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# HISTORY OF LITTLE ROCK JUNCTION RAILWAY BRIDGE, OF THE ST. LOUIS, IRON MOUNTAIN AND SOUTHERN RAILWAY COMPANY, OVER THE ARKANSAS RIVER AT LITTLE ROCK, ARKANSAS, 1883-1914*

By C. E. Smith, M. Am. Soc. C. E.

With Discussion by Messrs. Henry H. Quimby, M. L. Byers, Lee Highley, Theodore Belzner, Robert H. P. Ford, C. D. Purdon, F. G. Jonah, and C. E. Smith.

## Synopsis.

*Object.*—This paper was written for the purpose of informing the Engineering Profession of the troubles encountered at the Little Rock Junction Railway Bridge, due to the defective construction of the piers, in order that such defective construction may be avoided in the future; its purpose is also to point out the methods suggested and used to accomplish the correction of the defects, in order to guide the Profession in the correction of similar defects which may cause trouble in future in similar piers.

*Digest.*—The bridge consists of three 253 ft. 4-in., through truss spans, one 127 ft. 11-in., through truss span, and one 352 ft. 10-in., through truss swing draw-span, all single-track, resting on masonry

* Presented at the meeting of December 16th, 1914.

piers and one abutment. Four of the piers are supported on pneumatic caissons and timber cribs. The pneumatic caissons are of ordinary timber construction, and rest on bed-rock, approximately 45 ft. below low-water line.

The timber cribs over the pneumatic caissons, extending up to low water, consist of 12 by 12-in. timbers, 3 ft. from center to center, sheeted outside with 3-in. planks. The spaces between the timbers were supposed to have been filled with rip-rap, but only a small quantity was placed, the greater number of the cavities having been filled with sand discharged from the caissons.

The caissons were poorly located, and when the working chambers were finally sealed, the tops of the timber cribs were considerably out of place. As the steel superstructure was on the ground at the time of the commencement of the masonry work, the masonry piers were located on top of the cribs in such a way that the coping courses were the proper distances apart to receive the steelwork, which made it necessary to place the piers at one side or the other of the timber cribs and use different batters.

The bed of the Arkansas River is composed of fine sand and silt, which is scoured to great depths during floods, especially around obstructions such as piers. The scouring of the river around these piers caused the sand to run out of the cribs through the spaces between the sheeting planks, and the timbers, being deprived of the support of the filling material, settled under the weight of the bridge and traffic.

As the masonry piers were not located concentrically with the cribs, the timbers compressed unequally and caused the piers to lean, their tops moving in various directions. The piers were a constant source of trouble and expense from the date of construction in 1883 until recently when they were reconstructed.

The reconstruction consisted in placing annular pneumatic caissons around the old piers, filling the spaces in the old cribs with concrete, enlarging the footing by filling in with concrete over the new annular caissons, and encasing the old piers in reinforced concrete following symmetrical lines, and enlarged for a double-track superstructure in the future.

The excessive scour of the Arkansas River renders practically impossible the maintenance of falsework for long periods, and swift run-outs have been experienced in all months. As the hazard attending the maintenance is very great, the work was carried out without falsework.

The paper also describes in detail the various investigations to which this bridge was subjected by engineers, and the various unsuccessful attempts, made at great expense, to correct the trouble in advance of the final reconstruction.

*Conclusions.*—Timber cribs extending from pneumatic caissons to low-water level are entirely unsuitable for bridge pier foundations unless they are of solid timber construction, or, preferably, if the spaces between the timbers are carefully packed full of rock and thoroughly grouted, or, best of all, if the spaces are filled carefully with concrete and well rammed so as to fill all voids.

When defects are discovered in bridge piers, and trouble results, correction should be applied at the seat of the trouble; expenditures for temporary expedients are a waste of money. The continuation of the trouble without adequate correction involves constant hazard, which can be avoided by efficient engineering talent.

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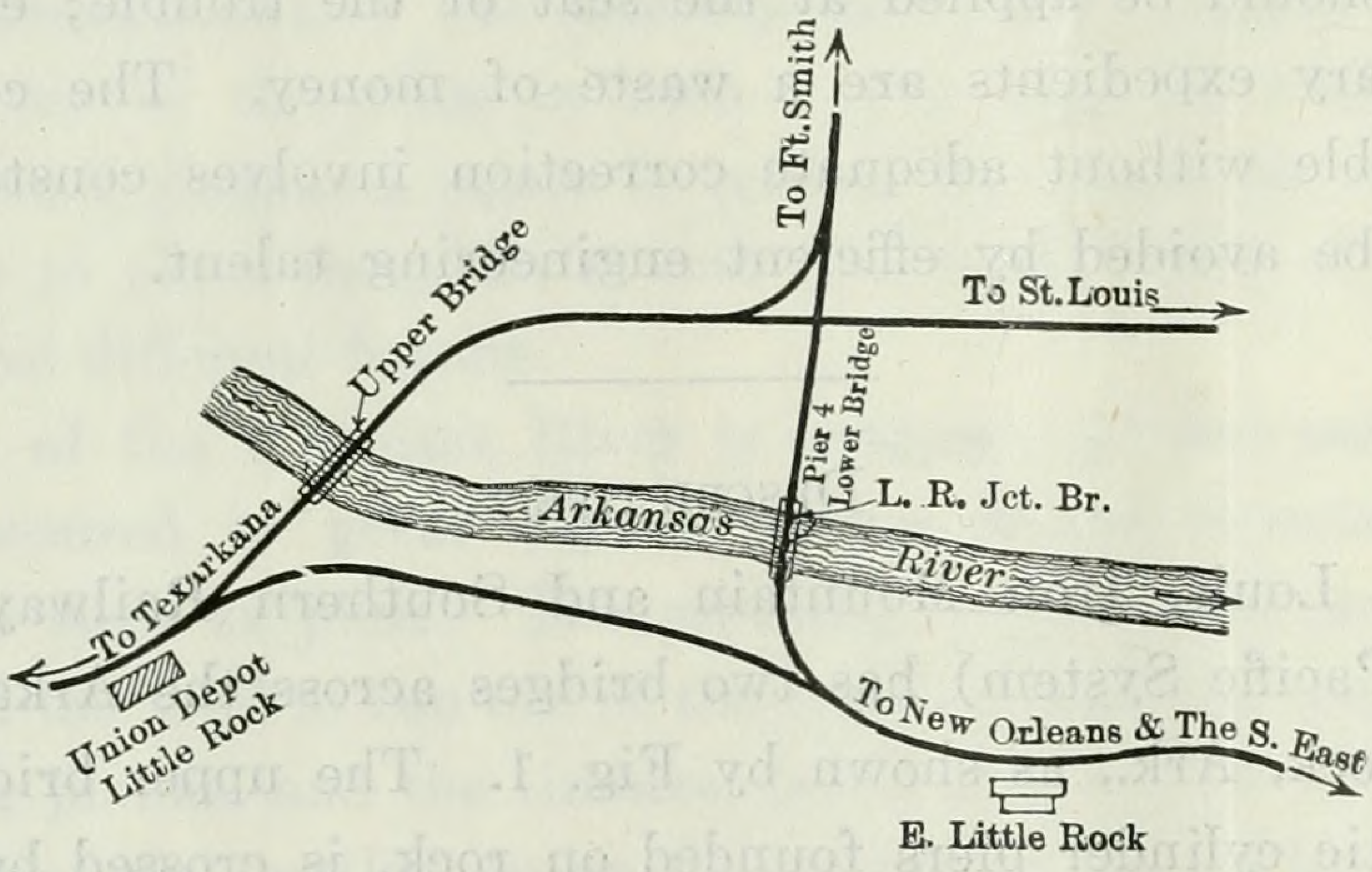
## Descriptive.

The St. Louis, Iron Mountain and Southern Railway Company (Missouri Pacific System) has two bridges across the Arkansas River at Little Rock, Ark., as shown by Fig. 1. The upper bridge, resting on pneumatic cylinder piers founded on rock, is crossed by main-line freight and passenger trains from points northeast of Little Rock to Texas and the Southwest. The lower bridge, founded on masonry piers, timber cribs, and pneumatic caissons on rock, is used by freight trains only from northeastern points to Louisiana and Southeastern Arkansas. Plate I gives an elevation of this structure, commonly known as the Little Rock Junction Bridge. It consists of one 352 ft. 10-in. swing draw-span, three 253 ft. 4-in. simple truss spans, and one 127 ft. 11-in. simple truss span and trestle approach, all single-track, built in 1883. Fig. 2 is a view of the structure. The south abutment is of masonry built on the rock that outcrops on the south bank. The pivot pier, commonly known as Pier 2, and Piers 3, 4, and 5, are rock-faced, concrete-filled, masonry piers, about 45 ft. high, resting on filled timber cribs and pneumatic caissons about 40 ft. high, the masonry of the draw-pier being annular, with a well down to the crib. Piers 6 and 7, are rock-faced, concrete-filled, masonry piers built on piles. The only specifications that can be found for the piers are as follows:

"The piers to rest on pneumatic caissons sunk to rock filled with concrete, timber cribbing to reach from roof of caissons to 4 ft. below low-water mark.

"This crib to be drift-bolted and planked on outside and filled with sand and stone; on this crib the masonry to be started and built up to grade line.

"Piers to be 6 ft. 6 in. wide under coping and 20 ft. long, with semi-circular ends, with a batter of ½ in. per ft. on sides and up-stream ends, but no batter on down-stream ends; piers to consist of solid walls, averaging 2 ft. thick, built of dimension stone so as to make joints not exceeding ½ in.; inside space to be filled with concrete. This refers to three piers.




LOCATION OF LITTLE ROCK JUNCTION BRIDGE, LITTLE ROCK, ARK.

FIG. 1.

"Draw-pier to be 30 ft. in diameter under coping, with 8-ft. wall; center to be left open; pier to rest on caissons sunk to rock and filled with concrete with crib as before.

"Fifth pier on east bank to rest on piles sawed off and capped below low-water mark; to be 6 ft. 6 in. wide under coping and 20 ft. long, with semicircular ends, to have a batter of ½ in. per ft. on sides, but no batter on ends; in other respects to be the same as Piers 1, 2, and 3. All work to be done in a thorough workmanlike manner and to the satisfaction of the General Manager of the Little Rock Junction Railway.

"The draw protection and draw-pier to be completed by the first day of June, 1884, and all the work embraced in this contract to be completed by the first day of September, 1884, unless some disaster by flood or by other uncontrollable cause shall prevent.

PLATE L.
TRANS. AM. SOC. CIV. ENGRS.
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SMITH ON
REPAIRING BRIDGE PIERS.

SIDE ELEVATION OF LITTLE ROCK JCT. BRIDGE


LITTLE ROCK JUNCTION BRIDGE
PLAN SHOWING CENTER LINE OF TRACK AFTER LEVELLING UP DRAW PIER AND PIER 4 IN 1899

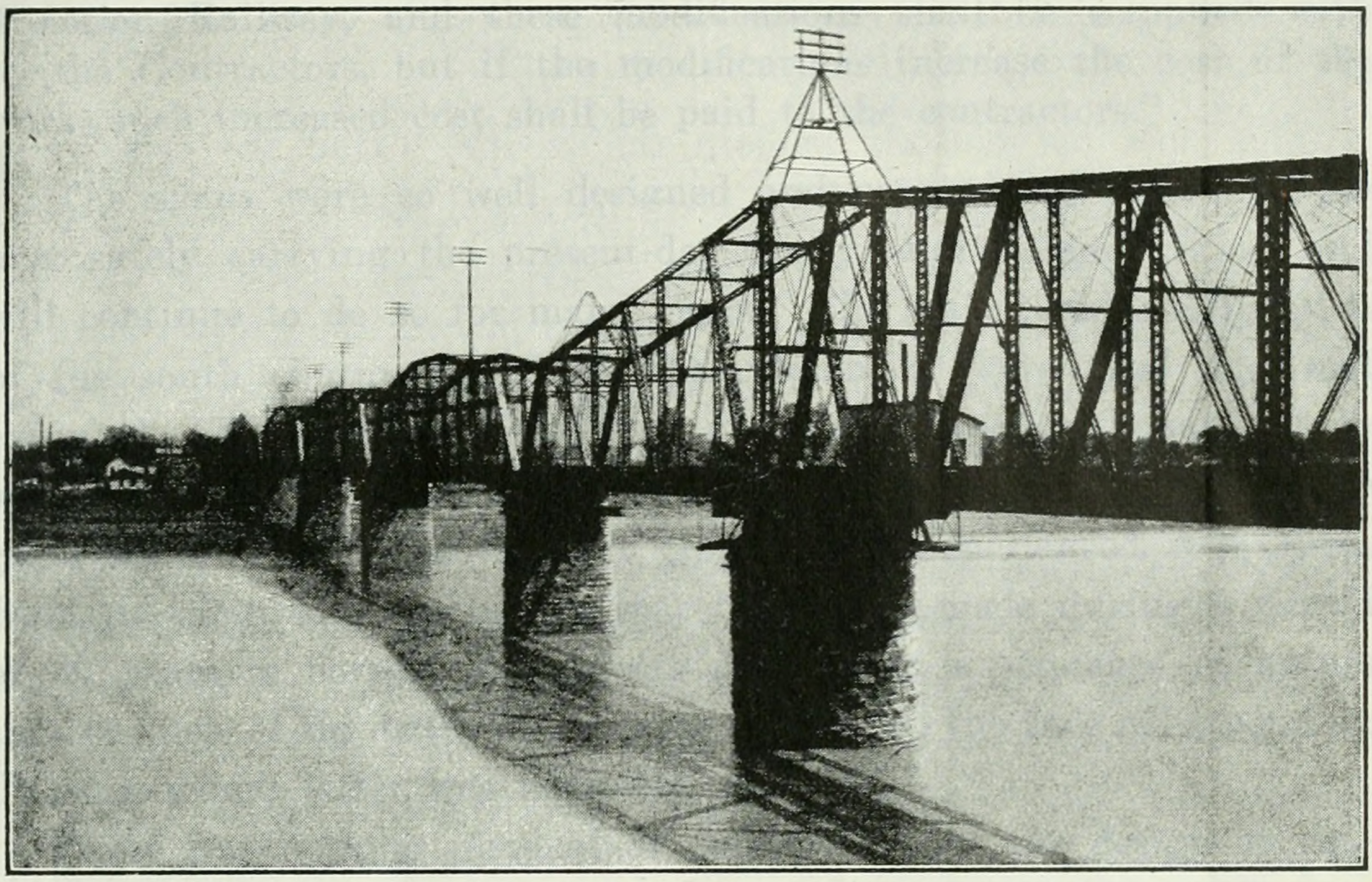


FIG. 2.—LITTLE ROCK JUNCTION BRIDGE, LITTLE ROCK, ARK.

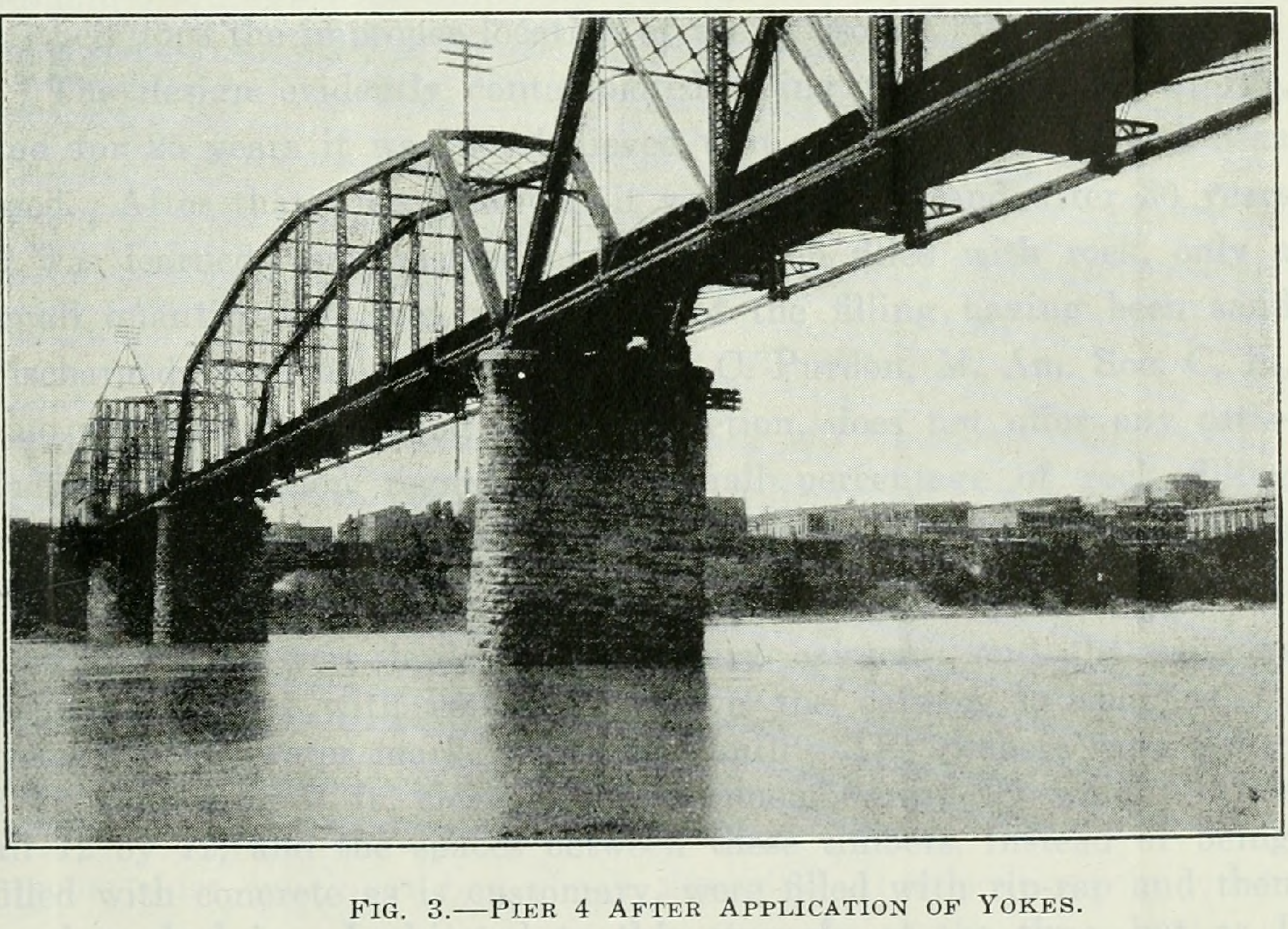


FIG. 3.—PIER 4 AFTER APPLICATION OF YOKES.

"Modifications may be made in these plans and specifications upon the request in writing by the General Manager of the Little Rock Junction Railway, and these modifications shall be complied with by the Contractors, but if the modifications increase the cost of the work, such increased cost shall be paid to the contractors."

The spans were so well designed and constructed that they are now safely carrying the present-day heavy engines and trains, and will continue to do so for many years. The design and construction of the south abutment and of Piers 6 and 7 were good and well executed. The design of the four pneumatic piers, although not in accordance with the best present-day practice, was adequate, but the construction was so faulty that trouble was experienced with them from the first, and the efforts that have been made during a period of 30 years to correct the defects resulted in a sequence of events that partook of the nature of a farce comedy in the face of impending disaster, which latter was narrowly averted.

There was nothing unusual or defective about the design or construction of the caissons, but they were very poorly located and carelessly controlled during sinking, resulting in their having been founded considerably out of place—from 2 to 3 ft. in one or two cases. The timber cribs, extending vertically upward from the caissons, reflected at their tops the improper location of the caissons.

The design evidently contemplated filling the cribs with rip-rap, and for 25 years it was not believed that any other filling had been used. After that time, however, it was suspected, and after 30 years it was learned, that, instead of having been filled with rock, only a small quantity had been used, most of the filling having been sand discharged from the caisson. C. de la C. Purdon, M. Am. Soc. C. E., who was inspector during the construction, does not offer any satisfactory explanation regarding the small percentage of rock filling and large percentage of sand filling, a letter from him in reference thereto reading as follows:

"The piers were built with ordinary caissons, and the caissons themselves filled with concrete. Above the caisson to about 4 ft. below the low-water mark, a crib was built. The timbers were either 3 ft. centers or 3 ft. clear—I don't remember exactly which—being all 12 by 12, and the spaces between these timbers, instead of being filled with concrete as is customary, were filled with rip-rap and then sand washed in. I objected to this strongly at the time, but as I did not design the piers, this work being done by the late Mr. T. E. Sickels, I was not responsible for them. I told Mr. Wood at the time that I was satisfied the timbers would eventually crush and put the piers out of shape, which it seems occurred."

This does not entirely explain the trouble. Had the cribs been properly filled, the rip-rap filling every part, and then with sand washed into the interstices of the rip-rap, little, if any, settlement would have taken place. Very little rip-rap was placed, the greater part of the filling being sand, and, when this leaked out, the small quantity of rip-rap settled through the cribs, leaving the timbers to carry all the load. No satisfactory explanation has been found for filling the cribs with sand instead of stone.

The incorrect location of the caissons and cribs was discovered before starting the masonry, and as the spans were on the ground, the errors in location were corrected partly by placing the masonry piers to one side or the other of the cribs, partly in the batter of the piers, and partly in the placing of the bed-plates on the pier tops.

Pier 4 was built near the north edge of the crib and given equal batter on the two sides, and Pier 3, the north rest pier of the draw-span, was built near the center of the crib; but the north face was given a batter of 1½ in. per ft., and the south face was built plumb; the draw-span barely got a bearing on Pier 3, and the next fixed span reached well over on the pier.

Fig. 4 shows the location of the footing courses of Piers 3 and 4 with reference to the tops of the cribs, the cross-section of Pier 4, and the location of the intermediate span from Pier 3 to Pier 4.

## Early Trouble.

The early record of the trouble is not clear, but it appears that, immediately after the completion of the bridge, the pivot pier under the draw-span (Pier 2) and Pier 4 began to settle and lean. As the bed of the Arkansas River is composed of fine sand which scours and shifts greatly during floods, it was thought that the settling was due to scour, the opinion immediately being formed that the cutting edges had not been founded on rock. Consequently, large quantities of rip-rap were unloaded around the piers, only to be washed down stream in following floods and requiring replacement. In addition, from time to time as necessity arose, the spans were shifted back and forth, to keep their bearings on the piers, the tops of which had been made so small that very little variation could be permitted. The movement of the pivot pier was quite pronounced, and necessitated frequent leveling and adjustment of the draw-span, at great expense.

The matter was the subject of continual correspondence between the various officers, and, in reply to inquiry as to the best manner of strengthening the piers, Chief Engineer James W. Way, on December 6th, 1897, recommended as follows:

"Replying to your inquiry as to best method of proceeding with the work of strengthening the foundations of the pivot pier and pier 4 (numbering from the south) of the Little Rock Junction Bridge across the Arkansas River at Little Rock.

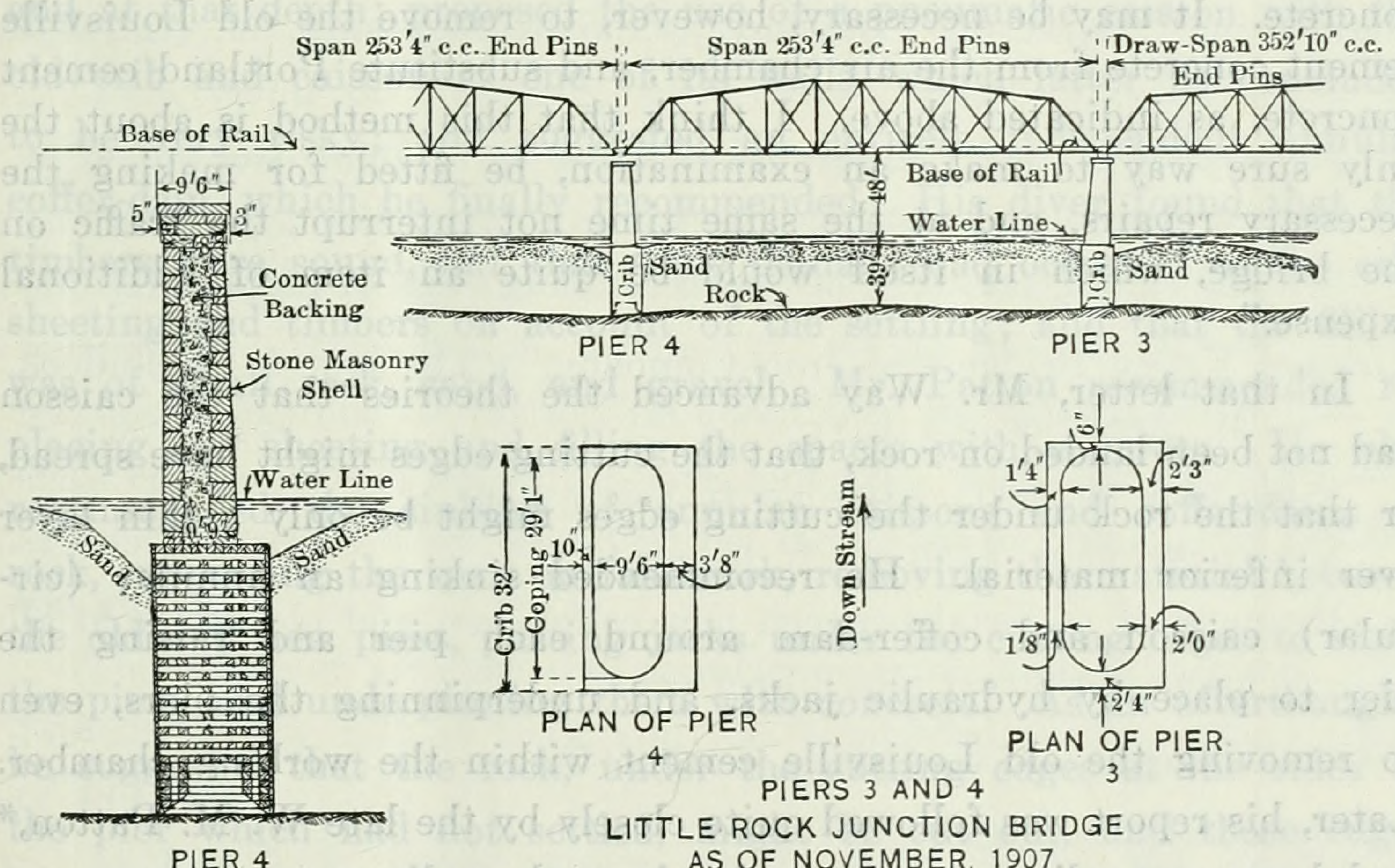



FIG. 4.

"One theory which may be presented for consideration is that the caissons are not properly landed on bed-rock, or possibly they may be faulty in construction and have spread at the cutting edges or on the corners. Again, it may be that what was termed bed-rock and believed to be such when the caissons were put in place, was but a thin stratum of shale overlying softer material; and that the respective weights of the piers, with their loads have caused this stratum to settle.

"This can readily be determined, if indeed it has not already been done, by making borings three or more feet below the elevation of the cutting edges of the caissons. Should the borings show solid rock, then the natural inference is that the caissons are imperfectly constructed. I would therefore suggest that a careful examination of the bed of the river be made and the character of the obstructions ascertained. Boring should then be driven to disclose the nature of the rock on bottom. This should be done very carefully; and finally the caisson or crib should be inspected to ascertain condition of timbers, etc.

"A double steel caisson of sufficient diameter and with four or five compartments could then be sunk to bed-rock, using compressed air to remove the débris between the two cylinders. When this is done the space between the inside cylinder of the steel caisson and the wooden crib can be pumped and cleaned out to bed-rock; when an inspection will disclose the best method of correcting the trouble.

"It is possible that by the use of hydraulic jacks the pier can be raised to place and the air chamber filled with Portland cement concrete. It may be necessary, however, to remove the old Louisville cement concrete from the air chamber, and substitute Portland cement concrete, as indicated above. I think that this method is about the only sure way to make an examination, be fitted for making the necessary repairs, and at the same time not interrupt the traffic on the bridge, which in itself would be quite an item of additional expense."

In that letter, Mr. Way advanced the theories that the caisson had not been landed on rock, that the cutting edges might have spread, or that the rock under the cutting edges might be only a thin layer over inferior material. He recommended sinking an annular (circular) caisson and coffer-dam around each pier and raising the pier to place by hydraulic jacks, and underpinning the piers, even to removing the old Louisville cement within the working chamber. Later, his report was followed quite closely by the late W. M. Patton,* and large expenditures were made along those lines.

After the Railway Company's forces had handled the problem for 15 years, Mr. Patton was called in as Consulting Engineer. He studied the history of the bridge and, after making borings through the timber crib and caisson under the pivot pier, within the well inside the pier, and examining the exposed portions of the crib by divers, came to the conclusion that the caissons were not founded on rock, and gave the Railway Company a full and very plausible report and recommendation, which, on account of its unusual nature, is reprinted in full in Appendix A.

* Author of "Treatise on Foundations."

### Patton's Report.

In brief, Mr. Patton concluded that one corner of the cutting edge of each pier rested on rock and the remainder on inferior material, which condition, together with the eccentricity of loading, caused the settlement; that greater scour at one corner than at the others caused the greatest settlement at the corner of greatest scour. He suggested pumping grout into the underlying sand to convert it into concrete; removing the inferior material under the caisson and replacing it with concrete, and, to accomplish the latter, discussed freezing the sand to the river bed to form a frozen sand coffer-dam. He also suggested an ordinary coffer-dam, which he dismissed on account of the difficulty of getting it tight in that material and at that depth; proposed the use of a pneumatic caisson with the old crib and caisson as one of its walls, which latter he concluded to be very risky; and suggested an entirely independent annular coffer-dam, which he finally recommended. His diver found that the timbers were sound, but that some damage had occurred to the crib sheeting and timbers on account of the settling; and that the filling was of small rock, sand, and gravel. Mr. Patton recommended replacing the sheeting and filling the spaces with concrete. He also recommended the sinking of annular caissons and coffer-dams to rock, supporting the span on falsework, removing the material between the old and new piers, putting jacks under the cutting edges to right the piers, and underpinning them with concrete. As an afterthought, he suggested that the rock, under the cutting edges at the sides of the pier which had not settled, might be cut out, and those edges lowered to make the piers assume perpendicular positions. He went so far as to say that from 30 to 35 hydraulic jacks, with main cylinders 3½ in. in diameter and plungers ¾ in. in diameter, would raise 30 tons each. It is not known how he proposed to work the jacks when under the cutting edge, as he recommended letting the annular caisson flood while jacking so as to reduce the weight to be lifted. His estimated cost was $40 000 for the coffer-dam around the pivot pier, with $4 000 for raising and leveling it, and $34 000 and $3 500, respectively, for Pier 4, a total of $81 500.

It is puzzling that Mr. Patton did not determine by simple calculation that, if Pier 4 could be righted by such a method as he suggested, the top would be in such a position that the ends of the spans supported by it would not fit the top of the pier in the new location, as it would have been moved over 3 or 4 ft. It also appears that he ignored the statements of the contractor and resident engineer who built the piers that they were surely founded on rock. Later, the sinking of the coffer-dam around Pier 4 disclosed the fact that the rock slopes in a direction opposite to the slope on which he based his theory, a fact that could easily have been determined by running jet pipes down to rock at several places around the pier.

### Annular Coffer-Dams Sunk in 1898 and 1899.

Mr. Patton's report was accepted, and bids were requested on his plans and specifications, with the following results:

Engineering-Contracting Company. (Charles Sooysmith, M. Am. Soc. C. E.):

Pivot pier, $38 332. $1 500 per ft. below 40 ft. below low water.

Pier 4, $36 010. $1 200 per ft. below 45 ft. below low water.

$18 per cu. yd. for work below the cutting edge of both piers.

Missouri Valley Bridge and Iron Company. (The late A. J. Tullock, M. Am. Soc. C. E.):

Pivot pier, $31 600. $800 per ft. below 40 ft.

Pier 4, $27 950. $750 per ft. below 45 ft.

Removal of material between new coffer-dam and old pier and all other work, cost plus 10 per cent.

McGee-Kahmann and Company, Kansas City:

Both piers, $116 000.

Excavation of material between, $1 per cu. yd.

Three companies made propositions for building new piers, as follows:

McGee-Kahmann and Company proposed to build four new piers, 50 ft. north of the present piers, launch the draw-span 50 ft. north, and construct a new span 50 ft. shorter between Piers 5 and 6 and a deck plate-girder at the south end, for $99 000. They also made an alternate bid to build a new draw-span, 80 ft. longer than the old one, reaching from the south abutment to the new piers, renewing Piers 2, 3, and 4, farther north, and to build a new span between Piers 4 and 5, for $125 000. The latter plan would have left in the defective Pier 5.

The Missouri Valley Bridge and Iron Company proposed to build an entirely new set of piers, according to the best modern practice, for $125 000.

All propositions for new piers were rejected, and the bid of the Missouri Valley Bridge and Iron Company for going ahead on Mr. Patton's recommendation was accepted. Mr. A. J. Tullock, then Proprietor of the Missouri Valley Bridge and Iron Company, had made a careful investigation before bidding; the correspondence accompanying his bid pointed out the weaknesses of Mr. Patton's scheme, and made certain recommendations. On account of the value of Mr. Tullock's conclusions, his letters of August 17th, 18th, and 19th, 1898, to Mr. E. Fisher, then Engineer of Bridges and Buildings, of the Railway Company, are given in full in Appendix B.

As a result of his study, Mr. Tullock raised a doubt as to the correctness of the theories formerly advanced regarding the trouble, and attributed it to the crushing of the crib timbers. He pointed out the impracticability and probable impossibility of carrying out the Patton scheme, and recommended against it, giving as his opinion that it was too dangerous to warrant its adoption. He recommended that the cribs be cleaned out and filled with concrete. Although recommending against the repair work, he submitted the lowest bid for it, and received the award.

The work of sinking the annular caissons and coffer-dams went forward in the fall of 1898, and was completed early in the summer of 1899.

At Pier 4, a timber caisson, about 50 by 70 ft., was constructed around the old pier, the intention being to carry out the work, as nearly as practicable, in accordance with Mr. Tullock's proposal of August 17th, 1898 (Case 2, Appendix B).

Two rows of piling were driven around the old pier, about 8 or 10 ft. apart, and were capped and cross-capped; the caisson and crib were built on top of these caps to a height of 12 ft. Large screws, 16 ft. long, were then used to lower the crib until it floated. The crib projected 4 ft. above the water, and the cutting edge floated about 4 ft. above the bed of the river; sand was used to fill the crib to sink it, while men were raising timber on top of the crib.

On March 1st, 1899, with the cutting edge on the bed of the river at an elevation of 11 ft. below zero, air was forced into the working chamber and excavation was made through the following material:

From Elevation 11 to 17..........Sand.
From Elevation 17 to 23..........Rip-rap and sand.
From Elevation 23 to 41..........Sand.

On April 2d, 1899, at 41 ft. below low water, hard shale was struck near the center of the up-stream end. From 41 to 45 ft. below zero, excavation was made through very hard black shale on the north side and at the up- and down-stream ends. This rock was nearly as hard as granite, requiring dynamite to make the excavation.

At an elevation of 45 ft., the inside cutting edge on the south side was landed on rock, except about 10 ft., where the rock was 6 in. below the edge. The rock under the outside cutting edge on the south side was from 12 to 13 in. below it. However, the sand was taken out down to the rock, and the working chamber was sealed with from 2 to 4 ft. of concrete, depending on the depth of rock.

The crib was built 58 ft. high, the top being 13 ft. above low water when the caisson was sealed. Later, the top of the crib was disconnected, from 6 to 7 ft. below low water, after concrete had been placed between the old and new cribs. The sealing of the working chamber was completed on April 24th, 1899.

The river began rising very rapidly on April 22d, and on the 23d a 7-ft. rise was reported at Fort Smith. This reached Little Rock a few hours after the work of sealing the working chamber had been completed, the water rising over the top of the crib. Work was suspended from April 25th until June 30th, and then two pumps and an air-lift were used to remove the water between the old and new cribs, and men commenced excavating the loose sand and sediment from around the old pier, but no effort was made to go below the depth uncovered by the pumps, or to remove the silt. The silt and sand were cleaned out to a depth of 5 ft. on the up-stream and 7 ft. on the down-stream end below the top of the old crib. Investigation of the timber in the old crib disclosed crushing on the north side, but only to the extent of compressing the timber, and not dividing the grain. The timber was good and sound.

A great deal of the 3-in. sheeting was found to be torn off, and it was seen that the spaces between the timbers of the crib were filled with sand and loose rock. The sheeting which had been torn off was replaced. It was also observed that the deck or top of the old crib dipped from 1 in. to 1½ in. from a point near the center on the south side of the pier toward the up-stream end.

On July 1st, while the loose material between the new coffer-dam and the old crib was being excavated, it was discovered that the pier had settled about ½ in. This led to the immediate abandonment of the excavation, but the spaces on the north and west sides were driven full of piles, with a penetration of about 15 ft., and the space already excavated was filled with concrete up to the top of the old crib. None of the material within the old crib was removed, and no effort was made to grout it or to fill in the vacant spaces with concrete. In fact, the sheeting that was replaced effectually prevented the concrete from flowing into the vacant spaces within the crib. The concreting around the old pier was completed on July 6th, 1899, and both walls of the annular coffer-dam were then removed, down to 6 or 7 ft. below low water.

The location of the new annular caisson and coffer-dam around Pier 4, with reference to the old crib, together with the general construction of both, is shown by Fig. 5, which also shows in cross-section the concrete, from 3 to 5 ft. thick, that was placed between the old crib and the new coffer-dam. The annular caisson was about 50 ft. wide and 70 ft. long, the sides were 10 ft. apart, and spaces from 6 ft. to 7 ft. 6 in. wide were left between the old and new work.

The work at the pivot pier was similar in character, except that the new caisson was 70 ft. square and the concrete about 15 ft. thick, the extra depth having been caused by scour and not by excavation. (Fig. 5 does not show correctly the pier top at this time (1898), but as it appeared several years later, after additional movement had taken place.)

Mr. Tullock considered the removal of the material between the new and old caissons to be very hazardous, and he continued to impress this opinion on the officials of the Railway Company. He was so much impressed by it that he continually recommended and urged that only part of the material be removed and that the remainder be confined by placing concrete over it. Unfortunately, the Railway Company was guided by his advice in this matter. Two of Mr. Tullock's letters to Mr. Fisher, relative to this matter, dated November 24th, 1898, and May 16th, 1899, are printed in full in Appendix C.

It is to be regretted that, after having incurred the great expense of sinking the annular caissons, more benefit was not derived from them. The scheme of jacking up the piers and underpinning them

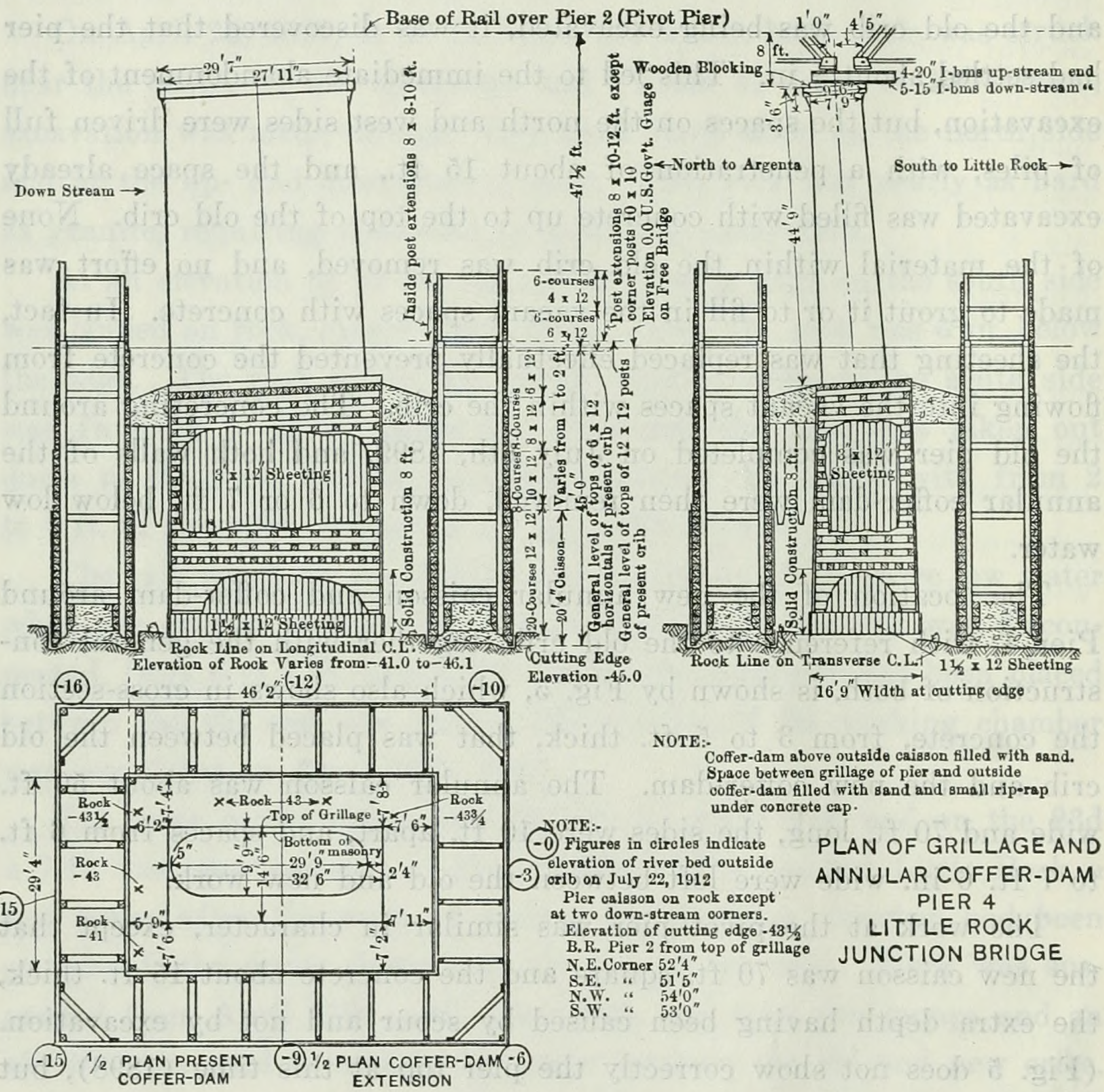



FIG. 5.

appears to have been abandoned early, as no reference to these matters can be found in the files during the work. Neither was any effort made, by exploring under the cutting edges of the new caissons, to determine the depth to which the original caissons had been sunk.

During May, 1899, the concrete having been placed around the pivot pier, the wheel-tread under the drum of the draw-span was leveled up and underpinned with concrete, the minimum rise being 2⅝ in. and the maximum 6½ in.

At the same time, but prior to the placing of the concrete around Pier 4, the spans on that pier were also leveled up and carried on oak blocking in place of the bed-plates, the spans being raised from 1¼ to 6 in. This work was done too soon, as a slight settlement of Pier 4 during the work threw the track out of line.

The pier tops had moved around so much, and their upper surfaces were so small, that the trusses could not be placed on a straight line. The trusses had been built with extra wide clearance to provide for highway traffic, and this permitted considerable latitude in the location of the track. The trusses were permitted to remain out of line, and the track was placed on a tangent, being nearer to one truss than to the other where the spans were out of line. The location of the center line of the track with reference to the track stringers and trusses is shown on Plate I.

### Further Movement of Pier 4.

On account of the large quantity of concrete placed around the pivot pier, and the depth to which it reached, 15 ft. below the top of the crib, no further movement has been detected in this pier. However, the movement of Pier 4 was not arrested, but as the settlement and movement continued, a policy of "watchful waiting" was followed for several years. The situation again became critical early in 1906, when Pier 4 had moved so far that one of the spans was in imminent danger of falling off.

At that time J. C. Bland, M. Am. Soc. C. E., was retained as Consulting Bridge Engineer of the Missouri Pacific Railway, and was asked to look into the matter and pass on it. He arranged to have John N. Ostrom, M. Am. Soc. C. E., visit the bridge and report on it. That portion of Mr. Ostrom's report having reference to the foundations is as follows:

"The roller nests at north end of span, which is next to the draw-span on the north, are badly shifted to the south, so that two of the rollers do not bear.

"The main trouble with the bridge is in the foundations, and, like the Baring Cross Bridge, about one mile above, there are no original records showing the exact conditions of the bearings on the bottom.

The pivot pier, Pier 3 and Pier 4, on the north side of the pivot, are all tilted up stream and also sideways.

"The pivot pier and Pier 4 have been protected by concrete additions extending clear around the base on the outside and reaching down into the rock. It is believed that the tilting of the pivot pier, at least, has been arrested.

"The piers also have well-defined vertical cracks extending through several courses, indicating uneven bearing on the bottom, but the cracks are not bad enough to endanger the structure at present.

"The south abutment has a deep crack in the up-stream wing-wall, and the north face next to the river has several bands, one above the other, held by bolts which pass south into the abutment.

"Pier 7 on the north shore is cracked, and banded with tie-rods running through yokes on the up- and down-stream ends.

"The most important matter at present is to make careful measurements at least once a month on all the piers and abutments with a view of determining whether or not the tilting and cracking has stopped. If these measurements show that the masonry has become fixed in position, it may be assumed safe for the life of the present superstructure, but it would not be suitable for a new bridge designed under present specifications.

"If the cracks in piers increase, they should be banded, and the cracks should be pointed as soon as practicable, to exclude water.

"Owing to the tilting of foundations, the surface and alignment of the track is very bad on the bridge. As the piers have tilted up stream the track has been shifted down stream to keep the alignment as good as possible until the down-stream stringers are carrying considerable more than half the load. Furthermore, the clearance between the train and the down-stream truss has been reduced by the amount of shifting of the track."

"Jno. N. Ostrom."

"To Mr. J. C. Bland.

"May 21, 1906."

In transmitting Mr. Ostrom's report to M. L. Byers, M. Am. Soc. C. E., then Chief Engineer of Maintenance of Way, Mr. Bland wrote in part as follows:

"June 4, 1906.

"M. L. Byers.

"One can hardly tell much about the masonry tilting. The plans you sent show the tilting but do not say the character of foundation, nor whether the condition is becoming worse. You will notice that Mr. Ostrom says:

"'It is believed that the tilting of the pivot pier, at least, has been arrested.'

"Who is it that says so, and on what grounds?

"I think you should use slow speed over the bridge, and also I would prohibit the stopping and starting of trains on bridge, if such an order is practicable.

"J. C. BLAND."

Following this report no immediate action was taken.

One of the first duties assigned to the writer when he entered the Bridge Department of the Railway Company, late in 1907, was an inspection of this bridge in order to determine how to maintain it in safe condition. At that time, the location of the pedestals of the spans with reference to the coping courses on Piers 3, 4, 5, and 6, was as shown in Fig. 6. Pier 4 had moved out so far from under the shoes that the center of the end pins was almost exactly over the edge of the timber blocking under the shoe; the edge of the shoe overhung the edge of the pier, as shown in Fig. 7.

PLAN SHOWING RELATIVE POSITIONS OF
TRUSS PEDESTALS AND TOP OF PIERS
LITTLE ROCK JUNCTION BRIDGE
DEC. 1907

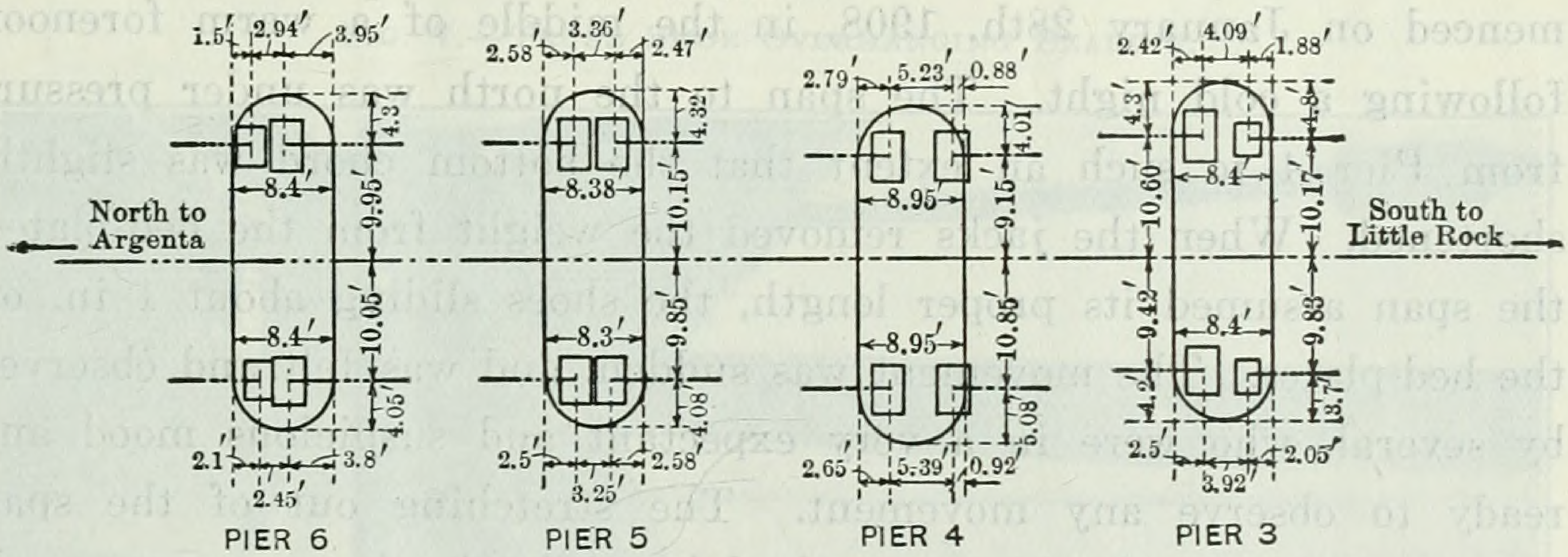



FIG. 6.

The roller end of the span to the south, being on Pier 4, permitted the pier to move out from under. The fixed end of the span to the north being on Pier 4, the thrust caused by the leaning of the pier in that direction had crowded the roller end of this span on Pier 5 hard against the fixed end of the next span. This thrust, added to the similar, though less, defective construction of Pier 5, caused the latter to lean north, crowding the roller end of the next span to the north, hard against the fixed end of the north span on Pier 6, bringing three spans in hard contact. On hot days, when the bridge was not loaded, the chord bars in the end panels of these spans could be seen to be more or less buckled, but they always straightened out under trains, undoubtedly because the elasticity of the timber cribs permitted the piers to move back and forth.

Immediately following his first visit to the bridge, the writer worked up plans for placing a nest of I-beams under the truss shoes at each end of Pier 4, so that the overhanging ends of these beams would afford support for the end of the next span south to keep that span in the air instead of in the water. Fig. 9 shows the arrangement of I-beams for this purpose. There was only sufficient depth for 15-in. I-beams at the high end of the pier, but at the low end, there was sufficient depth for 20-in. beams, the difference in height being due to the settlement.

The plans first contemplated driving piles on both sides of Pier 4 to be used for jacking during the placing of the I-beams, but, on account of the extreme length of the piles required (from 80 to 90 ft.) and the hazard attending their maintenance in the Arkansas River, it was decided to avoid their use and jack from the pier top.

The jacking arrangement was set in place and jacking was commenced on January 28th, 1908, in the middle of a warm forenoon following a cold night. The span to the north was under pressure from Pier 4 to such an extent that the bottom chord was slightly shortened. When the jacks removed the weight from the bed-plates, the span assumed its proper length, the shoes sliding about 1 in. on the bed-plates. The movement was sudden, and was felt and observed by several, who were in a very expectant and suspicious mood and ready to observe any movement. The stretching out of the span was overlooked, as it was not noticed immediately that no corresponding movement had taken place under the roller end of the other span on the same pier. The pier had such a bad record that all the men engaged on the work believed it had suddenly moved and was going to fall, and the forces, led by the foreman, fled from the structure, headquarters being advised by telegram as follows:

"Began jacking bridge this A. M.; raised 1 in. when Pier 4 moved north 1 in. Will be necessary to yoke Piers 3 and 4 to span before it will be safe to handle driver for falsework. It will be necessary to put spans on falsework before we can resume traffic."

As an emergency matter, to retard the movement of Pier 4 and to avoid any such scare during the work, the yokes and rods shown

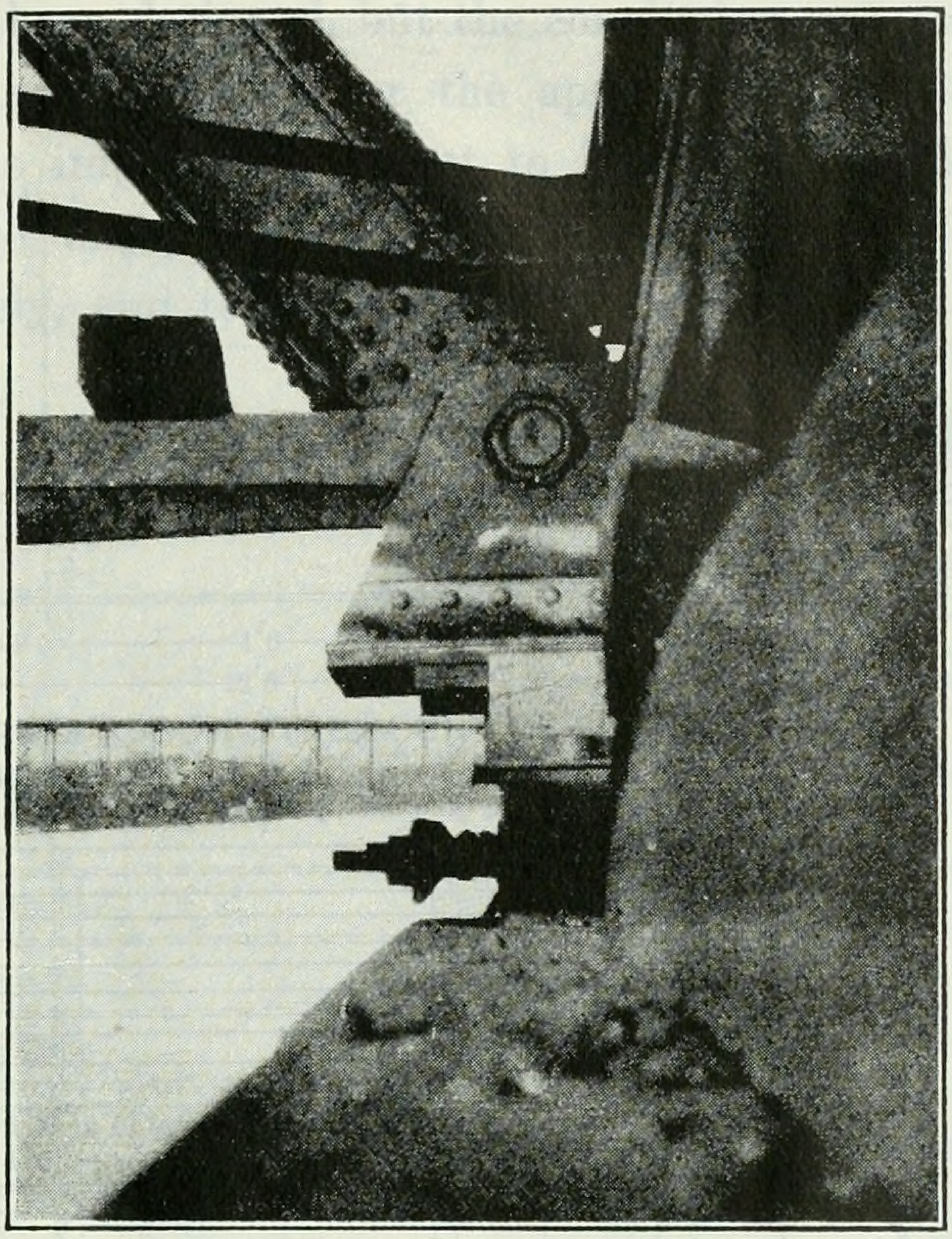


FIG. 7.—TRUSS SHOE OVERHANGING BEARING.

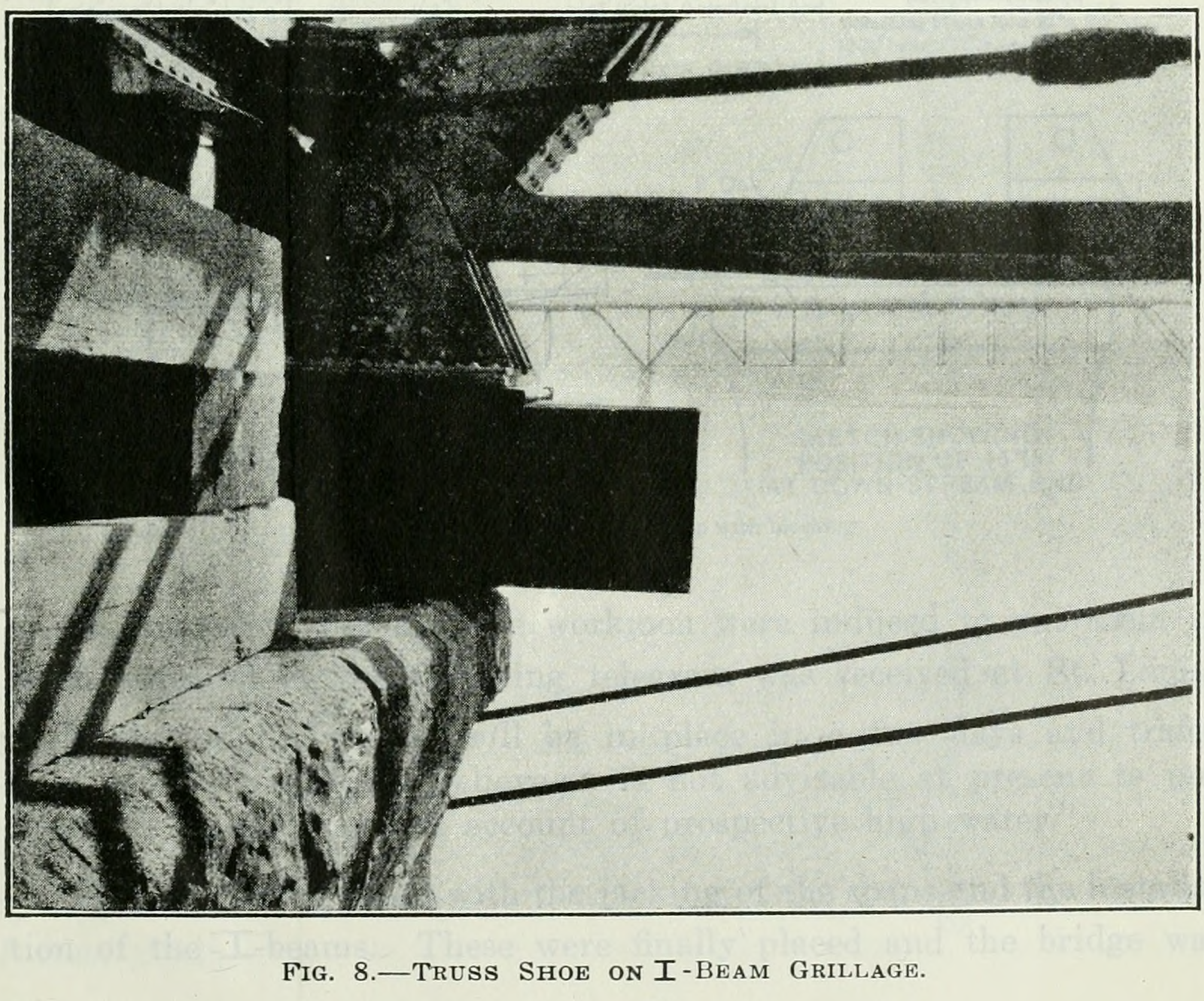
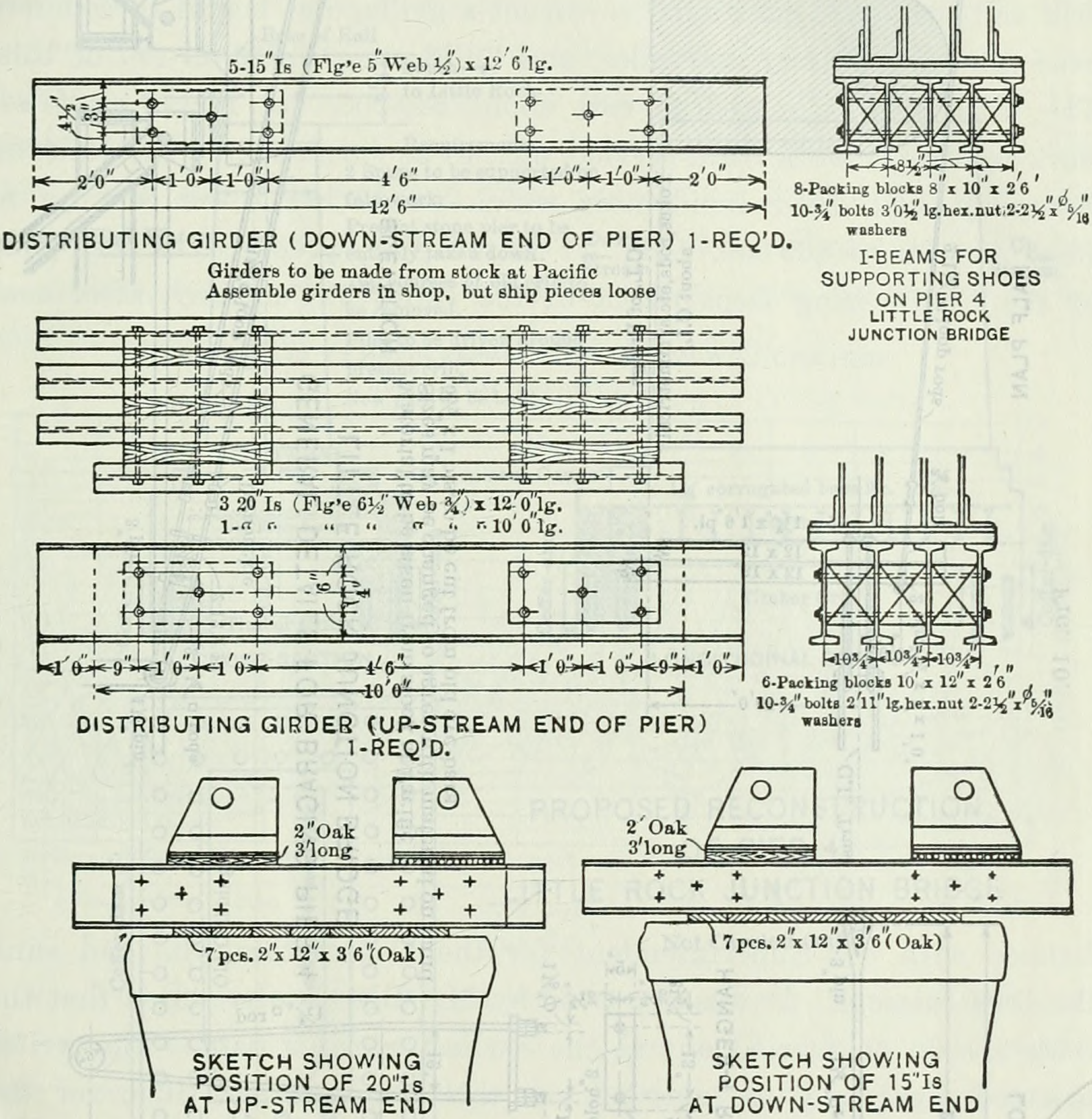


FIG. 8.—TRUSS SHOE ON I-BEAM GRILLAGE.

by Fig. 10 had been designed, but the conclusion was reached that they would not be necessary. After the apparent movement of the pier, however, it was impossible at first to induce the workmen to return to the structure, and arrangements were completed to make the rods, etc., immediately, and to apply them—for their moral effect as much



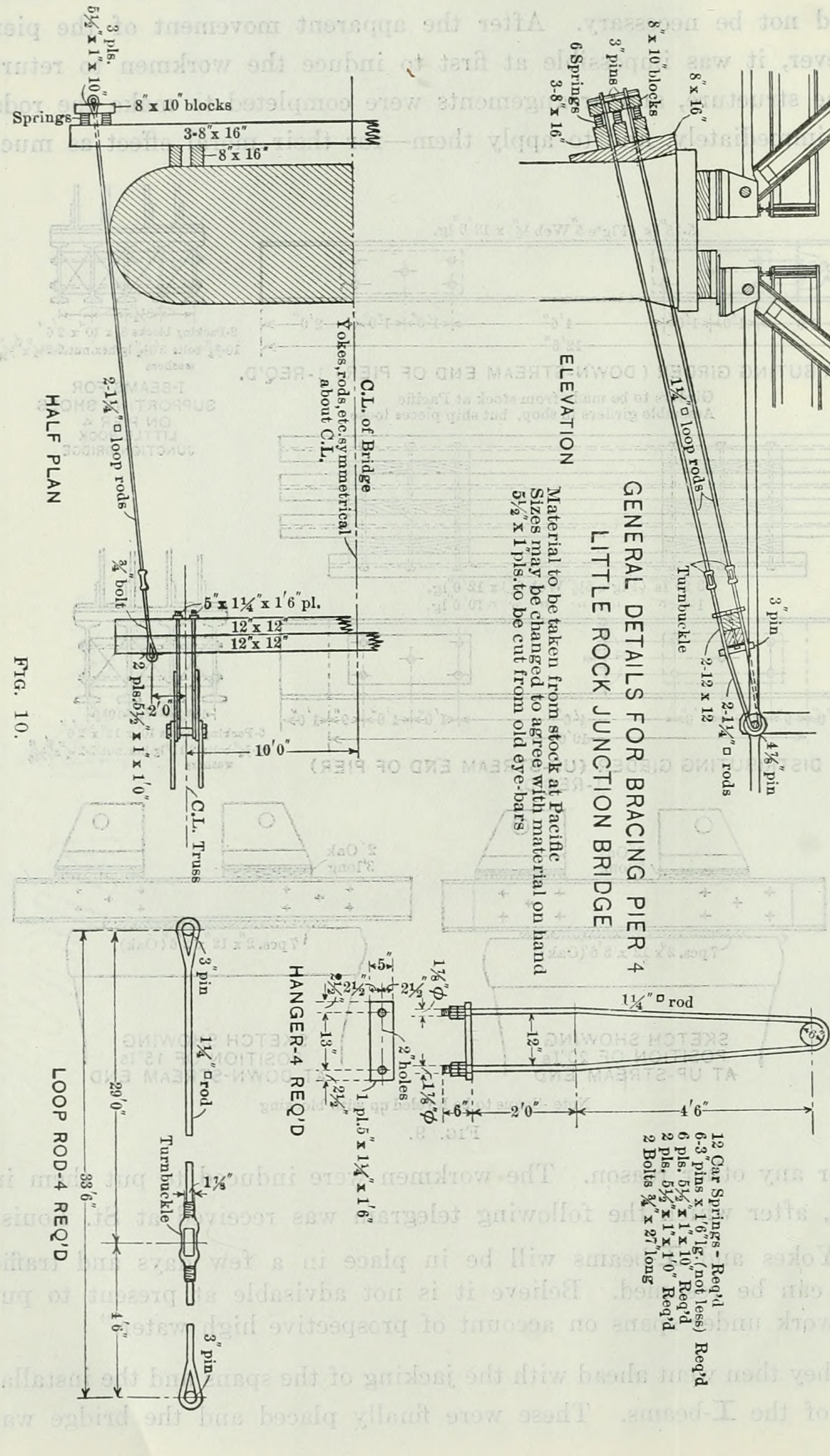

Note -Spans to be leveled up with blocking

FIG. 9.

as for any other reason. The workmen were induced to put them in place, after which the following telegram was received at St. Louis:

"Yokes and I-beams will be in place in a few days and traffic then can be resumed. Believe it is not advisable at present to put falsework under spans on account of prospective high water."

They then went ahead with the jacking of the spans and the installation of the I-beams. These were finally placed and the bridge was



GENERAL DETAILS FOR BRACING PIER 4
LITTLE ROCK JUNCTION BRIDGE
Material to be taken from stock at Pacific
Sizes may be changed to agree with material on hand
5½" x 1" pls. to be cut from old eye-bars
ELEVATION
HALF PLAN
C.L. of Bridge
Yokes, rods, etc. symmetrical about C.L.
C.L. Truss
HANGER-4 REQ'D
LOOP ROD-4 REQ'D
12 Car Springs - Req'd
6-3" pins x 1'6" lg. (not less) Req'd
6 pls. 5½" x 1" x 10" Req'd
2 pls. 5½" x 1" x 10" Req'd
2 Bolts ¾" x 27" long


FIG. 10.

restored to service on February 1st, 1908, 4 days after the commencement of the jacking.

After placing the I-beams, the spans were shifted slightly to remove their interference, and the rollers were cleaned and oiled. The yokes were left in place, and instructions were issued to have them tightened

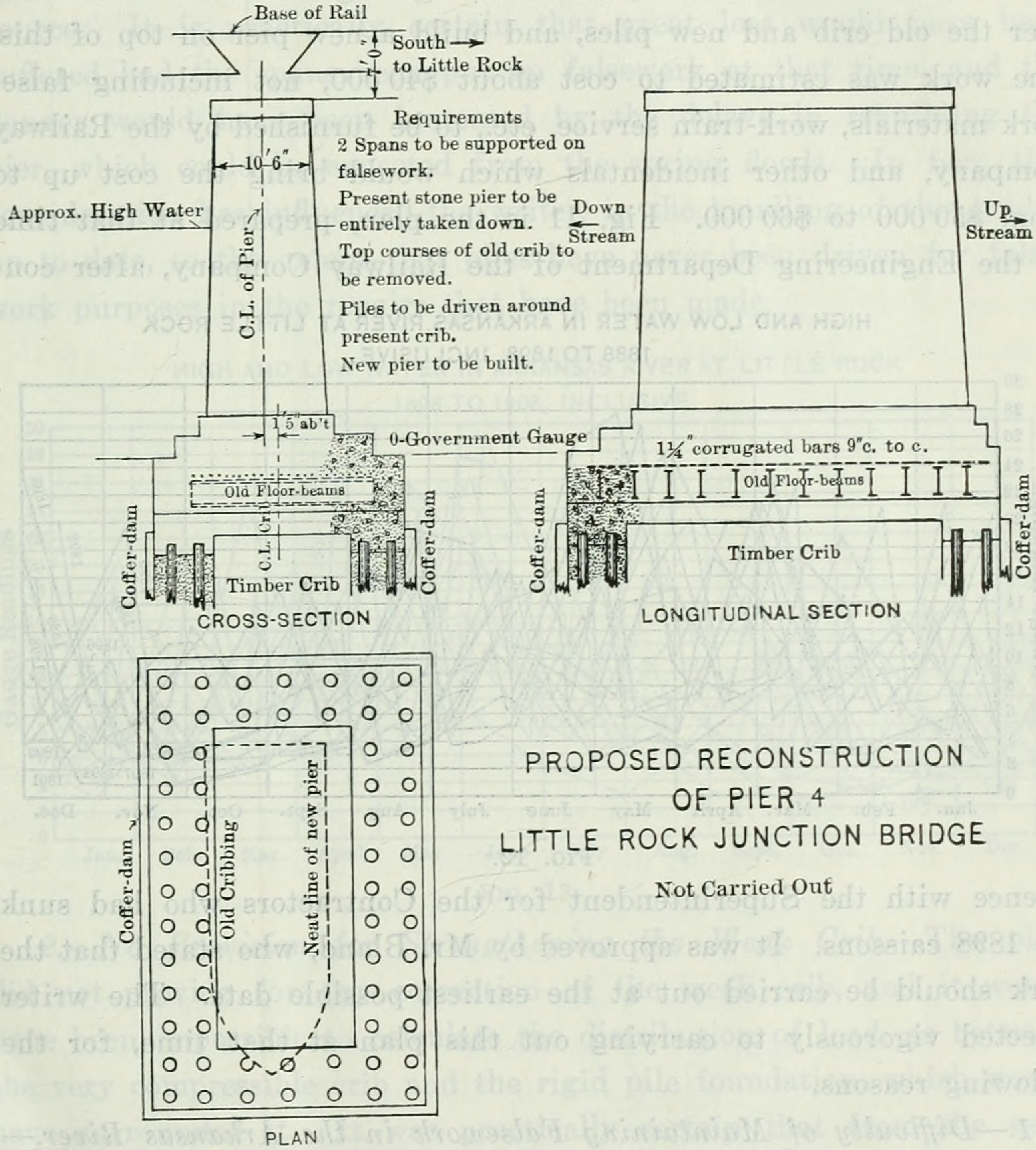



FIG. 11.

every month. No further attention was paid to the placing of the falsework. The condition of the bearing under the expansion end of the span to the south, before the I-beams were placed, is shown by Fig. 7. Fig. 8 shows the condition afterward. The bearing having been made safe, the matter of permanent repairs was then given further study.

## Plans for Reconstruction of Pier 4.

Late in 1907 tentative plans had been made to replace Pier 4 by a larger one. It was planned to place the two spans resting on Pier 4 on falsework, take down the masonry pier to the top of the crib, drive as many piles as possible in the annular space between the old crib and the 1898 coffer-dam, construct a grillage of beams in concrete over the old crib and new piles, and build a new pier on top of this. The work was estimated to cost about $40 000, not including falsework materials, work-train service, etc., to be furnished by the Railway Company, and other incidentals which would bring the cost up to from $50 000 to $60 000. Fig. 11 is the plan, prepared at that time by the Engineering Department of the Railway Company, after con-

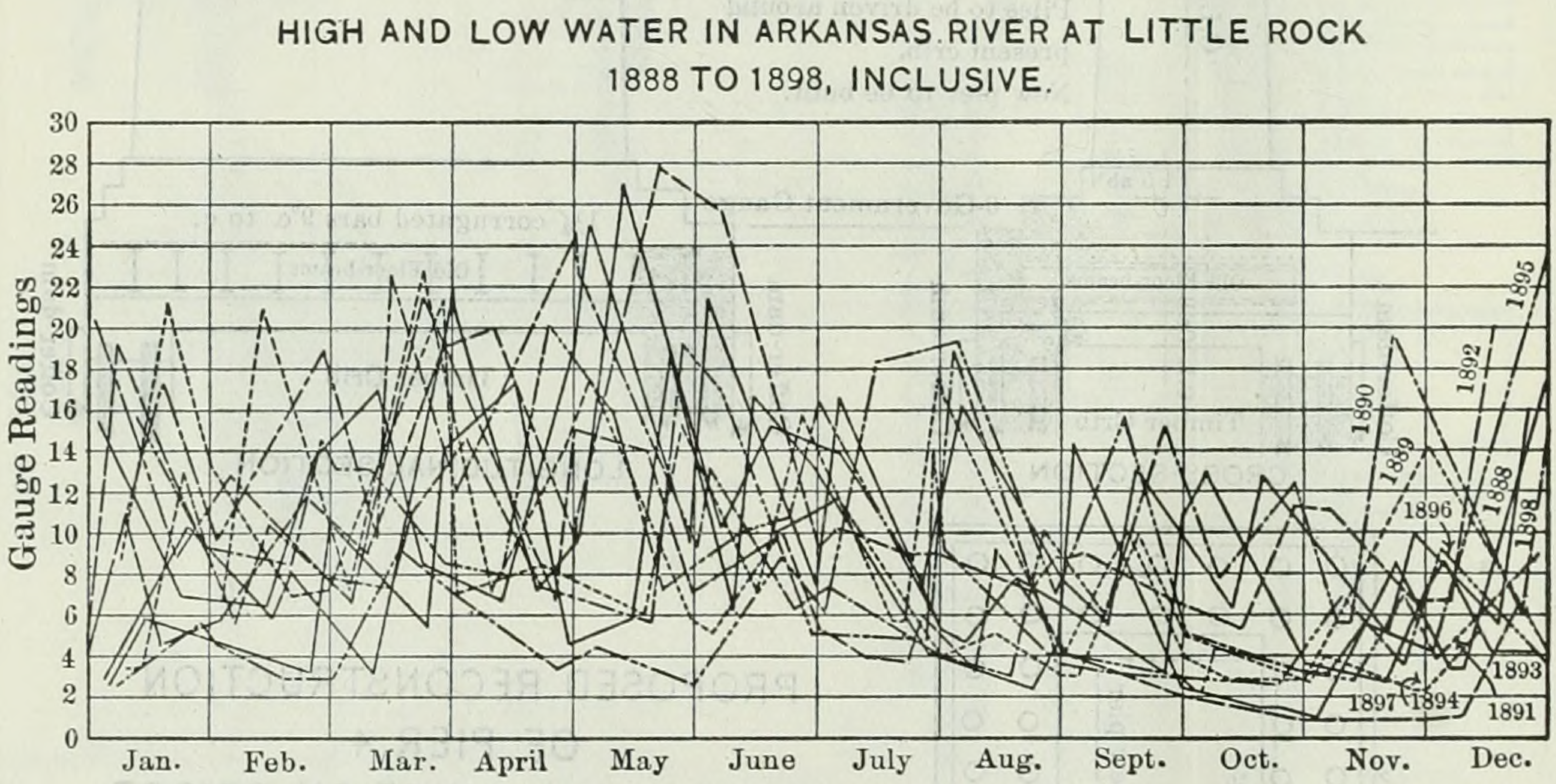



Fig. 12.

ference with the Superintendent for the Contractors who had sunk the 1898 caissons. It was approved by Mr. Bland, who stated that the work should be carried out at the earliest possible date. The writer objected vigorously to carrying out this plan at that time, for the following reasons.

*1.—Difficulty of Maintaining Falsework in the Arkansas River.*— Figs. 12 and 13 are hydrographs of the Arkansas River for 20 years, 1888 to 1908, and show that in the spring, when it would have been necessary to maintain two 253 ft. 4-in. spans on falsework with 80-ft. piles in the middle of the river, the floods are greatest. They also show that sudden rises can be expected in any month of the year, and are greatest in spring and least in early fall. Rises in the Arkansas are invariably rapid, and are characterized by excessive quantities of drift, some of it whole trees, 80 or 90 ft. long, from 2 to 3 ft. in diameter and full of branches, and also by deep and rapid scour, down to rock, of the fine sand and silt forming the bed, especially around obstructions of any nature. In the past the Arkansas has taken heavy toll in falsework and spans, and there is hardly a bridge across the river where there has not been some trouble from this source. It is practically certain that great loss would have been suffered had the spans been put on falsework at that time, and the danger would have been increased by the delays in rebuilding the pier, which could be expected from the spring floods. In fact, this consideration has influenced the writer, in the handling of this bridge up to date, to the extent that piles have never been driven for false-work purposes in the repairs that have been made.

HIGH AND LOW WATER IN ARKANSAS RIVER AT LITTLE ROCK
1898 TO 1908, INCLUSIVE.

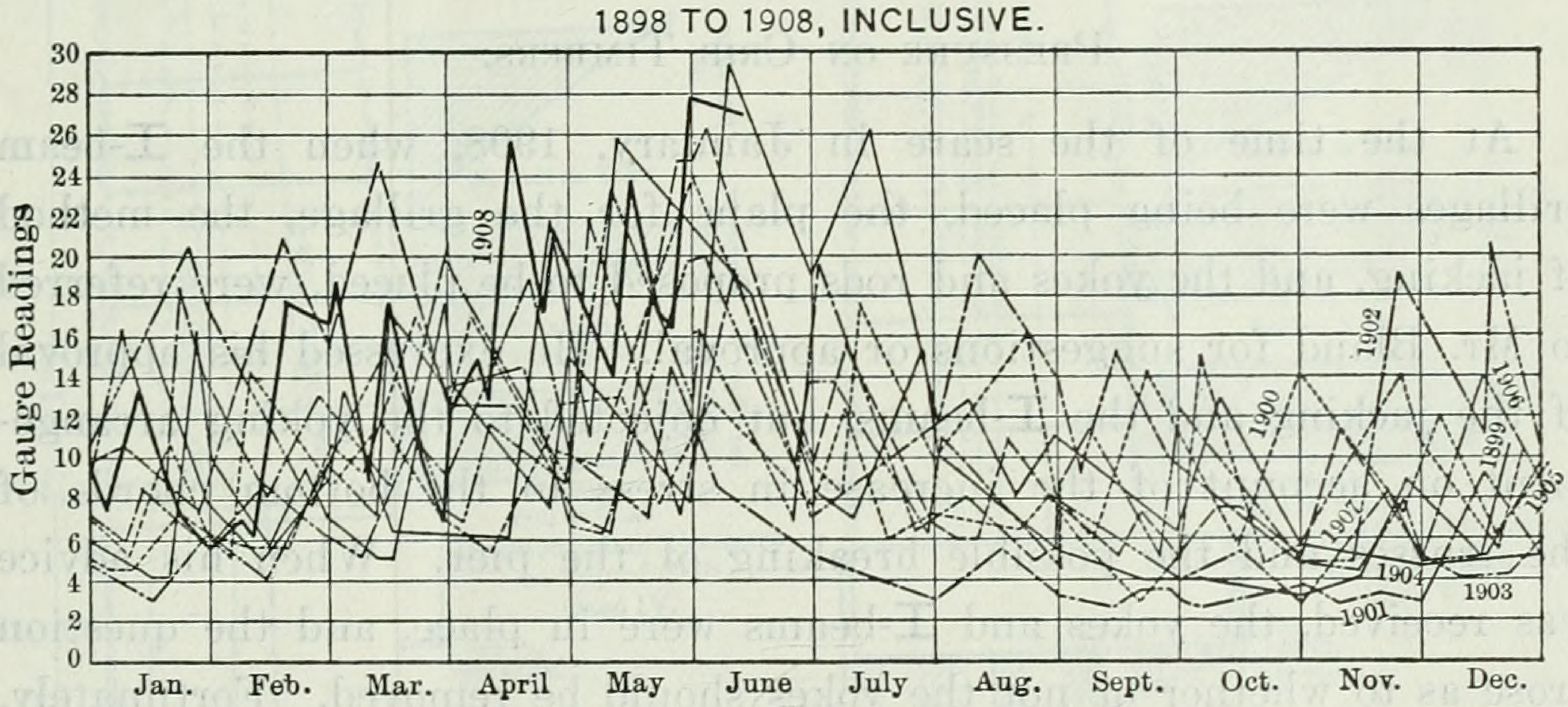



FIG. 13.

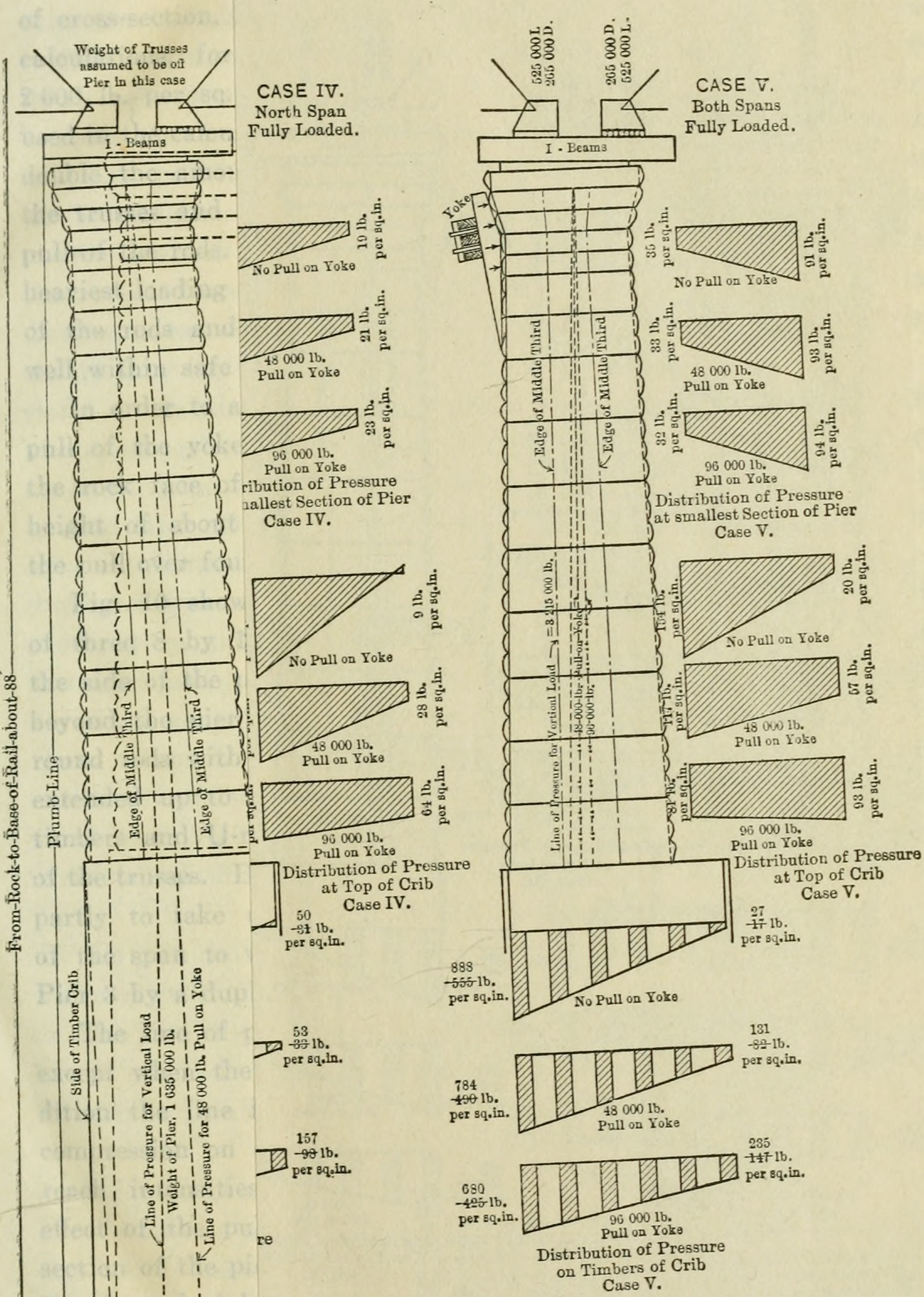
*2.—No Provision for Strengthening the Weak Crib.*—The plan did not provide for any correction of the weak crib, and it would have been impossible to calculate the distribution of load, as between the very compressible crib and the rigid pile foundation, which would have surrounded it. It was practically certain that from the very first the proposed piles surrounding the crib would be badly over-loaded, and failure of some sort could be expected. In fact, the proposed pier was so much larger than the old pier that, if the load could have been distributed uniformly over the base, the weak crib would have been required to carry more load than before.

*3.*—Better results could have been obtained at greatly reduced expense by driving piles as proposed and building up on them a reinforced concrete shell enclosing the old pier, thereby saving the latter and avoiding the cost of its renewal, all the cost and hazard of falsework, and, to a great extent, the uncertainty as to the distribution of the loading. The art is sufficiently advanced to insure absolutely efficient bond between the new encasement and the old masonry (the old was rough rock-face). The reduced uncertainty as to the distribution of the load is due to the fact that from the first the crib would carry its maximum load and be fully compressed during the construction of the encasement, so that the new support would work well with the old.

These three reasons were sufficiently potent to prevent the adoption of this scheme, but it was not possible for the writer to secure in the near future authority to go ahead with the driving of additional piles and the encasement of the pier.

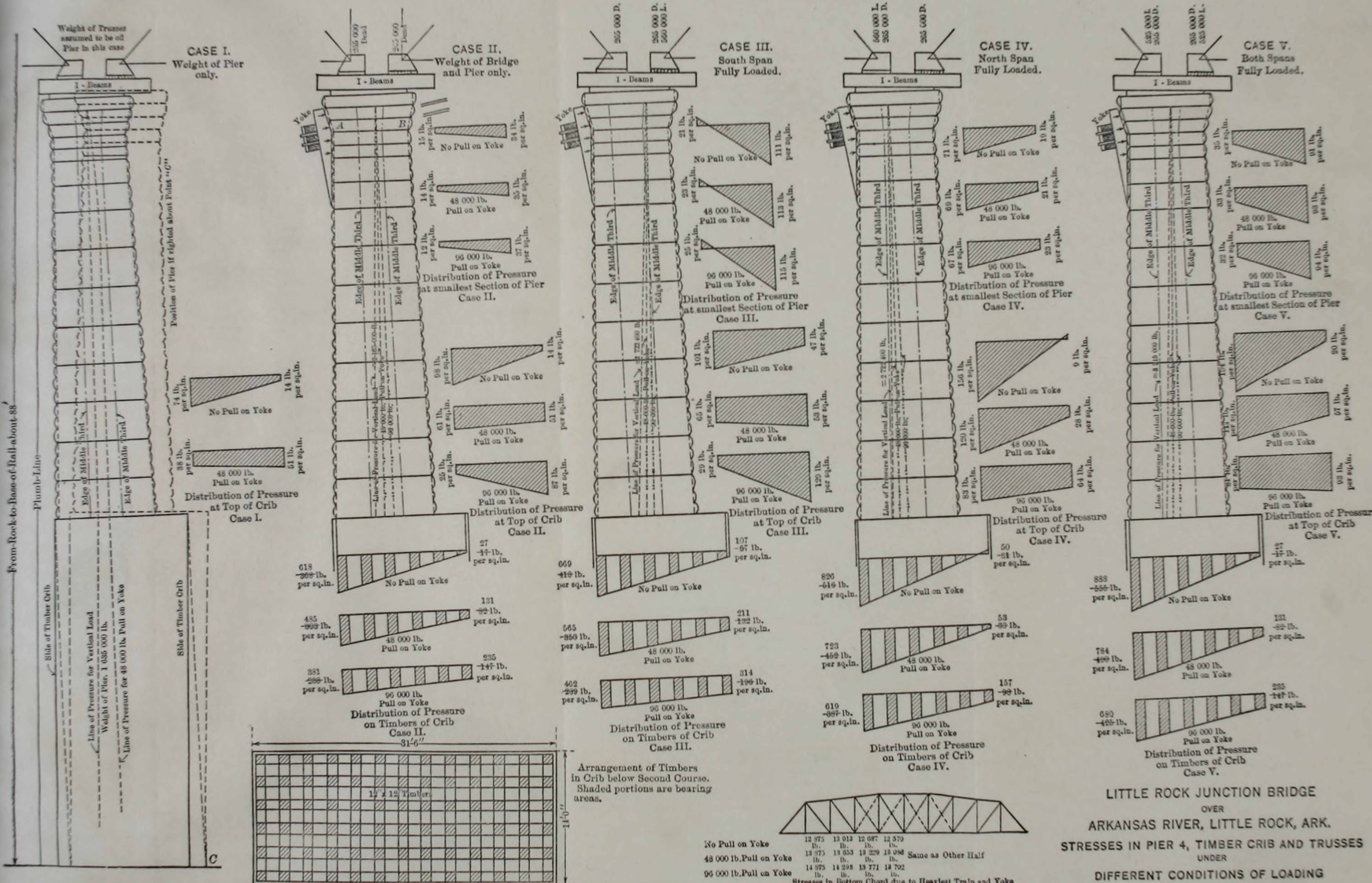
### Pressure on Crib Timbers.

At the time of the scare in January, 1908, when the I-beam grillages were being placed, the plans for the grillage, the method of jacking, and the yokes and rods proposed to be placed, were referred to Mr. Bland for suggestions or approval. He expressed his approval of the jacking and the I-beams, but objected to the yoking arrangement on account of the increase in stress in the bottom chords of the trusses and the possible breaking of the pier. When his advice was received, the yokes and I-beams were in place, and the question arose as to whether or not the yokes should be removed. Fortunately, no one was prepared immediately to assume the responsibility of removing them, and as the writer had suggested putting them on, he was requested to show cause why they should be permitted to remain. Rough figures had previously been prepared, showing the pressure on the crib timbers and the effect of the yokes, but to show better the beneficial effect of even a moderate pull near the top of the pier, the lines and intensities of pressure were determined for all probable conditions of loading and assumed stresses in the yokes. Plate II shows the results, and indicates that even a moderate pull at the top of the pier would be of considerable advantage. The nuts were tightened from time to time, and the springs were kept at such a pressure as to maintain a pull of about 50 000 lb. As the end panels of the bottom chords of the trusses had 48 sq. in.




LITTLE ROCK JUNCTION BRIDGE
OVER
ARKANSAS RIVER, LITTLE ROCK, ARK.
STRESSES IN PIER 4, TIMBER CRIB AND TRUSSES
UNDER
DIFFERENT CONDITIONS OF LOADING

PLATE II.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXIX, No. 1335.
SMITH ON
REPAIRING BRIDGE PIERS.




LITTLE ROCK JUNCTION BRIDGE
OVER
ARKANSAS RIVER, LITTLE ROCK, ARK.
STRESSES IN PIER 4, TIMBER CRIB AND TRUSSES
UNDER
DIFFERENT CONDITIONS OF LOADING

of cross-section, figures of 48 000 and 96 000 lb. were assumed in the calculations, for the amounts of pull corresponding to 1 000 and 2 000 lb. per sq. in., respectively, the latter figure having also been used in the calculations to ascertain the results if the pull should reach double the amount assumed. The results showed conclusively that the trusses and the masonry pier were not adversely affected by the pull of the rods. The maximum stress in the bottom chord under the heaviest loading was about 13 000 lb. per sq. in. before the application of the rods and about 15 000 lb. per sq. in. afterward, an amount well within safe limits.

In order to avoid damage to the pier by the concentration of the pull of the yokes, bearing timbers had been cut to fit the shape of the rock face of the pier and placed in contact with the pier for a height of about 10 ft., resulting in spreading the greater part of the pull over four or five courses.

Fig. 10 shows the yokes and rods. The arrangement consisted of three 8 by 16-in. timbers laid horizontally and blocked against the side of the pier toward which it was leaning, the ends projecting beyond the pier ends and being attached at each end to two 1¼-in. round rods with upset ends. The rods passed close by the pier and extended up to the first panel points of the trusses, where, by the timbers and U-rods, the pull was transmitted to the bottom chord of the trusses. Heavy car springs were introduced at points of bearing, partly to take up the expansion and contraction. The other end of the span to which the yoke had been connected was attached to Pier 3 by a duplicate of this arrangement.

The line of pressure is well within the middle-third for all cases except when the south span only is fully loaded, under which condition the line is outside the middle-third for the top 20 ft. The compression on one side and the tension on the other side did not reach intensities that would cause any alarm, however, and the effect of the pull on the rods was only barely appreciable at that section of the pier.

Alarm had been felt, and the opinion was freely ventured, that the pier was held standing by the weight of the trusses. To dispel this alarm, Case I was chosen; as might have been expected, it shows the fallacy of that opinion and the entire safety of the pier when standing alone.

The records indicated that the crib timbers were 2 ft. 6 in. apart, the old plans showing six longitudinal and thirteen transverse timbers in alternate courses, the bearing areas being the intersections shown cross-hatched in Plate II, a total of 78. The timbers were assumed to be 12 in. wide, thus giving a bearing area of 78 sq. ft. The diagrams showing the distribution of pressure on the timbers of the crib were prepared on this basis, on the assumption that the timbers carried the entire load, and the intensities that have been crossed out were the result. Several years later, when the crib was uncovered, it was learned that there were only five longitudinal and eleven transverse timbers in the alternate courses, and that the center intersection had been omitted in order to make room for the shaft, giving 54 intersections instead of 78. The timbers were found to be of various sizes, from 11 to 12 in. wide, so that the total bearing area was in reality about 50 sq. ft. It was also learned that the timbers carried practically all the load. Calculation with reference to the true conditions would have increased their intensity about 60%, or to the figures given above those crossed out. The maximum pressure of 555 lb. per sq. in. on one side, with 17 lb. per sq. in. on the other, calculated from the information available when the study was first made, easily accounted to the writer for the uneven settlement of the pier, but he had few adherents. Had the correct figure of about 888 lb. per sq. in. in cross-bearing been available at that time, all might have been convinced.

The position of the cross-section of the pier above the crib in Plate II was plotted from very careful measurements in 1908 from the plumb-line shown at the left. The position of the crib and caisson, shown in full lines, was estimated on the assumption that the tilt of the pier was caused by the crushing of the timbers uniformly distributed throughout the height.

The position which the crib and caisson would have occupied, on Mr. Patton's theory of settlement into the foundation and no uneven crushing of timbers, was found by projecting the sides of the crib at right angles to the top, the location and slope of which had been measured. The right-hand cutting edge of the caisson would have been at *C*, and if, by jacking under the other edge, the pier had been revolved about *C* to plumb position, it would have reached the position shown by the dotted lines. The absurdity of that theory is indicated by the position the top of the pier would have occupied with reference to the pedestals of the trusses. The span to the right was never any farther to the right, its position being controlled by its proximity to the draw-span and the proximity of the latter to the south abutment. There would not have been room for the south pedestal of the next span to the north, shown at the left on Plate II.

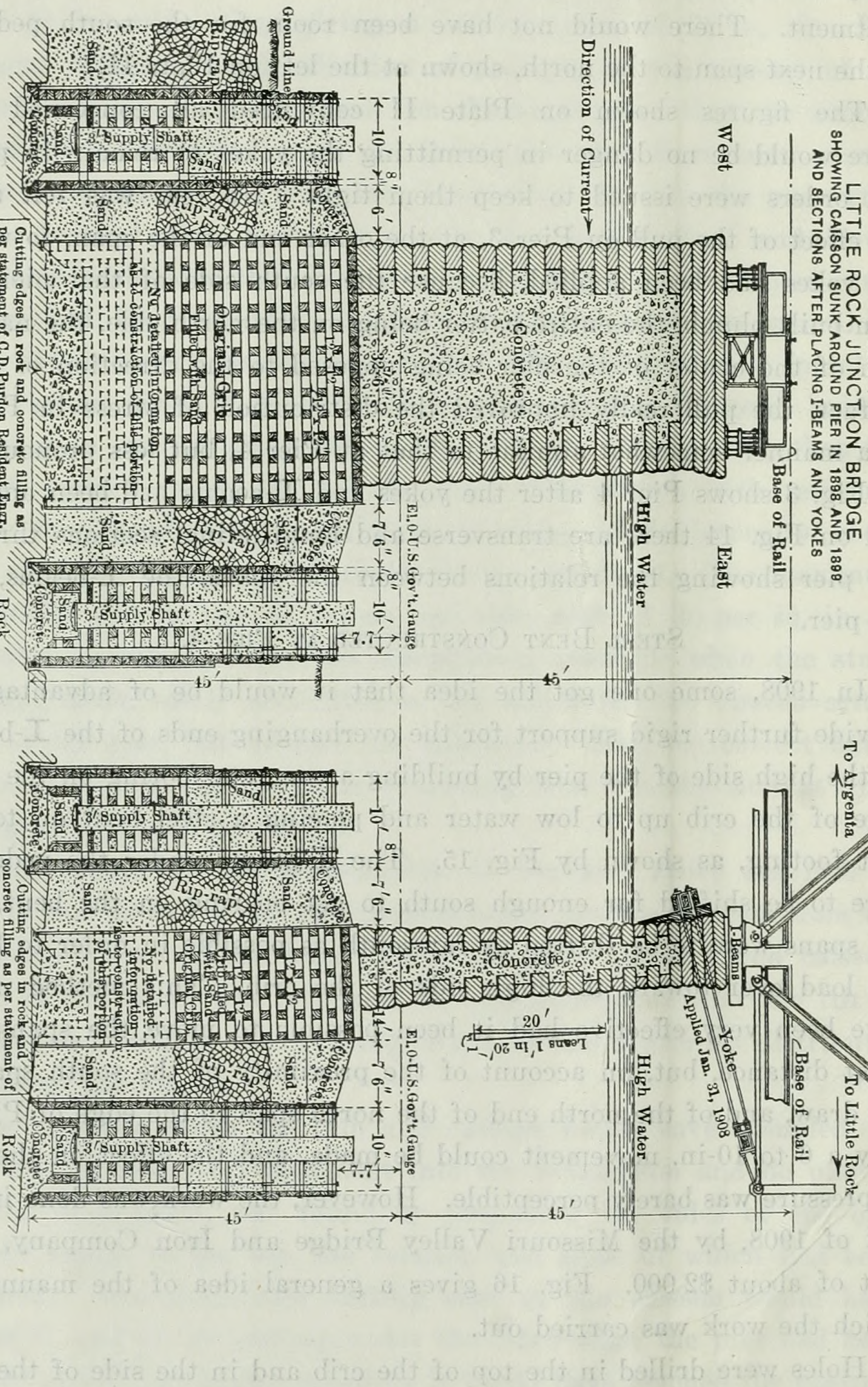
The figures shown on Plate II convinced all concerned that there would be no danger in permitting the yokes to remain in place, and orders were issued to keep them tight. No fear was felt as to the effect of the pull on Pier 3, at the other end of the span, to which the yokes had been applied, because the south side of that pier had been built plumb, the entire batter being on the north side, the natural lean of the center of the pier being opposed to the direction of pull; in fact, the pull really improved the distribution of stress in Pier 3 in a manner somewhat similar to that at Pier 4, but less pronounced.

Fig. 3 shows Pier 4 after the yokes and I-beams had been applied, and on Fig. 14 there are transverse and longitudinal sections through the pier showing the relations between the yokes, the I-beams, and the pier.

### Steel Bent Constructed at Pier 4.

In 1908, some one got the idea that it would be of advantage to provide further rigid support for the overhanging ends of the I-beams on the high side of the pier by building a concrete footing on the wide edge of the crib up to low water and placing a steel bent on top of that footing, as shown by Fig. 15. The I-beams under the pedestals were to be shifted far enough south to get bearing on the bent, and the spans were to be shifted as far south as possible in order to bring the load over toward the high side of the crib. This method might have been very effective had it been possible to move the spans any great distance, but, on account of the proximity of the south span to the draw, and of the north end of the north span to the edge of Pier 5, only a 6 to 10-in. movement could be made, and the effect on the line of pressure was barely perceptible. However, the work was done in the fall of 1908, by the Missouri Valley Bridge and Iron Company, at a cost of about $2 000. Fig. 16 gives a general idea of the manner in which the work was carried out.

Holes were drilled in the top of the crib and in the side of the pier at low water, and bent reinforcing rods were placed in them. A form

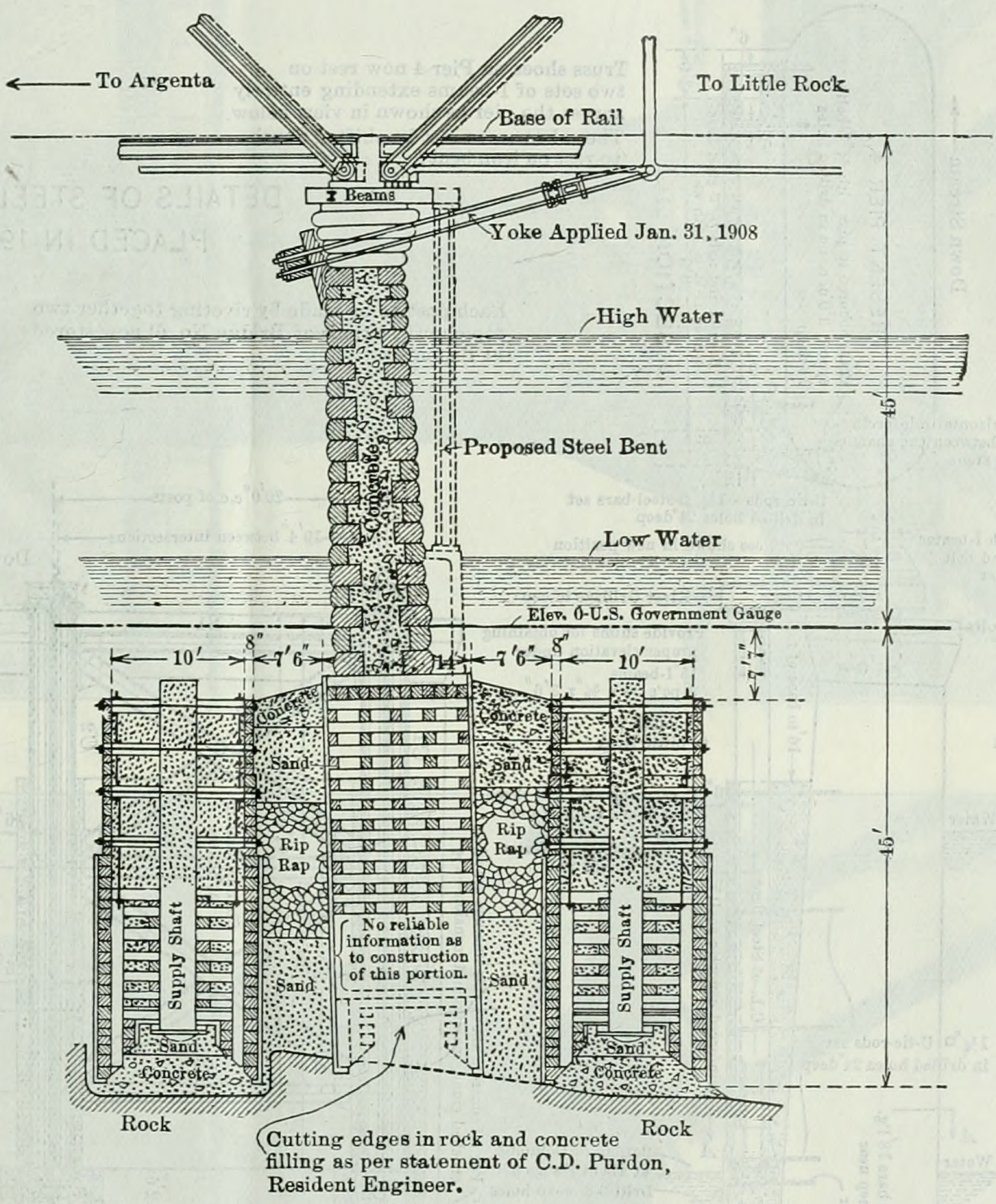



LONGITUDINAL SECTION

SECTIONAL END PLAN

Fig. 14.

was lowered through the water to the top of the crib, and the concrete was deposited by a bottom-dump bucket. A steel bent, made of old top-chord sections, was then placed on this footing and held to the pier by **U**-shaped reinforcing rods set in grouted holes. The col-




SECTIONAL END PLAN
PIER 4
LITTLE ROCK JUNCTION BRIDGE
SHOWING CAISSON SUNK AROUND PIER IN 1898 AND 1899.

FIG. 15.

umns were then encased in concrete up to high water, and a reinforced concrete shell was constructed between them to ward off drift.

Then the **I**-beams and spans were shifted as far as possible, in order to throw the greatest possible load on the new bent. The work was carried out carefully and expeditiously, and offered no unusual difficulties. Fig. 17 is an end view of Pier 4, showing the new bent in place.

Following this work, no appreciable movement in the direction of the bridge was apparent for several months, but the movement at

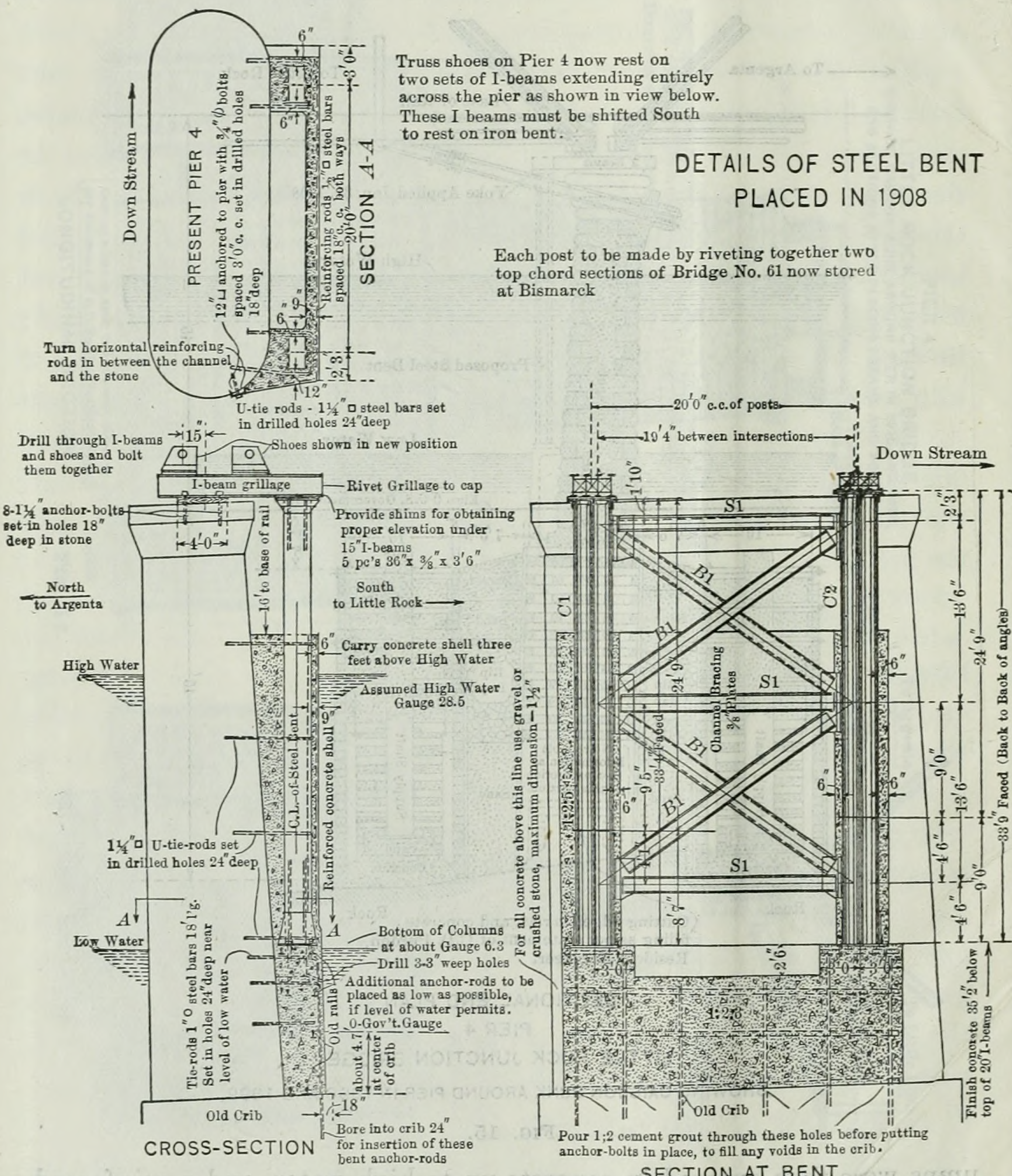



FIG. 16.

right angles to the bridge appeared to increase its rate, indicating that the work had no appreciable effect.

The movement of the pier was greatly dependent on the scour line. When the current shifted away from the pier, the bed of the

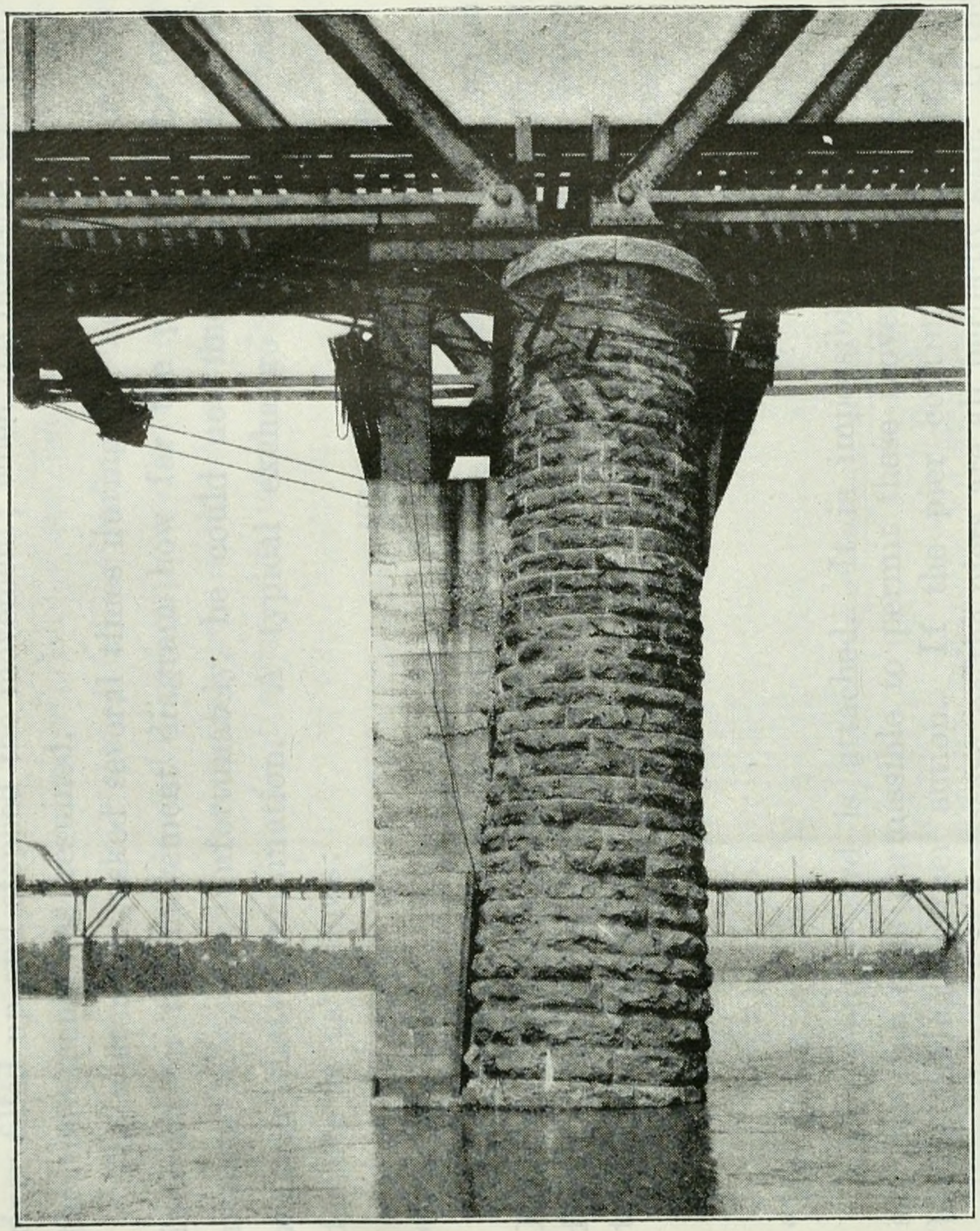


Fig. 17.—Pier 4, Showing Steel Bent Encased in Concrete.

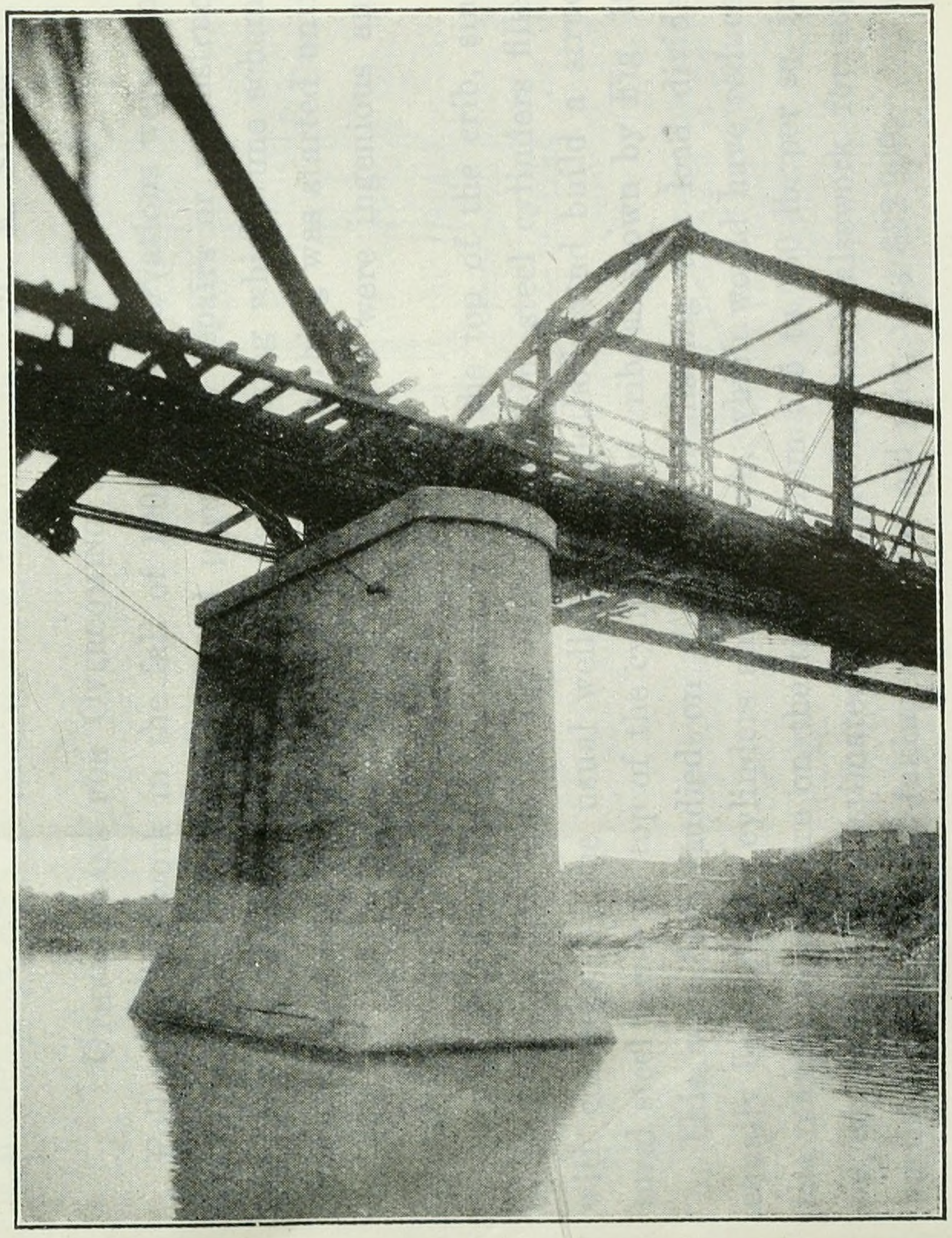


Fig. 18.—Pier 3 After Work was Completed.

river filled up and stopped the movement; when the opposite was true, the movement was resumed.

The writer was asked several times during the next year or two to indicate on the movement diagram how far the pier could go and remain safe, but, unfortunately, he could not find any method of making that determination. A typical exchange of notes on that feature is as follows:

"St. Louis, August 7, 1909.

"Mr. Hale:

"I presume you are in touch with the movement records which Mr. Ford is keeping, and would like to have your opinion as to how far it is permissible to permit these movements to continue before taking further action.

"M. L. Byers."

"8-17-09.

"Mr. Hale:

"Movement record is attached. It is impossible for any one to say how far it is permissible to permit these movements to continue before taking further action. If the pier continues stationary, no action whatever is necessary, as the piers are all perfectly safe. If the movement resumes we must take action.

"C. E. Smith."

### Other Plans for Overcoming Trouble at Pier 4.

Following the work in the fall of 1908, the observations were continued, and the matter of proposed permanent repairs or reconstruction was kept constantly alive for 3 years, during which time scheme after scheme was evolved and considered, but nothing was started until the fall of 1911. As a number of the schemes were ingenious and interesting, some of them will be described.

It was proposed to take down Pier 4 to the top of the crib, sink to rock along each side of the crib 12 or 15-in. steel cylinders filled with concrete, by the usual well-drilling methods, and build a structural steel tower on top of the cylinders and crib, as shown by Fig. 19.

This was first studied on the basis of having the load divided equally between the cylinders and the crib, which would have reduced the maximum pressure on the timbers from 555 to 150 lb. per sq. in., on which basis the estimated cost, including the falsework for supporting the spans and taking down the old pier, was $32 200.

It was realized, however, that on account of the great stiffness of the cylinders and the steel tower, and the great elasticity of the crib, it would be impossible to control the distribution of load among the supports, and, in any event, most of the load would go to the cylinders. If the cylinders were made large and numerous enough and the steel tower strong enough to carry the entire load, the cost was estimated at $43 200.

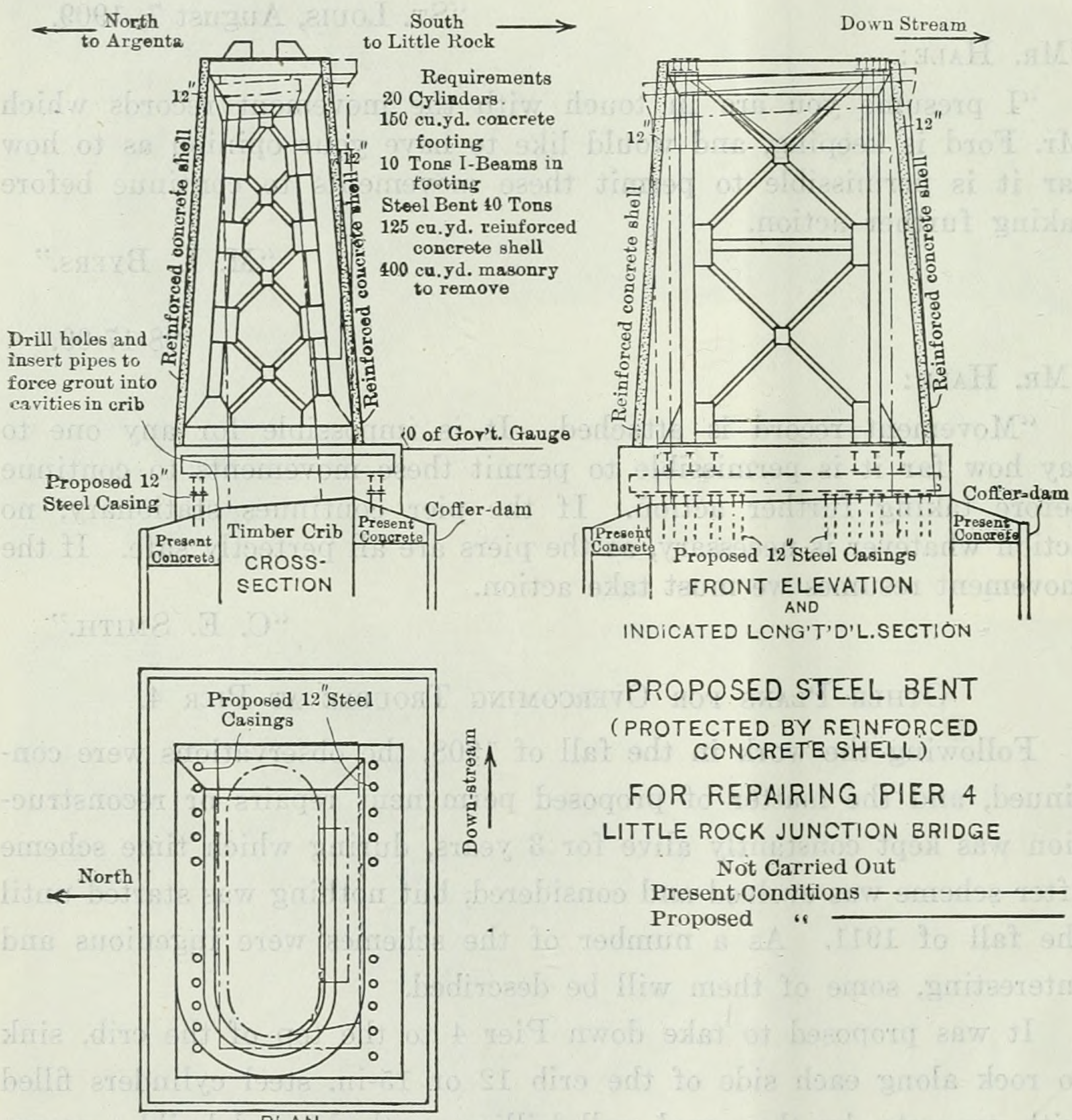



Fig. 19.

On account of the high cost and the uncertainties attendant on this scheme, it was abandoned.

The success obtained in placing the steel bent on the south side of the pier, and the small expense incurred, encouraged the proposition of building another steel bent on the north side. As there was no projection of the timber crib on which to rest such a bent, and as the north edge was badly overloaded and thought to be crushing, it was proposed to sink a row of steel cylinders on the north side on which to rest the bent. This scheme also necessitated the use of longer and heavier beams on top of the pier, in order to distribute the load out to the bents. On account of the pedestals of the trusses being so far on the pier, it was almost impossible to study out any plan that would reduce the load on the pier an assumed amount, but, by changing the point of contact between the I-beams and the top of the pier, it was found possible to throw about 250 000 lb. on the new bent, thereby reducing the maximum pressure on the timbers from 555 to 477 lb. per sq. in. This was estimated to cost about $10 000. The scheme was abandoned on account of its uncertainty.

Of course, it would have been possible to have taken the weight entirely off the old pier and provide cross-girders sufficiently strong to throw the entire load on the steel bent, but the extra expense and uncertainties of this scheme ruled it out.

In the meantime the writer had worked up the plan shown on Fig. 20, which contemplated driving piles to rock by jetting, within two sides of the annular space between the crib and the coffer-dam, toward which the pier was moving, the plan being to remove the concrete cap a section at a time, drive several piles, and replace the concrete as a sub-footing course, and incidentally to preserve the side support afforded by the concrete. To accomplish this it was proposed to build a puddle coffer-dam around the pier within the 1898 coffer-dam in order to hold the water out against about a 10-ft. head, and to force as much concrete and grout as possible into the crib.

After grouting the crib, driving the piles, and restoring the concrete cap, it was proposed to construct, around the old pier and on top of the projections of the crib and on the new piles, a solid reinforced concrete structure which would materially enlarge the base, restore the symmetry, and effectually protect the masonry for all future time.

The rough rock-face and round ends of the pier made it particularly suited to encasement, but, in order to make the bond as intimate as possible, it was planned to drill through the body of the pier at several places near the bottom and place second-hand eye-bars through the pier, with suitable anchors at each end to be embedded in the concrete shell; also to curve the horizontal reinforcing rods continuously around the ends of the pier, and to replace the top by a new thick reinforced concrete cap. This plan had the advantage that no false-work would have been necessary, and it could have been carried out for $12 000.

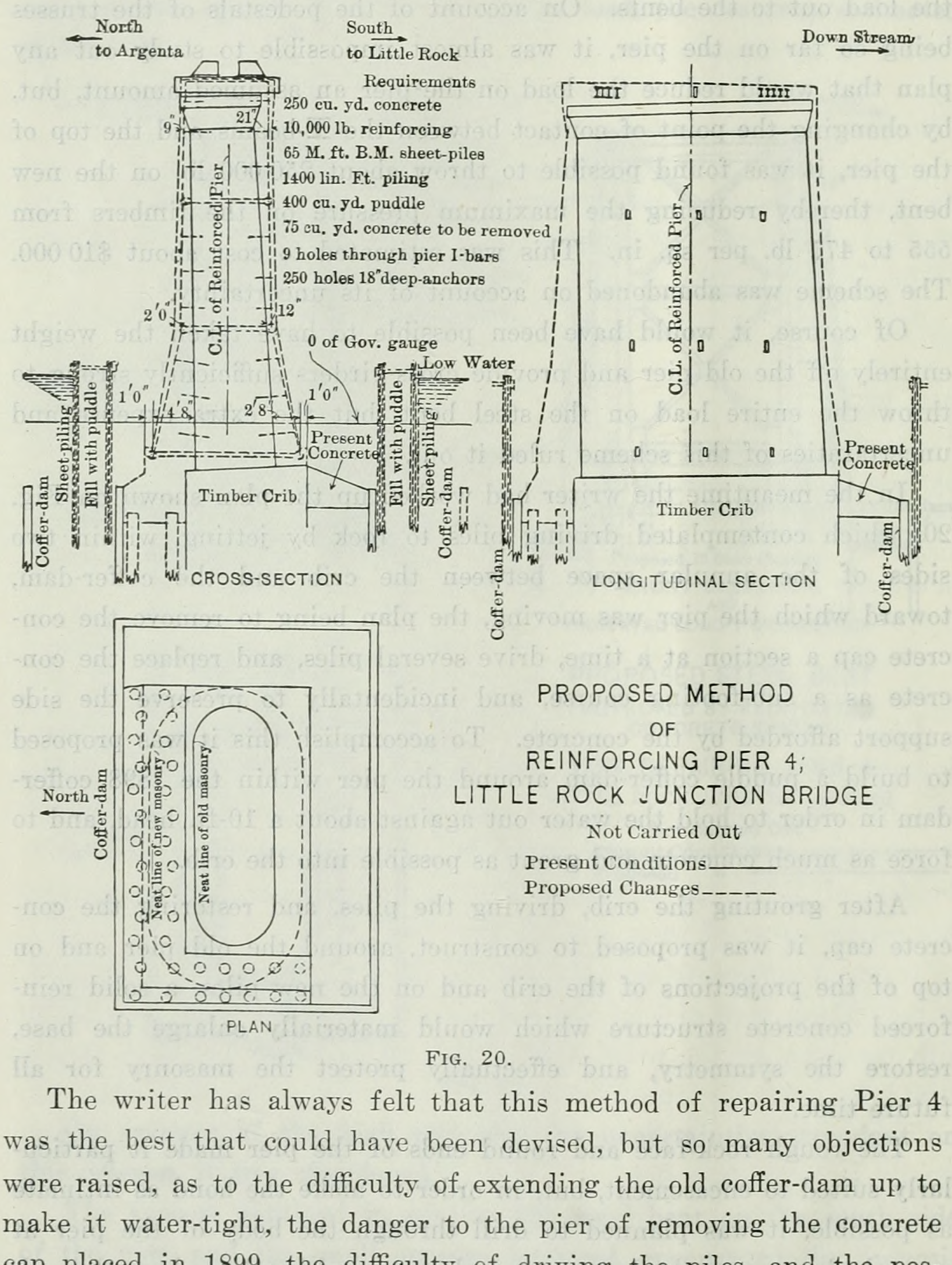



FIG. 20.

The writer has always felt that this method of repairing Pier 4 was the best that could have been devised, but so many objections were raised, as to the difficulty of extending the old coffer-dam up to make it water-tight, the danger to the pier of removing the concrete cap placed in 1899, the difficulty of driving the piles, and the possible damage to the pier by the adjacent pile-driving, the danger of boring holes in the old crib for grouting (and possibly letting the sand run out), the impossibility of getting proper bond between the new and old work under traffic, the danger of disturbing any of the former conditions without carrying the spans on falsework, etc., *ad infinitum*, that the scheme was dropped.

### Proposed Falsework for Supporting Spans.

Strange to say, several engineers who apprehended that if any work were done on the pier it would fall down, and desired the spans placed on falsework to save the steel spans in case of the collapse of the pier, proposed to support the spans in such a way that if the pier did fall it would knock the supports out from under at least one span and cause that to fall. When the writer pointed out this condition, he was requested to arrange for such temporary support of the spans resting on Pier 4 as would hold them up in case the pier should fall, the idea being to have plans for such temporary supports thoroughly understood by and in the hands of all concerned, with authority for the division forces of the Railway Company to erect the supports immediately on the further rapid movement of Pier 4.

FALSEWORK FOR SUPPORTING TWO SPANS OF LITTLE ROCK JUNCTION BRIDGE
CONTEMPLATING THE REMOVAL OF PIER 4

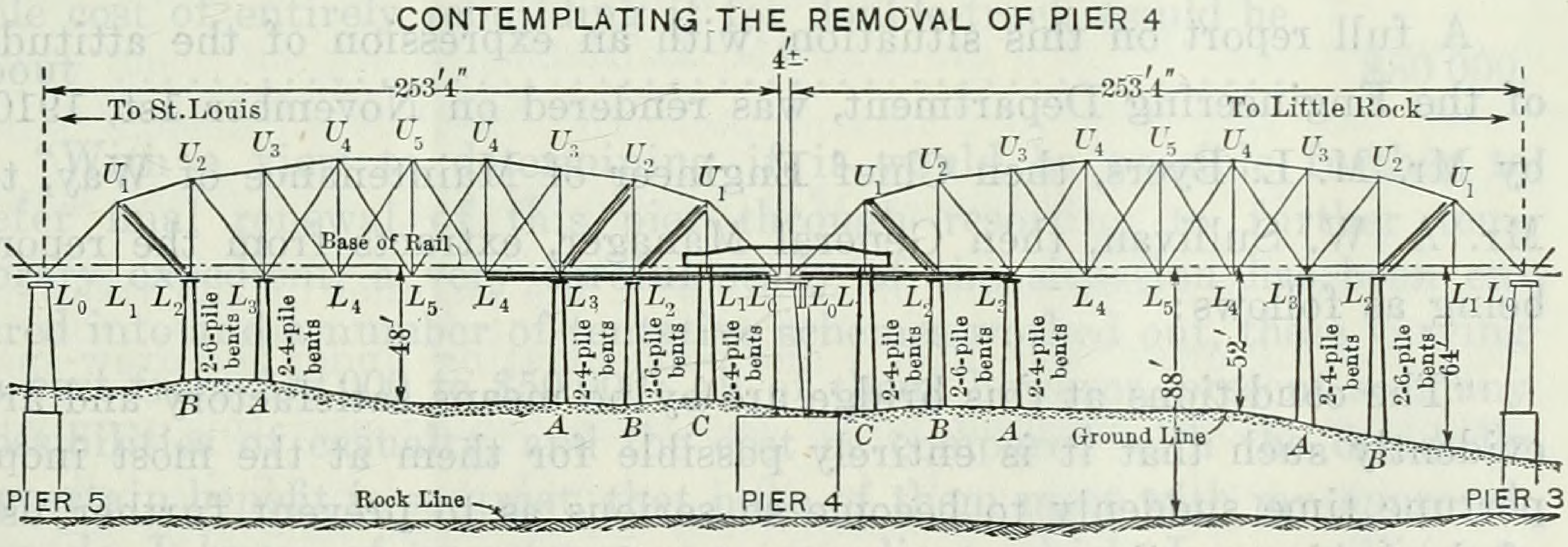



Fig. 21.

Fig. 21 shows the general plan that was worked up. On account of the necessity for retaining the greatest possible clear waterway, and the impossibility of maintaining any longitudinal bracing below high water except with disastrous results, it was proposed to place five double bents under each span, and to bridge over the pier with through girders, from which the floors would be hung. In the event of the unexpected happening at Pier 4, it was proposed to erect bents, *A*, under the third panel point on each side of Pier 4 and stiffen the tension members in the ends of the trusses so as to enable them to resist the compression that would result if the pier were removed. It was expected that when the spans had been supported in this way, traffic could be suspended while the pier was being taken down to prevent its collapse, if the emergency should require; or, the spans having been protected against the collapse of the pier, traffic could be maintained until its collapse, and the remainder of the falsework could be put in in the meantime. The material for two double bents and for stiffening the overhanging ends of the trusses was assembled at the bridge and held there for several years, until after the reconstruction of Pier 4.

### Further Studies.

Continuing into 1910, the entire matter was studied from every conceivable standpoint, including reconstruction of all the piers as single-track in their old location, reconstruction for double-track, an entirely new set of piers and shifting the spans, entirely new single- and double-track bridges, and rearrangement of the method of operation of the Little Rock Terminals so that the bridge could be abandoned, all traffic to use the main-line bridge. None of these plans was carried out, but the "watchful waiting" was continued.

A full report on this situation, with an expression of the attitude of the Engineering Department, was rendered on November 1st, 1910, by Mr. M. L. Byers, then Chief Engineer of Maintenance of Way, to Mr. A. W. Sullivan, then General Manager, extracts from the report being as follows:

"The conditions at this bridge are by no means satisfactory and are evidently such that it is entirely possible for them at the most inopportune time suddenly to become so serious as to prevent further use of the bridge until necessary action is taken to correct such new conditions. This may occur at a period of high water, which would prevent the use of the bridge for some six months to a year, although I do not believe there is serious danger of the loss of any of the superstructure of the bridge. It would probably be possible at any time (unless the failure were extremely sudden, which is unlikely) to drive such falsework as would be necessary to support the two spans resting on this pier, although in this case train service would have to be discontinued.

"There are a number of factors entering into the decision as to what should be done at this point. It may be that considerable time will be required to carry out the plans which may ultimately be decided upon. It is impossible to determine how long the present conditions may continue. It may be that they will change almost at once, or it may be that they will not change for years. It would seem desirable, therefore, if possible, to decide upon a plan of action in case of sudden change for the worse so that no time will be lost in the preparation of plans or in necessary further study of the situation. To this end the following is submitted for your consideration:

"An entirely new set of piers for a single-track bridge, either in the present location or at one side of the present location, would cost approximately.................... $250 000.

"An entirely new set of piers for double-track bridge, either in the present location or to one side of the present location, using the present spans, would cost approximately.. $450 000.

"A new double-track bridge (including the piers) would cost approximately.................................... $800 000.

"The present Baring Cross Bridge (at *Y*, see Fig. 2) will probably require renewal within five years at an estimated cost of approximately (for double-track)........... $900 000.

"In the event of the failure of Pier 4 alone, the probable cost of entirely rebuilding it for single-track would be about .................................................. $60 000.

"In the event of the failure of Pier 4 alone, the probable cost of entirely rebuilding it for double-track would be about .................................................. $80 000.

"With a view to determining if it would be possible further to defer final renewal of this pier through resorting to further temporary expedient, a very careful study of the situation has been entered into and a number of tentative schemes worked out, these varying in cost from $12 000 to $50 000; all of them, however, present so many possibilities of casualty, and the cost as compared with the decidedly uncertain benefit is so great, that none of them meet with my approval, nor do I know of any temporary expedient which I am willing to recommend.

"As before stated the further period during which the present temporary expedient can be continued is entirely uncertain and there is the possibility that it may fail on extremely short notice.

"Figure 8 is a general elevation of Pier 4 and the two spans resting thereon and shows in red the temporary falsework necessary to be put in place in order to prevent these spans falling into the river in case Pier 4 falls.

"Figure 9 shows the character of the temporary piers and the two plans indicate the amount and character of the work which must be done in order to save the spans in case of the falling of Pier 4. It must be borne in mind that it is quite possible this work, if it becomes necessary, must be carried out at the time of extreme high water, and it is absolutely impossible to foretell the amount of time that will elapse between the time when the rapid movement of Pier 4 is detected and the time when the pier will actually fall—we may have time to place this falsework and we may not. The falsework has been ordered and will be kept on hand at Argenta.

"Figure 8 shows in yellow the additional supports that must be provided in case of the loss of Pier 4 before the bridge can be again opened to traffic. During the period of high water there will, of course, be more or less amount of danger that drift or boats would destroy this falsework—such is the risk involved in the present conditions.

"Quite recently Pier 3 has begun to move longitudinally at a much faster rate than heretofore, and it is, of course, possible that the conditions with which we are confronted at Pier 4 may at any time have to be met in connection with movement of the other piers.

*"Recommendations.*

"In view of the varying circumstances above enumerated, it is my recommendation that it be decided at once what policy is ultimately to be followed in connection with this bridge. I believe all of the facts essential to this determination are stated in this report and the matter would seem to be one of policy rather than engineering.

"Yours truly,

"M. L. Byers,

*"Chief Engineer, M. of Way."*

PROPOSED MAT AROUND PIER 4.

For two or three years prior to 1911, the channel of the river had been moving away from Pier 4 and concentrating under the draw-span, resulting in the building up of the river bed around this pier with clear fine sand which early in 1911 covered the top of the crib and reached up on the masonry within 1 or 2 ft. of extreme low water. This sand evidently filtered into the crib and gave increased supporting power in addition to that provided by the sand that enclosed it. As a consequence, the movement of Pier 4 gradually slowed down, so that it was barely perceptible, and the great uneasiness that had prevailed for several years was partly allayed. The decrease in the movement was attributed to the steel bent placed at the back of the pier, by those responsible for that monstrosity.

In order to protect and preserve this sand surrounding the pier, the writer attempted in the fall of 1910 to secure authority to spend about $2 000 to construct a standard brush and pole mattress, about

150 ft. square, around Pier 4, to be securely bound together with wire and wire strand, and covered with rip-rap placed in pockets of the mattress to be formed by placing two sets of poles one across the other on top of the mattress to prevent the rip-rap from rolling off.

At the low stage of the river following the request for authority, the work could have been done without barges or other floating equipment and brought to completion in 30 days. The authority was not granted, and, after the next flood, it was not needed, as much of the sand had been washed away.

## Rapid Movement of Pier 3.

While the river bed was building up around Pier 4, it was scouring away around Pier 3, the north rest pier of the draw-span, and this pier started to move quite rapidly directly up stream, at right angles to the axis of the bridge.

The movement in 1911 was more rapid and constant than any experienced previously in the other piers, and indicated the necessity for immediate action. The pier did not move dangerously in the direction of the bridge. Its natural tendency would have been to move south, as the plumb south face and eccentric bearings of the spans made the pressure heaviest on the south side. It was restrained from movement in that direction, however, by the rods and yokes which made this pier an anchor for the pull of Pier 4. In fact, during the frequent tightening of the yoke rods, Pier 3 was observed to move slightly north into a more erect position.

## Plans for Reconstruction of Pier 3: Modjeski's Recommendation.

The first plan prepared for the reinforcement of Pier 3 was somewhat similar to the writer's last plan for Pier 4, which had been rejected. (See Fig. 20.)

It consisted of a reinforced concrete shell, tied to the old pier and resting on additional piles to be driven to rock around the old crib, as shown by Fig. 22. Here, however, there was no surrounding cofferdam, and it was deemed advisable to furnish protection for the piles and additional stability for the pier.

This was to be obtained by sinking around the pier mud-cell mattresses in layers about 4 ft. deep, with enough rip-rap in them to sink them. The result would be a building up of mattresses of decreasing sizes and rock; sand sediment would immediately deposit until the top of the crib was nearly reached, when the entire mass would be covered by a heavy layer of rip-rap, the latter and the surrounding bed of the river would then be covered by another large protecting mattress. It was also the intention to bore holes in the crib and get in as much grout as possible. The writer believes this method of repair would have been entirely satisfactory; it also had the advantage of being very cheap. Five bids were received, the lowest (from an entirely reliable contractor) being about $8 500, which, together with the extras and incidentals, would probably have made the total cost of the work $10 000.

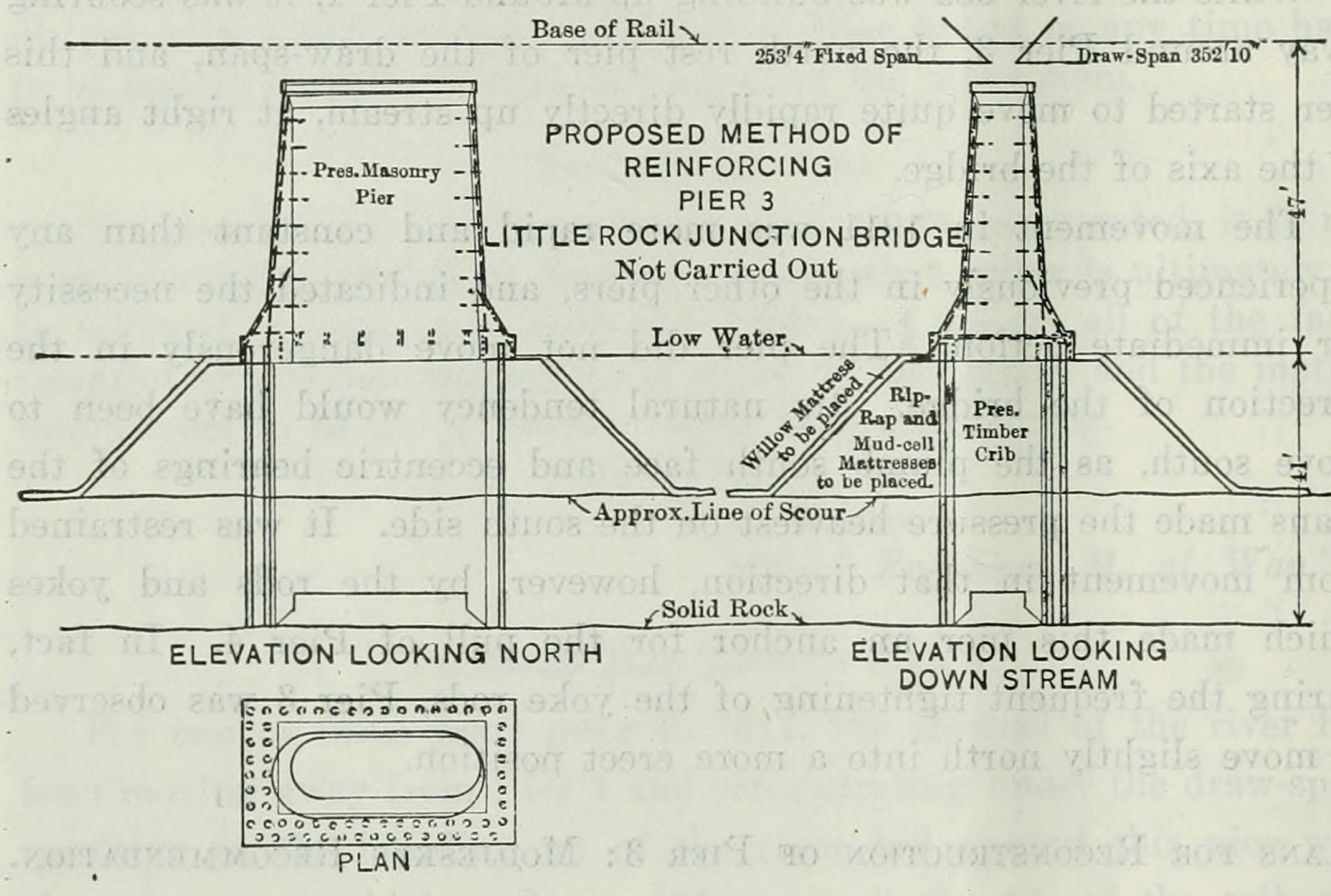



Fig. 22.

Before proceeding along these lines, however, the management desired an expression of opinion on the entire problem by a disinterested engineer, and Ralph Modjeski, M. Am. Soc. C. E., was consulted. The writer disclosed to Mr. Modjeski all the information in possession of the Railway Company on this subject, and accompanied him on an inspection of the bridge.

Copies of Mr. Modjeski's reports of August 5th, August 7th, and August 19th, 1911, are given in Appendix D.

It was arranged between Mr. Modjeski and the writer to bore holes down through the crib to rock, and this was done as far as possible. It was found to be very difficult to get the pipe down; it would encounter solid timber, then sand, then loose rock, and combinations of all these. However, it was finally driven to the solid timber roof of the caisson, which was encountered at such an elevation as to leave no doubt that the cutting edge rested on rock, the level of the latter having been ascertained by running a jet pipe down through the sand around the pier. In sinking the pipe through the crib, efforts were made to secure the services of expert well drillers, but they all refused to guarantee to get the pipe down.

In brief, Mr. Modjeski recommended first that the sand in the crib of Pier 3 be removed and the crib filled with concrete. To accomplish that, he recommended driving 50-ft. triple-lap sheet-piling entirely around the pier, 6 ft. from the crib, and examining the old crib by partly removing the old planking. He also recommended that the up-stream end of Pier 3 be supported on shores resting on piles driven alongside the old cribs. This work involved supporting the spans on falsework.

A later report suggested placing the coffer-dam 12 in. from the old crib (if it was found that the filling of the cribs was sand which could be pumped out), excavating the material between the old crib and the coffer-dam, and sealing the bottom with concrete. Then the top crib timbers and the material inside were to be removed and the crib refilled with concrete, this work necessitating the support of the spans on falsework and taking down the old pier.

Later, he recommended rebuilding Piers 3 and 4 entirely by supporting the spans on falsework, putting coffer-dams around the piers, taking down the masonry, filling the cribs with concrete, and building new piers on them.

After considerable study of these latest recommendations, it was tentatively decided to follow Mr. Modjeski's first recommendation, but, on account of the great head against which pumping would have to be done (up to 50 ft.), steel sheet-piling was contemplated. Detailed estimates, however, indicated that this method would be quite expensive and uncertain, and would involve the hazard of carrying the spans on falsework. As a slight August rise in this river, a few days before, had swept away 1 000 lin. ft. of falsework at a bridge about to be erected farther up stream, those responsible for this bridge were not enthusiastic about carrying the spans on falsework.

Taking down the piers to rebuild them entirely would have been fully as hazardous, and very expensive.

Mr. Modjeski was then requested to pass opinion on the writer's plan of driving piling around Pier 3 and resting on it a reinforced concrete encasement around the pier, protecting the piling with mud-cell mattresses and rip-rap, as shown by Fig. 22. This he objected to as somewhat uncertain as to results and the eventual stability of the pier.

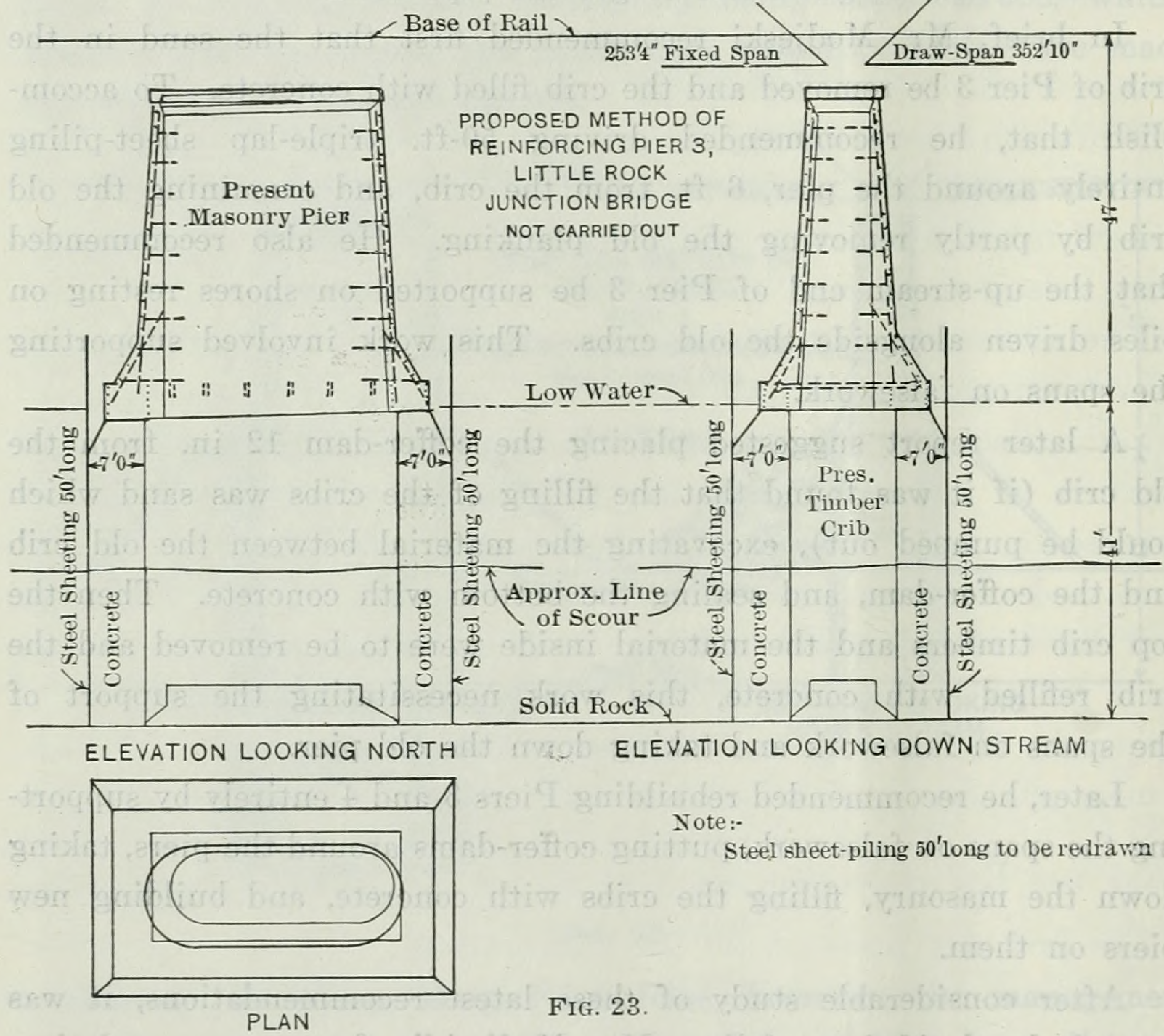



Fig. 23.

He was also asked to pass on a plan for driving steel sheet-piling about 6 ft. from the old crib, excavating the space between it and the old crib, and filling that space and the crib with concrete, the pier to be encased in a reinforced concrete shell, the whole to be done without falsework. Fig. 23 shows this scheme. He pronounced it to be very expensive, and said:

"To attempt to carry out this scheme without supporting the spans on falsework would seem to me extremely risky. The excavation around the crib would deprive it of considerable skin friction and would probably open up more places through which sand now in the crib could leak out. The crib is now settling at the rate of 1 in. per month by the crushing of the timbers and this settlement may under the new conditions get so rapid as to endanger the whole structure.

"I am convinced that the pier could be built new for less money than the schemes shown on your plan. The new pier would probably contain about 500 cu. yd. of concrete and there may be another 500 or so necessary to fill the crib, making, say, 1 000 cu. yd. of concrete in all, besides, the work would be more certain of accomplishment and with the least amount of unforeseen expensive contingencies. I would therefore strongly recommend that this pier be rebuilt as stated in my former letter to Mr. Pearson. While it is very difficult to make even an approximate estimate on the cost of such work, my opinion would be that the new pier would cost very little more, if any, than the cheaper one of the two schemes in question, assuming in all cases that it would be desirable to support the adjacent spans, as there is great uncertainty how the present crib would behave while any work is being done around it.

"To rebuild the pier I would proceed as follows: Build temporary supports for the span, carrying the ends on a set of girders. Take down the old pier to the crib work. Drive wooden triple-lap sheet-piling or steel sheet-piling around the present crib. Excavate present crib and fill with concrete by methods which will become more apparent as the work goes along. Build the new concrete pier on top of the crib work thus reinforced."

The method of reinforcement that was finally brought to successful conclusion was first suggested by E. J. Pearson, M. Am. Soc. C. E., First Vice-President of the Railway Company. To overcome all uncertainties, he suggested securing the necessary additional supporting power by the use of a pneumatic caisson on each side of the old crib. This was extended, later, by adding caissons for the ends, forming an annular caisson surmounted by a coffer-dam, the space above the annular caisson to be filled with concrete, doing the same to the crib, and encasing the old pier in a new reinforced concrete shell, as shown by Fig. 24. This was also referred to Mr. Modjeski by the writer, in a letter setting forth the plan, as follows:

"I have never fully abandoned the idea which you first proposed of filling the pockets within the crib with concrete, and think if this work can be accomplished that the problem will be solved. I find upon investigation that it will cost very little more to sink an annular pneumatic caisson entirely around the crib than to carry out the scheme formerly proposed to use steel sheet-piling and concrete filling.

"I hand you herewith blue print, showing in red the construction of the caisson. I would construct the working chamber entirely of steel, as this can be done, by the use of second-hand bridge members now on hand at our store yard, for very little cost. I would leave off the inside wall of the coffer-dam above the roof of the working chamber, and construct a water-tight outer casing wall braced by latticed steel members extending up to low water.

"After sealing this working chamber with concrete, this outer shell would form a coffer-dam entirely around the pier.

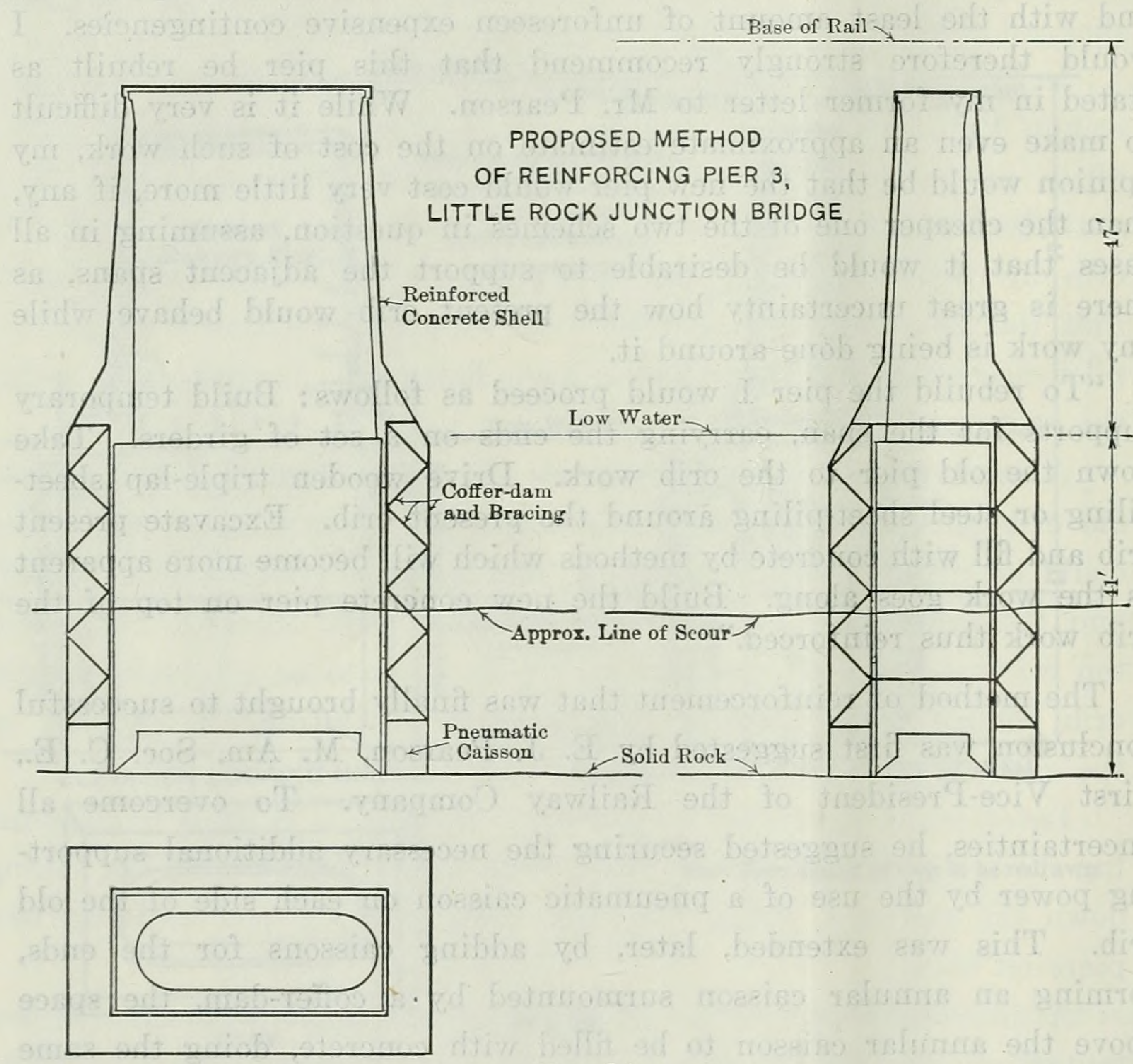
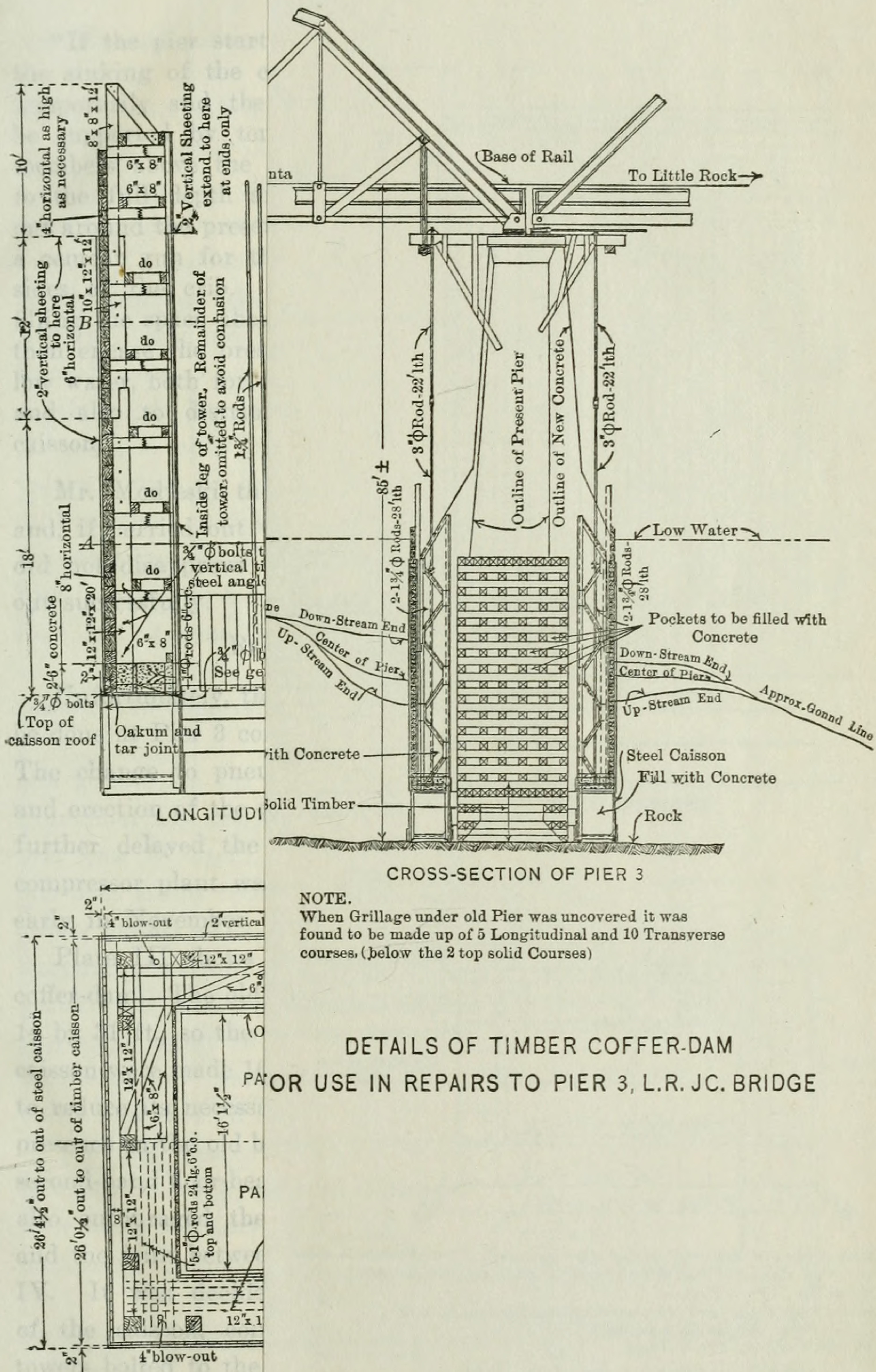



FIG. 24.

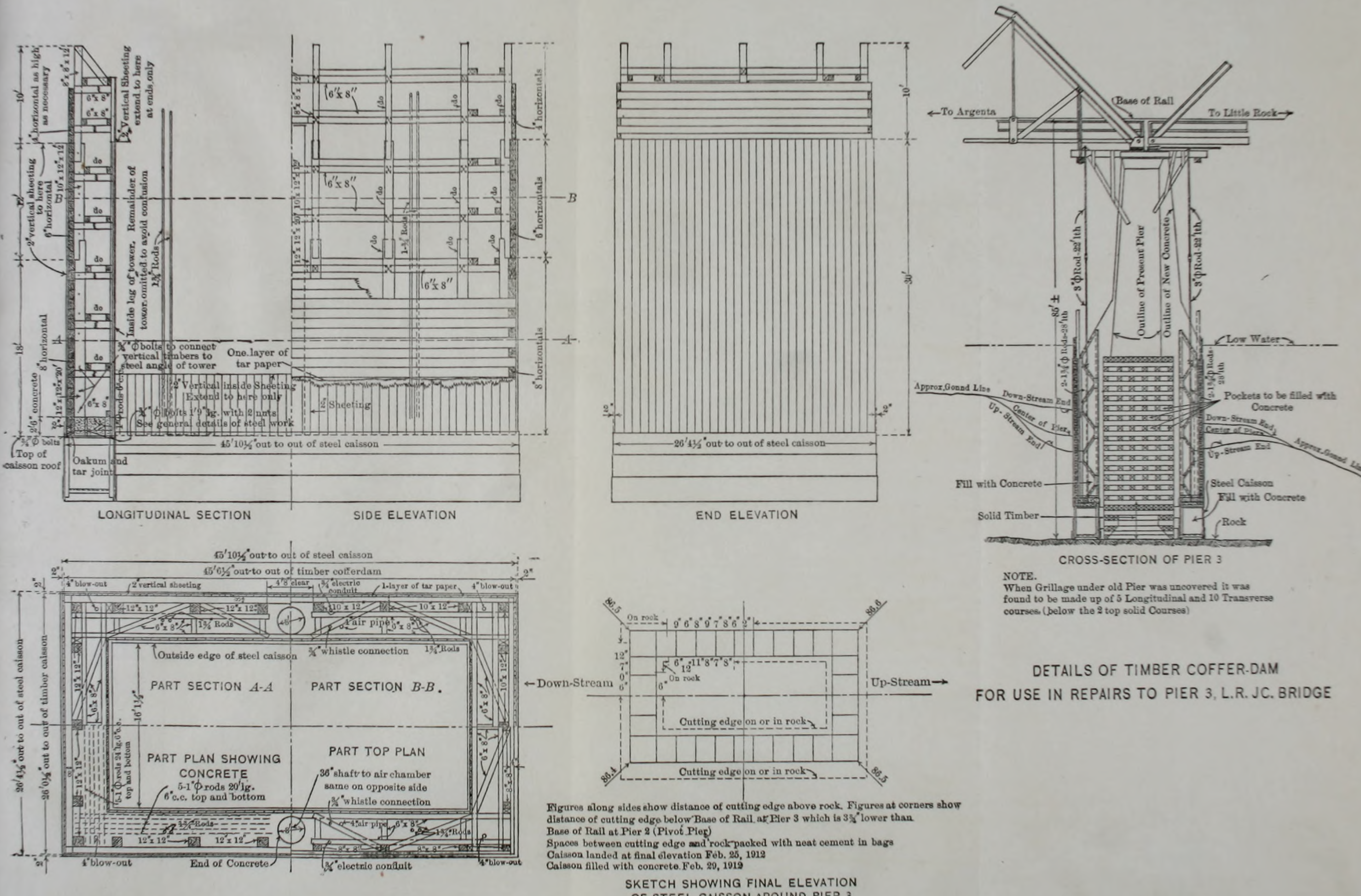
"The Arkansas River is subject to very rapid rise and excessive scour, and at such times carries an immense amount of drift. It is a hazardous proceeding at any time to carry spans on falsework in this river. During the construction of our Baring Cross Bridge, I understand, one of the spans was lost on this account. The Arkansas Bridge Company recently lost 1 000 lin. ft. of falsework in this same river a few miles above Little Rock.

"For this reason I do not like to place spans on falsework and take down the pier, except as a last resort.




DETAILS OF TIMBER COFFER-DAM
FOR USE IN REPAIRS TO PIER 3, L.R. JC. BRIDGE

PLATE III.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXIX, No. 1335.
SMITH ON
REPAIRING BRIDGE PIERS.




DETAILS OF TIMBER COFFER-DAM
FOR USE IN REPAIRS TO PIER 3, L.R.JC. BRIDGE

"If the pier starts to show signs of more rapid movement during the sinking of the caisson, traffic could be removed from the bridge temporarily and the sinking proceeded with. The pier could then be supported by temporary struts and shores resting on the steel members above the working chamber. After the caisson were sunk to the full depth and the working chamber sealed, I would pump out around the present crib and ram the pockets full of concrete, using a cement gun for the purpose, if necessary, and working from both sides of the crib. I would then complete the work by completely filling the space above the working chamber with concrete, and would then encase the present masonry pier with reinforced concrete above low water, both for the purpose of securing a symmetrical appearance and also to distribute a considerable portion of the load to the caisson."

Mr. Modjeski thought that this plan would be unduly expensive and, if carried out without falsework, entirely too hazardous. As he did not disapprove the scheme, however, it was adopted and carried out successfully.

## Reinforcement of Pier 3 in 1912.

Unfortunately, the delay in arriving at a decision as to what would be done at Pier 3 consumed the best months of the year for the work. The change to pneumatic construction, necessitating the assembling and erection of the pressure plant and the construction of the caisson, further delayed the work up to the time of the flood period. The compressor plant was finally ready, and the steel caisson was shipped early in November.

Plate III shows the general outlines of the annular caisson and coffer-dam. The old records showed the old caisson under Pier 3 to be 14 by 31 ft., so the dimensions of the inner cutting edges of the new caisson were made 16 by 33 ft. The caisson was made of steel primarily to reduce its necessary width and consequently the displacement; the presence in the old bridge-material yard of a large number of duplicate second-hand floor-beams which could readily be converted into a caisson also encouraged the use of steel. The details of the steel caisson and the joint between its roof and the coffer-dam are shown on Plate IV. It was decided to build up a coffer-dam on the outer wall of the caisson, connecting the coffer-dam to steel lattice work or towers bolted to the roof of the caisson. These towers were provided in order to form the backbone of the rigid framework it was known would be required to brace the new coffer-dam against the old crib during excavation.

The greatest care was taken in the design of the joint between the caisson and the coffer-dam. The timbers in the bottom row, 8 in. thick, were cut to fit the steel as closely as possible, and were set in a bed of hot tar and oakum. Surfaced timbers were used, and each layer was set on the next below in hot tar and caulked. Tar-paper was then placed over the timbers and 2-in. matched sheeting placed outside. The lower ends of the sheeting were driven into a groove, filled with hot tar and oakum, over the roof of the caisson, formed between the bottom timber and the upstanding leg of the angle at the top corner of the caisson. A space about ½ in. wide, between the sheeting and the angle, was then caulked. To bind all parts together effectually and to provide additional weight for sinking, a 2 ft. 6-in. layer of concrete was then placed over the roof of the caisson enclosing the bottoms of the towers. This concrete was banded to the steel roof by a large number of ¾-in. bolts, 21 in. long, fastened to the steel plate and extending vertically into the concrete.

The construction of the remainder of the coffer-dam was similar to that just described.

For the support of the annular caisson during the assembling and sinking, until the entire load rested on the river bed, the temporary support from the pier and trusses shown on Plate V was provided. Two 8 by 16 in. by 28-ft. timbers were placed across each end of the pier, as close as possible to the truss shoes. The coping stones at each end had to be removed in order to place the timbers low enough to permit the draw-span to swing over them. The ends of the timbers were held up by inclined struts gained into their under sides and set in grouted notches cut into the masonry of the pier. For additional stability and stiffness, the north end was connected by rods and struts to the end posts of the north span which, in turn, were stiffened by timber struts (similar to collision struts) running down to the first panel points. On account of the necessity of having the draw-span free to swing, it was not possible to provide corresponding connection with the end post on the south side of the pier.

Four 3-in. steel rods, threaded for their entire length, were passed through between the ends of the timbers, the nuts on them resting on heavy plates over the timbers, and the lower ends of the rods

PLATE IV.
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SMITH ON
REPAIRING BRIDGE PIERS.


AL DETAILS OF ANNULAR CAISSON
PIER 3, LITTLE ROCK JUNC. B'R.
LITTLE ROCK–ARK.

PLATE IV.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXIX, No. 1335.
SMITH ON
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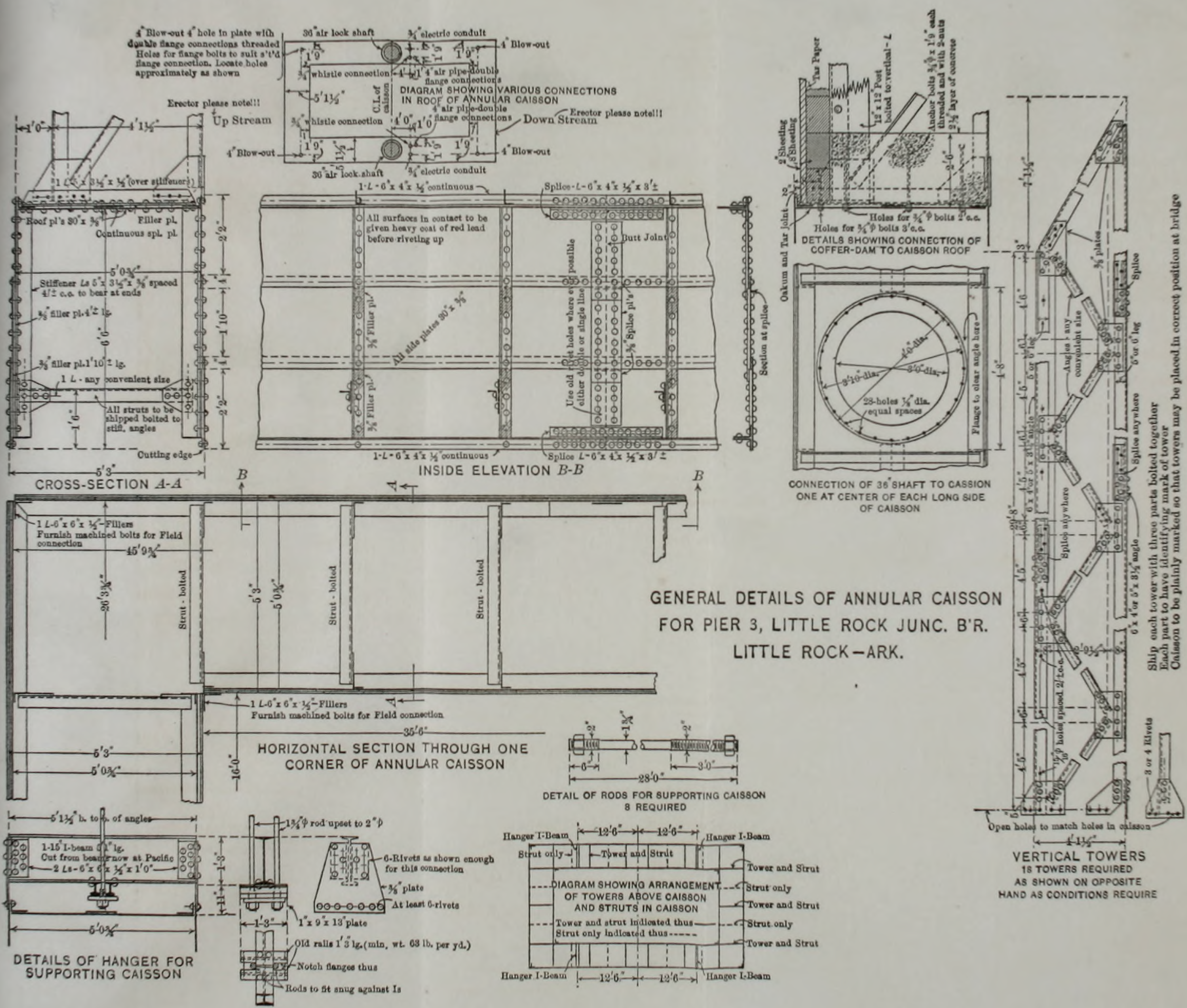



GENERAL DETAILS OF ANNULAR CAISSON
FOR PIER 3, LITTLE ROCK JUNC. B'R.
LITTLE ROCK—ARK.

reaching down to chairs made of rails supporting other smaller rods in pairs, on which the long sides of the caissons were supported near the water level after being floated out to the pier. The short sides or ends were then floated on barges and connected to the long sides by machine bolts. After the caisson was assembled and caulked, and all shaft, pipe, and wire connections were made, it was lowered into the water and the construction of the coffer-dam was started.

During and after the placing of the 30-in. layer of reinforced concrete over the roof of the caisson, the sinking progressed as fast as the work permitted. At the commencement of sinking, the river bed at the down-stream end of the caisson was several feet higher than at the up-stream end. As the caisson was lowered, the sand scoured deeper and deeper at the up-stream end and the workmen shoveled the sand from the down-stream end of the caisson into the water at the up-stream end until the cutting edge landed all around, following which the sand and other material, much of which consisted of heavy rip-rap and logs (almost petrified), was removed in buckets through the locks. The removal of the sand formerly against the down-stream end of the pier relieved it of pressure to such an extent that it partly righted itself. Trouble was continually experienced by the caisson catching on the protruding upper ends of the sheeting planks of the old crib, which had been torn loose by the settlement of the timbers and bulged by the pressure of the material escaping from the crib. These were particularly annoying before the cutting edge rested on the river bed, as the workmen had to pick their footing in the caisson. On all the old records available the caisson of the old pier was shown to be plumb, and a clearance of 2 ft. was supposed to have been allowed between it and the new caisson, but it was found that the old caisson had a sharp batter, which necessitated ripping off the old vertical sheeting before the new caisson could be landed. The cutting edge of the old pier was found on rock everywhere except at short dips which had been filled with concrete.

All the material within the new caisson had to be removed through the locks because sufficient pressure could not be maintained to force the sand through the blow pipes. This was caused by all the material between the old and new work running into the caisson and leaving the inner cutting edges usually exposed; and, when an attempt was made to increase the pressure to blow out the material, the air would blow out under the inner cutting edge instead. As it was desired to avoid the resulting washing out of sand from the old crib caused by the commotion in the water during these blow-outs, the efforts to use the discharge pipes were abandoned. Mattson locks were used, and permitted the rapid removal of the material. No other particular difficulties were encountered.

The cutting edges were everywhere landed on rock, except over short dips, which were cleaned out and filled with concrete. The working chamber was filled with concrete, carefully rammed, to the roof, and before it had set, the lower sections of the shafting were also filled with grout.

Fig. 25 shows the steel caisson after it had been lowered partly into the water and construction of the coffer-dam had commenced. Fig. 26 shows the upper edge of the coffer-dam after the caisson had been landed and the reinforcing rods for the concrete encasement were being placed.

While the caisson was supported from the pier the inspector was required to compute daily and report weekly the weight supported. To guide him in the control of the work, and to avoid overloading the temporary supports, he was told the maximum weight that could be allowed, and was given a copy of a typical programme of work and a tabular summary of weights, together with the following instructions, the whole idea being to control the construction and sinking in such a manner as to keep the smallest load on the rods and take advantage of the immersion:

"Instructions.

"The support that has been provided for lowering the caisson into its final position is capable of safely supporting a total load of 325 000 lb., and the total weight of the caisson and coffer-dam and other materials above the caisson suspended from the rods should not exceed the above weight.

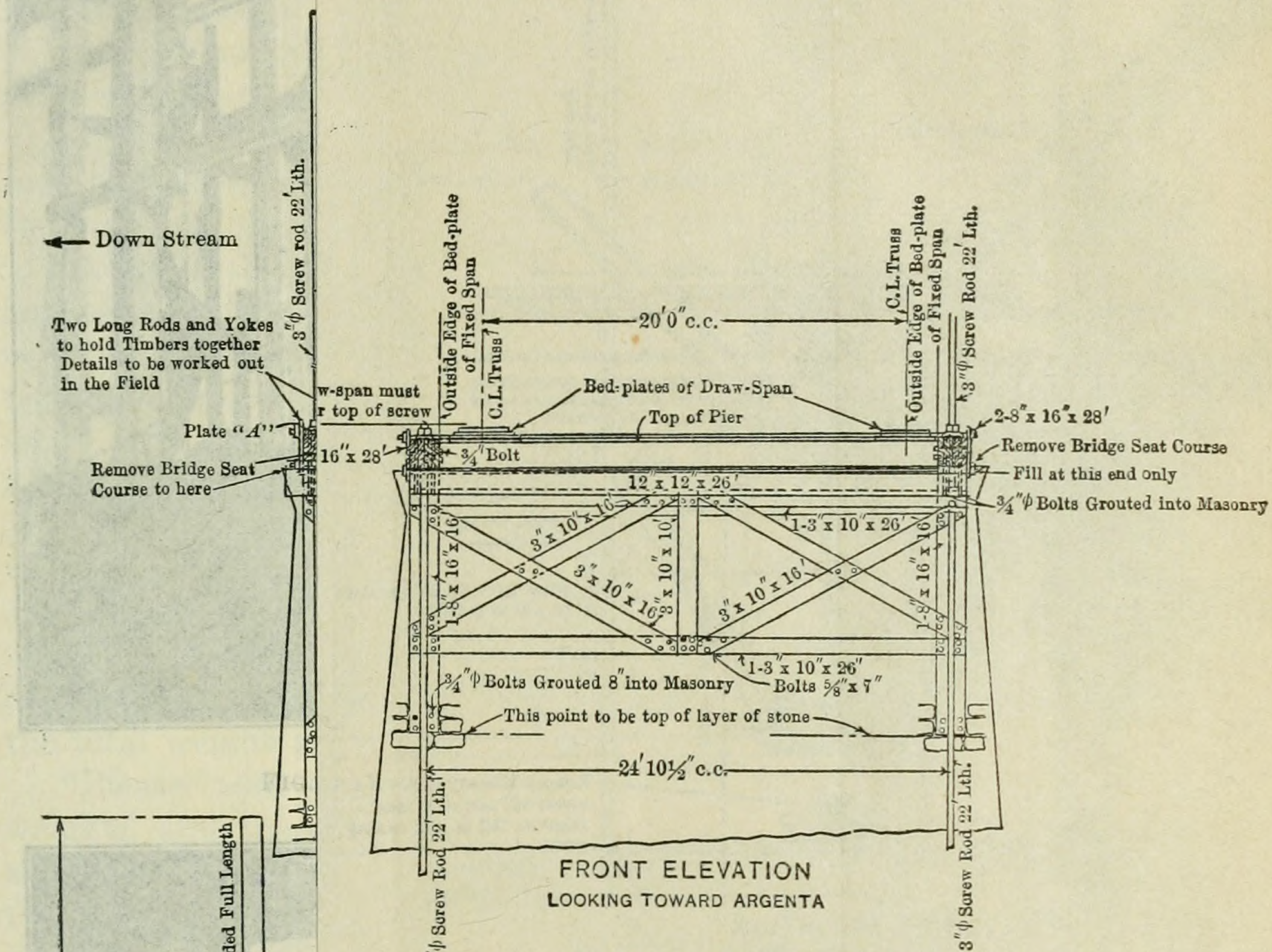
"There are five conditions that must be met in the sinking and founding of this caisson.

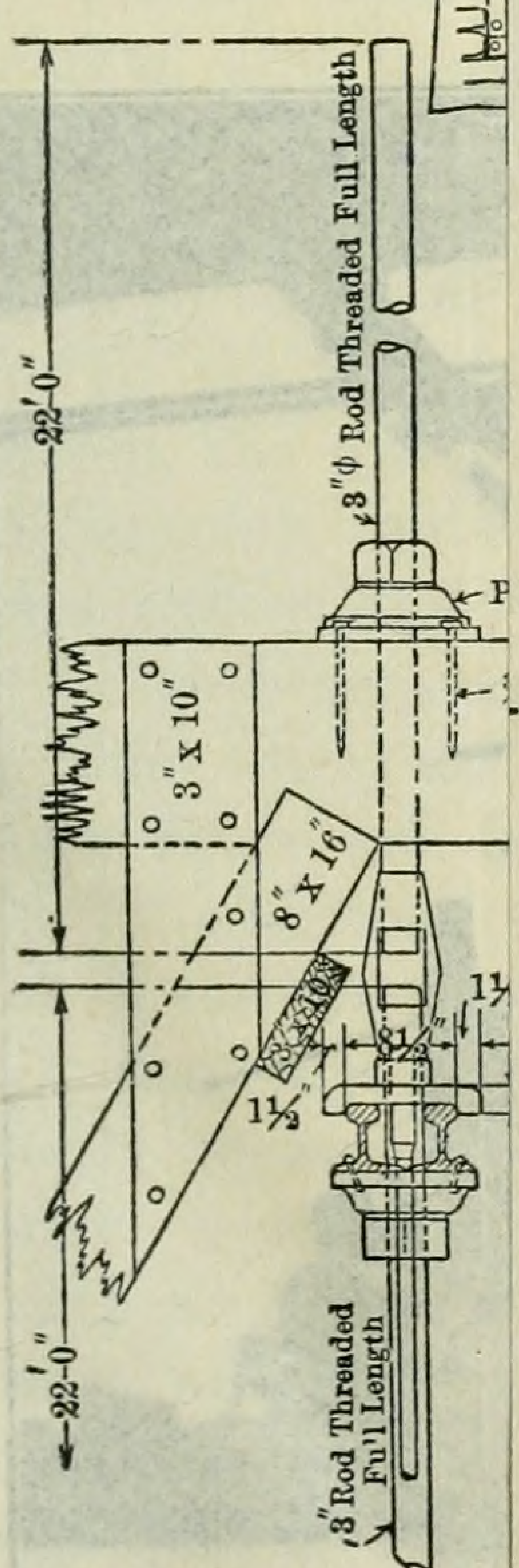
"They are as follows:

"1. Total weight of structure before lowering into water must not exceed the strength of the supporting rods.

"2. Total weight of structure decreased by the buoyant effect of the water displaced during sinking must not exceed the total supporting power of the rods.

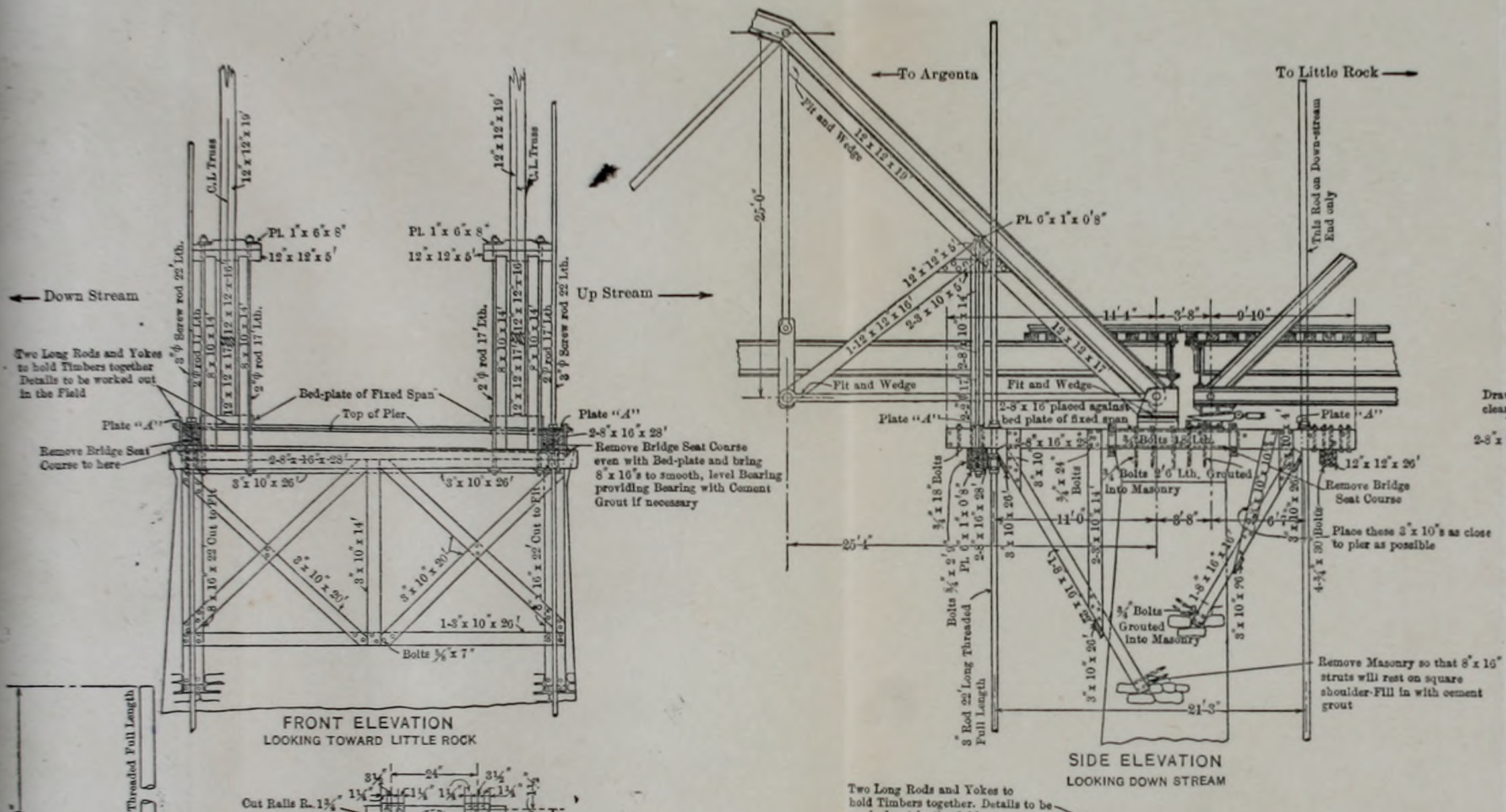
PLATE V.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXIX, No. 1335.
SMITH ON
REPAIRING BRIDGE PIERS.

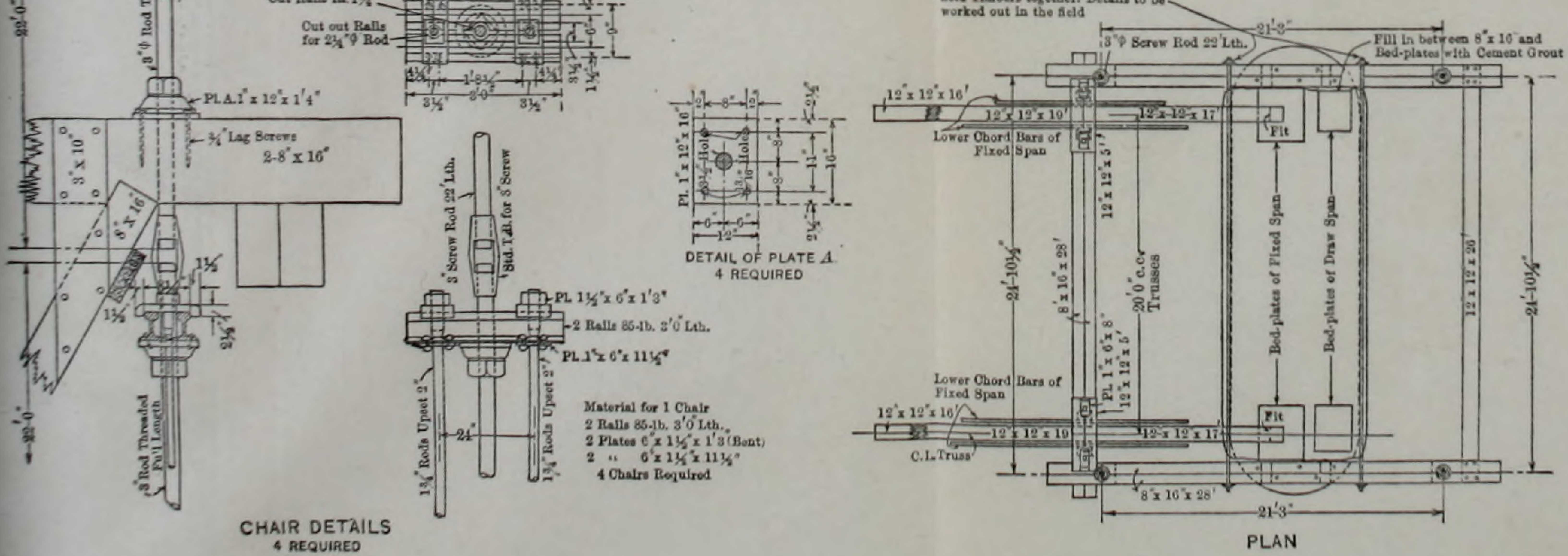


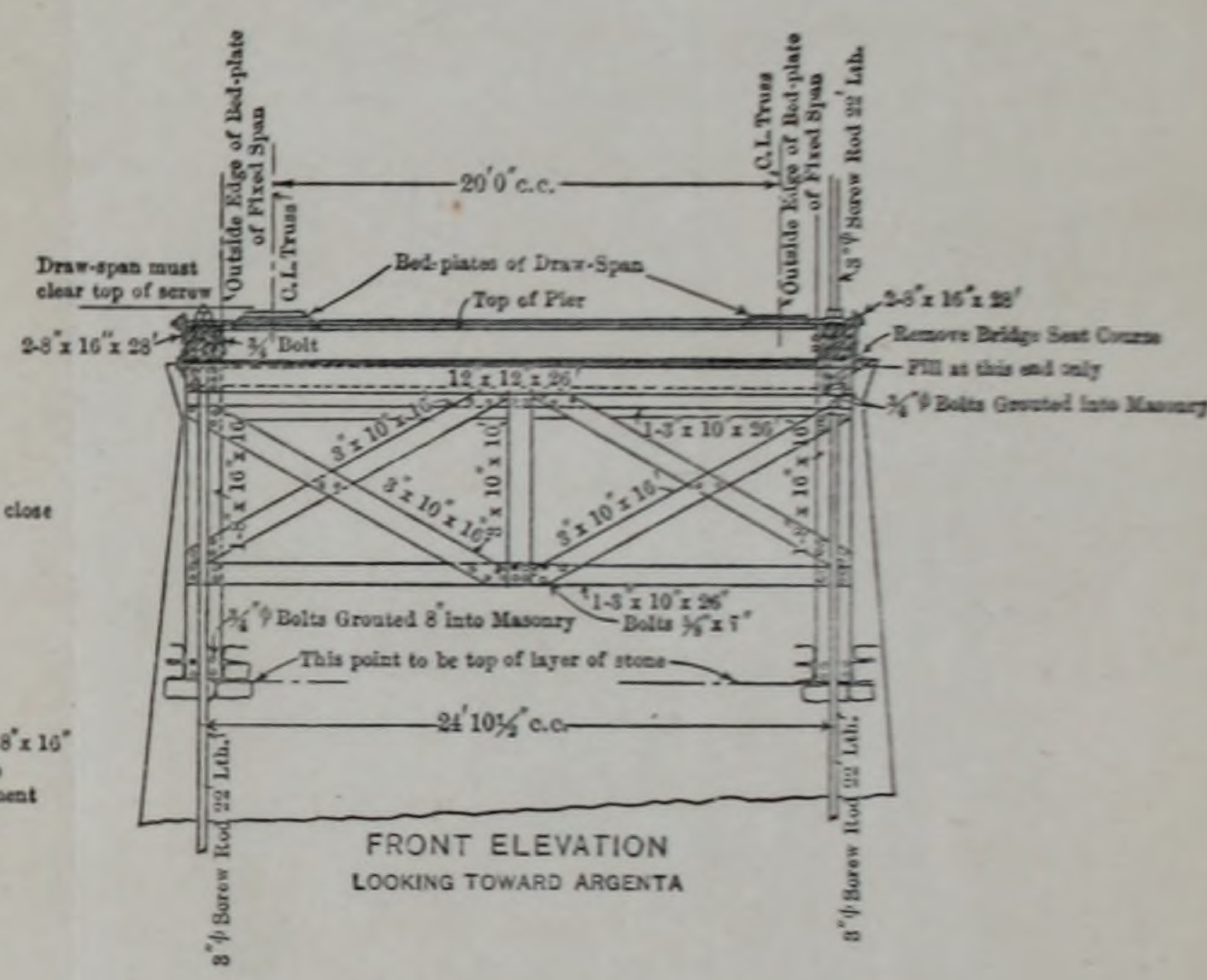




LAN SHOWING METHOD OF SUPPORTING
AND LOWERING ANNULAR CAISSON
USED IN REPAIRING PIER 3
LITTLE ROCK JCT. BRIDGE

PLATE V.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXIX, No. 1336.
SMITH ON
REPAIRING BRIDGE PIERS.




PLAN SHOWING METHOD OF SUPPORTING
AND LOWERING ANNULAR CAISSON
USED IN REPAIRING PIER 3
LITTLE ROCK JCT. BRIDGE

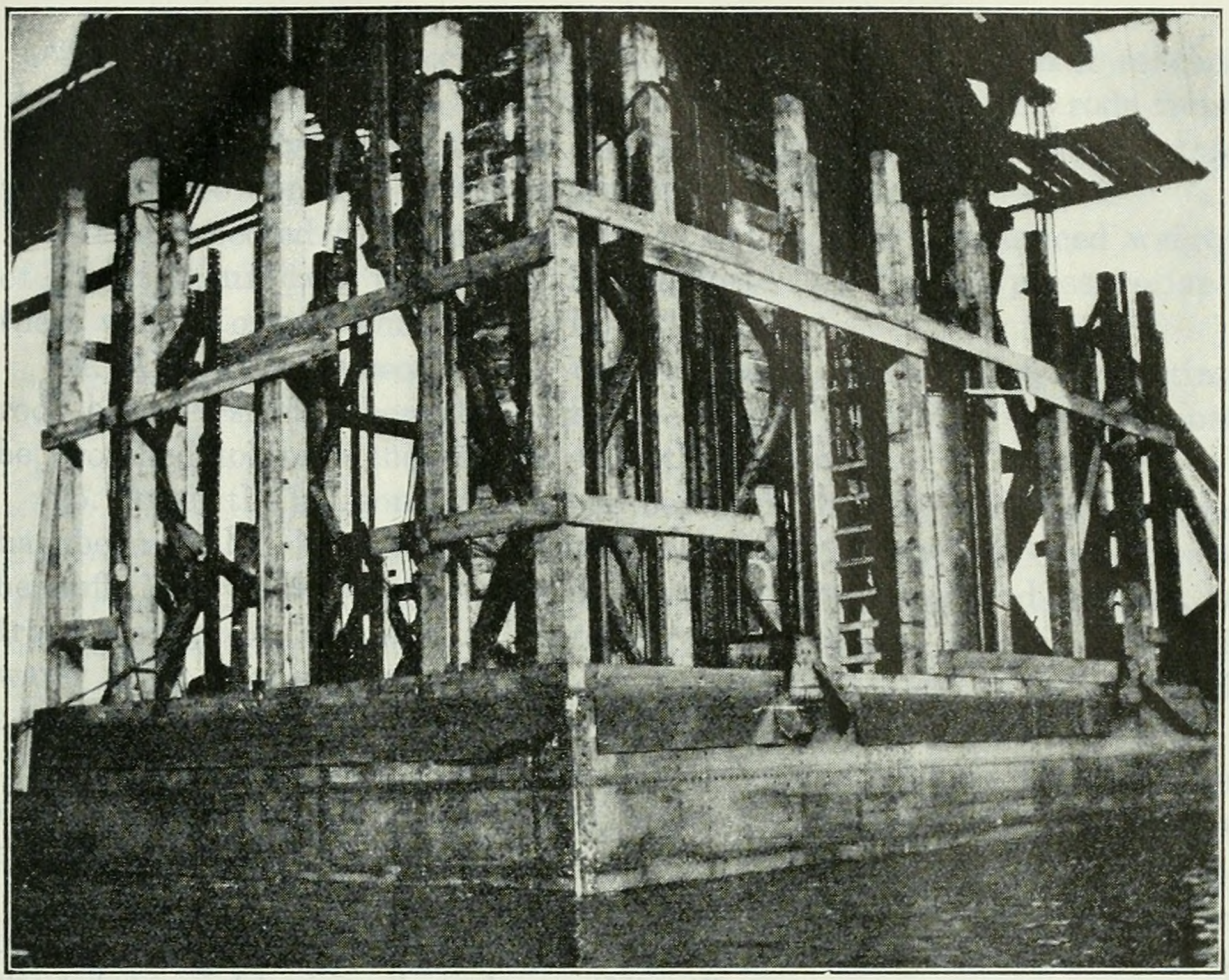


FIG. 25.—LOWERING COFFER-DAM AROUND PIER 3.

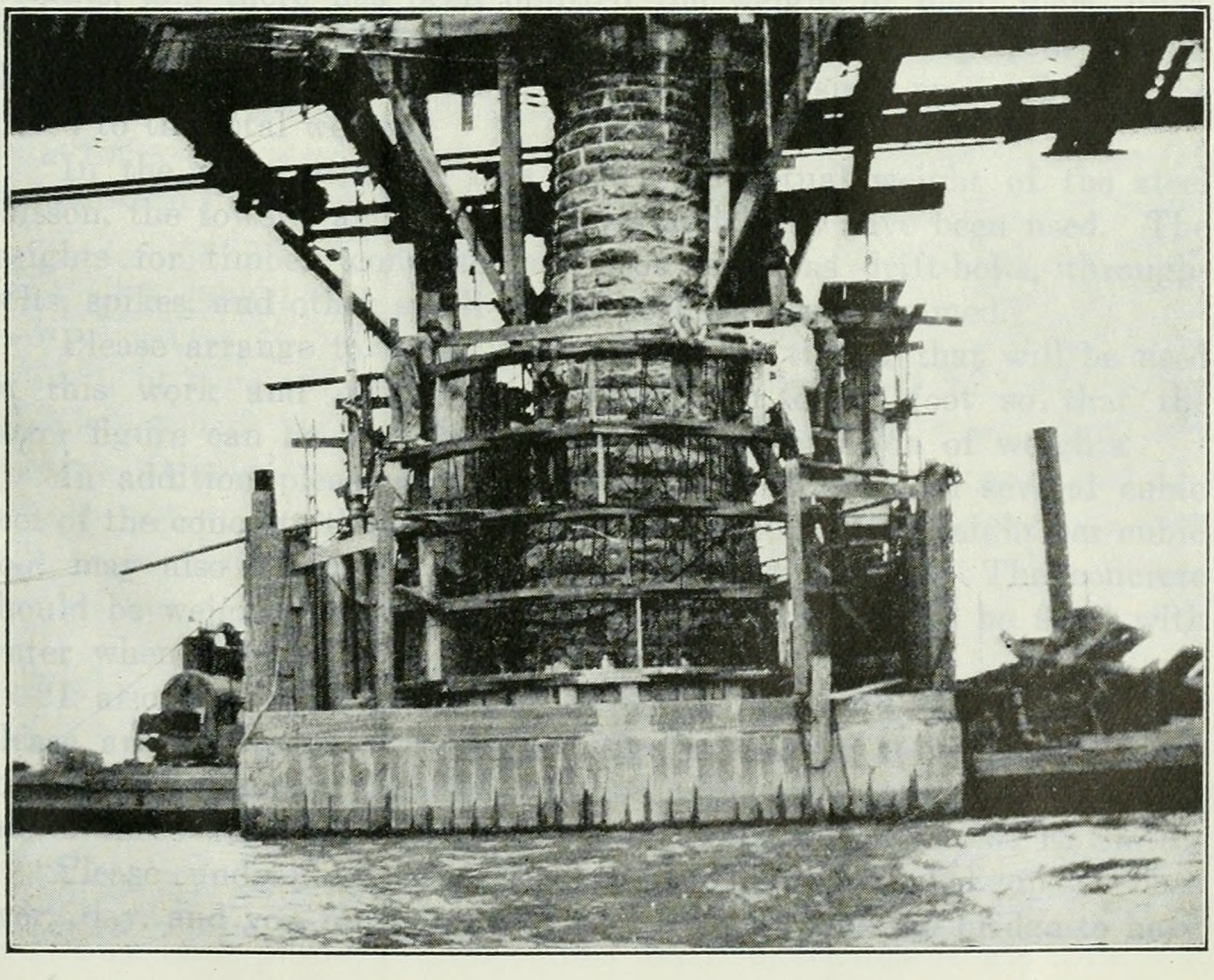


FIG. 26.—STEEL CAISSON AND COFFER-DAM AROUND PIER 3.

"3. In order that the caisson may be filled with air when it reaches the bed of the river, the total weight suspended from the rods must be approximately equal to the weight of water within the caisson, which will be expelled by the application of the air.

"It is expected that when the air is applied the unbalanced weight of the structure will be practically supported by the air pressure, and there will be only a nominal load on the rods.

"4. After the caisson lands on the sand, so that the supporting rods become slack when the nuts are turned, additional weight must be provided to force the caisson into the ground.

"5. After the caisson has reached bed-rock and the working chamber has been sealed by filling it completely full of concrete, there must be sufficient total weight to hold down the structure and prevent it from rising, on account of water pressure caused by the head of water from the surface of the rock to water surface, to be assumed acting over the entire base of the caisson.

"The attached table has been worked out in detail to show the various steps that should be taken in the construction of this caisson and coffer-dam.

"It is probable, of course, that you will not follow the exact procedure outlined, but you should follow it sufficiently close, so that the total weight given in column 'N' will never exceed 325 000 lb.

"Please note that the weights given in the table are assumed weights, and there has been omitted the weight of men, tools, lines, and other small equipment that will be supported upon or within the coffer-dam during sinking; the weight of such material must be added to the total weight.

"In the preparation of this table, the actual weight of the steel caisson, the towers, and the air shafts and locks have been used. The weights for timber, concrete, and iron, such as drift-bolts, through-bolts, spikes, and other small hardware have been assumed.

"Please arrange to weigh sufficient of the timber that will be used in this work and estimate its weight per cubic foot so that the latter figure can be used in your accurate calculation of weights.

"In addition please arrange to make up and weigh several cubic feet of the concrete that will be used, in order that its weight per cubic foot may also be known for use in the calculations. The concrete should be weighed when full of water as it will always be filled with water when submerged.

"I also hand you a number of white prints in blank, on which please arrange to enter notes and figures similar to those shown on the typical summary handed you herewith and arrange to send me one of these weekly with copy direct to Bridge Engineer, C. E. Smith.

"Please understand that this table must be posted up to date every day, and you must instruct your Inspector at the bridge to have it always in shape for inspection and approval by the Bridge Engineer at all times, as the Bridge Engineer will inspect it at such times as he may visit the bridge.

"Please understand that an increase of the loads over the weights given you above would be very disastrous, as it would undoubtedly result in the breaking of some portion of the supporting structure, and might have a disastrous effect upon Pier 3.

"Please note by reference to the typical summary that the application of air to the caisson will make the structure practically self-supporting, but it is not safe to assume that the structure can be supported by the caisson full of air, as a leak in the caisson or in the supply pipe (which is very long), or a failure in the air compressor, or reservoir, or boilers, or a blow-out under the cutting edge, would immediately decrease the supporting power and increase the load in such a way as to throw a very heavy stress upon the rods, which might result in their failure.

"The caisson must be carefully adjusted level when it is first placed, and must at all times thereafter be kept perfectly level as the lowering of one corner faster than any of the others will result in racking the caisson and coffer-dam to such an extent that heavy leaks may be expected. It will be a very easy matter to keep this structure perfectly level by proper manipulation of the screws.

"In case one corner or one portion of the cutting edge rests upon an obstruction, the obstruction must be removed before further sinking is done. After the caisson reaches a bearing upon the bed of the river and the air has been applied, the structure will, to all intents and purposes, be floating, and it will be necessary to supply additional weight to force it down through the sand. This weight will be provided by placing concrete in the end compartments under water.

"The plans call for these compartments to be supplied with 2-in. forms for concrete for their entire height, so that, if necessary, the entire height of the structure can be built up at the ends to provide this additional weight. In addition it is desired that temporary 2-in. sheeting be placed on the inside of the long sides to prevent sand and other material running out of the old crib on top of the concrete. In no case, however, must any concrete be placed in the long sides, as it is desired that those spaces be left open until after the old crib is repaired.

"It will be impossible to add the weight in the end pockets while the structure is swinging from the rods, as it would not be practicable to provide a support of sufficient strength to support such a very heavy load.

"It is impossible to say how much concrete must be added in these end compartments to force the caisson through the material in the bed of the river, as that resistance cannot be calculated, but the conditions must be conquered when encountered.

"After the caisson has reached bed-rock and the working chamber has been filled with concrete, the end pockets will be filled with concrete to a height of 25 ft. above the reinforced concrete roof, part of this material being placed during sinking through the sand and the remainder after the caisson has been sealed."

The weight of the steel caisson, the coffer-dam surmounting it, and the layer of concrete over the roof were not sufficient to sink the caisson after the river bed took the load off the rods. Inner forms for concrete in the ends of the coffer-dam were built up as the caisson was lowered, and concrete was deposited in them with bottom-dump buckets as the weight became necessary. Rods were placed in this concrete projecting from the inner face so as to form a bond with the remainder of the concrete to be placed later.

While waiting for the concrete in the working chamber to set, preparatory to pumping out the coffer-dam, a rapid rise came down the river and overtopped the dam on February 29th, 1912. The water subsided in about 6 weeks, and when pumps were started it was found that the coffer-dam had acted as a settling basin and was full nearly to the top with fine packed sand. The removal of this sand proved very burdensome, slow, and expensive, especially on account of the presence of the numerous braces. In the face of another rise, the dam was extended up to 52 ft. above the caisson, but the water went away over that again several times and stayed up for a considerable period, depositing more sand within the dam. The removal of this material, however, presented no difficulty other than the cost and delay. One pump easily controlled the leakage up to a 50-ft. head, giving a dry dam within which to work on the old pier. The filling of the old pier was found to consist of some rip-rap and more sand. In order to remove the sand, much rock had to be taken out. In fact, all the loose rock was removed with the sand, and only the tight rock was permitted to remain. The latter and the entire inside of the crib was washed out with a strong jet and then filled carefully with concrete. On account of the rather rapid settlement of the pier up stream, that end of the crib was first concreted, and, following the placing of that stiffener, the squeezing of the timbers at the down-stream end caused the pier to settle in the other direction, righting itself several inches. The entire space inside the coffer-dam was filled with concrete, being brought up as the concreting of the crib progressed.

After filling the crib and the surrounding space with concrete, the pier was safe, but, as it was canted so much that it presented a poor appearance, and as the draw-span had only a very small bearing on the pier and was causing the upper courses of masonry to break away, the pier was encased in a reinforced concrete shell. As the new caisson had made the footing large enough, the reinforcement was built for double-track. Plate VI shows the details of the reinforced pier.

The tie-bars at the bottom were placed through bolts cut in the pier, and grouted in. The bridge seats under the spans were entirely renewed in concrete finished at the proper level for double-track spans. The difference in level was made up by concrete pedestals placed in sections, as shown by Fig. 27.

No falsework was used for the support of either span, and the bridge was never out of service during the conduct of the work.

The outer surface of the timbers in the crib under Pier 3 were squeezed down at the ends an almost imperceptible amount. The upper timber was burst open on account of the crushing load.

Fig. 18 is a view of Pier 3 after the completion of the work. The equipment used in this work is listed in Appendix E.

## Reconstruction of Pier 4 in 1912.

In anticipation of further work to be done at Pier 4, and in recognition of the fact that it was in much worse condition than Pier 3, it was decided to replace the rods and yokes holding Piers 3 and 4 to the intermediate span by a pair of cables attached in such a manner as to relieve the spans from the pull. As an anchor for each cable, two 4 by 1-in. eye-bars, together with substantial anchors, as shown by Fig. 28, were embedded in the new concrete of Pier 3 near the top just beyond the ends of the old pier.

Before proceeding with work at Pier 4, two $1\frac{3}{4}$-in. steel cables with cast-steel clevises were attached to the anchor-rods at Pier 3 and suspended from the span. At Pier 4 two 24-in. I-beams were laid on flat, north of the pier, and placed in contact with two 60-ton jacks which were placed horizontally with their bases securely braced against the face of the pier. Tension was put in the cables by the jacks, and the

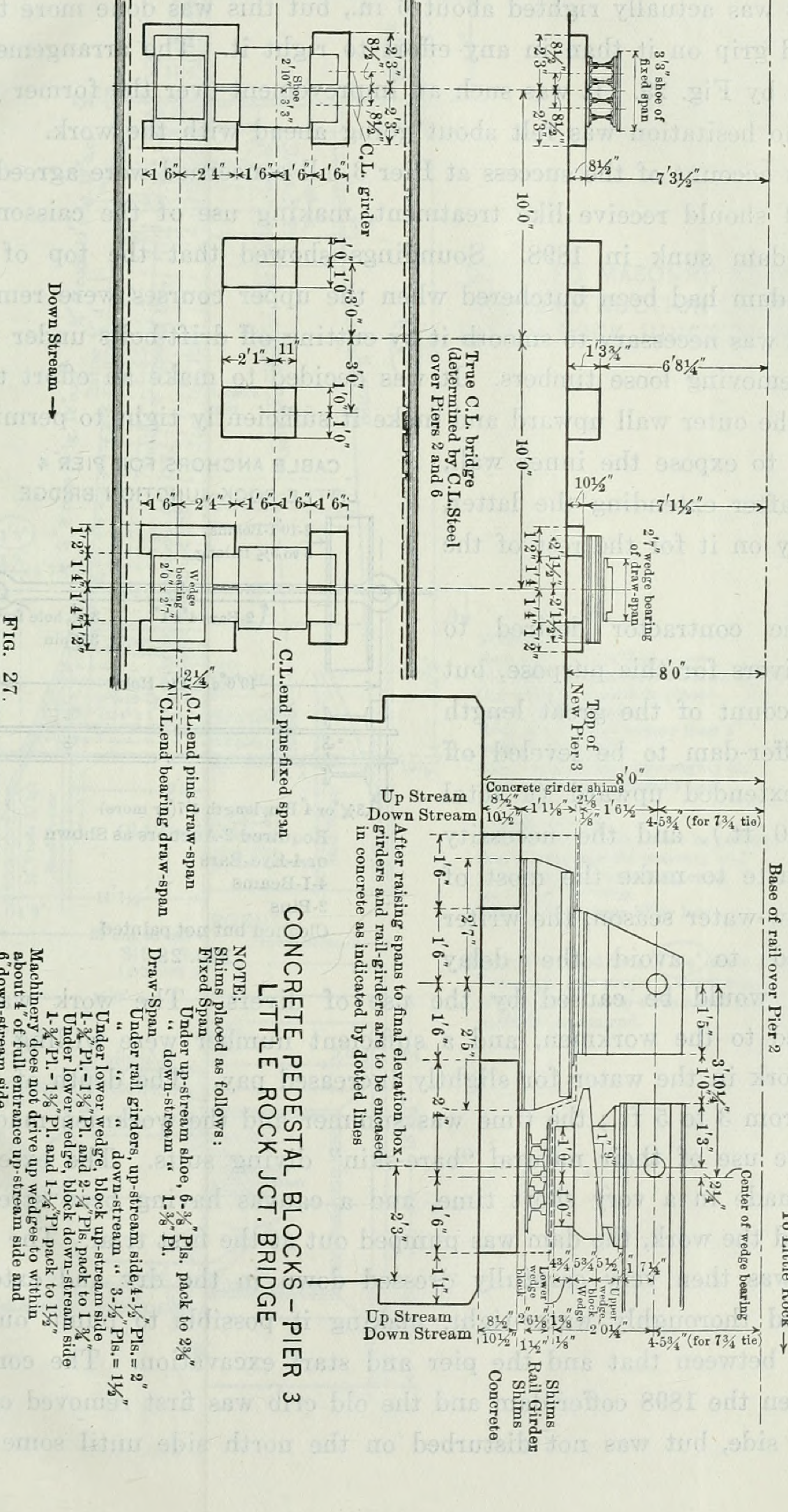

CONCRETE PEDESTAL BLOCKS – PIER 3
LITTLE ROCK JCT. BRIDGE
NOTE:
Shims placed as follows:
Fixed Span
Under up-stream shoe, 6-3/8" Pls. pack to 2 3/8"
" down-stream " 1-3/8" Pl.
Draw-Span
Under rail girders, up-stream side, 4-1/2" Pls. = 2"
" " " down-stream " 3-1/2" Pls. = 1 1/2"
Under lower wedge, block up-stream side
1-3/8" Pl. - 1 3/8" Pl. and 2-1/4" Pls. pack to 1 3/4"
Under lower wedge, block down-stream side
1-3/8" Pl. - 1 3/8" Pl. and 1-1/4" Pl. pack to 1 1/2"
Machinery does not drive up wedges to within about 4" of full entrance up-stream side and 6" down-stream side.
After raising spans to final elevation box girders and rail-girders are to be encased in concrete as indicated by dotted lines
True C.L. bridge (determined by C.L. Steel over Piers 2 and 6
3'3" shoe of fixed span
2'7" wedge bearing of draw-span
Shoe 2'10" x 3'3"
Wedge bearing 2'0" x 2'7"
C.L. girder
C.L. end pins fixed span
C.L. end pins draw-span
C.L. end bearing draw-span
Top of New Pier 3
Base of rail over Pier 2
Center of wedge bearing
To Little Rock →
Down Stream →
Up Stream
Down Stream
Concrete girder shims
Shims
Rail Girder
Shims
Concrete
Lower wedge block
Upper wedge block
4-5 3/4" (for 7 3/4 tie)

FIG. 27.

old yokes were removed. It was found possible to kick Pier 4 over and it was actually righted about 6 in., but this was done more to get a good grip on it than in any effort to right it. The arrangement is shown by Fig. 29. It was such an improvement over the former yokes that no hesitation was felt about going ahead with the work.

On account of the success at Pier 3, all concerned were agreed that Pier 4 should receive like treatment, making use of the caisson and coffer-dam sunk in 1898. Soundings showed that the top of that coffer-dam had been butchered when the upper courses were removed, and it was necessary to smooth it by cutting off drift-bolts under water and removing loose timbers. It was decided to make an effort to extend the outer wall upward and make it sufficiently tight to permit the pump to expose the inner wall, and, after extending the latter, to rely on it for the rest of the work.

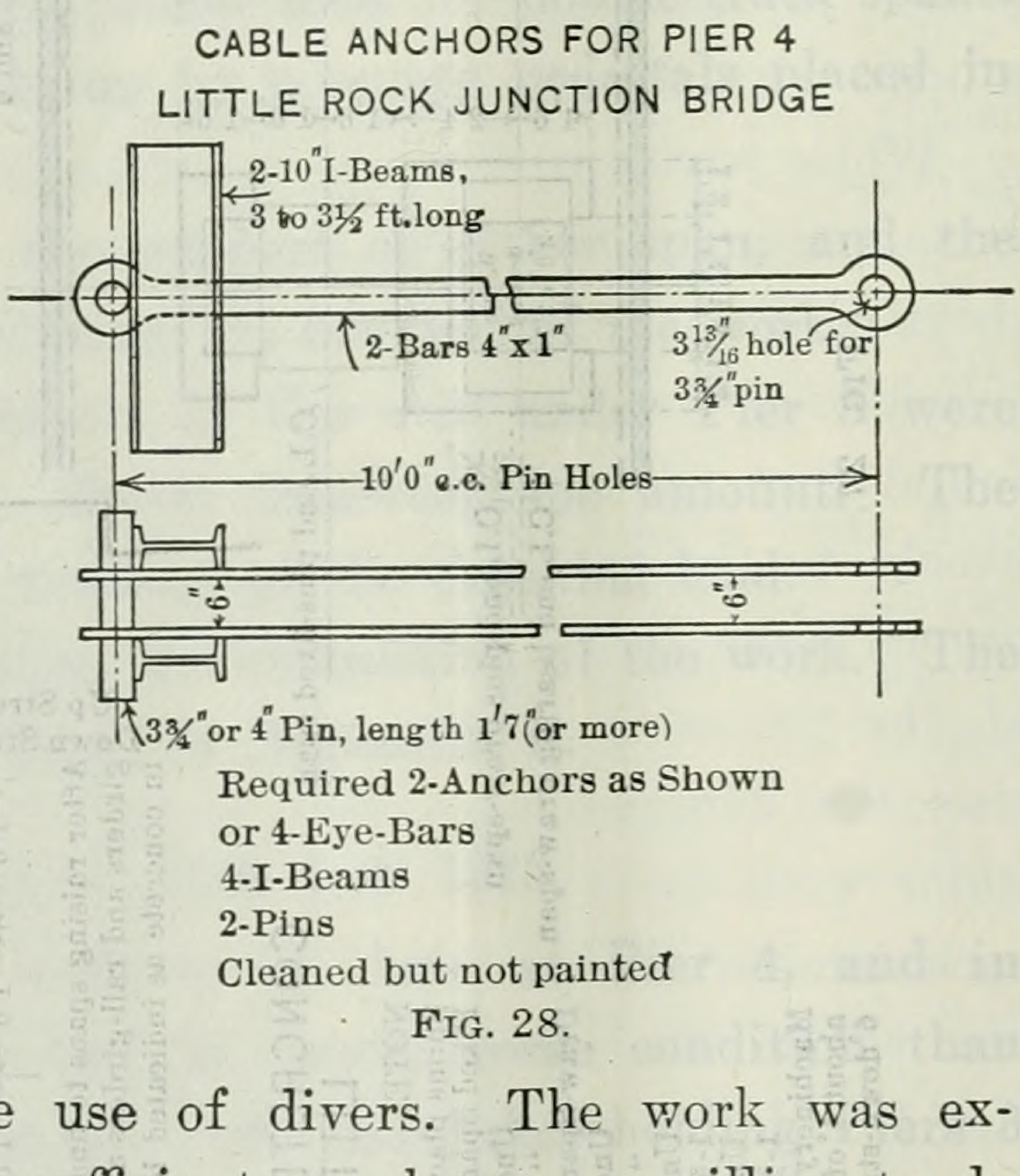


FIG. 28.

The contractor desired to use divers for this purpose, but on account of the great length of coffer-dam to be leveled off and extended upward (a total of 240 ft.), and the necessity for haste to make the most of the low-water season, the writer desired to avoid the delay which would be caused by the use of divers. The work was explained to the workmen, and a sufficient number were willing to do the work in the water for slightly increased pay. The depth of water was from 3 to 5 ft.; the time was summer and the workmen made extensive use of their natural "bare-skin" diving suits. The extension was made in a very short time, and a canvas having been stretched around the work, the dam was pumped out at the first trial. The inner wall was then very carefully dressed down in the dry and extended upward thoroughly water-tight, making it possible to pump out the water between that and the pier and start excavation. The concrete between the 1898 coffer-dam and the old crib was first removed on the south side, but was not disturbed on the north side until some time

# DETAILED MASONRY PLAN FOR RECONSTRUCTION OF PIER 3 LITTLE ROCK JUNCTION BRIDGE


NOTE:-
New work shown thus ———
Old work to be removed shown thus ——
Old work to remain in place " " ————
Use 1:2:4 Concrete
Rods not to come nearer than 3″ to face of concrete
Clean and moisten thoroughly old masonry where joined by new concrete.
Lap all rods 3′0″
Anchor-rods, 1″ Rd., must be grouted thoroughly into old masonry and hooked over outside horizontal bars thus ——⊃
Bevel 1″ all corners 90° or less

Figures enclosed thus (7′8½″) show pier as built.
Top of old pier projects above top of new pier 4″ at up-stream end and 9″ at down-stream end.

PLATE VI.
TRANS. AM. SOC. CIV. ENGRS.
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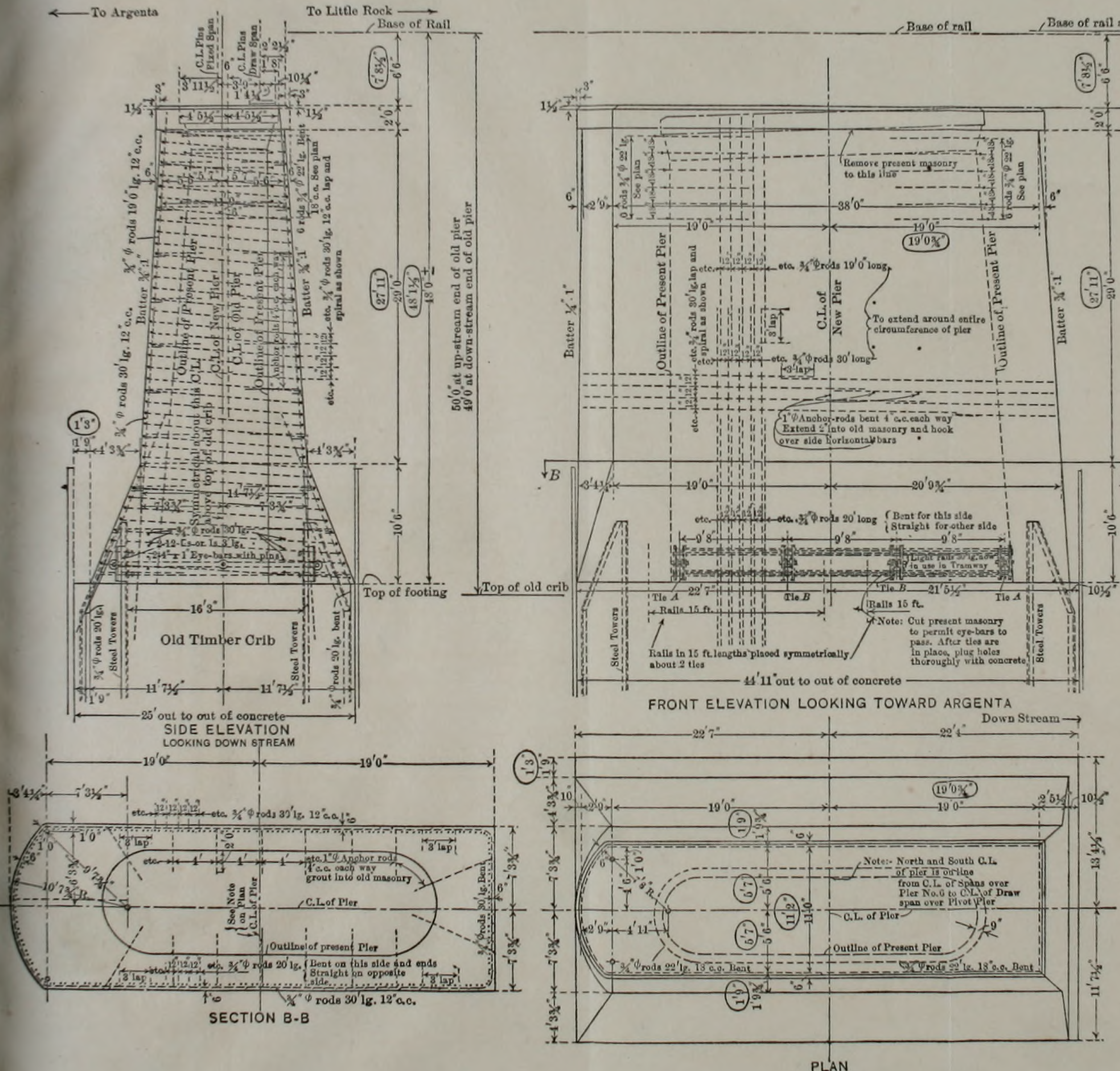
SMITH ON
REPAIRING BRIDGE PIERS.

# DETAILED MASONRY PLAN FOR RECONSTRUCTION OF PIER 3 LITTLE ROCK JUNCTION BRIDGE




NOTE:-
New work shown thus ——
Old work to be removed shown thus ----
Old work to remain in place " " -·-·-·-
Use 1:2:4 Concrete
Rods not to come nearer than 3" to face of concrete
Clean and moisten thoroughly old masonry where joined by new concrete.
Lap all rods 3'0"
Anchor-rods, 1" Rd., must be grouted thoroughly into old masonry and hooked over outside horizontal bars thus
Bevel 1" all corners 90° or less

Figures enclosed thus (7'8½") show pier as built.
Top of old pier projects above top of new pier 4" at up-stream end and 9" at down-stream end.

later, after the yokes and cables were in place anchoring the pier to Pier 3.

The removal of the material down to rock was slow and tedious. The old coffer-dam had been badly racked during sinking, and large leaks were found all the way down. They were overcome, and the rock was laid bare and covered with concrete up to the top of the caisson of the old pier, after which the crib was cleaned out, filled with concrete, and surrounded as at Pier 3.

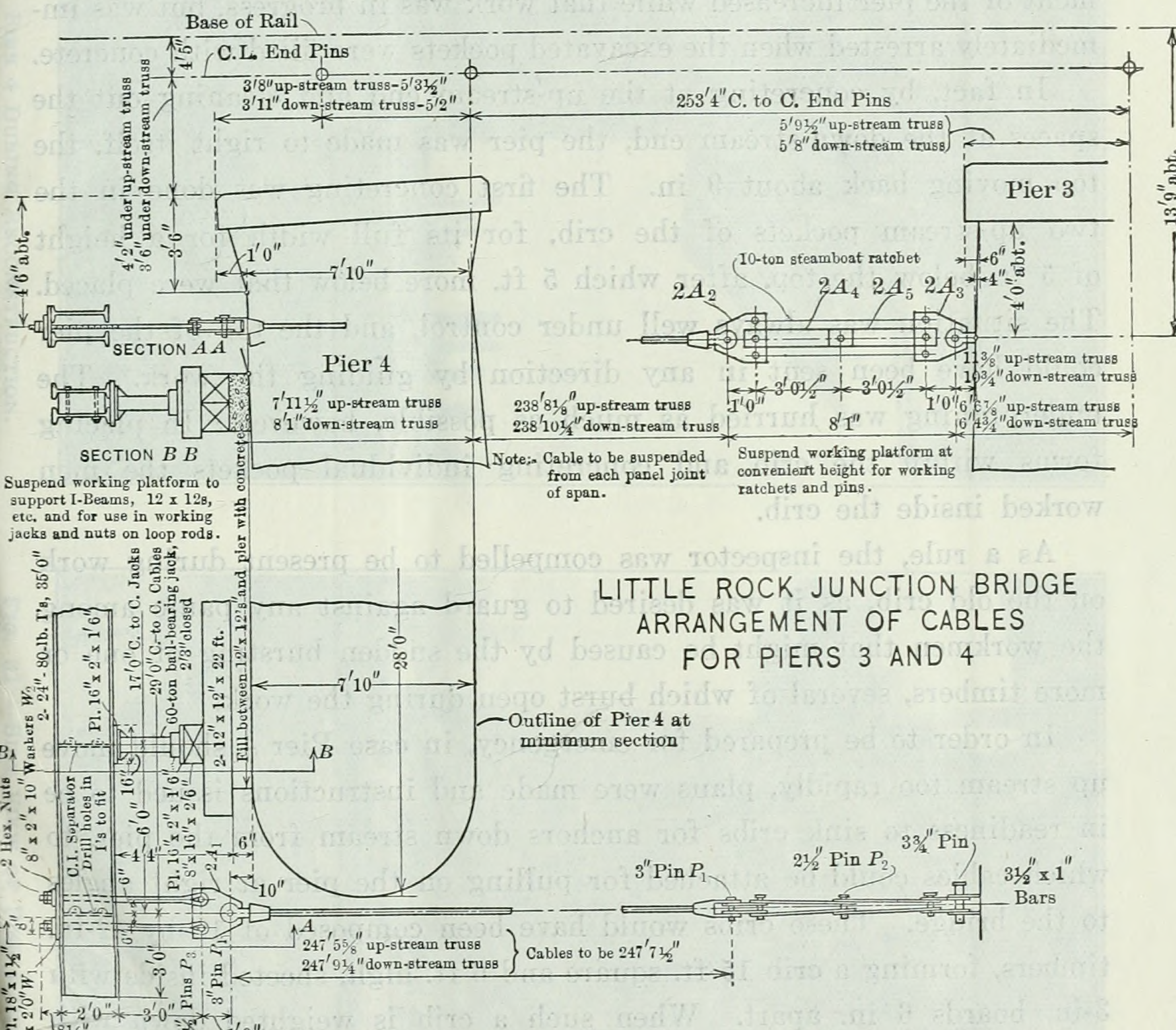



FIG. 29.

There was always a great flow of water from the south side, and in excavating down it was found that it came through under the cutting edges of the 1898 coffer-dam where a dip in the rock had been bridged over and was supposed to have been filled with concrete, but apparently was not. Several bad blows, carrying many yards of sand and flooding the excavation, occurred under the 1898 caisson, and it was not possible to pump down to the bottom until after the material had been removed and the leak stopped by placing a sealing course of concrete under water.

Some of the timbers were crushed to 6 in. in height, and on account of the inclination of the pier new cracks developed in the timbers while the excavation progressed. The weakest portions of this crib were concreted as they were reached. Attention was given to the up-stream end, and excavation was first made there. The movement of the pier increased while that work was in progress, but was immediately arrested when the excavated pockets were filled with concrete. In fact, by concreting at the up-stream end and cleaning out the spaces at the down-stream end, the pier was made to right itself, the top moving back about 9 in. The first concreting was done in the two up-stream pockets of the crib, for its full width for a height of 5 ft. below the top, after which 5 ft. more below that were placed. The situation was always well under control, and the top of the pier could have been sent in any direction by guiding the work. The underpinning was hurried as much as possible, however. In placing forms within the crib and concreting individual pockets the men worked inside the crib.

As a rule, the inspector was compelled to be present during work on the old crib, as it was desired to guard against any panic among the workmen that might be caused by the sudden bursting of one or more timbers, several of which burst open during the work.

In order to be prepared for emergency, in case Pier 4 should move up stream too rapidly, plans were made and instructions issued to be in readiness to sink cribs for anchors down stream from the pier, to which cables could be attached for pulling on the pier at right angles to the bridge. These cribs would have been composed of 12 by 12-in. timbers, forming a crib 15 ft. square and 6 ft. high, sheeted inside with 3-in. boards 6 in. apart. When such a crib is weighted down with rock and dropped on the bed of the Arkansas River it becomes buried immediately and forms an almost immovable anchor. It was not found necessary to sink such cribs, however.

No falsework was used while Pier 4 was under reconstruction; the pier carried traffic at all times.

Figs. 30 and 31 are two views of Pier 4 during the reconstruction. The old timber yoke and rods connecting to the trusses, placed in

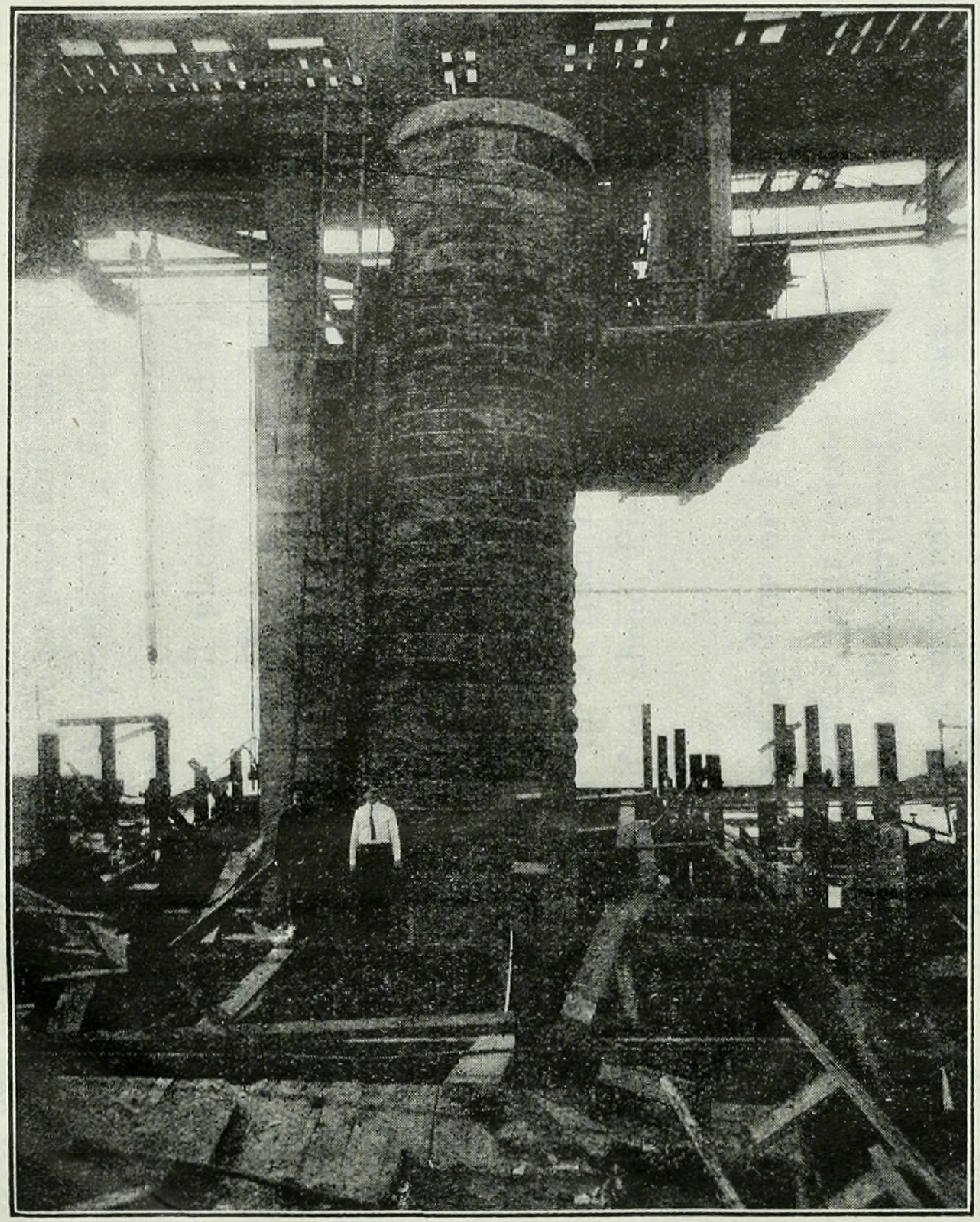


FIG. 30.—END VIEW OF PIER 4 DURING RECONSTRUCTION.

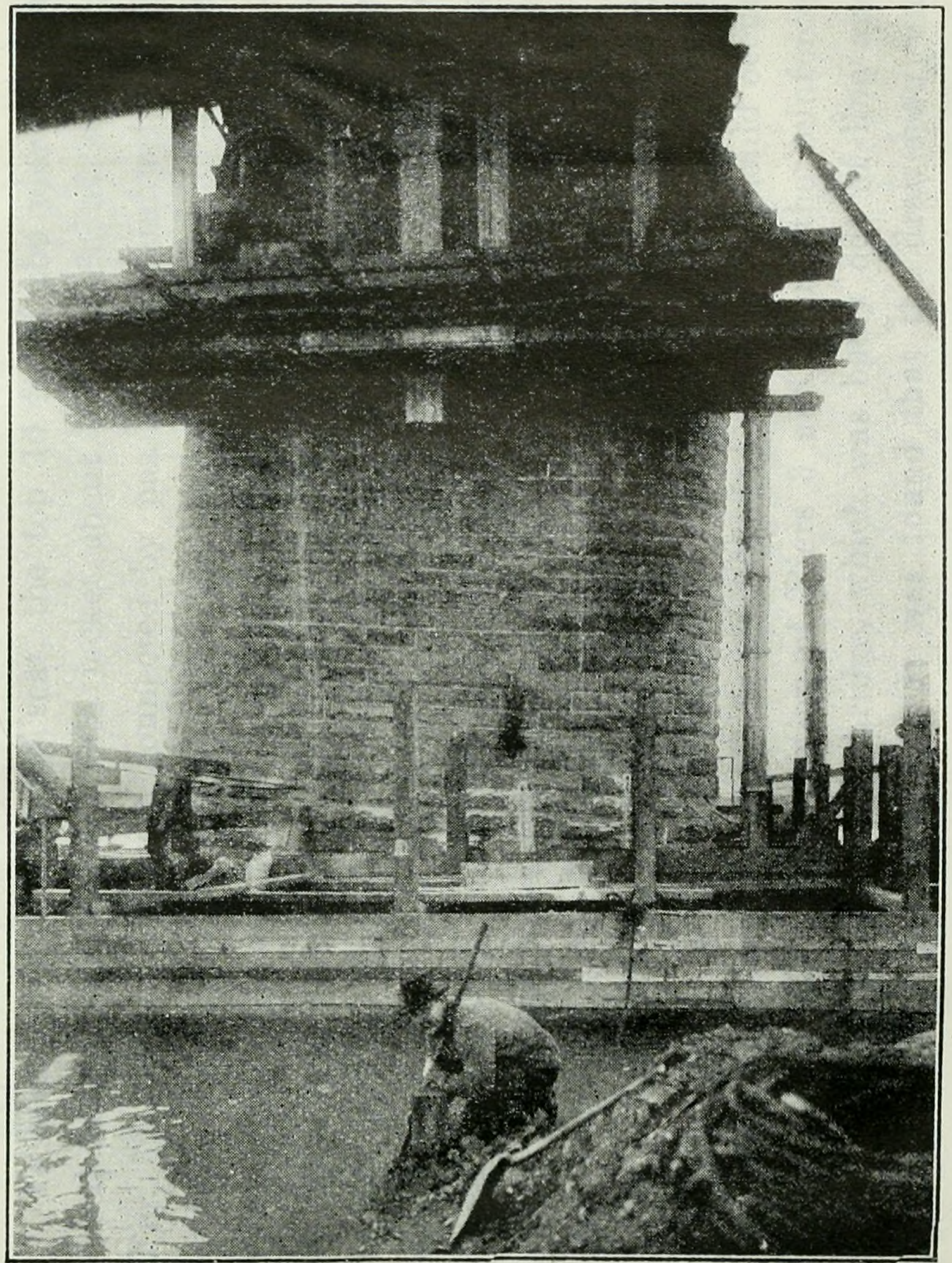


FIG. 31.—SIDE VIEW OF PIER 4 DURING RECONSTRUCTION.

1908, had not been removed at the time the picture was taken. The I-beams and $1\frac{3}{4}$-in. cables were in place and can be readily seen. The completed pier appears to be practically a duplicate of Pier 3, shown on Fig. 18.

The reinforced concrete shell placed around Pier 4 is practically a duplicate of that placed at Pier 3. It is shown on Plate VII. The tie-bars at the bottom were passed through the pockets in the crib and concreted in, instead of being passed through the pier. At this pier the ends of the spans were shifted sideways to permit the construction of each concrete pedestal in one piece.

As Pier 5 had moved north somewhat in the past, as a result of its own weakness and the thrust from Pier 4, anchors were buried in Pier 4 and the cables shifted ahead, Pier 4 now acting as an anchor for Pier 5.

### Reinforcement of Top of Pier 5 in 1913.

The small tops of these piers, their repeated movement, and the frequent shifting of the spans, all contributed to a very poor condition of the bridge seat on Pier 5, on which the stones were breaking out under the end of the south span which rested close to the edge of the pier.

To strengthen the bridge seat, the top 10 ft. of the pier was encased in a reinforced concrete jacket about 9-in. thick, as shown by Fig. 32. The sides were connected by passing the reinforcing rods around the curved ends of the pier and also by three sets of rails set vertically in the reinforced concrete at the middle and quarter points of the length of the pier. The lower ends of these rails were attached to the pier by 2-in. anchor-bolts set in grouted holes. Their upper ends were connected by 2-in. rods extending across the pier tops in channels cut in the bridge seat and filled with concrete. All cracks in the pier top were carefully grouted. The bridge seat appears to have taken on a new lease of life.

It is expected that, as Pier 5 is quite a distance from the ordinary channel, there is little likelihood of the material surrounding it washing away, and no trouble is apprehended unless that should occur.

Following the reconstruction of Piers 3 and 4 and the reinforcement of Pier 5, the entire bridge, which was badly out of line and level, was lined and leveled. It was found that the draw-span was

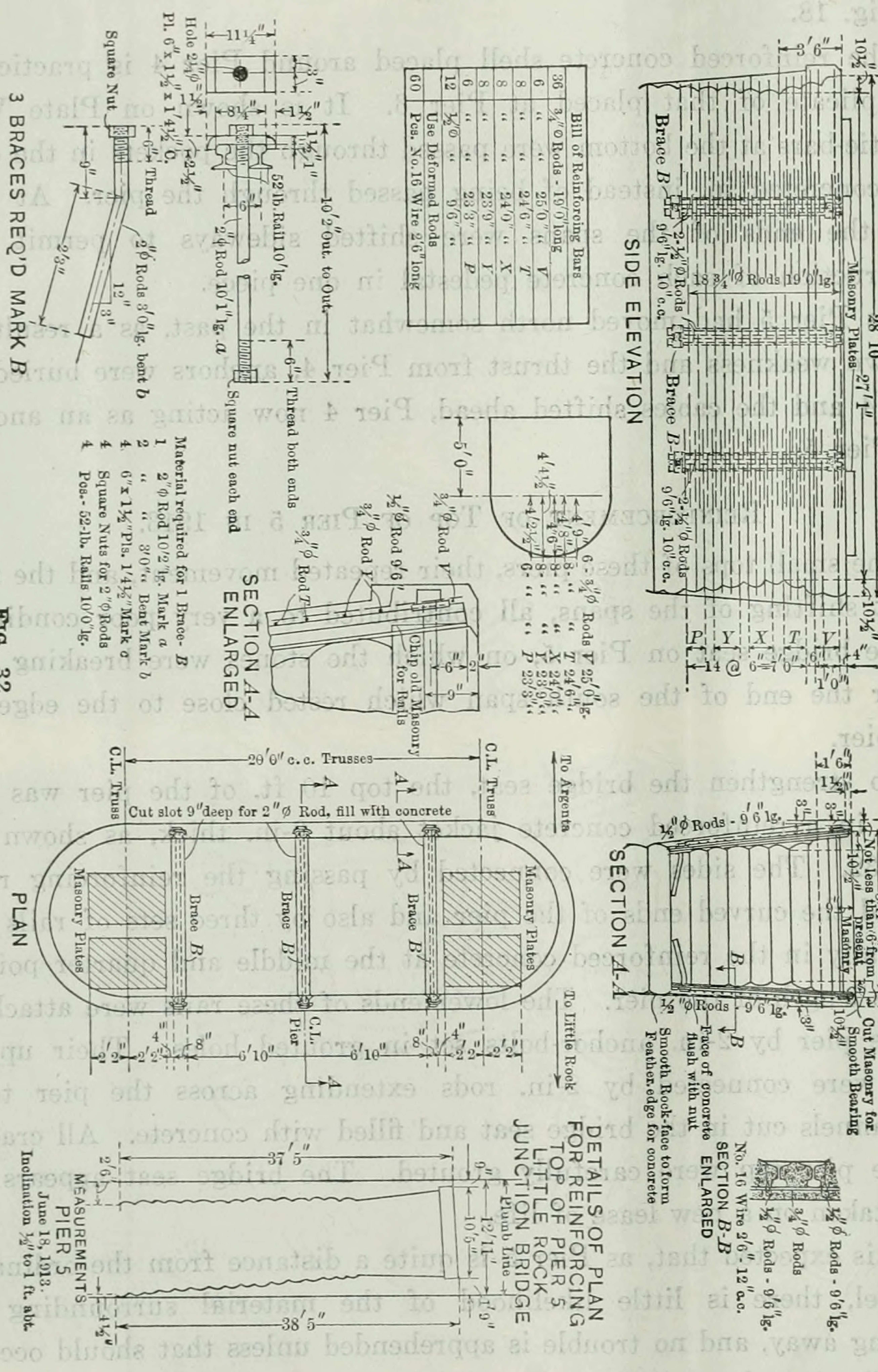

SIDE ELEVATION
Masonry Plates
Brace B
18 ¾"φ Rods 19'0" lg.
2-1¼"φ Rods 9'6" lg. 10" c.c.
Bill of Reinforcing Bars
36 ¾"φ Rods - 19'0" long
6 " " 25'0" " V
8 " " 24'6" " T
8 " " 24'0" " X
8 " " 23'9" " Y
6 " " 23'3" " P
12 ½"φ " 9'6" "
Use Deformed Rods
60 Pcs. No. 16 Wire 2'6" long
SECTION A-A ENLARGED
Chip old Masonry for Rails
52 lb. Rail 10' lg.
2"φ Rod 10'1" lg. a
Square nut each end
Thread both ends
2"φ Rods 3'0" lg. bent b
3 BRACES REQ'D MARK B
Material required for 1 Brace- B
1 2"φ Rod 10'2" lg. Mark a
2 " " 3'0" " Bent Mark b
4 6"x 1½" Pls. 1'4½" Mark c
4 Square Nuts for 2"φ Rods
4 Pcs.- 52-lb. Rails 10'0" lg.
SECTION A-A
½"φ Rods - 9'6" lg.
Cut Masonry for Smooth Bearing
Face of concrete flush with nut
Smooth Rock-face to form Feather-edge for concrete
No. 16 Wire 2'6" - 12" c.c.
SECTION B-B ENLARGED
To Argenta
29'0" c.c. Trusses
Cut slot 9" deep for 2"φ Rod, fill with concrete
C.L. Truss
Masonry Plates
PLAN
To Little Rock
DETAILS OF PLAN FOR REINFORCING TOP OF PIER 5 LITTLE ROCK JUNCTION BRIDGE
MEASUREMENTS PIER 5
June 18, 1913.
Inclination ½" to 1 ft. abt.

FIG. 32.

PLATE VII.
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SMITH ON
REPAIRING BRIDGE PIERS.

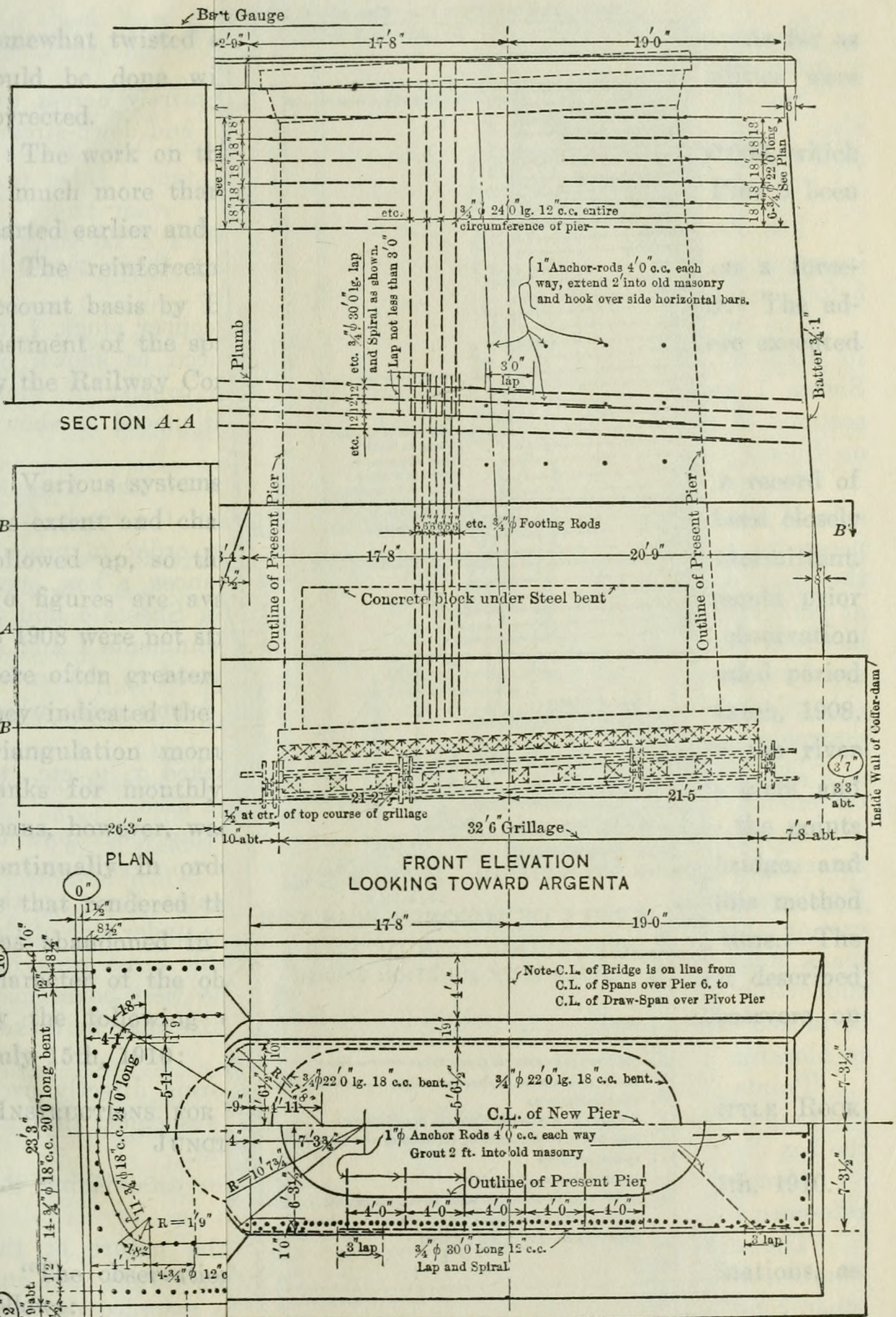
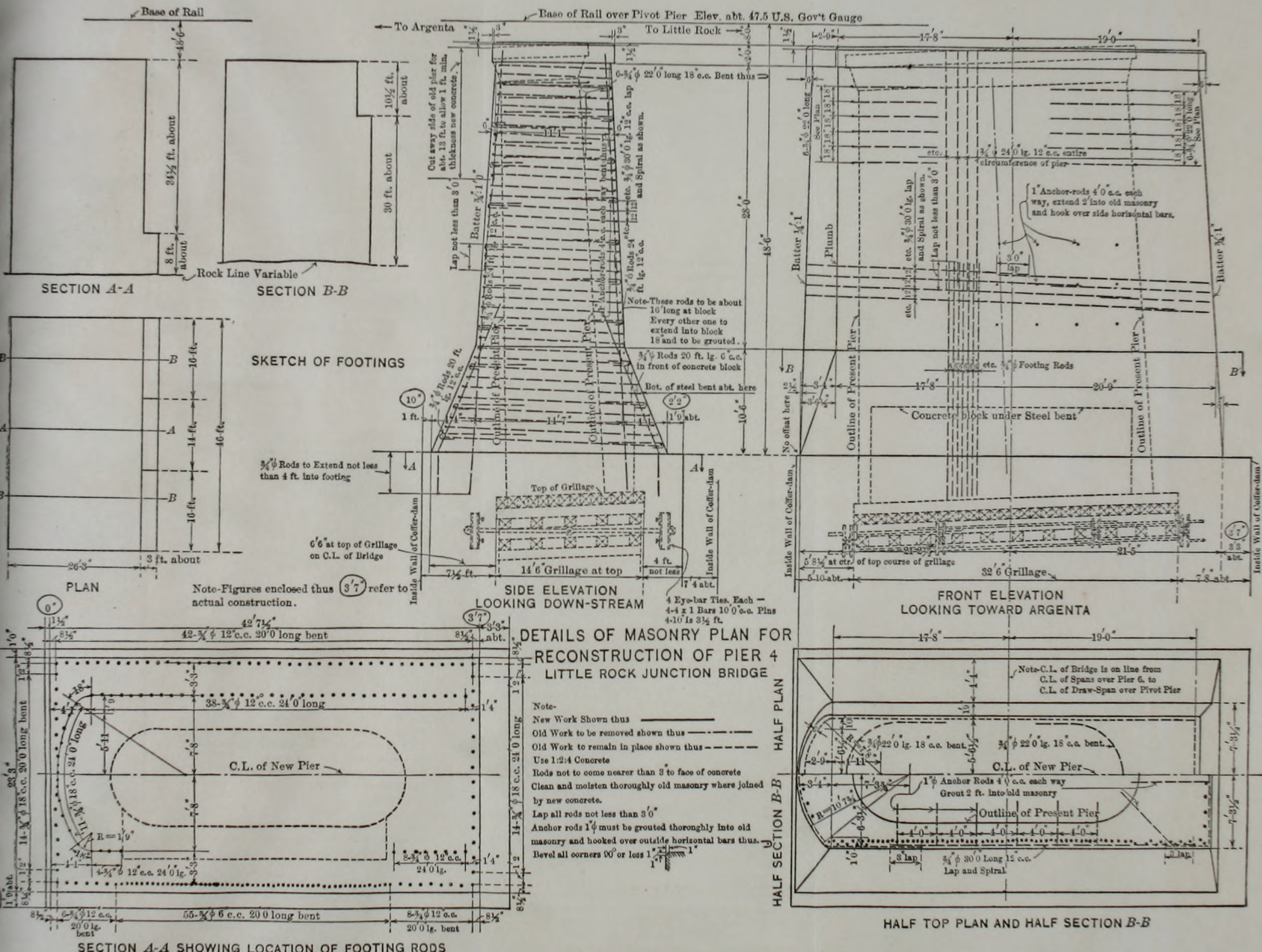


PLATE VII.
TRANS. AM. SOC. CIV. ENGRS.
VOL. LXXIX, No. 1335.
SMITH ON
REPAIRING BRIDGE PIERS.




DETAILS OF MASONRY PLAN FOR RECONSTRUCTION OF PIER 4
LITTLE ROCK JUNCTION BRIDGE

somewhat twisted and one end hung lower than the other. As far as could be done without injury to the span, the inequalities were corrected.

The work on the three piers and spans cost about $100 000, which is much more than it would have cost had the work on Pier 3 been started earlier and the floods avoided.

The reinforcement of Piers 3 and 4 was executed on a force-account basis by Bates and Rogers Construction Company. The adjustment of the spans and the reinforcement of Pier 5 were executed by the Railway Company forces.

### Instrumental Observations.

Various systems of observations had been used to get a record of the extent and character of movement, but they had not been closely followed up, so that the old records of movement are intermittent. No figures are available previous to 1905, and measurements prior to 1908 were not strictly comparative because the errors of observation were often greater than the movement, but over any extended period they indicated the general trend of the movement. In March, 1908, triangulation monuments were placed on Pier 4 and on the river banks for monthly observations. The movement of the piers and spans, however, was such that it was necessary to change the points continually in order to get a clear view through the bridge, and as that rendered the observations of questionable value, this method was abandoned in 1910 for that in use at the present time. The character of the observations taken since that time is best described by the following copy of the instructions issued to observers on July 15th, 1910:

"Instructions for Taking Observations on Piers of Little Rock Junction Bridge, Little Rock, Arkansas.

"St. Louis, Mo., July 15th, 1910.

"Character of Observations.

"The observations consist of four independent determinations, as follows:

"*Line.*—Determining the location of two points on each pier by line relative to fixed monuments on shore.

"*Distance.*—Determining the location of said points by measurements from fixed monuments on shore.

"*Grade.*—Determining the elevation of said points with reference to established bench-marks.

"*Soundings.*—Determining profile of river bed entirely across the river at the center line of track and at the up-stream and down-stream ends of the piers.

"General Remarks.

"The observer must provide himself with a complete copy of these instructions and accompanying drawings, and study them carefully before making the observations.

"The two points on each of the piers consist of copper plugs, ¾ in. in diameter, set in the masonry, located and placed as shown on Sheets 1 and 4. The fixed monuments on shore consist of short sections of old rails set in the ground, located and placed as shown on Sheets 1, 2, 3, and 4.

"The points on the piers and the monuments on the Argenta side of the river being several feet below the level of the track, it is necessary to use a plumb-bob over each point. In order to protect the plumb-bob and string from atmospheric disturbances, a box, open at both ends and cut to proper length, as shown on Sheets 4 and 5, has been provided for each point. The boxes for Monuments *I* and *K* are fixed in position at the top end by hinges screwed to the under side of the bridge. This enables the boxes to be swung aside when desirable.

"The boxes for the points on the piers are marked *x, y,* etc., to correspond with the point over which they should be used.

"The boxes are held in place by cleats connecting their tops to the ends of the bridge ties. Those on the west or up-stream end of the piers extend 6 in. above the top of the floor-beams, those on the east or down-stream ends of the piers extend up to the under side of the plank walk. The boxes are provided with adjustable cross-arms for supporting the plumb line. The cross-arms for the west boxes may be tacked directly to their top; those for the east boxes may be tacked to blocking supported on the plank walk.

"Points are located on these adjustable cross-arms directly over the points on the piers by means of a plumb-bob suspended through the box directly over the respective points on the piers.

"Monuments *B, C, I,* and *K* are to be used for establishing the reference lines.

"The direction and character of the wind, the nature of the weather, distance base of rail to water surface, temperature, and any other conditions affecting the observations must be recorded on each occasion.

"Method of Procedure for Line.

"Set the transit over Monument *C* and check line *A B C D*; then set it over *H* and check lines *G H I* and *H J K L*; set over *M* and check lines *M J I* and *N M K*. If these lines check, the monuments may be assumed to be correct. With transit at *M* and foresight on *I* the location of $x_7$ may be checked.

"Next move transit up to deck of bridge and set it over point *K*, sighting on *C* and establishing line at points, $y_7$, $y_6$, $y_5$, and $y_4$; then over point *I*, sighting on *B* and establishing points, $x_6$, $x_5$, $x_4$, and $x_3$.

"Next move transit to other end of bridge and set it over *C*, sighting on *K* and establishing points, $y_1$, $y_2$, $y_3$, and $y_4$.

"The distances between the points thus established and the original points formerly established on the copper plugs measured on the cross-arms, at right angles to the line of sight, must be recorded, as these distances indicate the movement of the piers in an east and west direction, at right angles to the direction of the bridge.

"This observation must be taken at least twice, the observers changing places and repeating all operations until their observations check.

"Method of Procedure for Distances.

"The measurements from fixed point on shore are made along lines *B I* and *C X*, points *B* and *C* being taken at Station 0, and the station of each of the points, *x*, *y*, etc., as well as *I* and *K* being recorded.

"On line *C K* the tape is permitted to rest on the tops of the floor-beams; on line *B I* (which follows the footwalk) wood blocks about 4 in. high must be placed over each floor-beam to reproduce the conditions of support obtained on line *C K* and to eliminate the effect of the temperature of the walk on the tape.

"The distances are measured with a 200-ft. tape stretched to a tension indicated as 15 lb. on a spring balance. Monuments $S_1$ and $S_2$ have been carefully set 200 ft. apart for standardizing the tape, which is correct at 62° Fahr. For other temperatures the measured distances must be increased (+) or decreased (—) by the amounts shown in the following table.

"Average Temperature.

| Meas. | 12 | 22 | 32 | 45 | 52 | 62 | 72 | 82 | 92 | 102 | 112 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bx* | — .057 | — .045 | — .034 | — .023 | — .011 | 0 | .011 | .023 | .034 | .045 | .057 |
| *Bx* | — .112 | — .089 | — .067 | — .044 | — .022 | 0 | .022 | .044 | .067 | .089 | .112 |
| *Bx* | — .174 | — .139 | — .104 | — .069 | — .035 | 0 | .035 | .069 | .104 | .139 | .174 |
| *Bx* | — .258 | — .206 | — .155 | — .103 | — .052 | 0 | .052 | .103 | .155 | .206 | .258 |
| *Bx* | — .340 | — .271 | — .203 | — .135 | — .068 | 0 | .068 | .135 | .203 | .271 | .340 |
| *Bx* | — .422 | — .338 | — .253 | — .168 | — .084 | 0 | .084 | .168 | .253 | .338 | .422 |
| *Bx* | — .466 | — .373 | — .280 | — .186 | — .093 | 0 | .093 | .186 | .280 | .373 | .466 |
| *Cy* | — .053 | — .043 | — .032 | — .021 | — .011 | 0 | .011 | .021 | .032 | .043 | .053 |
| *Cy* | — .109 | — .087 | — .065 | — .043 | — .022 | 0 | .022 | .043 | .065 | .087 | .109 |
| *Cy* | — .170 | — .136 | — .092 | — .068 | — .034 | 0 | .034 | .068 | .092 | .136 | .170 |
| *Cy* | — .254 | — .203 | — .152 | — .101 | — .051 | 0 | .051 | .101 | .152 | .203 | .254 |
| *Cy* | — .338 | — .270 | — .203 | — .135 | — .068 | 0 | .068 | .135 | .203 | .270 | .338 |
| *Cy* | — .418 | — .335 | — .251 | — .167 | — .083 | 0 | .083 | .167 | .251 | .335 | .418 |
| *Cy* | — .461 | — .368 | — .276 | — .184 | — .092 | 0 | .092 | .184 | .276 | .368 | .461 |

"Method of Procedure for Grades.

"The top of the steel rail in Monument *C* is the bench-mark elevation. For purposes of checking, any other monument may be used, the elevations being shown on Sheets 2 and 3.

"Set the level about half way between *C* and the south abutment, use point *y* for turning point. Move level to middle of first span and use point *y* for turning point. Continue across all the spans and back in this manner, checking on bench-mark *C* and taking readings on all points on piers in each direction for a check.

"In case the levels check upon returning to *C* and the two readings on each point check, this observation need not be repeated. Otherwise it must be repeated until a check is obtained.

"Method of Procedure for Soundings.

"Soundings shall be taken along the lines $P\ P_1$; $P_2\ P_3$, and $P_4\ P_5$, shown on Sheet 6, preferably by use of a lead line from a boat, except where the ground line is above water, where it can be taken by a weighted tape from the bridge floor. The distance from base of rail to water surface shall always be recorded.

"Soundings shall be taken close to the foundation under each pier, but far enough out to miss it, and at every second floor-beam of each span (about 50 ft. apart).

"This observation for soundings need be taken only once, there being no necessity for its repetition."

Fig. 33 shows the location of the base lines, points on pier, transit points, and other monuments. No movement has been detected in the pivot pier since the repairs in 1898; no movement has ever been detected in Piers 1, 6, and 7.

Fig. 34 shows the movement curve for Pier 3; practically no movement was detected up to 1908. In that year, following the application of the rods and yokes to the ends of the span resting on Piers 3 and 4, Pier 3 moved north (parallel to the bridge) about 10 in. from 1908 to 1913, during which period the reconstruction was carried out, since which work the pier has been stationary. No movement east or west (at right angles to the bridge) was detected in Pier 3 until the summer of 1910, when, for no apparent reason other than the deep scour of the river around the pier, it started up stream at the rather rapid rate of 9 in. in 14 months, the up-stream end settling several inches. This movement brought about the reconstruction of the pier in 1911 and 1912, during which it was found possible, by controlling the underpinning, to make the pier partly right itself, the curve showing that the top moved back (east) about 6 in. during the work.

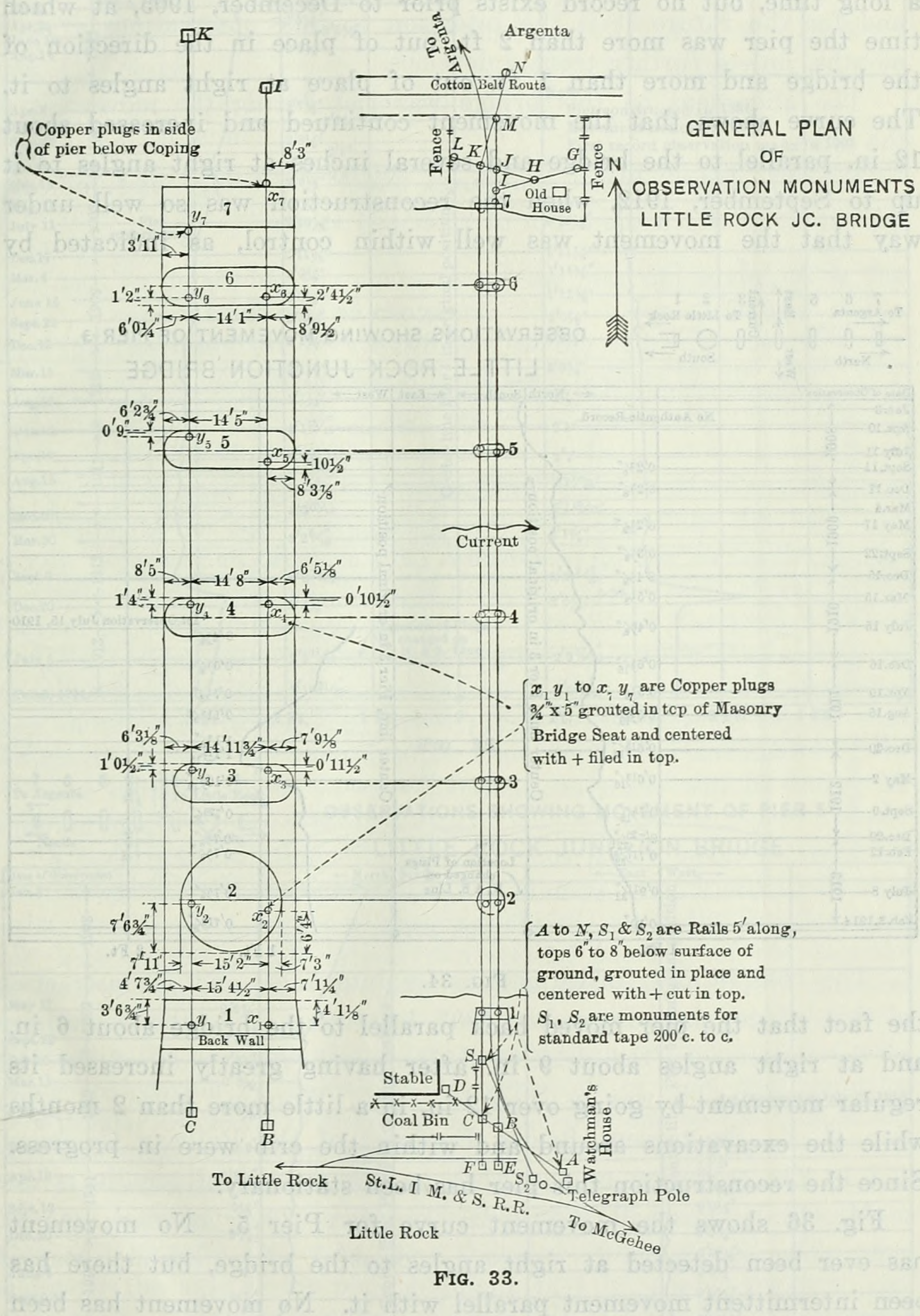

GENERAL PLAN
OF
OBSERVATION MONUMENTS
LITTLE ROCK JC. BRIDGE
Argenta
To Argenta
Cotton Belt Route
Fence
Old House
Copper plugs in side of pier below Coping
Current
$x_1$ $y_1$ to $x_7$ $y_7$ are Copper plugs ¾"x 5" grouted in top of Masonry Bridge Seat and centered with + filed in top.
A to N, $S_1$ & $S_2$ are Rails 5' along, tops 6" to 8" below surface of ground, grouted in place and centered with + cut in top.
$S_1$, $S_2$ are monuments for standard tape 200' c. to c.
Back Wall
Stable
Coal Bin
Watchman's House
To Little Rock
St.L. I. M. & S. R.R.
Telegraph Pole
To McGehee
Little Rock

FIG. 33.

Fig. 35 shows the movement curve for Pier 4. The position of the pier in 1898 made it evident that the movement had taken place for a long time, but no record exists prior to December, 1905, at which time the pier was more than 2 ft. out of place in the direction of the bridge and more than 1 ft. out of place at right angles to it. The curve shows that the movement continued and increased about 12 in. parallel to the bridge and several inches at right angles to it up to September, 1912, when the reconstruction was so well under way that the movement was well within control, as indicated by

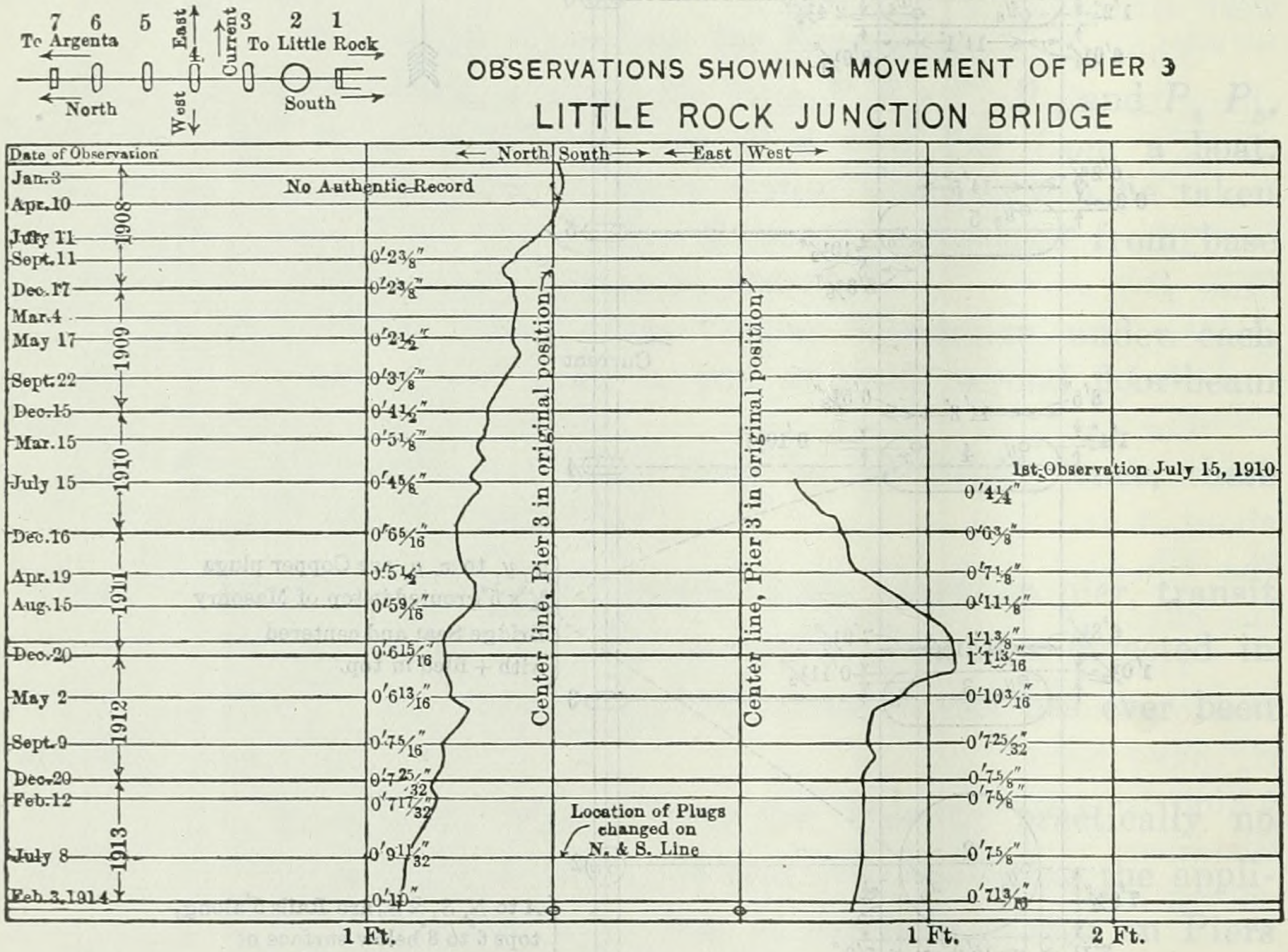



FIG. 34.

the fact that the pier moved back parallel to the bridge about 6 in. and at right angles about 9 in. after having greatly increased its regular movement by going over 12 in. in a little more than 2 months while the excavations around and within the crib were in progress. Since the reconstruction this pier has been stationary.

Fig. 36 shows the movement curve for Pier 5. No movement has ever been detected at right angles to the bridge, but there has been intermittent movement parallel with it. No movement has been detected since the application of the cables anchoring this pier to Pier 4, and no further movement is expected.

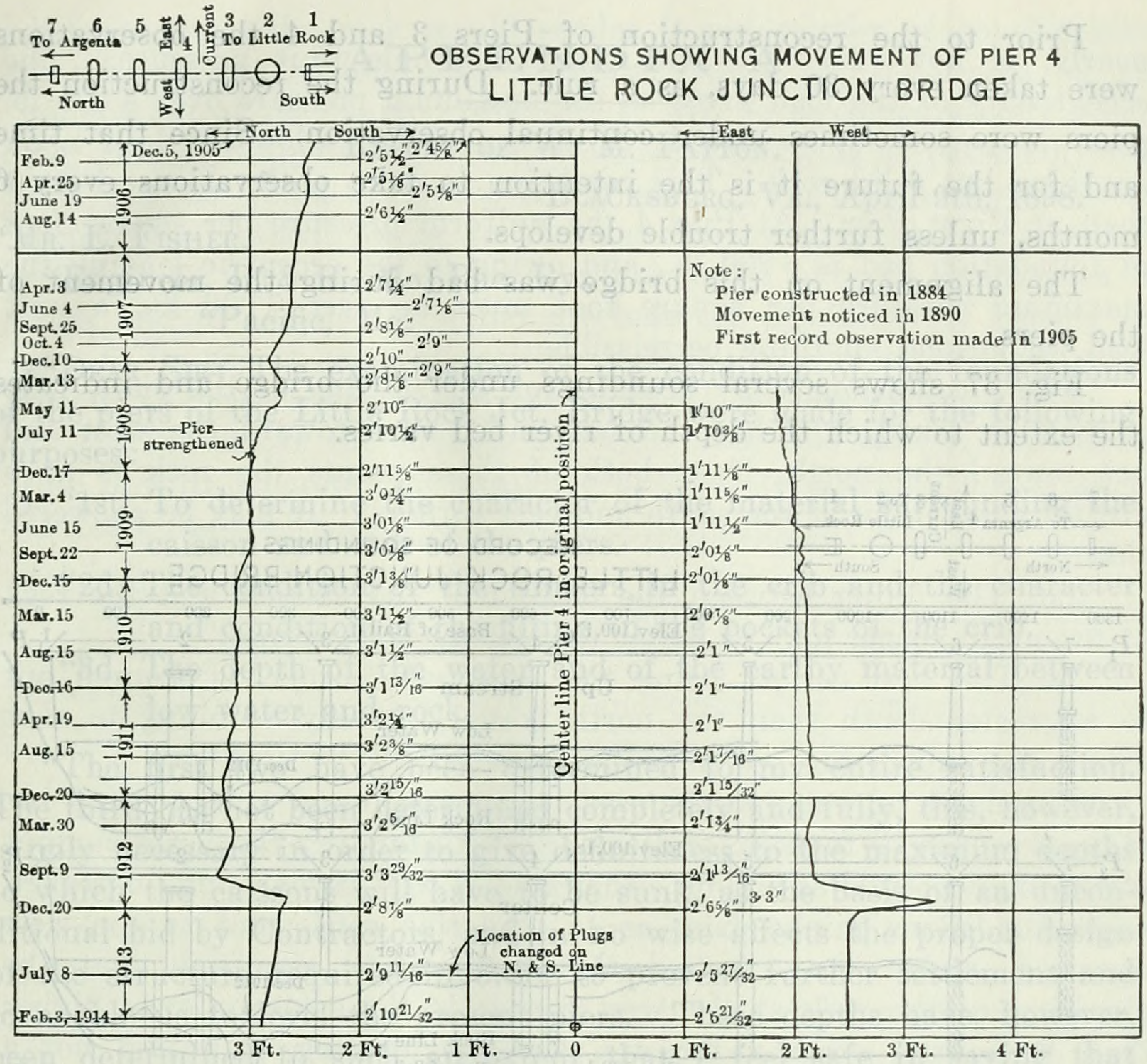

OBSERVATIONS SHOWING MOVEMENT OF PIER 4
LITTLE ROCK JUNCTION BRIDGE
To Argenta
To Little Rock
North
South
East
West
Current
7 6 5 4 3 2 1
Note:
Pier constructed in 1884
Movement noticed in 1890
First record observation made in 1905
Pier strengthened
Center line Pier 4 in original position
Location of Plugs changed on N. & S. Line
Dec. 5, 1905
1906
1907
1908
1909
1910
1911
1912
1913
Feb. 9
Apr. 25
June 19
Aug. 14
Apr. 3
June 4
Sept. 25
Oct. 4
Dec. 10
Mar. 13
May 11
July 11
Dec. 17
Mar. 4
June 15
Sept. 22
Dec. 15
Mar. 15
Aug. 15
Dec. 16
Apr. 19
Aug. 15
Dec. 20
Mar. 30
Sept. 9
Dec. 20
July 8
Feb. 3, 1914
3 Ft.
2 Ft.
1 Ft.
0
1 Ft.
2 Ft.
3 Ft.
4 Ft.

FIG. 35.

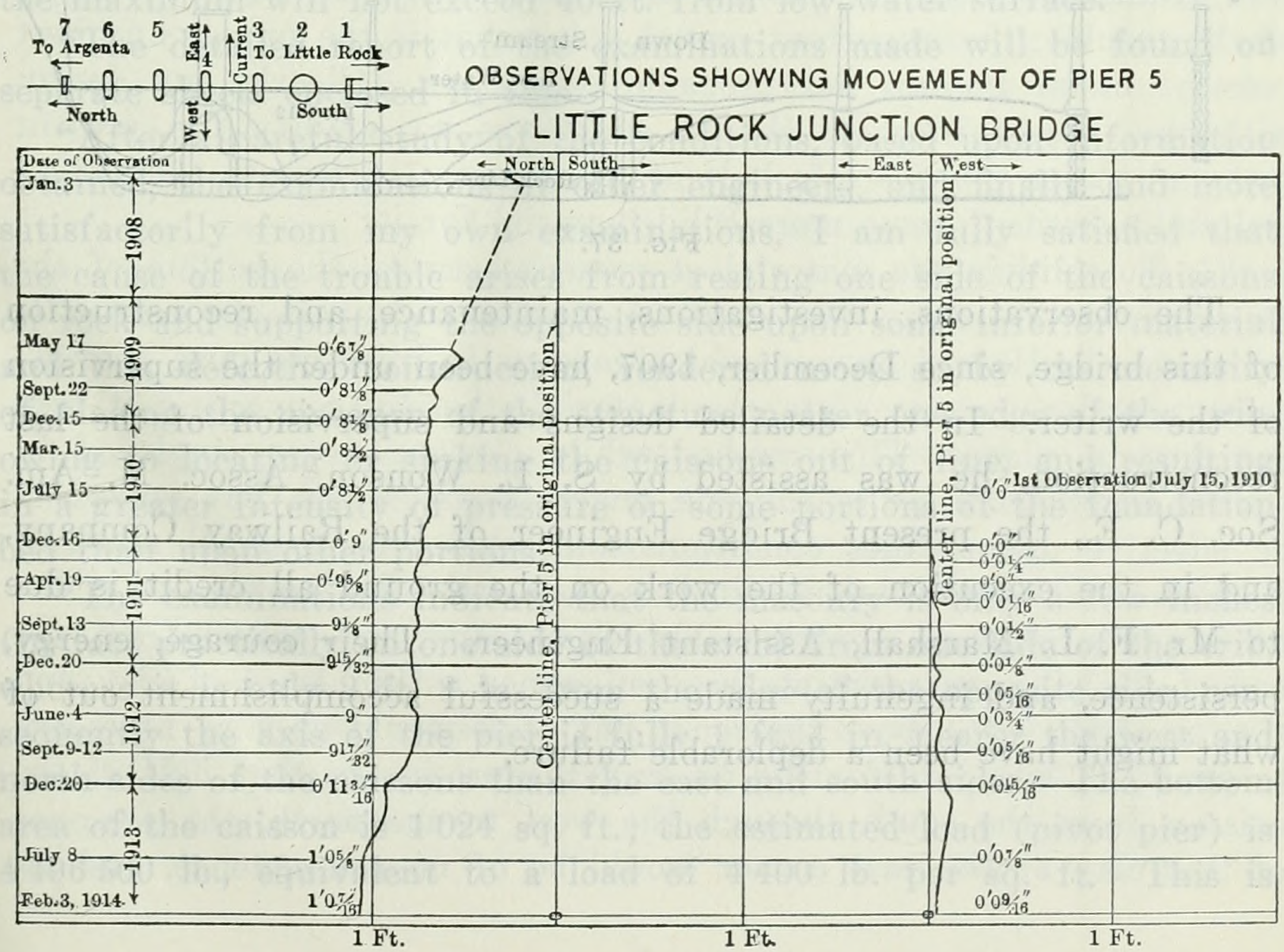

OBSERVATIONS SHOWING MOVEMENT OF PIER 5
LITTLE ROCK JUNCTION BRIDGE
To Argenta
To Little Rock
North
South
East
West
Current
7 6 5 4 3 2 1
Date of Observation
Center line Pier 5 in original position
1st Observation July 15, 1910
1908
1909
1910
1911
1912
1913
Jan. 3
May 17
Sept. 22
Dec. 15
Mar. 15
July 15
Dec. 16
Apr. 19
Sept. 13
Dec. 20
June 4
Sept. 9-12
Dec. 20
July 8
Feb. 3, 1914
1 Ft.
1 Ft.
1 Ft.

FIG. 36.

Prior to the reconstruction of Piers 3 and 4 the observations were taken every 30 days, as a rule. During the reconstruction the piers were sometimes under continual observation. Since that time and for the future it is the intention to take observations every 6 months, unless further trouble develops.

The alignment on this bridge was bad during the movement of the piers.

Fig. 37 shows several soundings under the bridge and indicates the extent to which the depth of river bed varies.

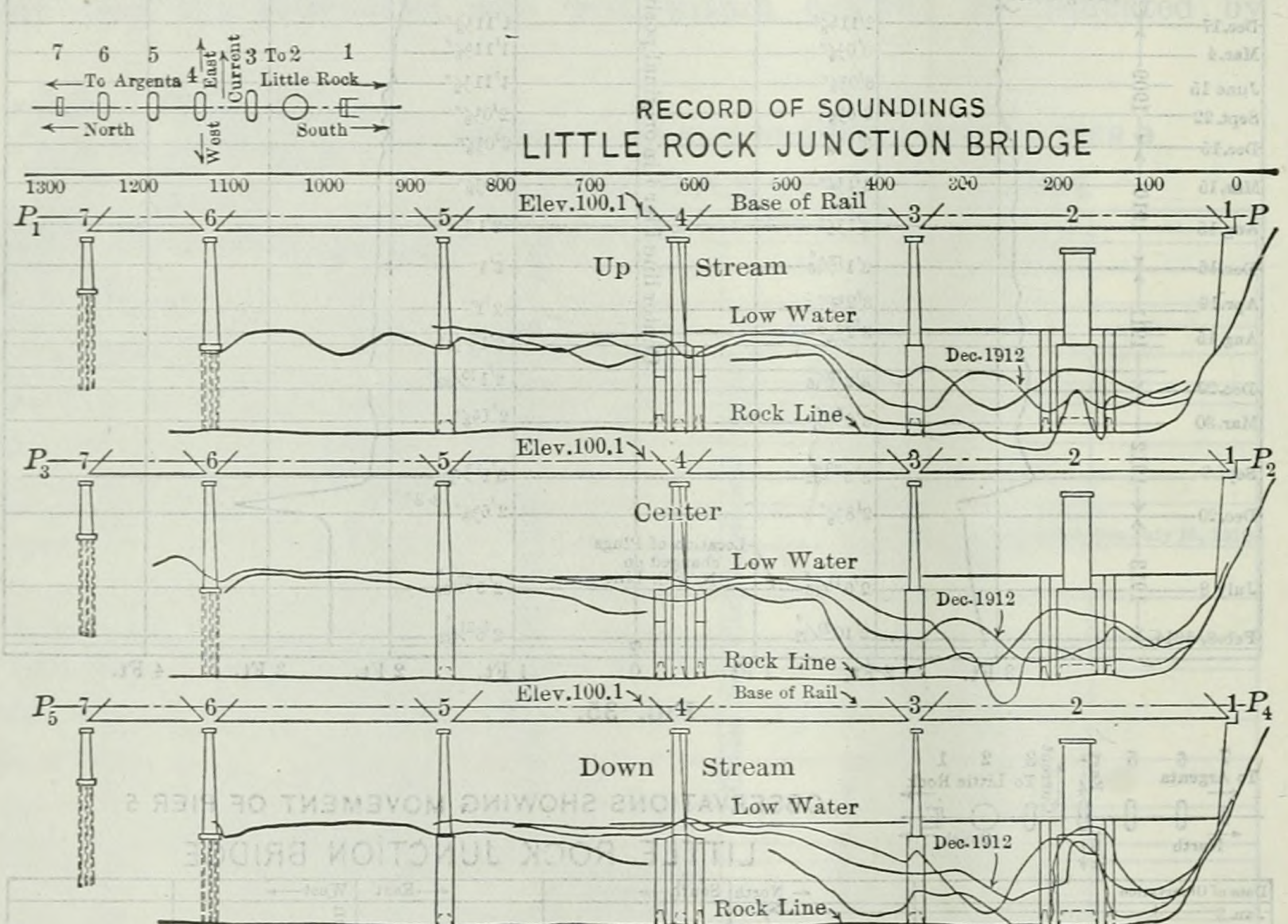



FIG. 37.

The observations, investigations, maintenance, and reconstruction of this bridge, since December, 1907, have been under the supervision of the writer. In the detailed designs and supervision of the last reconstruction, he was assisted by S. L. Wonson, Assoc. M. Am. Soc. C. E., the present Bridge Engineer of the Railway Company, and in the execution of the work on the ground all credit is due to Mr. F. L. Marshall, Assistant Engineer. Their courage, energy, persistence, and ingenuity made a successful accomplishment out of what might have been a deplorable failure.

# APPENDIX A

REPORT OF W. M. PATTON.

"BLACKSBURG, VA., April 9th, 1898.

"MR. E. FISHER,
"Engineer, B. & B., Mo. Pac. Ry.,
"Pacific, Mo.

"DEAR SIR: The examination of the condition of the foundations of the piers of the Little Rock Jct. Bridge were made for the following purposes:

"1st. To determine the character of the material surrounding the caisson and crib of the piers.

"2d. The condition of the timbers in the crib and the character and condition of the filling in the pockets of the crib.

"3d. The depth of the water and of the earthy material between low water and rock.

"The first two have been determined to my entire satisfaction. The third has not been determined completely and fully, this, however, is only necessary in order to give definiteness to the maximum depths to which the caissons will have to be sunk, as the basis of an unconditional bid by Contractors, and in no wise affects the proper design of the structure required in order to prevent further settlement and to enable us to level the present piers. These depths have, however, been determined to such an extent that I feel safe in saying that the maximum will not exceed 40 ft. from low water surface.

"The detailed report of the examinations made will be found on separate sheets enclosed in this.

"After a careful study of the conditions, based upon information obtained, the examinations of other engineers, and finally and more satisfactorily from my own examinations, I am fully satisfied that the cause of the trouble arises from resting one side of the caissons on rock and supporting the opposite side upon some inferior material and this defective construction, rendered more so by the necessity of placing the masonry of the structure nearer one edge of the crib, owing to locating or sinking the caissons out of line, and resulting in a greater intensity of pressure on some portions of the foundation bed than upon other portions.

"The examinations indicate that the masonry is only a few inches (in fact practically on one side of the crib) from one side of the crib, whereas it is only 2 ft. 8 in. from the edge of the opposite side, consequently the axis of the pier is fully 1 ft. 4 in. nearer the west and north sides of the caissons than the east and south sides. The bottom area of the caisson is 1 024 sq. ft.; the estimated load (pivot pier) is 4 496 500 lb., equivalent to a load of 4 400 lb. per sq. ft. This is nearly, if not quite, the maximum allowable unit pressure. The eccentricity of the load gives as the maximum pressure over 4 300 lb. pressure per sq. ft., which is in excess of the allowable load upon anything but solid rock. This condition is more noticeable at Pier 4 than at Pivot Pier. At Pier 4 the uniform pressure per square foot of foundation bed is 6 200 lb., and owing to the eccentric loading the maximum pressure per square foot must be over 7 000 lb., a unit load far beyond anything permissible.

"These conditions fully account for the settling of the piers, here it may be asked, why has the settlement been toward the west and not toward the north, if at both of these points the rock is at a greater depth than at the south and east corners? It may be answered that:

"1st. The filling between the bottom of the caisson and the rock at the north corner may be better than at the west corner.

"2d. The west corner, being the up-stream corner, is scoured out to a greater depth than the north corner, thereby reducing to that extent the supporting power of the material.

"The depth of water at the east corner was found to be 16 ft. 9 in., at west corner 22 ft. 5 in. and this, notwithstanding the large amount of rip-rap deposited at and on either side of west corner, and, moreover, other conditions might exist as to why this settlement to the west occurred, rather than toward the north, even assuming that the elevation of the rock at the west corner is the same or even higher than the north corner. We are, however, dealing with fact not a theory, and whatever may be the difference of opinion as to the cause of the trouble, the important question is, what is the proper and best remedy, under known, not probable conditions. Clearly any design with this object in view should enable us to solidify the present material under the westerly half of the caisson, or remove that material and substitute some more solid material for it:

"1. To solidify the material at present between the bottom of the caisson and the rock. The only practicable and available method is known as the Harris' process, which consists in injecting pure (liquid) cement under pressure into the material, thereby converting it into concrete in place. This method while perhaps never employed in a case exactly similar to the one under consideration, has proved to be effective under other conditions and where the original material is clean sand, I am satisfied it is a safe and effective method. The examination showed a remarkably clean sand and gravel from the bed of the river to rock; at the east corner a thin layer of clay and silt, at about 7 ft. above the rock; but as it would only be necessary to apply, at any rate for the present, the process to that half of the caisson from the south through the west to the north, the presence of this clay at the east corner would be of no consequence, and its distance from the rock would render it not worthy of consideration at all. The conditions are, therefore, exceedingly favorable for the application of the Harris' process. It will be a, comparatively speaking, rather inexpensive process, even recognizing it as patented, probably $10 000 would cover the entire cost. I do not, however, recommend this method, owing to the uncertainty that would necessarily exist as to the results obtained, which could only be determined by time, and in addition it would preclude the possibility of raising the pier to its proper vertical position. If you see proper you can correspond upon the subject with the Harris Company of New York.

"2. To remove the present material under the caisson and substitute it with concrete; the available methods to accomplish this are:

"1st. The Poetsch-Sooysmith freezing process.
"2d. The ordinary coffer-dam.
"3d. The pneumatic caisson, using the old caisson and crib for one of its walls.
"4th. An independent caisson and coffer-dam constructed entirely or partly around the old caisson and crib.

"1st. An ordinary coffer-dam let a few feet into the bed of the river and freezing a wall of the material below to the rock. This method can be relied upon as effective, and the only consideration is in respect to the cost. You can correspond with Wm. Sooy-Smith of Chicago or Charles Sooysmith of New York.

"2d. The ordinary coffer-dam is probably hardly worth considering, as it would be extremely difficult to make a water-tight dam in the kind of material around these piers and of the depth required. There would be many risks to incur of failure and the saving in cost, if any, would hardly justify the employment of such an uncertain method.

"3d. The method that at first seemed to me the best, surest, and most economical was to use a pneumatic caisson, making the old crib and caisson one of its walls. My own examination of the crib and its filling, which entirely corresponds with the report of the divers, discloses the fact that the crib is filled with small rip-rap, sand, and gravel, the latter in all probability was washed in subsequently to the completion of the structure, through the open sides and pockets. This condition convinced me that at least it would be a very risky method, and the risk is so great that I do not consider it justified by the saving in cost, if it should prove successful.

"4th. I have, therefore, been compelled to recommend the adoption of an entirely independent caisson, entirely or partly surrounding the old crib and caisson, leaving a working space of 6 ft. between the old and new caisson. The working designs for this structure with bill of material, estimate of cost and full detail, are sent by express to your address.

"While this design in many of its main features is similar to that designed for many piers constructed by me, there are some novel features introduced which are justified and demanded by the novel conditions, to which it is adapted. The design commends itself for the following reasons:

"1st. It gives absolute assurance of success, in exposing the material between the bottom of the caisson and the rock, and affording the opportunity of removing that material and substituting in its place concrete, which will unquestionably prevent further settling, due to the yielding material at present under the caisson.

"2d. It affords the opportunity of raising and leveling the pier in its original and proper position.

"3d. It affords the opportunity of making a thorough examination of the timbers of the crib and the caisson, and of repairing any damage done to the crib, arising from the settling.

"The report of the diver, confirmed by my own examinations, leads me to believe that some damage has been done to the upper timbers and the sheathing planks during the settlement, and I consider it important to either restore the sheathing plank or to fill the pockets to a certain distance inward on the several faces to hold the filling in the crib. This being done, the present filling, although of small stone, sand and gravel, will no doubt be sufficient and satisfactory.

"During the examinations recently made, a number of 12 by 12-in. timbers were bored entirely through at depths varying from 10 to 30 ft. below the water surface, and in every instance the timber was found to be firm and sound.

"The design shows the new caisson as constructed entirely around the old one. It may not be necessary to construct it around more than one-half of the old one; that is, around the west corner and extending the length of the side toward the north and south corners, respectively. This, however, forces us to utilize the old caisson as one wall of the coffer-dam, and it is possible, if not probable, that this will not hold the water back, so that the space between the two caissons may be pumped out. However, this half can be sunk as a section and the other half sunk, if found necessary; no change in the design will be necessary. It will be necessary to make a water-tight connection between the ends of the new caisson and the old caisson at the north and south corners. It will also be necessary to bolt two channel irons at each end of the new caisson, so that, in the event of adding the second section around the east corner and extending the south and north corners, the two sections can be united so as to form a water-tight joint.

"The estimated cost of the caisson and coffer-dam constructed entirely around the old caisson is about $40 000, and of the half caisson and dam about $20 000 to $25 000.

"The filling above the deck of the caisson required to sink the caisson may be of any material desirable, as far as practicable, the material taken out of the working chamber during the sinking may be used for this purpose, and in fact this should be required, or at any rate no payment should be made for the filling if the contractor prefers to get it from other sources; also the material between the new caisson and the old one can be dredged during the process of sinking and used for filling. This, however, should be done with judgment, as it will evidently be unwise to remove the material at and near the west corner of the old crib until we have at least given some temporary support to the caisson to the west of the center line of the pier, or that diagonal line joining the north and south corners.

"Owing to the relatively small depth of the earthy material, through which the sinking is to be done, it is possible that no filling above the deck of the caisson will be necessary. Filling this space with water may answer every purpose. It may not be necessary to fill the working chamber itself if a water-tight joint can otherwise be formed between the bottom of the caisson and the rock. If not, a concrete or clay puddle must be used of sufficient thickness to secure water-tightness. Owing to the shaly and inclined nature of the rock, it may be necessary to cut a longitudinal trench in working chamber and to fill this with puddle or concrete in order to cut off seeping water along the seams of the rock. These are matters to be determined by observation and the exercise of good judgment at the time. It is proposed to obtain water-tightness of the structure above the deck of the caisson by means of caulking the timbers and plank walls, and not by means of the filling material. One or both walls should be caulked for this purpose.

"The air-tightness of the working chamber must be secured by thorough and perfect caulking. These and other similar matters will be embodied in the outline of the specifications accompanying the drawing. You will note the upper half of the structure is so designed and connected that it can readily be removed. The lower half being below the bed of the river, or at least of sufficient depth below the water surface not to interfere with navigation, can be left in place. I, therefore, respectfully submit the accompanying drawings, marked Sheets 1, 2, and 3, accompanied with the following suggestions and recommendations.

"1st. Sinking the caisson in two sections, the one section extending from the south corner around through the west to the north corner, which may be all that will be required, and sinking the second section from the south corner around through the east to the north corner, if found necessary, owing to the open condition of the old crib.

"2d. Excavating the material from the north and south corners of the old crib and between the old and new structures to a point, say, half way between the south and north, respectively, and the west corner, removing the loose material from beneath the old structure and replacing with concrete, or some temporary support.

"3d. Then excavating the material from, at and near the west corner, exposing the space below the old structure, removing the loose material and replacing the concrete or some temporary support. This temporary support contemplates raising the pier to its original and vertical position.

"4th. If practicable, I would suggest supporting the superstructure on temporary supports during the time occupied in cleaning out the material between the old and new structures and until the permanent filling is in place and has had a reasonable time for hardening.

"5th. For the purpose of lifting the pier, I would recommend the employment of hydraulic jacks. It is estimated that hydraulic jacks having a main cylinder of 3.5 in. diameter and a pump plunger of $\frac{3}{4}$ in. diameter, will raise 20 tons of 2 240 lb., without excessive steam pressure. Upon this basis there will be required from 30 to 35 jacks, assuming that the superstructure is temporarily lifted from the pier; the cost of this portion of the work will be little more than the cost of the jacks.

"6th. With the structure supported on jacks the removal of the loose material and substitution of concrete (for which the best Portland cement should be used) can be proceeded with without risk or danger; otherwise this work should be carried on in sections, and precautions taken not to reduce the supporting resistance, as it now exists, at and near the west corner, until the caisson is well supported, two-thirds to three-fourths of its area. The amount of concrete estimated for filling under the caisson will not exceed from 150 to 200 cu. yd.

"7th. As the design submitted will afford ample opportunity for a full examination of the caisson and crib, I would suggest filling the open spaces on the sides with concrete to the depth of from 12 to 18 in., forming a wall to hold in place the present loose and imperfect filling. A good sheeting of timber, well bolted to the timbers of the crib, will probably answer every purpose.

"The character and extent of this work necessary, can only be determined at the time.

"With the drawings you will find a bill of material, estimate of concrete required, and a detail report of the character and extent of the examinations and the information obtained.

"Trusting that you will find everything in satisfactory shape, I am,

"Yours truly,

"W. M. Patton.

"P. O. Box 209

"Blacksburg, Va.

"In the event that it is deemed better or found necessary to entirely enclose the old structure with caisson and coffer-dam, it may be found more economical and satisfactory to excavate the rock at and near the south and east corners, and to lower this portion of the structure, thereby bringing the pier to its original vertical position, rather than lifting the westerly portion by means of hydraulic jacks."

Report in Detail of the Examinations Made at Pivot Pier, Little Rock Junction Bridge, Mo. Pac. Railway.

"*South Corner.*—Depth of water, 28 ft. 11 in. below low-water surface. Depth of rock, 35 ft. 6 in. below low-water surface. Drilled into rock 4½ in.

"The pipe was driven through fine sand, followed by a layer of coarse white sand mixed with black scales, feeling and looking like graphite; immediately overlying the rock was found a layer of fine and coarse gravel mixed with coarse sand. The rock is commonly called slate, is a black shale, which yields readily to the drill. Time occupied in setting and sinking pipe about 3½ hours.

"*East Corner.*—Depth of water, 13 ft. 6 in. below low-water surface. Depth of rock, 37 ft. 6 in. below low-water surface. Drilled into rock 3 in.

"The pipe was easily driven in medium sand, passing into sand mixed with gravel to a depth of 23 ft. below low water. This continued to a depth of 30 ft., where sand and gravel mixed with a soft but tenacious clay was found. At 34 ft. down a rather fine sand was found, mixed with clay. Rock was reached at 37 ft. 6 in. below low-water surface. There was found no well-defined stratum of gravel at this corner. The rock was of the general character, as already indicated. Time occupied in sinking about 4 hours.

"*North Corner.*—Depth of water, 22 ft. 7 in. below low-water surface. Depth of rock, 39 ft. below low-water surface. Drilled into rock 3½ in.

"Pipe was easily driven through medium sand to a depth of 29 ft. 3 in. below low water. At 26 ft. 9 in. was found fine and coarse sand mixed with fine and coarse gravel, and black scales, which continued for about 2 ft. to a depth of 28 ft. 9 in., the driving being somewhat difficult to a depth of 30 ft. 9 in., below this the pipe entered a fine flowing sand, which rapidly filled up the pipe for several feet whenever the jet was stopped. This material consisted of fine white sand, suggesting quicksand by its readiness to flow. From this point it was necessary to run hammer and jet simultaneously. The large pipe followed the small pipe readily, but would fill up if jet stopped. This fine sand continued to a depth of 39 ft. Drilled into the rock about 3 ft. Rock similar to that at other places. Time about as at other points.

"*West Corner.*—At and near this corner large quantities of rip-rap have been deposited. It was impracticable to find an opening through this sufficiently large to permit the passage of the 3-in. pipe. The small jet pipe was easily run to a depth of 33 ft. 6 in. below low-water surface. Further progress was prevented by a bed of gravel and the friction on the pipe above. Several attempts were made to force the 3-in. pipe through the rip-rap, which invariably resulted in the squeezing and mashing of the large pipe and the parting of the small pipe. On Saturday, March 12th, however, we succeeded in getting the 3-in. pipe through the rip-rap.

"Depth of water 19 ft. 3 in. below low-water surface.

"At 24 ft. down, the pipe brought up on a log. This log was bored through, it proving to be 12 in. thick. The timber was found to be firm and sound. The 3-in. pipe was driven through this log, and at 26 ft. 10 in. the pipe struck another log, which was partly bored through, when further work was stopped at 6 P. M. It had been raining hard all day, which continued through the night. The river rose rapidly, so much so that it was necessary to remove the barge to a place of safety. Work in the river was then abandoned for one week. This ended the first week's work. There were many delays, caused by time required to cut and thread pipes, and pump getting out of order, foaming of the boiler, etc. These were, no doubt, incident to and unavoidable in this kind of work, and it is not intended to attach any blame to any one, as all parties seemed disposed to do anything when called upon, and on the whole I was entirely satisfied with the work done the first week.

"Seeing no prospect of getting to work in the river, preparations were made to get into the crib within the well in the center of the pier, and on Thursday, March 17th, work was commenced. The well was found to be filled to about 11 ft. with silt, logs, and stone. After several efforts, a 3-in. pipe was forced to the timbers of the deck, and these timbers, about 2¼ in. thick, were bored through, admitting the small pipe without difficulty several feet below the deck and into the filling of the crib. This filling proved to be small stone, sand, and gravel. In attempting to drill through a stone the small pipe parted, resulting in loss of drill.

"On Monday, March 21st, the river having fallen a few feet, an effort was made to resume work in the river. A large portion of the day was consumed in getting the barge in position, and little was done subsequently, owing to the almost continuous foaming of the boiler, and consequent failure to supply requisite pressure. On Tuesday, with a rising river, a new pipe was sunk near the west corner, but it could not stand the constant vibrations caused by a strong current acting on some 40 ft. of unsupported length, and broke. At this time the river had risen considerably, and it was deemed necessary to remove the barge to a place of safety.

"I desire to express my appreciation of the uniform kindness, consideration and faithfulness of officers and laborers on this work.

"With great respect,

"W. M. Patton."

Specifications for the Construction and Sinking of Caissons for the Purpose of Repairing the Pivot Pier and Pier 4 of the Little Rock Junction Bridge, Missouri Pacific Railway.

"There will be constructed two caissons, the one for the pivot pier and the other for Pier 4. These caissons may be of such design and dimensions as will entirely surround the old piers of the bridge or will extend around any portion of these piers, as may be directed by the Engineer of B. & B. of the Mo. Pac. Ry. These caissons shall be constructed according to designs given on Sheets 1, 2, and 3 accompanying and forming a component part of these specifications, or according to such other design as may be accepted or approved by said Engineer of the Railway Company.

"Sheets 1, 2, and 3 give plan, elevation, section, and exterior and interior detail of the caisson and coffer-dam to be constructed entirely around the pivot pier.

"The structure is built of timber and iron; all timbers are 12 by 12 in. in cross-sections, excepting a few pieces 9 by 12 in. and 6 by 12 in., used for supporting braces, and 3-in. planks necessary for lining the caisson and coffer-dam. Exact lengths are given and where not given variable lengths are allowed. All necessary dimensions are given on the drawing and require no description. In the event that Engineer determines to construct a caisson of only one-half the dimensions given in the plan, no change in design will be required except closing up the free ends as indicated in the drawing.

"*Timber.*—All timbers used in the construction of the caisson and coffer-dam may be what is known as merchantable, and may be either pine or oak. *The outside verticals forming the lower half of the structure must be of the best long-leaf yellow pine and showing clear heart on the exposed face.* All timbers must be free from all defects that will impair their strength, such as rot, dotiness, or sponginess, large knots, or deep shake, or cracks of any kind. All framing and fitting must be done in a workmanlike manner and to the approval of the said Engineer.

"The upper and lower halves of the structures are to be built entirely independently and not bolted together in any manner. The two halves being held together solely by the 1¼-in. hook-rods, as indicated in the drawings. The lining plank in the caissons, as well as in the coffer-dam, shall be planed on the edges for a caulking joint.

"*Caulking.*—The caulking of the inner plank of the air or working chamber shall be thoroughly done, so as to make the sides and top of the air chamber completely air-tight and paved over with tar or pitch. Oakum shall alone be used in caulking. The joints of the top deck course shall also be sufficiently caulked to form a water-tight surface. The verticals forming the sides of the caisson, or lower half of the structure, shall be caulked on the outside, so as to form a water-tight surface. The inner plank lining of the coffer-dam shall be caulked, so as to make water-tight surfaces, as reliance for keeping out water is placed entirely on this caulking.

"*General Construction.*—The exposed surfaces of the lower half of the structure are built of timbers 12 by 12 in. by 23 ft., thoroughly bolted to these on the inside are five layers of horizontal timber, one layer on top of the other, which are well bolted to each other; spiked to these horizontal timbers are two layers of 3-in. plank, the first course placed diagonally and the second or inner vertical and caulked. Resting on top of the horizontals and plank, is placed a solid layer of 12 by 12-in. timbers, bolted at the ends to the horizontals; on top of this another solid layer of 12 by 12-in. timbers, placed diagonally and bolted at intervals of about 5 ft. to the first course, with 1-in. square by 22-in. drift-bolts. Over this course another solid course of 12 by 12-in. timbers laid longitudinally and similarly bolted to the course below. These three courses constitute the deck of the caisson proper. To the underside of this deck a layer of 3-in. plank is spiked and caulked. Above the deck and between the vertical sides, an open crib of 5 courses of timber is constructed, bolted to the verticals, to the deck and to each other. Above the crib is one set of cross-braces between the verticals and resting on longitudinals, bolted to the verticals. Diagonal rods are used in spaces between these braces and in a horizontal plane. Another set of cross-braces are placed at the top of the outside verticals. This completes the lower half of the structure and may be denominated as the caisson.

"*Coffer-Dam.*—Sills are placed on top of the verticals on both walls of the caisson, and upon the sills, at a general interval of 5 ft., center to center, vertical posts 12 by 12 in. by 21 ft. are placed, and on top of these posts caps are placed. These posts may be spiked or bolted to caps and sills, or they may be mortised and tenoned. Two layers of 3-in. plank are then spiked to caps, sills, and posts on the inside. The first layer is placed diagonally and the second or inner layer horizontally and caulked.

"Cross-pieces are then placed over the caps and projecting 18 in. beyond outside verticals, through which the 1¼-in. rods with hooks, pass. These rods are connected with the I-bolts, let into the verticals. Plate washers are used at the top, as the two halves, upper and lower, are to be pulled and held together by these hook-rods. The two joints between sills and top of the verticals of the caisson are to be well caulked after the two portions are pulled firmly together. An inner strap, countersunk, encircles the caisson, to which it is well spiked just above and resting against the I-bolts. There are three sets of braces between the walls of the coffer-dam, with diagonal rods between them and horizontal planes, as indicated in the plan and sections. These rods have swivels or couples at some intermediate position.

"The coffer-dam is framed in four sections, two of which are 70 ft. long and two are 44 ft. long. These sections are connected at the ends by diagonal rods with swivels and couplings, double posts being used at the junction of the sections; also 18-in. channels are let into, but not bolted to, these posts, in order to hold the sections together.

"Removing these channel irons and uncoupling the diagonal rods, sever all connections between the sections of the coffer-dam as well as the two walls of the same section, so that the upper half of the structure can be readily removed at the completion of the work. The lower half of the structure is intended to remain permanently in place. All other details, with bolts, straps, and braces, are shown on the drawings, and also the dimensions of the same, as well as the bill of material accompanying.

"*Iron.*—All iron is to be good, tough, ductile, and fibrous, except that all washers may be cast iron. The top washers for 1¼-in. hook-rods should be wrought-iron plate, about 1 by 6 by 6 in. In all cases the grip of screw bolts, that is, net length of washers, is billed. Proper allowance must be made for heads, nuts, and washers. The weights given are for full lengths, including heads, nuts, and washers. All bolts must be wrapped with oakum under head before driving, and at the threaded ends before placing nut and washer on.

"All drift-bolts are billed as 1 in. square. Round drifts 1 in. in diameter may be substituted, except for those bolts used in the outside verticals of the caisson.

"*Filling Material in Caisson and Coffer-Dams.*—All these caissons are only used for a temporary purpose and for convenience and certainty, and, after being sunk to the proper depth, serve only the purpose of coffer-dam, the material used in the filling is of secondary importance. The filling in the coffer-dam is only required to give weight necessary to sink the caisson and may therefore be any material. As far as practicable, the material taken out of the working chamber may be deposited above the deck of the caisson and in the coffer-dam, thus furnishing weight to sink the caisson. Also the material between the old caisson and new caisson may be excavated by dredging and likewise deposited in the coffer-dam, care being taken, however, not to remove the material at and near the west corner of the old caisson until it is safely secured by permanent supports, or temporary supports, from further settling. It may not be necessary to entirely fill the coffer-dam in order to secure sufficient weight. If necessary or desirable, water may be let into the coffer-dam so as to supplement the weight of other material, in such case, the water can be ultimately pumped out, thus facilitating the removal of the coffer-dam.

"The filling in the working chamber of the caisson after it has reached the rock, or its final position, is only necessary to prevent leaking under the caisson. It must be such material, and in such quantity, and so placed as to prevent any under flow of water. No filling of any kind may be necessary, and will not be if the water surrounding the old caisson and between it and the new caisson can be pumped out and kept out. In this case some additional cross-bracing in the working chamber may be found necessary. It may be found necessary to fill the working chamber in the whole or in part with clay puddle, a water-tight joint between the caisson and rock being the important object.

"*Excavating the Material Between the Old and New Caissons.*—This may or shall be done in part during the sinking of the caisson, and the material thus excavated used to weight the caisson. In any event, the material at and near the west corner of the old caisson must not be disturbed or removed until a sufficient and safe support has been placed at other portions of the caisson. The material at and near the west corner can then be removed, thus exposing the entire surface of the old crib and caisson from its top to rock.

"*Raising or Leveling the Old Caisson.*—It is the intention of the Railway Company to lift and return the pier to its original and proper position, for which purpose the use of hydraulic jacks will be necessary. It will be necessary for this purpose, or at any rate may be advisable, to support the superstructure on trestles or some other form of temporary supports. The posts of the coffer-dam should not be used for this purpose. However, a sufficient number of additional posts may be inserted in the coffer-dam to carry the load. It will be better and safer, however, to support the superstructure by supports entirely independent of the coffer-dam.

"After inserting the jacks, with proper and safe bearing for uniform distribution of pressure, it may be found necessary to flood the coffer-dam, thereby reducing the weight to be lifted. In this case the pumps will have to be above the water surface and connected by means of small pipes to the main cylinders of the jacks. An additional number of jacks should be provided, and as the water is again pumped out, these should be brought into bearing so as to support the extra weight brought into action when the water is removed.

"In the event of constructing a caisson entirely around the old structure, it may be easier to excavate the rock from the south corner around through the east corner and as far as may be necessary toward the north corner, and to level the structure by lowering the high portion of the caisson, rather than by raising the lower portion by means of hydraulic jacks.

"*Filling Under Old Caisson.*—In whatever manner the old caisson is restored to its proper position, or whether it is left in its present position, all loose material is to be removed from beneath the old caisson and good Portland cement concrete substituted. The concrete shall be composed of such material, mixed in such manner and placed and rammed in accordance with the approval and direction of the said Engineer of the Railway Company. Unless the structure is safely and securely supported by jacks, this work of underpinning must be done in sections, so as at no time to endanger the structure by further settling at any point. The jacks, if used, must be left in position until in the judgment of the Engineer the concrete has been sufficiently hardened to be able to carry the load with safety. The jacks can then be removed and the spaces filled with concrete, if the Engineer may so require.

"*Refilling Between Old and New Caisson.*—The space between the old and new caisson, from the rock to the bed of the river, will be refilled with material, if so required by the Engineer.

"*Removing the Coffer-Dam.*—The upper half or section of the structure, known as the coffer-dam, will be removed as already indicated.

"*General Remarks.*—In the bill of iron no mention is made of shafts, pipes, or other appliances required to sink the caisson, as these are regarded as belonging to the contractor's plant.

"The contractor shall furnish all material, tools, machinery, and apparatus of all kinds required to construct and sink the caisson, pump out water, and remove material. The contractor shall be responsible for any damage to the old structure, and shall take all risks incident to such work. The Railway Company shall be in no wise responsible for loss of life, damage to property, or interference with the safe navigation of the river. He will be responsible for all acts of his employees, and shall discharge any of his employees, when so directed by the Engineer, who fail or refuse to perform the work in accordance with the direction of the Engineer or his duly authorized representative.

"All material is to be approved and accepted by the Engineer before being used in the work. All work must be done in a thorough and workmanlike manner and to the approval of the Engineer or his duly authorized representative.

"*The Caisson for the Pivot Pier.*—The caisson for the pivot pier is composed of four sections; two of these are 70 by 13 ft. in plan and the other two are 44 by 13 ft., when the caisson entirely surrounds the old caisson. If it is determined to enclose only one-half of the old caisson, only three sections will be required: one 70 by 13 ft.;

and two 38 by 13 ft. All sections are 46 ft. 3 in. from bottom of caisson to top of coffer-dam, and 47 ft. 3 in. over all. Estimated cost on first plan $40 000, and on second $21 200.

"*The Caisson for Pier 4.*—The caisson for Pier 4 is composed of four sections; two of these are 70 by 13 ft. in plan and two are 27 by 13 ft., when the caisson entirely surrounds the old caisson. If it is determined to enclose only one-half of the old caisson, only three sections will be required, one 27 by 13 ft. and two 35 by 13 ft.; all sections are 46 ft. 3 in. from bottom of caissons to top of coffer-dam and 47 ft. 3 in. over all. Estimated cost on first plan $34 000, and on second $17 000.

"In either case the designs are essentially and substantially the same, only differing in axial length."

## APPENDIX B

Letters of A. J. Tullock Accompanying Bid of Missouri Valley Bridge and Iron Company for Carrying Out Patton's Recommendations at Pivot Pier and Pier 4.

"Leavenworth, Kan., Aug. 17, 1898.

"Mr. E. Fisher,
"Engineer B. & B., Mo. Pac. Ry.,
"Pacific, Mo.

"Dear Sir: Referring to your claims and specifications for the repairs of Piers 2 and 4 of the Little Rock Junction Railway Bridge, will say that I have gone into that subject quite fully and submit you herewith three separate propositions, covering the main portion of the work to be done in said repairs, leaving, however, certain parts of the work, the nature of which cannot now be determined, to be arranged at a later date when it can be clearly seen what is required. Such work can very well be done on a percentage basis, and probably so to best advantage.

"It is quite clear that the settling of the piers mentioned in the Little Rock Bridge arises either from the caissons not having been originally properly founded in solid rock, or from the crushing of the timbers in the cribs between the caissons and the masonry, as it is well known that these cribs were not well constructed when the work was built. Present appearances would indicate settlement due to the caissons not having been properly founded in the solid rock, rather than to the crushing of the cribs, but as against that, we have the written statements of the contractor who built the work, Mr. Barr, and of the Resident Engineer in charge of the work, Mr. Purdon, both reputable gentlemen, both of whom agree in saying that the caissons were properly founded in bed-rock and that the settlement of these two masonry piers must be due to crushing of the cribs. However, this can only be satisfactorily determined by actual examination, after sinking outside surrounding caissons as is now proposed.

"From a careful reading of your specifications, I conclude that, inasmuch as no concrete or filling of any kind is required in the caissons, that it was the intention of Prof. Patton that these caissons should be used simply for the purpose of getting down into the rock around the old piers to permit the underpinning or other repairs suggested by him, and that he contemplated relying entirely upon the underpinning or repairs made directly in the body of the old piers for permanent stability.

"It seems to me that we cannot safely rely on such underpinning for safety in this case, and it is very doubtful indeed if such underpinning can be done at all, without greatly endangering the entire structure of the old piers. It is my opinion that the work to be done in this case should properly consist of sinking the caissons as proposed in your specifications, but that they should be filled with some material sufficient to provide permanent lateral stability, and that the space between the new caissons and the old piers should be excavated down to bed-rock, pumped out, and filled with concrete to a sufficient height to thoroughly support the old pier and prevent any lateral movement. This being done, and the outer caisson being sunk into rock so as to absolutely shut off any outward movement of soft material, which may underlie your present pier, the absolute stability of the pier against further settlement or movement of any kind will undoubtedly be assured, providing this settlement is due to lack of perfect foundation under the original caissons. I have therefore arranged my proposals with a view of carrying out this plan, as well as making them applicable to the programme apparently contemplated in your specifications, in case when the excavations are made, it might be found possible to make the repairs as suggested by Prof. Patton.

"I will not hesitate to say in advance, however, that I consider the method of repairing proposed entirely impracticable, and too dangerous to warrant its adoption, except under conditions so extremely favorable that we have no right to assume they will exist in this case.

"The caissons necessary to surround these old piers properly are necessarily so unusually large as to become very expensive as compared with the ordinary caissons used underneath piers of that kind in original construction, and in addition to the fact that a very large volume of material, both in construction and excavation, is involved, the peculiar form of these caissons is such that they must be very strongly constructed and braced in all directions to prevent danger of their becoming twisted in sinking, and being wrecked in that way. The cost of these caissons in place, therefore, becomes very much larger in proportion than the cost of ordinary caissons for new piers.

"We have figured out these caissons in detail, and submit you herewith blue prints of same, numbered respectively 3 928 and 3 929.

"I submit the following proposals for doing this work:

"*Case 1.*—This case includes furnishing, building, and sinking to the depth specified by you, the timber caissons and coffer-dams described in your specifications, and shown on our drawings, including the excavation of all material within the caissons to such specified depth, and the excavation and pumping out of the material between the new caissons and the old piers down to bed-rock, providing it can be excavated that far without endangering the old piers. This case, however, does not include the filling of any of the caissons with concrete.

"Furnishing, building, and sinking as above described,

"Pier 2 (draw pier) . . . . . . . . . . . . . . . . . . . . . . . . $28 600.
Furnishing, building, and sinking Pier 4. . . 25 600.

"*Case 2.*—Caissons and coffer-dam constructed and sunk precisely the same as in Case 1, and all necessary excavation same as in said case, adding thereto, however, the sealing of the caissons in the working chambers with Portland cement concrete to a height of 2 ft. above the cutting edge, all the way around, and remainder of the working chambers and caissons to be filled with pure sand:

"Pier 2, as above described..................$31 600.
Pier 4, as above described.................. 27 950.

"Steel caissons 6 ft. wide in the clear, height same as for wooden caissons, Cases 1 and 2, surmounted by wooden coffer-dams as in Cases 1 and 2—these caissons to be sunk to the same depth as the others and to have the entire working chambers of same filled with Louisville cement concrete, the remainder of the caissons to be filled with sand. Excavation between caissons and piers same as in Cases 1 and 2. This case presents some advantages and would perhaps be preferable to the wooden caissons, but for the fact that it may be practically impossible at the present time to get the plates necessary to construct these caissons of steel quickly enough to insure the work being done within the low-water period in the river. I have only considered this case within the past 24 hours, and am therefore unable to submit you a complete drawing of the steel caissons, but hand you herewith a pencil sketch which will serve the purpose of showing the construction contemplated. This caisson being only 6 ft. in width at the bottom, while the wooden caisson is 12 by 13 ft., it will serve the same purpose so far as shutting off the outflow of material from underneath the old pier is concerned, but not having so wide a base, it has been considered best to fill the entire working chamber of these caissons with concrete, whereas in the other case, with the wider base, we can probably, with perfect safety, use part concrete and part sand as described in Case 2.

"Pier 2, as above described..................$30 770.
Pier 4, as above described.................. 26 655.

"In connection with this work, I will furnish and put in place the concrete filling required for the spaces between the new caissons and the old piers, at the following prices per yard:

"For Louisville cement concrete...............$4.85
For Portland cement concrete............... 7.38

"In all of the concrete work herein contemplated, the proportions for mixing are assumed at 1, 2, and 4 for Louisville cement concrete, and 1, 3, and 6 for imported Portland cement concrete. The quality of Portland cement assumed to be equal to Alsen's German.

"In this connection, I wish to say that we have a plant on hand ready to do this work, and could commence it immediately, our plant being now idle at Jefferson City, Mo. I will be glad to do any extra work that may be required, not covered by these proposals, on a basis of cost plus 10%, including, of course, the equipment costs as well as labor costs.

"For the purpose of comparison, and illustrating the expensive character of the repair work contemplated on these two piers of your bridge, will say that I should be glad to furnish all material and build an entire new set of piers for that bridge according to the best modern specifications and practice, for the sum of $125 000.

"Very respectfully submitted,

"A. J. Tullock."

"Leavenworth, Kans., Aug. 18, 1898.

"Mr. E. Fisher,
"Engineer, B. & B., Mo. Pac. Ry.,
"Pacific, Mo.

"Dear Sir: Referring to the caissons for the repair work of your piers at Little Rock, we figure the cost for sinking the extra depth on these caissons, assuming that they are to go through bed-rock, at about $800 per foot for the large caissons for Pier 2 and about $750 per foot for the smaller caissons Pier 4. We assume, of course, that if this extra depth is required, that the excavation will be practically all solid rock, which makes the cost run up quite high. I have to-day carefully examined the record of the borings made by ourselves a few years ago, and also those made as reported in your specifications, and I feel quite certain that the depth you have specified will prove to be about right, and that no extra depth will be required. Certainly none will be required, unless we should strike a fissure in the rock, which it would be necessary to shut off, and even then in that event, we could probably clean it out and plug it with concrete inside the caisson much cheaper than sinking the whole caisson farther down. In figuring the cost of the entire work, we have distributed the plant charge, machinery, repairs, maintenance, use of plant, and all charges of that kind over the depth specified, and as this charge would remain the same, or practically the same, for a less depth, the saving for sinking less than the depth specified would not be a great deal, particularly if we assume that down to that depth only a portion of the excavation is rock. We figure, therefore, that the saving, in case we do not go as deep as specified, would be about half the price named per foot for extra depth.

"The price which we name for extra depth would only apply for a depth of 5 ft. below the depth specified in your specification. For any further depth, there will be an increase of about 50 per cent. This increase for extra depth is partly due to the fact that the schedule of wages paid the pressure men or 'sand hog' increases for every foot below 20 ft.

"In reference to completion of the work, we would expect to complete the entire work in four months, providing we receive the order for it immediately, and I will undertake to do it in that time, barring accidents or floods or any such things as would be beyond the control of the Contractor. I feel certain, however, that nothing is likely to occur that would stand in the way of the entire completion of the work in about four months, and we have made our figures on that basis. If it took much longer than that time, we would be the principal losers, as the cost would increase very fast by the extra time used.

"In going over the figures on this work to-day carefully, I find that we have made them exceedingly close, and if we do that work, we should want to know at once about it, or within the next few days at farthest. I shall be glad, therefore, if you will reach a conclusion as soon as possible and notify us.

"Yours truly,

"A. J. Tullock.

*"Proprietor."*

"Leavenworth, Kans., Aug. 19, 1898.

"Mr. E. Fisher,

"Engineer, B. & B., Mo. Pac. Ry.,

"Pacific, Mo.

"Dear Sir: I have your favor of the 17th inst. with reference to modifying the dimensions on caissons for repairing the piers of your Little Rock Bridge, and have carefully noted what you say. I hardly think that it would do to figure on reducing the size of these caissons, nor do I think it would be desirable to do so. In the first place, we have no greater width between the caisson and the pier than is necessary to properly support the pier. In the second place, we cannot very well work closer to the old pier safely than 6 ft., as by getting much closer we would be likely to encounter more serious difficulties than are now contemplated and add to the cost. Further, in caissons of this character, on account of being so unwieldy and difficult to handle, it is not likely that they can be kept in exact position; in other words, the caisson is liable to be from 6 to 12 in. out of position in almost any direction, and this perhaps cannot be avoided. Of course, we will endeavor to keep it in position, or if out of position at all, to have the greatest distance between caisson and pier on the side to which the pier leans, so as to have the heaviest supporting wall on that side. We might save some caisson material by cutting down the dimensions of the caissons a little, but we would at the same time, increase the cost per unit quantity in certain parts of the work, so that on the whole there would not be much saving. It will be a difficult job at best to keep the wooden caissons of that character from racking to pieces on account of uneven support, even with a width of 12 or 13 ft., and the more we reduce its width the greater this difficulty becomes. So far as the caisson itself is concerned, and as to the opening between the caisson and the old pier, if we get much closer to the pier than we have figured, we will increase the cost of sinking more than the saving made in caisson material by reducing its exterior dimensions.

"In the case of the Kansas City draw-pier, where this plan was followed with a circular caisson constructed of steel, the caisson was brought closer to the pier than in your case, being only 3 or 4 ft. from it, but in sinking that caisson, the average progress per day was from 3 to 5 in. for each day of 24 hours, and the entire cost for that pier was between $40 000 and $50 000, being somewhere close to the latter sum. We have studied the subject quite thoroughly and carefully from an engineering standpoint, and also from a practical standpoint with Foreman Stewart, who has had large experience in such work, and it seems to me that we have hit upon the best construction for the place at the least possible cost. I realize fully that this is a good deal of money to put on repairing two old piers, but I do not see any way to better the situation unless you should decide to put in entire new piers throughout the whole bridge, and in answer to your inquiries about that project, will say that the price I gave you of $125 000 for replacing the entire piers contemplated putting the further pier on the Argenta side on piles, which could probably be safely done. However, we could make that pier a pneumatic pier also putting it down to rock, by increasing the cost to $135 000, or thereabouts, and of course in these new piers we would not expect to use Cabin Creek stone except for backing, the face stone to be strictly first-class masonry, both in quality of stone and workmanship, instead of cheap rubble, as in the case with the present old piers of that bridge.

"I find that I shall probably have to be in Chicago on Monday on some bridge business for the Santa Fe, but can be in St. Louis Tuesday, or if you wish to take up the subject Monday and could wire me to-morrow, I might postpone my Chicago business until Tuesday. Should you decide to have us do this work, I would thank you to have Mr. Spoor, your Timber Agent, give me the names and addresses of the mills which could furnish this timber quickest and best, as it would be necessary to move at once in the matter of getting timber and equipment on the ground in order to be sure of getting the work done before there is danger of high water.

"Very truly yours,

"A. J. Tullock,

*"Proprietor."*

# APPENDIX C

LETTERS OF A. J. TULLOCK, WHILE CARRYING OUT WORK RECOMMENDED BY PATTON.

"ST. LOUIS, November 24, 1898.

"E. FISHER, ESQ.,
"Engineer, B. & B., Missouri Pacific Railway,
"Pacific, Missouri.

"DEAR SIR: We have the caisson of the center pier built up about 8 or 10 ft., and last night we placed the second course of decking on the caisson. It is already lowered, so that one-third of its weight is taken up by water displacement, thus relieving the lower screws and supporting piles. We are, therefore, safely past one state of danger, which arose from the fact that our piles did not have much penetration and being difficult to brace. The matter of supporting so large a caisson on lowering screws was naturally a deal of a problem and somewhat risky. We feel, however, that we are now safely past any danger from the trestle support, and we shall, within the next two days, unless something unexpected interferes, have the caisson resting entirely on water and the screws relieved and removed to Pier 4. As soon as the screws can be set up on Pier 4, we will proceed with the building of the caisson, while we continue the sinking of the caisson at Pier 2. As near as I can tell, we should have air in the caisson of Pier 2 in about ten days or two weeks at the farthest. This, however, depending somewhat upon how much trouble we have in getting a proper bearing for this large caisson on the bed of the river. You will readily understand from the shape of this caisson in its unusual dimensions, that it becomes very necessary to handle it gently and lay it on the bottom in a good and reasonable uniform support, in order to prevent it from being strained and the joints opened so that it will not serve its purpose. Very little irregularity of support when the caisson commences to be loaded would likely spring it badly, notwithstanding the fact that we have built it unusually strong. It, therefore, becomes very important to get it carefully landed and this is our next critical movement. The fact that the sand has all been scoured away from that pier, which we did not expect, increases this difficulty very greatly, and it is impossible to make a fill around the pier by wing-dams above, as there is not enough material carried by the water at present to make such a deposit practicable. We have to depend, therefore, upon leveling off as much as we can before resting the caisson on the bottom, and then using sacks of sand for building up underneath the cutting edge of the caisson for support at the low points, and with this in view, I have already shipped several thousand coffee sacks from St. Louis to Little Rock so as to be in readiness. Superintendent

Stewart has the work well in hand and understands thoroughly every move to be made and every emergency likely to be met with.

"We are now approaching a time on this work when we must think carefully about what yóu are going to do when these caissons are down in position and the excavations made between the new caissons and the old piers. Of course, you cannot tell exactly until these excavations are made, but you must contemplate to some extent in advance, what material will be required, so that this material, such as Louisville cement and crushed rock, can be procured, on hand ready for use. You will recollect that while our contract provides a price for the concrete filling of this area between the new caisson and the old pier, the work of so doing is left for later determination. Therefore, I have provided no materials for such filling, and can only do so on your order. I would suggest that you authorize me to procure a certain amount of Louisville cement and crushed rock, which you think will safely be needed, immediately, so as to have it on hand when we are ready for it. You can certainly approximate the minimum quantity needed, and it is more than likely that you will want to fill this whole area as far as possible with concrete, in order to get the best results. Now, while it is important for the Contractor, on account of the coffer-dam and caisson and danger of floods in the river, that this work should be dispatched very rapidly after the excavation is made, it is still more important for the Railway Company and the owners of the old bridge that the structure should not be left exposed a *single hour longer than is absolutely necessary after this excavation is made.* There are abundant reasons for this, which you will doubtless recognize at once, and I now only mention one or two of them. In the first place, that old pier, caisson, and crib was so poorly constructed at the beginning that even if it were in as good condition as when first built, it would be very bad judgment to allow it to remain any length of time with the material all excavated away from it, as we are required to excavate. There is always danger in such performance of something of the unexpected happening, even if the pier stands perfectly square and true and is well built. Again, the timbers in that old caisson and crib, which are rough hewn timbers, improperly framed and about half enough in quantity, have now been soaking in the river about 14 or 15 years, and there is no telling what effect exposure to the air, for even two or three days, might have on these old timbers, heavily loaded as they are, without being reinforced by any interior filling of concrete or any other material of value. It has probably come to your notice that certain kinds of timber long submerged in water when taken to the surface, apparently in excellent condition, come to pieces very quickly after exposure to the air. I do not know that there is any danger to the timbers of these old piers, but at the same time it is possible that there may be and it is a matter worth thinking about. So on the whole, it is undoubtedly the best policy to be ready to act quickly when the excavation is made, and to get the filling with concrete made around the old pier as high as possible and within the shortest possible time after the excavation is made.

"In the case of Pier 4, I have a suspicion that that pier is already taking a good deal of its lateral support from the material, sand, etc., which now surrounds the old crib and caisson. It is possible that it may be held directly in position by this material, which you will notice extends up quite high in that pier. This being the case, we will have to proceed very carefully indeed with our excavation, both in sinking the caisson and in making the excavation between the new caisson and the old pier, as that portion will necessarily be attended with a great deal of danger, and conditions may be discovered as the work progresses, particularly with reference to the excavation between the caisson and the pier, which would make it necessary to change your plan of operations materially. I mention this now only that you may be thinking about it in advance, as I have been for some time past.

"In this connection, you will see at once the necessity of having very frequent observations taken as to the movements of these piers from the time we commence excavating, even in the new caissons alone, until we are through with the work. It is altogether likely that at certain stages of the work, it will be necessary to take these observations several times a day, and even almost hourly, so that any movement whatever of the old piers will be detected and made known to our men in charge. I mention this now so you will make arrangements with your Assistant Engineer, who has been taking these observations, to be present on the work when our excavations commence, ready to report promptly any appreciable movement of the piers. I do not anticipate any movement of consequence at the center pier (Pier 2) but of course that depends on what we may find the conditions to be underneath. I have a young office engineer, Mr. St. John, on the ground, who has experience in the use of field instruments, and I shall be glad to have him assist your engineer in taking these observations when the time arrives. Please let me know in good time if you will arrange to have your engineer present to look after this matter during our excavations. It is important that this matter should receive careful and accurate attention. Write me at Leavenworth.

"Very truly yours,

"A. J. Tullock."

"Mr. E. Fisher, "May 16, 1899.

"Engineer, B. & B., Missouri Pacific Railway,

"Pacific, Mo.

"Dear Sir: Your favor of May 6th, written at Little Rock, Ark., was duly received during my late absence. I note your instructions in reference to the work remaining to be done at Pier 4, that is, the concrete filling, etc. I believe the plan which you propose, which is substantially that adopted at Pier 2, is a very good one, and will get the best results with the least possible expense. I think the idea of supporting the old crib as high up as possible with concrete, as we have done at Pier 2, is the best solution of this difficulty, and I also believe that the material below the concrete, if of a reasonably substantial character, such as sand or rip-rap, is equally good when covered with a sufficient amount of concrete on top, which permits you to give the desired support to the old crib and pier, with the use of a minimum amount of concrete, much less in fact, than was originally contemplated. We will, therefore, probably have considerable extra cement left on hand, which your Company can no doubt dispose of or use to advantage.

"I note what you say in regard to pumping down and excavating between the coffer-dam and the old crib, and in reply will say that I will be glad to pump down and excavate just so far as it is practicable to do, but cannot undertake to go farther. This is precisely the conditions of our contract, and you no doubt fully realize that any attempt to do more than is practicable to be done in this case, would not only be a needless waste, not contemplated, but might also, particularly in the case of Pier 4, greatly endanger that pier. You will recollect further that when you had plans and specifications prepared for this work by some eastern professor or school teacher, your specifications provided for doing a whole lot of theoretical experimental work which was absolutely absurd, and which could not possibly have been carried out under any condition. I called your attention to this at the time, and I think that you agreed with me at that time in reference to it, and I suggested the present plan of work in my proposal, which was adopted. When the contract was drawn by your attorney, which was done during my absence and afterward presented to me for signature, I called attention to the fact that in drawing it, your attorney had provided for what was probably impossible, explaining that it would probably be impracticable to do certain work which seemed to be contemplated in the contract, the character of which was somewhat the same as you had in the professor's original specifications. Your attorney then modified his language in the contract by adopting my own expression in regard to pumping and excavating, which was that we should do just so much as was practicable to be done. Now this is the meaning of our contract, and I wish to make it clear to you, as you seem in your letter to want to swing a club over the head of your contractor, by talking about compelling him to pump down below the cutting edge of the old crib and caisson and do certain other impossible and absurd things, and you know very well that there is no object whatever in doing this, even if it could be done, and if that material, which is in this case mostly all rip-rap stone, could be taken out, you would simply have to put it back again to give the necessary support to the pier or to substitute concrete in its place, which would cost your company several thousand dollars more than the present arrangement and would be practically no better. Furthermore, you must be aware that the inclination of Pier 4 is so severe to one side that it would be extremely dangerous and inviting disaster to excavate that material between the new caisson and the old crib to any great depth. This is all clearly manifest. I am writing you thus fully as I wish to make my views clear on the subject and wish to put them on record. In sinking the caisson around Pier 4 we went down as you know on all sides through rip-rap most of the way. There was a little less rip-rap on the down-stream side of the pier than on the up-stream side, but nearly all the filling, at least, the main mass of the material around the old crib and between it and the coffer-dam, is now rip-rap, and by putting a good solid bed of concrete on top of it, you will have supported that pier in the best possible manner, as with the new caisson in position it cannot get away.

"I dislike very much to complain, but I must say that the whole tenor of your demands and instructions seems to be of the nature of threats of putting your contractor to unwarranted costs and expense rather than for the purpose of getting the best results on work or of giving any special benefit to the job or your company. You seem to lose sight entirely of the dangerous and costly nature of the work we have to perform around these two piers successfully, and of the great cost and heavy loss which has been sustained in carrying out this work safely. You seem to be looking only for a chance to put your contractor to needless and foolish expense of one or two hundred dollars in doing something which you imagine you have a right to demand, whether it is any value to the work or not, and to entirely ignore the fact that in sinking these tremendous large caissons around your old piers through rip-rap, piles and everything else, and through a large amount of solid rock, we have been compelled to proceed so slowly in order to avoid injuring your old piers, that the cost of doing the work has been double what was contemplated.

"I note that you say in your letter 'before concrete is put in, the depth of the cutting edge must be determined.' Now, when we have pumped down between the coffer-dam and the old crib of Pier 4 and have gotten that crib ready for concreting, we must be ready to concrete at once and finish quickly, as it will be dangerous and absurd to endeavor to hold that pumped out coffer-dam against chances of rises in the river and other disasters any length of time, for a foolish effort to try and determine the depth of the cutting edge of the old caisson. At best, the determining of the elevation of this cutting edge is only to gratify a curiosity and can serve no purpose.

Whatever its location might be found to be, if possible to find it, it would not in any way affect the character of the work to be done, the treatment of the pier would remain the same. Furthermore, as you must be aware, Pier 4 is surrounded with rip-rap, and in sinking our caissons around that pier we went through a solid mass of rip-rap stone nearly all the way down; consequently, it will be practically impossible to get a rod or a hook down the side of the old crib, so as to reach the cutting edge of the old caisson underneath it. This I believe was finally accomplished with some uncertainty at Pier 2, but in my judgment it will be entirely impossible at Pier 4, and it will be very foolish, after the coffer-dam is pumped out and we are ready to concrete, to waste any time or assume any risk in any such idle experiments. You may safely take it for granted, that wherever the cutting edge of that old pier is, the pier is settling and leaning dangerously, and must have the support which we propose putting in there, and that just as quickly as possible when the water is pumped out.

"Answering your question directly as to hunting for this cutting edge, will say that, of course, if your company will assume all responsibility and all costs, direct and indirect, and all consequent damages, which might occur from floods and other disasters, by delaying the putting in of that concrete around Pier 4, after we are ready for it, then, of course, we will hunt for the cutting edge of that caisson, at your expense, just as long as you want to continue such investigations, but when you think the matter over carefully, I think you will agree with me that no time should be lost, after we are ready to concrete, for the purpose of satisfying curiosity. I am thoroughly satisfied myself as to where the cutting edge is under that old pier, and when you see the top of the old crib, you can satisfy yourself beyond a doubt as to where the bottom is.

"Very truly yours,

"A. J. Tullock,

*"Proprietor."*

# APPENDIX D

## Letters of Ralph Modjeski Containing Recommendations for Reinforcement of the Piers.

"Chicago, Ill., August 5, 1911.

"Mr. E. J. Pearson,
"*First Vice-President,*
"Missouri Pacific Railway Company,
"St. Louis, Missouri.

"Dear Mr. Pearson:—As had been prearranged, I visited, last Thursday, in company with Mr. C. E. Smith, Bridge Engineer, your two bridges at Little Rock, Arkansas. Most of the time was devoted to the examination of your Little Rock Junction Bridge, which is in a precarious condition. I have also carefully examined the plans and records of the old structure, together with what has been done to repair it.

"It would seem that the coffer-dams which were placed by pneumatic process around Piers II and IV did not get at the seat of the trouble, and as shown by Pier IV did not correct it. The original caissons were sunk to rock and the air chamber filled with concrete, but the cribwork above was filled with sand and possibly some rip-rap. There is no doubt in my mind that the concrete in the caisson chamber rests on rock. It would be difficult to suppose that the engineers had come within a foot or two from rock and had failed to remove that thickness of material before sealing the chamber. The records as well as the tradition seem to indicate positively that the air chambers were sealed with concrete. There seems to be no doubt therefore that the trouble occurs in the cribwork above, which, instead of being filled with concrete as it should have been, was filled with sand and possibly some rip-rap. This sand is probably leaking out through the openings in the outside sheeting and is settling away from the timbers, so that the entire load is carried on those timbers, which under a load of something like four or five hundred pounds per square inch are crushing.

"I should like to have one or two more days to consider this whole matter carefully, and will therefore not make this my final report as to what is best to be done. I have no doubt, however, that what we should attempt to do is to remove the sand from the inside of the cribs and replace it with concrete. If that is done to all the piers it would afford excellent foundations for future piers which you may wish to construct for a new bridge or else it would support the present piers as long as the piers themselves held together.

"Pier III is the one which should receive immediate attention as it is gradually settling at a rate which in a few months time would mean its total destruction. In conference with Mr. Smith it was agreed that a plant be rigged up on a barge for taking wash-borings around the pier to find out if there is sufficient rip-rap present to prevent driving a wooden triple-lap sheet-piling coffer-dam. It is also desirable to arrange as soon as possible to bore at least two holes in the up-stream corners of the coffer-dam to find just how much material is left inside of it, and also incidentally to find whether the working chamber has actually been sealed with concrete.

"My present plan would be to drive a coffer-dam around the pier at a distance of say 6 ft., from the walls of the old crib and to pump it out, lowering the water level sufficiently to examine the old crib by partly removing the outside planking. While this is being done it would be quite advisable to partly support the up-stream end of Pier 3 by shores which in their turn would rest on piles driven alongside the old coffer-dam. Mr. Smith is familiar with what I have in mind.

"Whatever work is done, it will have to be performed carefully and step by step, in order not to endanger the present pier. It is not possible to foresee all the difficulties that may be encountered, but I am quite confident that the work can be done at a reasonable cost.

"I would recommend that the work be done by Company forces, thus saving considerable time and possibly expense as well.

"I expect to write you again Monday, after studying the situation a little further.

"Very truly yours,

"Ralph Modjeski."

"Chicago, August 7th, 1911.

"Mr. C. E. Smith,

"*Bridge Engineer,*

"Missouri Pacific Railway,

"St. Louis, Mo.

"Dear Mr. Smith.—I have been thinking a great deal about the Little Rock proposition since I saw you at St. Louis, and I cannot arrive at any more satisfactory solution than the one which I outlined. There is another possibility, however, which occurred to me, and that is that it may not be necessary to drive a coffer-dam around the pier at 6 ft. distance from the old coffer-dam. The farther away we go the more difficult it would be to keep the water out during pumping. I would suggest, therefore, that, as contemplated, you take the soundings and borings to ascertain how much rip-rap there is around the pier, and then either simultaneously or immediately thereafter arrange to bore a hole through the corners of the cribs vertically to find out how much sand or rip-rap or other material there is in the crib. It may be that if the material contained in these cribs is merely sand or such material as can be pumped out, it will be sufficient to drive a Wakefield sheet-pile coffer-dam at a distance of 1 ft., for instance, in which case it would be very easy to excavate the material between the old crib and the coffer-dam and seal the bottom with concrete. It would take very little concrete and of little thickness to hold water. After this is done we could pump out the coffer-dam sufficiently to get at the top timbers of the crib. We could then remove these timbers at least partly and remove as much as possible of the material inside. It is probable that we might be able to pump out the water from the interior of the crib and then fill it with concrete in the dry.

"Very truly yours,

"RALPH MODJESKI."

"CHICAGO, August 19, 1911.

"MR. E. J. PEARSON,

*"Vice-President, Missouri Pacific Railway,*

"St. Louis, Mo.

"DEAR MR. PEARSON: Since writing you the report on the Little Rock Junction Bridge, I have been thinking the matter over, and it occurs to me that if the Company desires to maintain this bridge for some years to come and perhaps build a new superstructure on it, it would be cheaper in the end to rebuild the piers of concrete, at least Piers 3 and 4, which are causing the most trouble. Pier 3 is in a precarious condition, and no method of repairing, unless it be a very expensive one, can be counted on with absolute certainty to produce satisfactory results, and at best the masonry in the present piers is not in the very best condition, many of the stones being cracked, and while it may last for many years, it would have to be replaced some time or other. I would respectfully suggest that you authorize the reconstruction of Piers 3 and 4 at this time. In this way the masonry can be taken down and the cribs filled solid with concrete at much less expense than could be done with the piers in place. The concrete piers could be built for a reasonable amount and part of that cost would be offset by the saving in the cost of the foundation repairs, which repairs, as stated, would be rendered considerably easier.

"Kindly advise me what your wishes are in this respect.

"Very truly yours,

"RALPH MODJESKI."

# APPENDIX E

## List of Equipment Used in Repairs to Pier 3.

1 barge, 24 by 80 ft., with derrick.
1 barge, 18 by 60 ft.
1 barge, 16 by 50 ft.
1 barge, 15 by 24 ft.
1 rowboat.
1 compressor, 18 by $18\frac{1}{4}$ by 24 in., with receiver and mains.
2 air locks.
2 hoisting engines.
3 horizontal boilers.
1 derrick.
1 orange-peel dredge, $\frac{3}{4}$-yd.
1 pile leads and hammer (not used).
1 No. 4 Emerson pump.
1 pulsometer.
1 12 by 7 by 12 Fairbanks-Morse pump.
1 D. C. centrifugal pump, 8-in.
2 steam jets.
1 diaphragm pump.
1 double-drum crab.
1 No. 11 Smith mixer.
4 steel concrete cars.
1 turntable.
6 steel concrete buckets.
1 steel tremie.

# DISCUSSION

HENRY H. QUIMBY,* M. AM. SOC. C. E.—It will probably be of interest to mention a timber crib pier foundation which is not solid, is more than 50 years old, is still doing its work satisfactorily, and probably will do so as long as it is wanted. The conclusions of the author are that timber cribbing is not suitable for bridge foundations unless it is solid. Mr. Quimby.

Chestnut Street Bridge, over the Schuylkill River in Philadelphia, was built during the Civil War. The foundations of the pier in the middle of the river were laid in 1862. A crib of hewed square yellow pine, 29 ft. high, extended from the bed of the river to a point 2½ ft. below ordinary low water. The overlying gravel was dredged from the rock, and measurements were made. Then the crib was built at the side of the river to fit the contour of the rock, and towed to place and sunk with stone and gravel screenings in all the coffers. The masonry work was then commenced.

The reason that crib is doing its work satisfactorily is that it was built in a very different way from that used in the cribs described in the paper. The cross-timbers, spaced so as to leave coffers about 3 ft. square, were notched over each other at their intersections. Each stick was notched in one-quarter on each side, so that the timbers were theoretically in bearing throughout their length. The structure settled as the masonry superstructure of the pier was built on it, and this settlement was a little unequal, causing a slight list to one side. The total settlement is said to have been 6½ in. in the depth of 29 ft., and could be accounted for in part by the inaccuracy of the fit of the notches, and in part by the compression of the timber, the roughnesses of the hewed sides probably causing much of it.

A rough calculation, making guesses as to the total load that the crib is carrying, and the quantity of timber it contains, indicates that the compressive stress in the timber is less than 100 lb. per sq. in. The average pressure on the crib described in the paper, according to the author's calculation, and supposing the load to be central, is about 400 lb. per sq. in. of intersection bearing. The drawings show the timbers merely resting on each other at the intersections, and not notched over. The eccentricity of the load, as computed by the author, however, brings the maximum pressure up to 880 lb. per sq. in., which is entirely too much for side-grain bearing, and too much for end-grain for a continuing load, even on dry wood.

Wood appears to flow under pressure, the same as steel, and as concrete is found to flow. Therefore a long-continued pressure ought not to be as great as that of a transitory load. Bridge men have been brought up to regard live-load as more serious than dead-load stresses, but the reverse may really be the case, because a continued stress far

* Philadelphia, Pa.

Mr. Quimby. below the rated ultimate strength may cause flow, and, as in the case of the Quebec Bridge, ultimate failure.

In a recent case of falsework, the vertical members were stressed, in some instances, up to 1 000 lb. per sq. in., and where the ends of the verticals bore on the side-grain of the sills and caps they crushed into it. The sills were blocked up, where adjustment was intended to be made, on blocks twice as long as they were wide, reducing the pressure on the blocks to one-half, or 500 lb. per sq. in., across the grain. The wood was saturated with water, the load was long continued, and quite a number of the blocks crushed. On some of them the sapwood split away from the heartwood, seemingly by reason of its swelling, under the action of the water; not being confined laterally, as it was vertically, it swelled in this direction as the blocks crushed.

The wood in the cribs described in the paper was evidently overloaded, and it simply crushed under the weight. The only wonder is that the engineers were not more alarmed about the condition of those piers. The illustrations show that it was very bad.

The most perplexing problems that structural engineers have to meet are generally found in such jobs as this—the repairing or strengthening of existing structures. The problem was met very successfully by the final strengthening.

Not the least interesting thing in this paper is the statement that the bridge superstructure, built 30 years ago, presumably for loads common in that day, is good for modern loads, and will be for many years to come. The probability is that that bridge, 30 years old, is of iron, not steel. Iron, in those days, was customarily stressed lower, in proportion to its ultimate strength, than steel is to-day, which accounts for the continued service of many old iron structures, including some of the elevated railways, under loads several times as heavy as were contemplated in the design.

Mr. Byers. M. L. Byers,* M. Am. Soc. C. E. (by letter).—The object of this paper, as stated by the author, is praiseworthy, and in connection with the subject there are quite a number of points of interest to the Engineering Profession.

The writer was surprised, however, to find in the paper several of his signed official communications. As these communications are separated from their context, they are, perhaps, somewhat subject to misinterpretation. For example, the communication commencing on page 42, which is given in part, seems to require, for a complete understanding of the reasons governing its character, the knowledge that there was contained therein, among the various matters submitted, certain other tentative plans for general improvement in the vicinity which contemplated the entire abandonment of this bridge, and, before

* New York City.

the final decision could be made as to the engineering features of the pier situation, it was necessary that these general development plans be finally passed upon by the management. Mr. Byers.

With reference to the effect of the temporary treatment of Pier 4 which was resorted to in 1908, the author seems to have changed his mind, as he states, on page 34:

"Following this work, no appreciable movement in the direction of the bridge was apparent for several months, but the movement at right angles to the bridge appeared to increase its rate, indicating that the work had no appreciable effect."

Whereas, in his memorandum to his superior, as of August 17th, 1909, which he has seen fit to quote on page 37, he states, "If the pier continues stationary, no action whatever is necessary, as the piers are all perfectly safe."

With reference to the yokes, the writer authorized their use with the express condition that they be constructed of such light section that it would be impossible for them to exert sufficient additional stress on the bridge members to be of vital importance.

It is a source of considerable satisfaction to the writer that, due to the successful temporizing with this problem for a number of years, during and immediately following the 1907 panic, when money was scarce and saving imperative, and at the expense of a very considerable amount of worry to himself and staff, the opportunity has been afforded to the present management to solve this difficult problem successfully and economically.

Lee Highley,* Assoc. M. Am. Soc. C. E. (by letter).—Mr. Smith has given a very lucid and complete history of the trouble at the Little Rock Junction Bridge and its final correction. The writer obtained his first knowledge of the leading facts concerning this structure while working in a minor position in the Bridge and Building Department of the Missouri Pacific-Iron Mountain System. In fact, it sometimes fell to his lot to make the measurements for finding the movement of Pier 4. The earlier measurements were comparatively simple and devoid of elaboration. They took into account only the movement of Piers 3, 4, and 5 in the direction of the center line of the track and there was no determination of movement at right angles to this direction. From a fixed point in the center of the track behind the south abutment, called Pier 1, direct tape measurements were made along and over the ties to Piers 3, 4, and 5, using a plumb-bob from the top of the ties to chisel marks on the coping stones. A 15-lb. pull was put on the tape, and temperature allowance was made in calculating its length. It happened sometimes that the ties were wet from rain or possibly covered by a light fall of melting snow, and thus the tem- Mr. Highley.

* New Meadows, Idaho.

Mr. Highley. perature of practically one-half of the tape might differ considerably from that of the other half which was not in contact with the ties. In all cases where there was a suspicious difference between the results of any measurement as compared with previous ones the work was re-checked. The character of the weather, direction of the wind, and gauge reading of the river were also recorded. Despite the crude features, there was no getting away from the fact that Pier 4 was steadily moving in the direction it was leaning, through some periods slowly, through others with more acceleration.

Time went on, and conditions grew worse. In 1908, the observations included additional features. A system of cross transit lines, intersecting on the up-stream end of Pier 4, was used in addition to the straight tape measurement. Gas-pipe wood-filled hubs, with brass screw centers, were sunk flush with the surface of the earth about 600 ft. up and down-stream from the Argenta or north end of the bridge. From these points a transit was sighted to fixed objects, corners of brick buildings, on the Little Rock side of the river. At the intersection of the transit lines a copper plug was fixed in the coping of the pier, and properly marked. From this intersection point lines were laid out at right angles and marked on the coping. One line was parallel to the center of the track and the other at an angle of 90° thereto. As the pier continued to move and future observations were taken, the point of intersection would necessarily fall within the quadrant determined by the two lines first laid down. By measuring the offset from the new intersection to the old lines, the movement of the top of the pier in two directions was determined. However, the transit observations, following this method, were not always satisfactory, were sometimes attended by difficult physical conditions, and did not always check reasonably close with the tape measurement. It should be remembered that the fore-sight objects were nearly half a mile away, across the river diagonally, and that fog and smoke often rendered it difficult to see. Also, as Mr. Smith points out, the continued movement of the pier soon brought bridge members across the line of sight and added to the complications. If the fixed time for observation fell on a dark, cloudy day it became necessary to use lights and reflectors to illuminate the plumb-bob cord, or small rod, which was used for obtaining points on the pier. The usual custom was to set three times on the fore-sight and give as many sets of points for determining lines, then take the mean of the three for the intersection line. Even under the most favorable light conditions, it was the writer's practice to take advantage of the sun's position, and lay one line of intersection in the morning and the other in the afternoon in order to get the truest reflection of light from the fixed fore-sight and the one on the pier.

The writer left the service of the Missouri Pacific System early in 1910, and has been out of touch with matters concerning the Little

Rock Junction Bridge since that time. Therefore he finds this paper of unusual interest. The newer method of observing pier movements, as shown by Fig. 33, is much superior to those formerly used. Mr. Highley.

The plan of procedure for depositing concrete in the crushed end and side of the old timber cribs as the excavation proceeded, thus causing the leaning piers to right themselves to a considerable extent, is regarded as particularly ingenious. On the whole, it is gratifying to know that Mr. Smith has terminated so successfully the work of transforming the unsteady old piers into substantial, permanent, and symmetrical structures.

Theodore Belzner,* Assoc. Am. Soc. C. E. (by letter).—In his report to Mr. Fisher, Mr. Patton suggested that the material between the bottom of the caisson and the rock might be solidified by "injecting pure (liquid) cement under pressure into the material, thereby converting it into concrete in place". If Mr. Patton or the author made any experiments with this process, it would be interesting to know the results. The writer recalls a few experiments, made some years ago, in New York City, by forcing grout into sand under pressure. When the material into which the grout had been pumped was removed, it was found that the cement had not been distributed uniformly. The material was lumpy and of no value whatever. Experiments with this process by other engineers may have produced different results. Mr. Belzner.

Robert H. P. Ford,† Assoc. M. Am. Soc. C. E. (by letter).—Mr. Smith has contributed an important and interesting paper, which should prove of value to engineers having to deal with foundations and piers, especially in the large streams throughout the South and Southwest, practically all of which carry large quantities of sediment, and are subject to an erratic rise and fall combined with excessive scour, giving opportunities for skill and resourcefulness in work of construction or repair. Mr. Ford.

The writer was connected with the Engineering Department of the Missouri Pacific System during the period when the steel bent referred to by the author was added to Pier 4, or the "Sick Pier", as it was popularly known, and he speaks from a somewhat personal knowledge of the work that Mr. Smith has done, first as a subordinate and afterward in direct charge of reconstruction, which has been both ingenious and skillful, demonstrating resourcefulness as well as engineering ability of a high order. The writer feels, however, that Mr. Smith has perhaps unwittingly erred in his reference to Mr. C. D. Purdon, an able and accomplished engineer, who was Inspector during the original construction, as well as to others who at

* New York City.

† Chicago, Ill.

Mr. Ford. various times during the past 30 years have been connected with this work.

Early in 1908, the writer, under the direction of the Chief Engineer of Maintenance of Way, had occasion to take over, among other matters, the work at the Little Rock Junction Bridge, shortly after it had been determined to support the spans on Pier 4 by falsework, preparatory to taking down this pier. It was found at the time that very little information was available that would give a precise technical history of Pier 4, or in fact of any of this work, and, in the judgment of the writer, this was so essential, before a proper conception could be had of the problem, that immediate steps were taken for its collection. It was during this study that the writer became convinced that the authority of Mr. Purdon, as an Inspector, would not have enabled him to prevent unwise methods or improper work.

During the admirable work of Mr. Smith and his assistants, he has had available a fund of information and material which has been developed as a result of long study on this problem by numerous engineers and others, many of the former having recognized standing in the Profession, as well as the effect produced by the various expedients during the time that this bridge has been a source of apprehension; this has also contributed in no small degree to the information bearing on this problem.

Until very recently, the engineers' problem on this work has been to temporize with the existing conditions and prepare for an emergency, and, at the same time, to guard, if possible, against a direct failure. How well they have succeeded is perhaps best shown by the fact that nothing did happen, and traffic was maintained. Whether this was due to engineering skill, the forces of Nature, or good fortune, the reader must determine for himself; but to the mind of the writer, the characterization of the matter, up to the time of actual reconstruction, as a "farce comedy", is hardly fair to any of the numerous engineers who were directly or indirectly connected with this work during all this period.

The fact that a large expenditure was made previous to 1908 to correct this trouble, but which failed to accomplish its purpose, may perhaps be considered as inefficient engineering. The writer, however, hardly thinks this is the case. The records show that the work was done contrary to the recommendations of Mr. Tullock, although apparently approved by the engineers of the Company; but, back of this is the unfavorable comparison between the cost of the work by the method which was adopted and the cost for complete reconstruction, the course which it is believed all concerned would have very much preferred had funds been available.

The situation is not a new one. The Railway Company, like numerous other corporations, doubtless felt that the sum required to enable it to take the safer course would be much greater than for that which seemed to be reasonably sure, although it contained a much greater element of chance. It is a well-known fact that, during the period when the conditions of this bridge were in a serious stage, traffic requirements on the Missouri Pacific System had out-distanced its physical condition to such an extent that the urgent demands for relief were not by any means confined to the Little Rock Junction Bridge. The financial condition of the property has not for years been such as to remedy a great many conditions which its management have at times felt should require attention. In any event, the records seem to show that it was beyond the power of its engineers at any time during this period to do what doubtless in their opinion should have been done, namely, to reconstruct the piers fully and finally, as was ultimately done under the direction of Mr. Smith. Mr. Ford.

The writer, though fully agreeing with Mr. Smith and his conclusions that, "When defects are discovered in bridge piers, and trouble results, correction should be applied at the seat of the trouble," differs however, with him in his deduction that, "The continuation of the trouble without adequate correction involves constant hazard, which can be avoided by efficient engineering talent."

The writer has every reason to believe that, had this matter been left solely to the judgment of the engineers connected with this work, even from its early inception, or during any of its later periods, the situation would never have been continued.

As is well known, the funds necessary for carrying out projects of this and like character are not always forthcoming, even though the engineer considers that they should be, and this case is no exception. Neither does the writer believe that, even with the numerous recurring changes of management on this property, which has had in its personnel a great many able and efficient men, who were in responsible charge of it, they were so derelict in their duty as to permit a condition to continue that could have been remedied if they had been able. He has reason to believe that the conditions were fully realized, although possibly not to the extent that the engineers may have felt on this as well as other important pieces of work, and, furthermore, that the situation prevailing on the Missouri Pacific in such matters did not differ from that on many other railway properties, where the advancing methods of railroading have caused the need for additional funds which have not always been forthcoming.

Mr. Smith's method of prosecuting the work, as well as his thorough study of the conditions preceding it, have doubtless resulted in saving the property considerable money. The writer, however, is inclined to agree with Mr. Modjeski, in his conclusions (given in Appendix D) that, given the problem as it was, his recommendations were justified. The element of chance in carrying out the work in

Mr. Ford. the manner in which it was done seems to have involved a greater risk, and one which the Railway Company was again willing to assume, thereby introducing an interesting comparison in this particular between the work performed previous to 1908, which did not accomplish its purpose, and the work of 1914, which did. Efficient construction and supervision, as well as good engineering, were the elements contributing to its successful conclusion.

Mr. Purdon. C. D. PURDON,* M. AM. SOC. C. E. (by letter).—The caissons referred to in the paper were located correctly, and the masonry fitted as well as it generally does, it being hardly practicable to sink a caisson in exact location.

When the rock was cut level, as soon as a part of the shoe of the caisson reached it, all the rest was cleaned out and blocked up with timber before placing the concrete.

The cribs were filled with rock to the top before any sand was pumped in, for the purpose of giving weight to the pier, and not with the intention of carrying the weight. It is possible that in time, with the shock of drift striking the piers, etc., the rock may have worked under the cross-timbers and caused a settlement.

The only trouble with the piers was that they were designed for spans 14 ft. wide, in the clear, and the masonry was well advanced before the superstructure plans were received; these showed that the spans were to be 18 ft. wide, in the clear, and it was necessary to widen and lengthen the tops of the piers to get a bearing. Even then it was a tight fit, but the spans fitted correctly on the piers. All the piers were practically complete before the steel for the superstructure was received.

The piers were all built in accordance with the plans and specifications, and the batter was the same on all, except that the pier at the north end of the draw-span was built with its south face vertical, to shorten the draw-span.

Any difference that may have been observed in the batter later is readily accounted for by the crushing of the timber in the cribs; because of the narrow base of the pier, a small settlement to one side would be largely multiplied at the top.

Mr. Jonah. F. G. JONAH,* M. AM. SOC. C. E. (by letter).—The writer has read Mr. Smith's valuable paper with interest, and from personal knowledge of the conditions believes that the work was handled with great skill and by the safest possible methods. The author was quite right in insisting on a plan which would obviate the use of falsework. To carry a span on falsework over the Arkansas River for any considerable length of time is a hazardous proposition. The records show that

* St. Louis, Mo.

serious rises have occurred in this river during every month in the year, and nearly every railroad which spans it has had trouble in the construction or renewal of bridges. Mr. Jonah.

One other plan might have been used in a case of this kind, and that would be to sink a cylinder at each end of the old pier, up and down stream, place a cross-girder between, and rest the ends of the spans on that, in which case the load could be taken from the old pier entirely. A defective pier in the Atchafalaya River Bridge, on the New Orleans, Texas and Mexico Lines, was handled in this way, but probably the plan pursued by Mr. Smith was, in the end, the best for the Arkansas River.

C. E. Smith,* M. Am. Soc. C. E. (by letter).—Mr. Quimby mentions a very interesting case in which considerable settlement took place in a timber crib about two-thirds as high as the Little Rock crib and of much better construction. Had the Little Rock cribs been constructed similar to those described by Mr. Quimby, no apprehension would have been felt, regardless of the settlement. Mr. Smith.

The writer was very much surprised and filled with regret to learn that any one thought the paper reflected on the ability of any of those able engineers who had to do with the construction of the bridge or the correction of the trouble, as no reflection or criticism was intended, the paper having been written merely as a recital of facts.

Fortunately, full detailed information in the shape of original papers was available, and quotations were freely used where available to render the subject matter more accurate and to avoid any misunderstanding that might have arisen through digests of the quoted matter.

The writer believes that, with the knowledge at hand during the construction of the bridge and during the trying period of repairs, all those who had any connection whatever with the work handled the matter according to their best judgment, in conformity with the facts developed and resources available. Unfortunately, funds for better construction and for the proper correction of the trouble were not at all times available, but, had they been, there is no doubt that any one of the large number of able engineers connected with this problem would have corrected the difficulty in an entirely efficient and satisfactory manner long before the writer had any connection with it.

This is definitely shown in the following quotation from Mr. Purdon's letter in the original report, which indicates that he objected strenuously to the type of construction:

"I objected to this strongly at the time, but as I did not design the piers, this work being done by the late Mr. T. E. Sickels, I was not responsible for them. I told Mr. Wood at the time that I was satisfied

* St. Louis, Mo.

Mr. Smith. the timbers would eventually crush and put the piers out of shape, which it seems occurred."

In closing, the writer desires to express his appreciation to those who helped him in the final solution of this problem and who contributed so largely to the information now available; he wishes to express his regrets and apologies to any one who may have felt injured in any way by the paper as presented.

The association of the writer with all who have been connected with the work has been a source of great pleasure and benefit to him, and he has appreciated to the fullest extent the efficiency and integrity of those able engineers who struggled so faithfully with this problem, without the funds for proper solution.