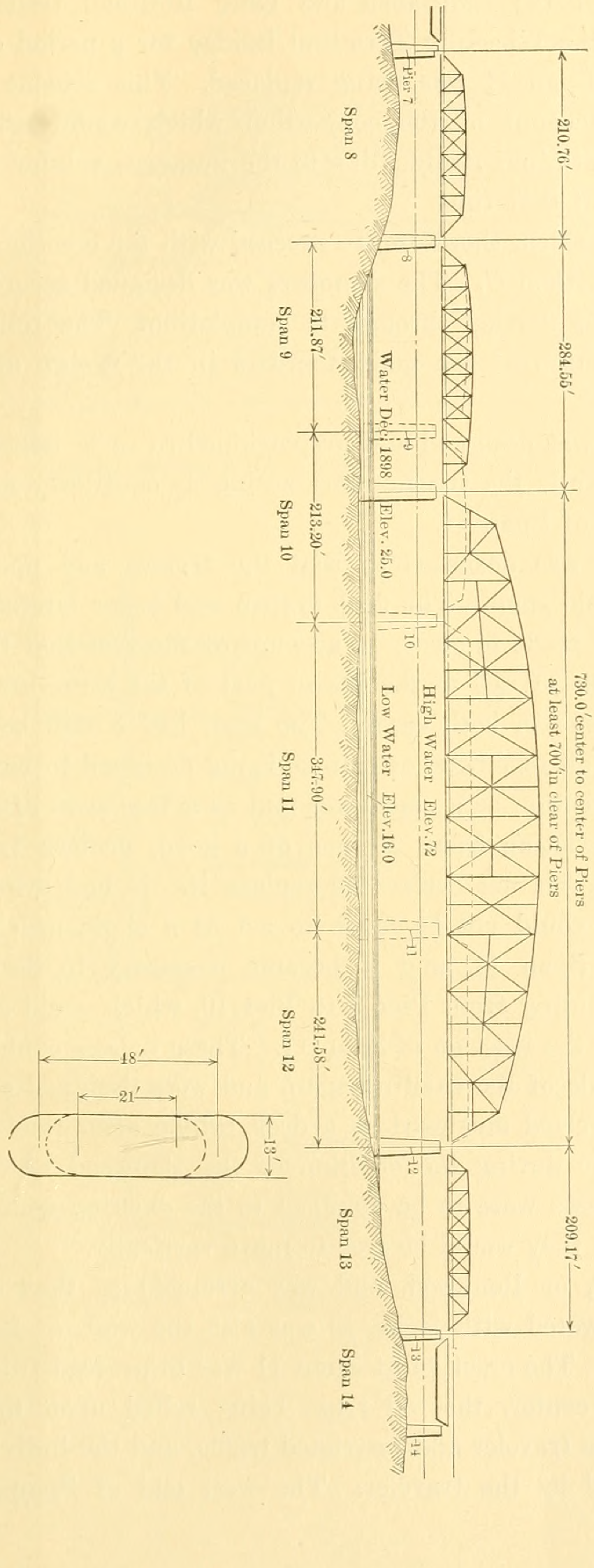

210.76'
284.55'
730.0' center to center of Piers
at least 700' in clear of Piers
209.17'
Pier 7
Span 8
8
211.87'
Span 9
Water Dec. 1898
Elev. 25.0
9
213.20'
Span 10
10
High Water Elev. 72
Low Water Elev. 16.0
347.90'
Span 11
11
241.58'
Span 12
12
Span 13
13
Span 14
14
48'
21'
13'

Fig. 2.

possibility of the Baltimore and Ohio Railroad transferring its traffic over the Wheeling Terminal Bridge for a period of 50 or 60 days while Span 11 was being replaced. This scheme was abandoned, on account of the congestion which would result on the Wheeling Terminal Bridge, due to the immense volume of business being done at that time.

It was decided, therefore, to proceed with the erection in accordance with Method *C*. The structure was designed accordingly, and the work was carried through to completion. The following is a brief description of the main features in the design of these two spans:

Span 12 was designed and proportioned so as to take up reversal of stresses while the trusses were acting as cantilever arms during the erection of Span 11.

Span 11 was designed so that the trusses and upper bracing cleared the old span. The floor system and lower laterals, however, could not be made to clear, on account of the fact that the distance from the base of rail to the lowest part of the structure has to remain the same in both cases. The span had a stiff bottom chord throughout, all members, of course, being designed to meet the conditions of erection as a cantilever and as a free span after erection.

As the existing Span 10 was of a good, modern type of construction, it was not desired to replace it. It had eye-bar bottom chords, and could not be made to act as a shore arm during the erection of Span 11, and it became necessary to design special trusses, extending from Pier 9 to Pier 10, which could act as shore arms during the erection of Span 11. These trusses could be erected on the outside of the existing span, and were designed so that they could be inverted and used as a deck bridge after they had served their purpose during the erection of the Benwood Bridge. These erection trusses were to be clamped to the existing span in such a manner that they would be free to move vertically.

The east, or Benwood, end was arranged so that it could be raised or lowered with jacks, as was also the west, or Bellaire, end of Span 12. The erection of Span 11 was to proceed from the piers toward the center, the old truss being relied upon to carry the weight of the traveler and restricted traffic, and the individual members handled by the traveler. The west end of Span 11 was on

PLATE XIII.
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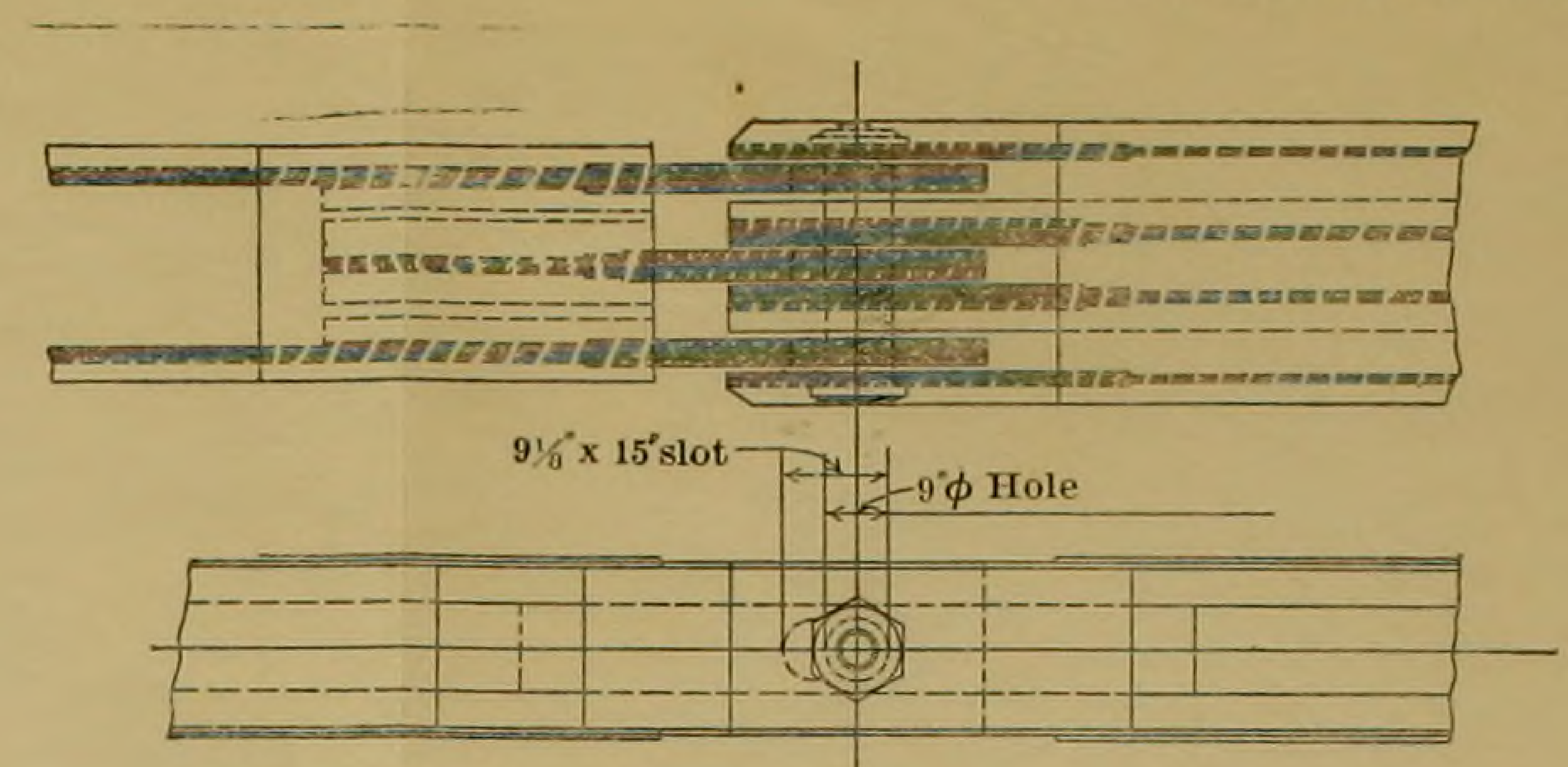
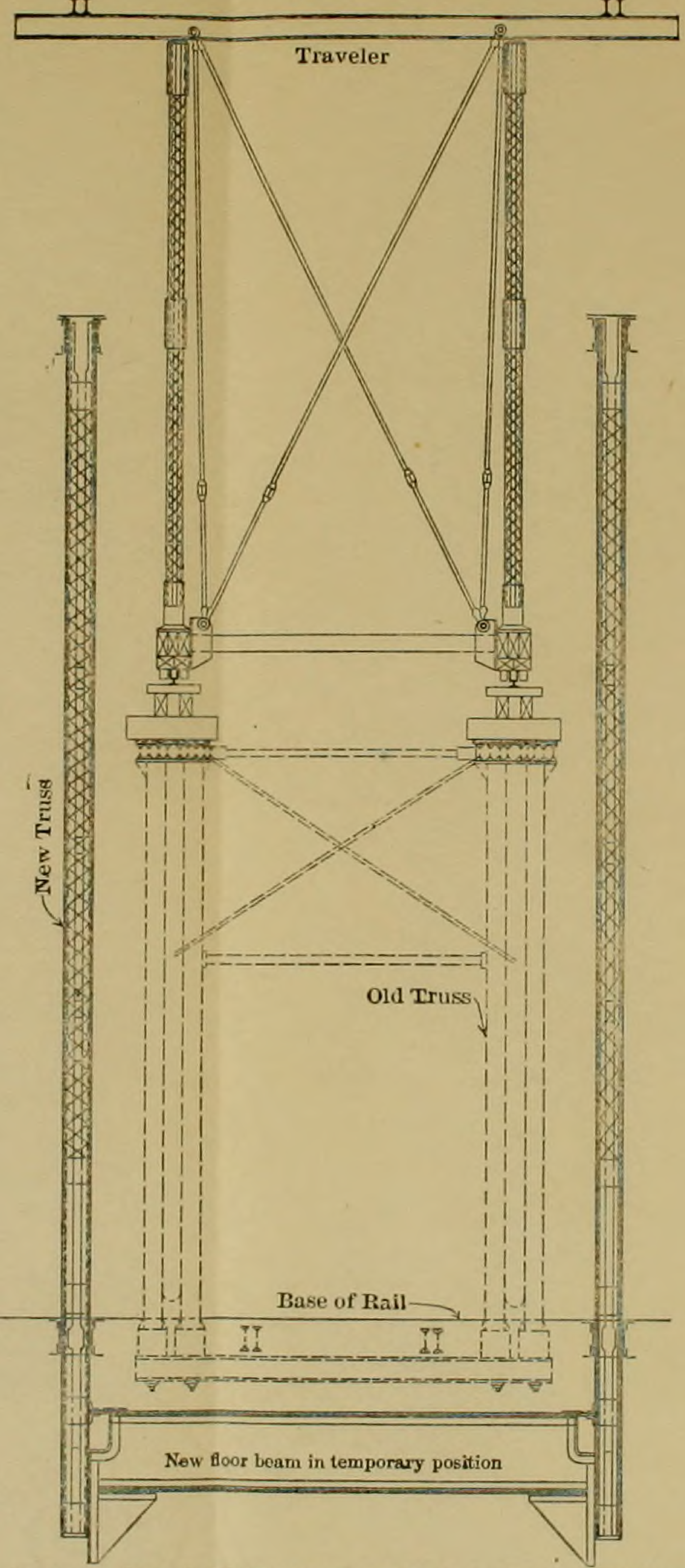
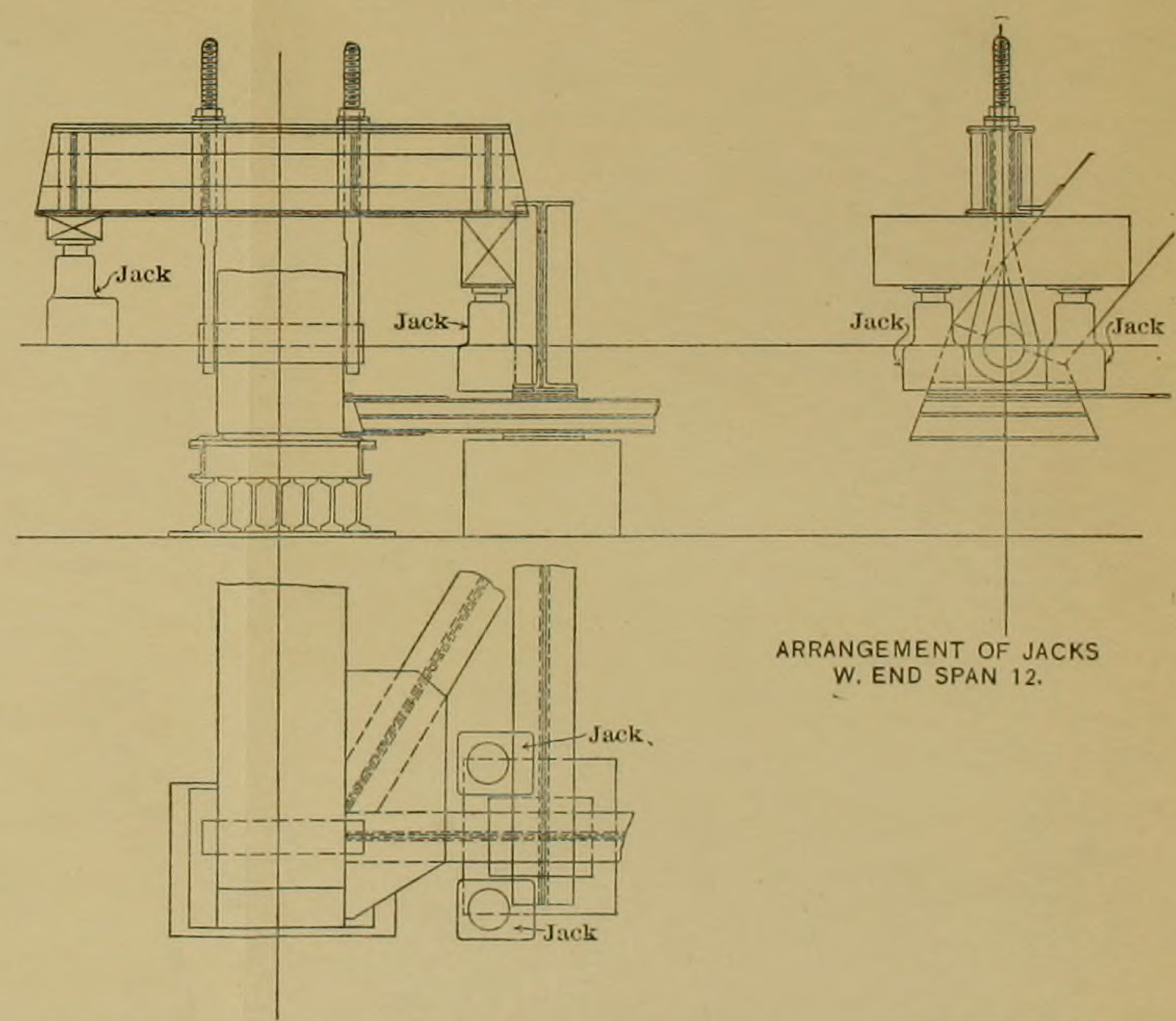


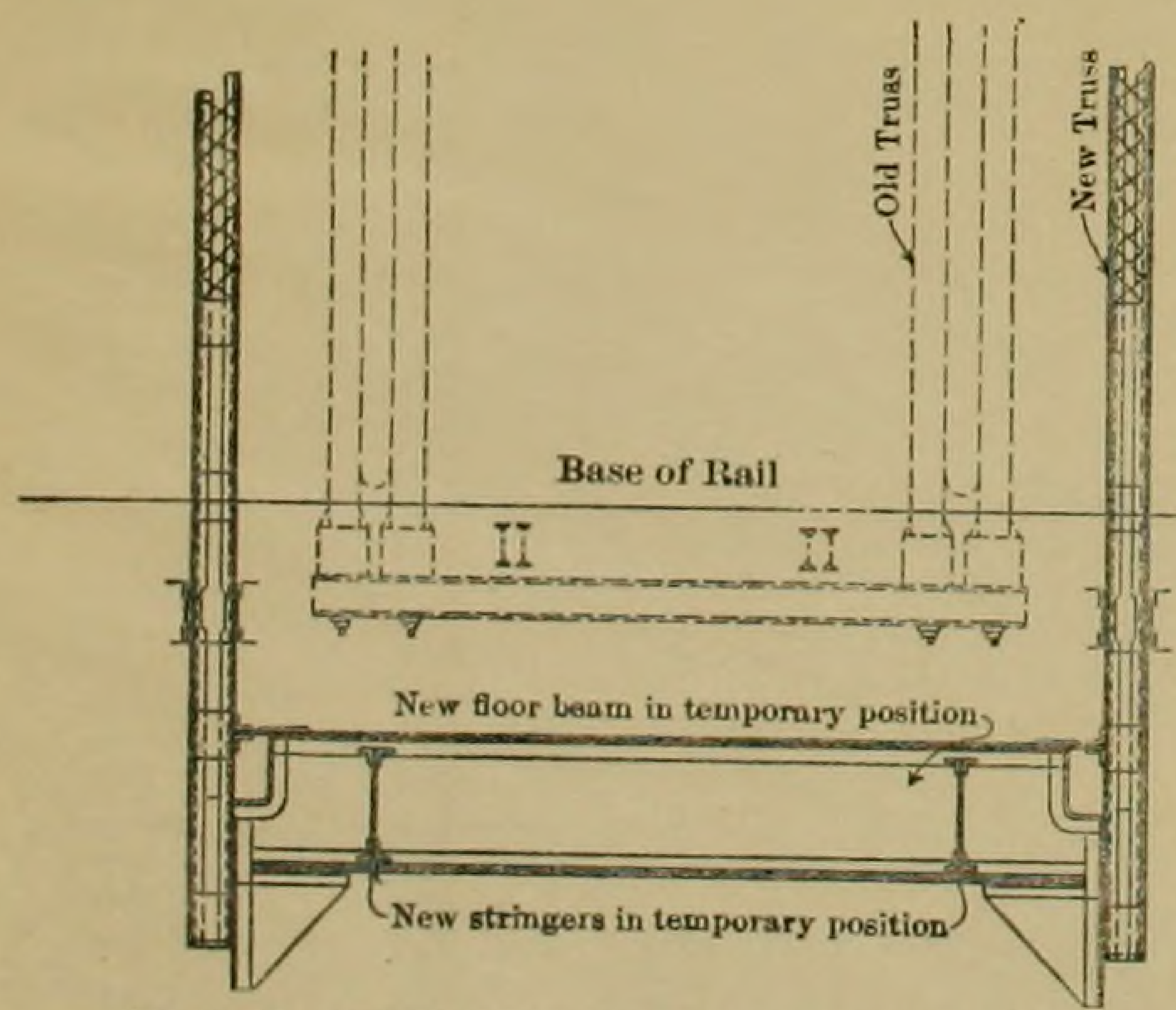
SLIP-JOINT IN CENTER PANEL OF BOTTOM CHORD



SPAN 11. CROSS-SECTION AT CENTER DURING ERECTION



ARRANGEMENT OF JACKS
W. END SPAN 12.



SPAN 11. CROSS-SECTION: NEW TRUSSES SWUNG

rollers. Attached to the end bottom pins at this end were struts which connected with cross-girders temporarily attached to Span 12. Each of these struts was in two sections, and these sections bore against a wedge arrangement. An overlap of $2\frac{1}{16}$ in. was provided in the bottom-chord center panel at low temperature, and about 10 in. clearance of the top-chord center panel, at high temperature. The west end of the center bottom chord was provided with a 9-in. slot, with a maximum movement of $4\frac{1}{2}$ in. each way. The wedge struts at the west end provided for a maximum movement of 8 in.

It will be seen from the foregoing description that, by jacking up the east end of Span 10 and lowering the wedges in the strut at the west end of Span 11, the top chords at the center of Span 11 could be lowered to their proper bearing; and, if, by some chance, there should not be sufficient movement attainable with the wedge arrangement there was still left an opportunity of jacking up the west end of Span 12 (see Plate XIII).

The Erection.

The method of erection of Spans 11 and 12 (see Plate XIV) was carried on as outlined in the following:

Span 12.—Falsework was placed under the old span, which was then taken down. The traffic was carried on this falsework while the new span was being erected. The falsework was not removed until Span 11 was swung, as it was required to support the live load, thereby avoiding vibration in the west half of Span 11 during erection.

The dead-load positive reaction per truss on Span 12 was 157 000 lb., and as the erection-stress negative reaction was only 56 000 lb., no counterweighting was required.

The East Shore Arm. Span 10.—For the east shore arm, the temporary trusses were erected outside of the trusses of Span 10, and on the same line as the trusses in Span 11. They were erected directly from the existing span, without the use of falsework, and were clamped to the existing trusses, the clamps being arranged so as to permit of movement up and down. The east ends of these erection trusses were dropped about 36 in. below the level. The dead-load positive reaction about equalled the erection-stress negative reaction, and, therefore, provision was made for about 25 tons counterweights for each truss.

Span 11.—The erection of this span was started at the east end, and, as the traveler moved toward the center of the span, the portals, top laterals and as much of the sway bracing as possible were removed. The floor-beams were placed upside down, in a temporary position below the bottom chord pins, and connected to the posts, which were lengthened for this purpose and which were cut off after the floor-beams were placed in their proper position. After the east half was completed as far as the center, and all bracing was placed, the west arm was erected in the same manner, connection being made in the center panel of the top and bottom chords.

No difficulty whatever was experienced in connecting the two halves of this span. The east end of Span 10 was jacked up and the wedges at the west end of Span 12 were withdrawn until the members came to their proper position. After this span was swung, the intermediate stringers were placed in their temporary position, under the old trusses, and connected by temporary timber laterals. The old trusses and floor were then blocked up and the trusses and bracing taken down, using the new span for support. The end panels of the laterals were placed in their permanent position, and temporary stringers provided, so as to clear these end laterals.

General.

The traveler used during this erection, as will be observed from the plan, was run on the top chords of the existing bridge. It weighed 40 tons. Nearly all the material was floated out under the spans on barges, then picked up and placed in position by the traveler.

During the erection of Span 11, it was necessary to take the greatest care in placing the traveler in a fixed position during the handling of material, and, before the erection proceeded, the old bridge was carefully adjusted and the posts braced with temporary wooden braces. The maximum tension strains in the old bridge during this erection did not exceed 16 000 lb. per sq. in., and the compression strains were in proportion.

As Span 11 was considerably wider than the existing bridge, and

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as the bearings were rather closer to the ends of the piers than was desired, the masonry was cut down, under traffic, and I-beam grillages were placed on top of the piers, with a view of distributing the weight.

The entire work of erection was conducted in a most careful and satisfactory manner, there being no hitch or errors of any moment, either in workmanship or in judgment, and the successful completion of this dangerous piece of erection, which was of an unusual character, perhaps without precedent, is very creditable, not only to the Erection Department of the American Bridge Company, but to Foreman J. W. Sweet, who had direct charge of the forces in the field.

DISCUSSION.

Mr. Hovey. O. E. Hovey, M. Am. Soc. C. E.—Spans 11 and 12, to be renewed at the same time, could be designed to suit the cantilever erection of Span 11, using the new Span 12 as one anchorage, with a temporary connection to Span 11. Span 10 was already built, and was of modern construction, with eye-bar bottom chords and ordinary top-chord splices, and could not be used as an anchorage without reconstruction, which was too expensive. It was proposed, therefore, to build a pair of temporary outside anchorage trusses for Span 10, with horizontal, stiff, bottom chords and uniformly inclined, stiff, top chords, designed to take anchorage tension; and a web system as light as consistent with safety. After this proposal was made, the Baltimore and Ohio engineers found that a deck bridge of the same length would be required on another location, and the light temporary anchor trusses for Span 10 were abandoned and deck trusses were designed to carry the regular Baltimore and Ohio Railroad loading when erected in final position. These trusses were designed to be erected upside down to serve as temporary anchorages for Span 11, and the necessary modifications in the sections were made. These deck trusses were erected outside of Span 10 and clamped to it, and were attached by temporary connections to Span 11.

The calculations of the relative positions of the old Span 11 and the new Span 11, erected as a cantilever, were quite laborious, and were made in a very satisfactory manner by W. M. White, Assoc. M. Am. Soc. C. E., under charge of the speaker, in the Pencoyd office of the American Bridge Company.

No difficulty was experienced in making the final connections in the field, as ample provision had been made for all necessary adjustments of the cantilevers formed by the two halves of Span 11.

No attempt was made to economize too much in the design of the various adjusting devices, as the experience of undue economy in the design of similar appliances for the erection of a large cantilever bridge several years ago was not satisfactory, and the delay in making connections was no doubt more expensive than complete adjusting devices would have been. The results attained at Benwood justified the expenditure for complete apparatus.

The bottom chord of the long span was stiff throughout. No eye-bars were used in the chord. It was not considered good practice to use a chord made up of a combination of riveted stiff members and eye-bars.