McGraw-Hill Publishing Company, Inc.

August 30, 1928

Engineering News-Record

Devoted to Civil Engineering and Contracting

Fort Steuben Bridge, Weirton, West Virginia, to Steubenville, Ohio

New Methods of Construction on Ohio River Suspension Bridge

Tall Reinforced-Concrete Building Involves Special Design

Palestine Developing Hydro-Electric Power Below Sea Level

New Freight Terminal at Houston, Texas, for M-K-T Lines

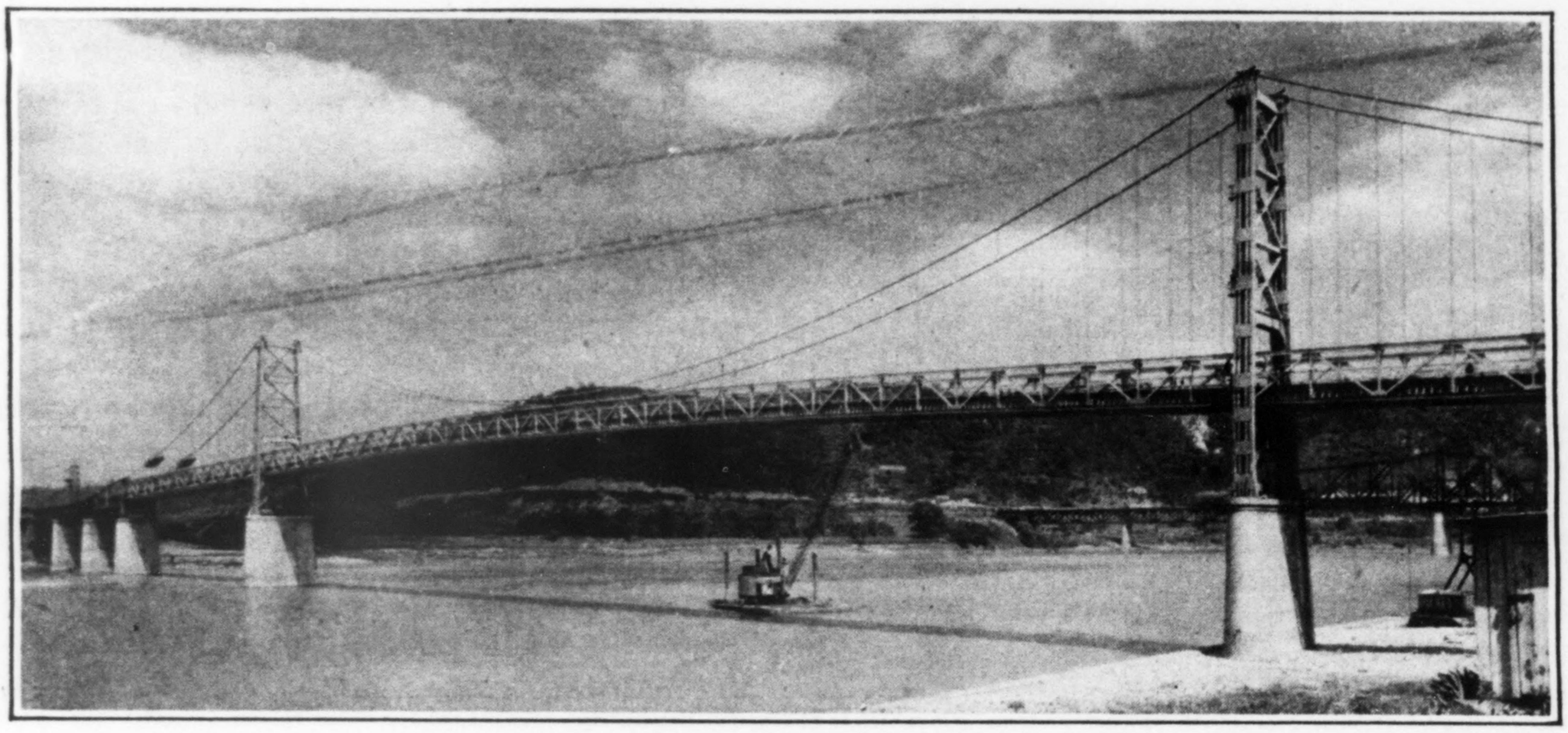

Fig. 1—Fort Steuben Suspension Bridge Over Ohio River

Ohio River Suspension Bridge at Steubenville, Ohio

Fort Steuben Structure With 689-Ft. Center Span Presents New Practices in Suspension Bridge Engineering; Namely, in Land Cable Spinning, in Strand Transfer and in the Use of Rolled Steel Sections for the Main Towers and the Web Members of the Stiffening Trusses

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Bridge Activity in the Ohio and Mississippi river valleys is unusually pronounced. No less than half a dozen bridges have recently been completed or are under construction over each of the rivers. Some of the new bridges over the Mississippi River are located at Cairo, St. Louis (Chain of Rocks), Vicksburg, Quincy, Ill., Memphis, and Cape Girardeau, Mo. Over the Ohio River, the unusual Gallipolis-Point Pleasant bridge and crossings at Paducah, Ky., Cincinnati, St. Marys, W. Va., and Louisville are completed or under construction. The Fort Steuben bridge over the Ohio River between Steubenville, Ohio, and Weirton, W. Va., is the second of a series of bridges being built by The Dravo Contracting Company. The first of this series, at Portsmouth, Ohio (*Engineering News-Record,* Oct. 20, 1927, p. 620), represented the entrance of this company into the field of suspension bridges as a builder of both substructure and superstructure. Based on this initial experience there were developed on the Fort Steuben bridge several special design features and erection methods which resulted in a marked saving in time and cost. These, together with general data on the design and construction of the bridge, are presented in the following article. Other Ohio and Mississippi river bridges which incorporate in their planning or erection important practices and details will be considered in other articles to be published in the future. —Editor.

A NUMBER of new methods in design and erection were inaugurated on the recently completed suspension bridge over the Ohio River between Steubenville, Ohio, and Weirton, W. Va. Chief among the design characteristics is the use of fixed-base main towers fabricated entirely from rolled steel sections, and the further extensive use of such sections for the web and floor members of the stiffening trusses. Conditions on the Ohio end required an unusually sharp bend in the cable after it passed over the cable bent, so the cable construction was stopped at the cable bent and eyebar construction was substituted; for symmetry and consistency, the same type of construction was used on the West Virginia end of the bridge.

The interesting features of the erection work center around the method of cable spinning on land on the West Virginia approach and the expeditious method of strand transfer; around the use of a 150-ft. tower boat for erecting the main towers, and the use of a standard derrick boat equipped with a special 130-ft. boom for erecting the stiffening trusses and floor system of the main span and West Virginia side span.

The bridge has a main span of 688 ft. 9 in. and side suspension spans of 283 ft. each. The cable-bent tower at the Ohio approach is the end of the structure, while on the West Virginia side there are three 90-ft. and one 60-ft. plate girder spans. The floor is of reinforced concrete carried on steel stringers, with a clear width of roadway of 20 ft. 3 in. The main-span cable sag is 70 ft., or approximately 1 : 9.85 of the span; the side-span sag was made 11.818 ft. in order to balance the horizontal cable pull between main and side spans under full dead load. The stiffening trusses, which are 14 ft. deep, or 1 : 49.2 of the main-span length, are spaced 24 ft. apart and are hung directly below the cables. They are of the continuous type.

Main Towers—Fixed towers were adopted in order to eliminate certain erection delays and difficulties that were experienced with the rocker towers on the Portsmouth bridge. (*Engineering News-Record*, Oct. 20, 1927, p. 620.) However, in order to have all the advantages of the rocker towers during erection, since it was necessary to incline the towers several inches toward shore at the start of erection, an I-beam grillage consisting of nine 15-in. 55-lb. beams 4 ft. long was embedded in the top of the pier under each tower leg. A 4x16-in. steel billet 5 ft. 8 in. long with the top machined to a 6-ft. radius (Fig. 3) was placed on top of the grillage to serve as a temporary rocker. Adjustable steel wedges were used under the sides of the steel base plate and served to keep the towers in any desired position during erection of the suspended spans and the placing of the concrete floor. The wedges were finally driven tight and all remaining space under the base was grouted. The bases of the tower legs were specially reinforced with heavy diaphragms and filled with concrete to carry the dead load on the line contact surface during the erection period. The anchor bolts were adjusted daily until the tower reached a vertical position.

The design of the towers was dictated by a desire to simplify the shop fabrication. This resulted in the adoption of the new Carnegie beam sections. The parallel surfaces of flanges in these beams made them readily adaptable for the splicing of main joints. The design as used consisted of four 30-in. Carnegie beams placed with the webs parallel and connected at the center of the webs by two 15-in. Bethlehem beams and one 24-in. standard beam in the lower tower section, which weighs 850 lb. per linear foot. The upper half of the tower legs was made up of similar beams of slightly lighter section. All shop riveting was $\frac{7}{8}$ in. and all splices and field connections were reamed for 1-in. field rivets. The towers were entirely assembled in the shop, and all reaming was done with the towers completely assembled, thus eliminating all field reaming.

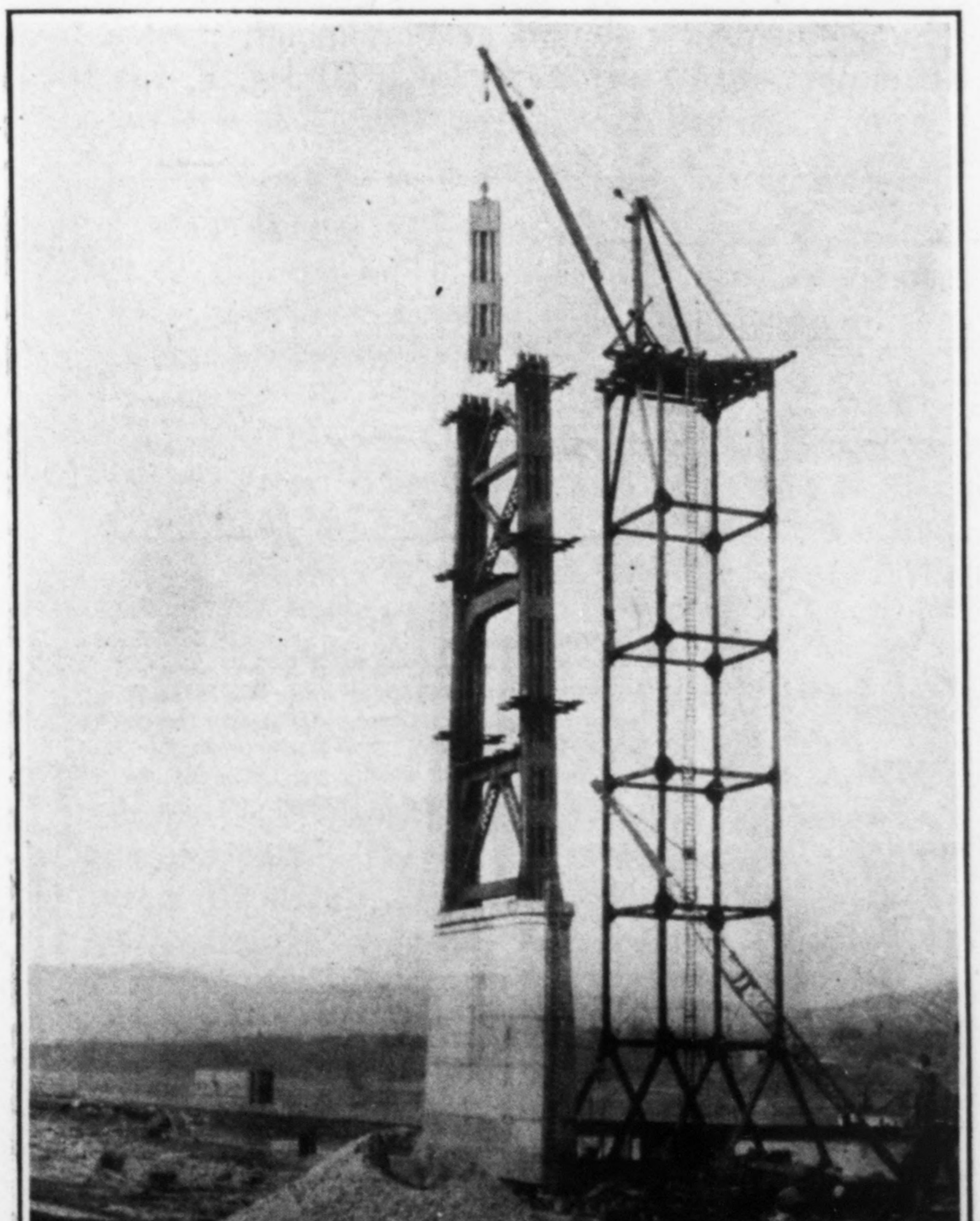

FIG. 2—FLOATING DERRICK WITH 150-FT. TOWER RAISING MAIN TOWER SECTION

The erection of each main tower took only six actual working days. This performance was made possible by the use of a floating erection tower derrick made up of a stiffleg derrick mounted on a wooden tower carried on two steel barges, as shown in Fig. 2. The barges were of the flush deck type 24 ft. wide, 102 ft. long and $6\frac{1}{2}$ ft. deep, and were fastened together by drilling holes through the sides and connecting with bolts. The tower, 24 ft. square and 150 ft. high, was composed of 12x12 timbers throughout, with $1\frac{1}{8}$-in. round tie-rods in the sides and 1-in. square rods in the horizontal plane at each strut. Steel gusset-plates were used to make all splices. At the base of the tower a truss was used spanning the full width of the two barges, adding greatly to the rigidity of the hull. The derrick was a standard wooden derrick with 14x14-in. boom 60 ft. long, a 16x16-in. by 30 ft. mast, 12x12-in. stifflegs and a bull wheel for swinging. All lines were carried down to and operated from engines on the deck of the barges, one engine carrying boom and load lines, and a swinging engine.

Anchorages—Due to the proximity of the Ohio cable bent to the main highway it was necessary to deflect the cable through a sharp angle after passing the cable bent, so the wire construction was stopped at the cable bent and an eyebar chain of heat-treated bars was carried down from the cable bent to a structural steel anchorage embedded in a concrete beam under the hillside. In order to secure a symmetrical cable, the same construction was used at the West Virginia side, except that the eyebar chains were longer and terminated in a reinforced-concrete caisson anchored in bedrock. This construction permitted all anchorage work to be completed while the cable spinning and tower erection were under way and greatly facilitated the erection of the cable strands, since all the cable work was in the open.

Design Loads and Unit Stresses—The floor system was designed for a maximum load of a 15-ton truck at any point and for the maximum loading of two 40-ton street cars. Although the bridge was designed for the future addition of street car tracks, decision was made by the owners after construction was under way that no tracks would be added. The original design for the floor was based on using a flat slab about 11 in. thick with grooves left for the rails, but with the abandoning of the idea of using street cars an arch design was substituted in order to lighten the dead load. An impact allowance of $33\frac{1}{3}$ per cent was used in the design of all stringers and floorbeams.

For the design of stiffening trusses, cables, towers and anchorages, the assumed live load was 1,200 lb. per foot of bridge. The estimated dead load for the downstream cable was as follows: Cables and suspenders 176 lb., stringers 182 lb., floor beams 100 lb., trusses 375 lb., bracing 35 lb., concrete 1,380 lb., rails (not used) 82 lb. and sidewalk 160 lb., making a total of 2,490 lb. per foot of cable. On the upstream cable there was only 2,305 lb., the difference being due to lack of symmetry caused by an overhung sidewalk on the downstream side.

The wind load was assumed as 30 lb. per square foot on $1\frac{1}{2}$ times the vertical projection of the structure, with a temperature variation of $\pm$ 60 deg. F., all setting calculations being based on a normal temperature of 55 deg.

Cross-sections of members were calculated on a basis of 18,000 lb. per sq.in. except for the stiffening trusses, where 20,000 lb. per sq.in. tension and 18,000 — 60 l/r compression were used. Allowable compression in tower legs was assumed at 18,000 lb. per sq.in. — 70 l/r with a limiting value of 13,500 lb. per sq.in. The actual allowable stress used with an l/r ratio of 73.4 was 12,860 lb. per sq.in. The maximum cable stress is 2,881,000 lb. under full dead and live load combined with temperature stresses. The main cable consists of seven strands, each containing 280 No. 8 bright wires, making a total net area of 40.376 sq.in. and a miximum unit stress of 71,350 lb. per sq.in.

Spinning the Cable Strands—The West Virginia approach to the bridge consists of $1\frac{1}{4}$ miles of new road construction. The 1,800-ft. section adjacent to the bridge, being quite level, above high water and almost directly in line with the bridge, offered an excellent location for the spinning of cables on land; therefore this method was adopted. The experience with land spinning at Portsmouth dictated several changes in the methods of procedure—namely, the use of mechanically straightened wire, the use of a central splicing plant and the control of strand length by hydraulic jacks.

The wire specifications called for an elastic limit of 144,000 lb. per sq.in. and an ultimate strength of 215,000 lb. Tests of the wire showed values considerably

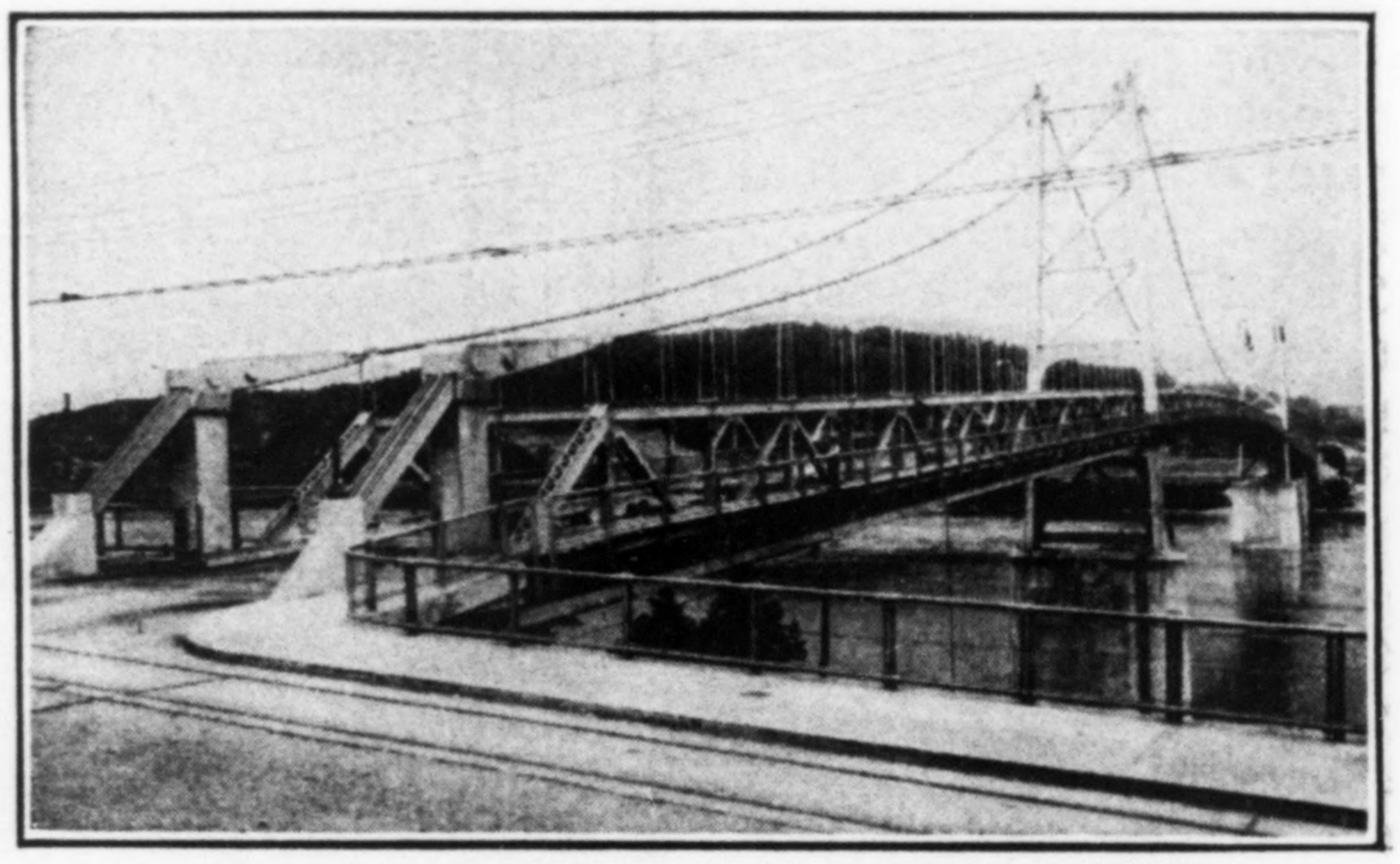

FIG. 4—COMPLETED BRIDGE, SHOWING JUNCTION OF CABLES AND EYEBARS AT OHIO CABLE BENT

higher than the specifications, and since mechanical straightening produced an average drop in the elastic limit and ultimate strength of only $2\frac{1}{2}$ per cent, the wire was kept well above the specification requirements. The result of the straightening was that the wire laid quietly at all times without tendency to coil.

The length of strands was about 1,300 ft. and the stress produced in a single wire hanging on a free span of 688 ft. 9 in. (the main span length) was approximately 60 lb. Since the ideal condition was to secure the same tension in spinning as the wires would later have while in course of adjustment, a tension of 60 lb. per wire was adopted, regardless of temperature changes. The land spinning method followed at Portsmouth used a basic tension per wire (such as 60 lb. at 50 deg. F. for No. 8

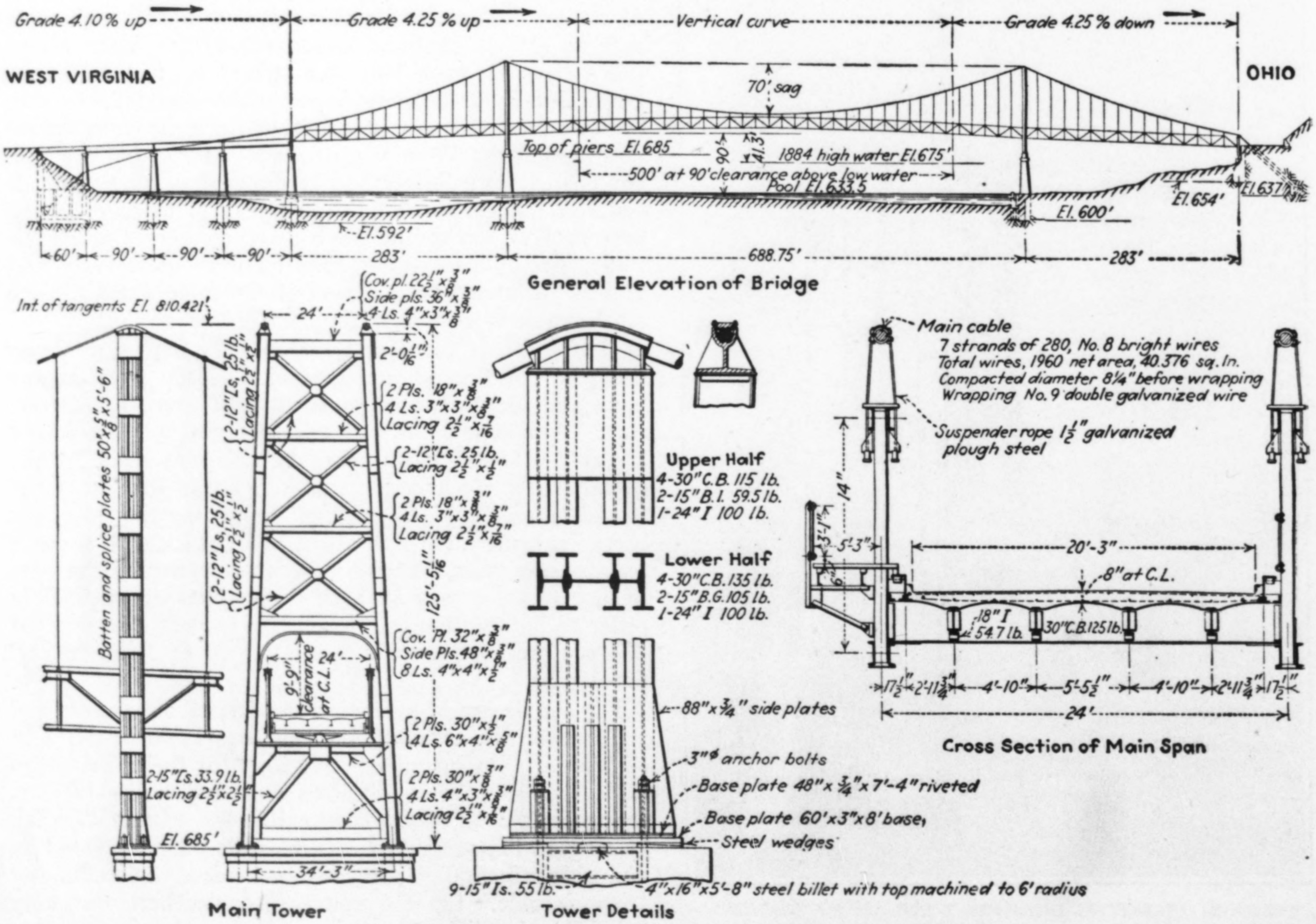

FIG. 3—DETAILS OF FORT STEUBEN SUSPENSION BRIDGE

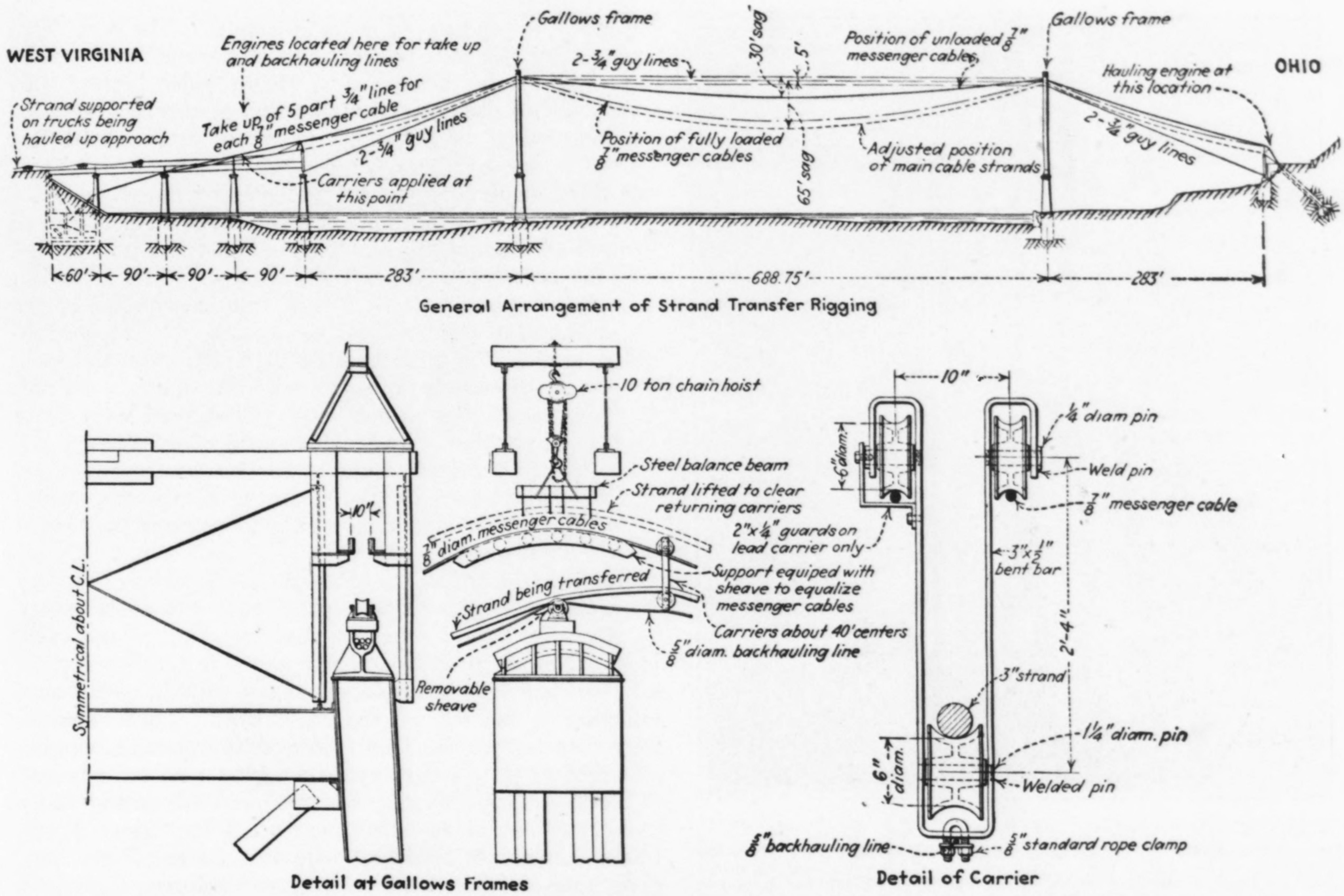

FIG. 5—ARRANGEMENT AND DETAILS OF RIGGING FOR TRANSFERRING CABLE STRANDS FROM SHORE INTO POSITION ON TOWERS

wire), and as the temperature changed the pull was varied at the rate of 4 lb. per degree of temperature change. This practice led to difficulties because at high temperatures work was interrupted due to the pull dropping below 20 lb., which was found to be the lowest practicable working pull, and at low temperatures the pull became too great. Another serious fault with the fixed-length method was that when the temperature dropped near zero, and particularly with strands almost finished, the temporary anchorages were subjected to a very large strain and had a tendency to pull together.

In order to permit spinning under a constant tension and to prevent the movement of the temporary anchorages, a hydraulic jack equipped with a calibrated gage was inserted between the strand shoe and the anchorage at one end only. The length of strand was then easily adjusted for temperature changes and the gage gave a direct reading showing the tension in the strand. When work ceased each night, the jacks were slacked off.

The spinning layout consisted of a standard-gage track about 1,400 ft. long with ties spaced about 5 ft. centers. Instead of using the customary continuous trough for land spinning, a V-shaped timber made of two 2x8 pieces was set up on the ends of each tie. This support was found to be quite sufficient and greatly facilitated the work of seizing the strand, since no removal of trough sections was necessary. All strands were spun from coils as delivered by the mill, the coils being about 40 in. in inside diameter and averaging about 350 lb. of wire to the coil. The ends of the coils were threaded by swaging and were equipped with ferrules for splicing, with the ferrules always on the rear end of the coil. Two parallel swifts were mounted at the end of the runway on each side of the track so that a spare coil would always be ready for splicing. The wire was hauled along the track by means of a car drawn by an endless cable operated from an engine located behind the swifts. Two roller-bearing swifts mounted on the car carried the bights of wire, so that one trip of the car laid two wires in each of two strands. The only stops in spinning were those necessitated by splicing, which took an average of two minutes for each splice. With this method of spinning as many as 110 wires were laid in each strand during a day. A standard two-drum hoisting engine with 24-in. drums was used for hauling the car.

Strand Transfer—The location of the bridge, only 625 ft. below Dam No. 10 in the Ohio River, dictated the use of an overhead system of strand transfer in order to eliminate interference with navigation. A study of previous methods of overhead transfer showed that all had used a single messenger cable with the strand carried on snatchblocks at about 50-ft. intervals. In general the method seemed satisfactory except that the removal and recovery of the snatchblocks offered some difficulty; particularly was this true at Steubenville, because the location was at times subject to a very swift current, depending on the position of the bear traps at the dam, which precluded the use of derrick boats without the risk of long delays due to river conditions.

With the definite object of controlling all operations from land, a parallel messenger-cable system was finally adopted with carriers so designed as to permit their convenient return to the point of application. The arrangement of the strand transfer rigging is shown in Fig. 5. Temporary steel and timber gallows frames were erected at the tops of the main towers to act as supports for

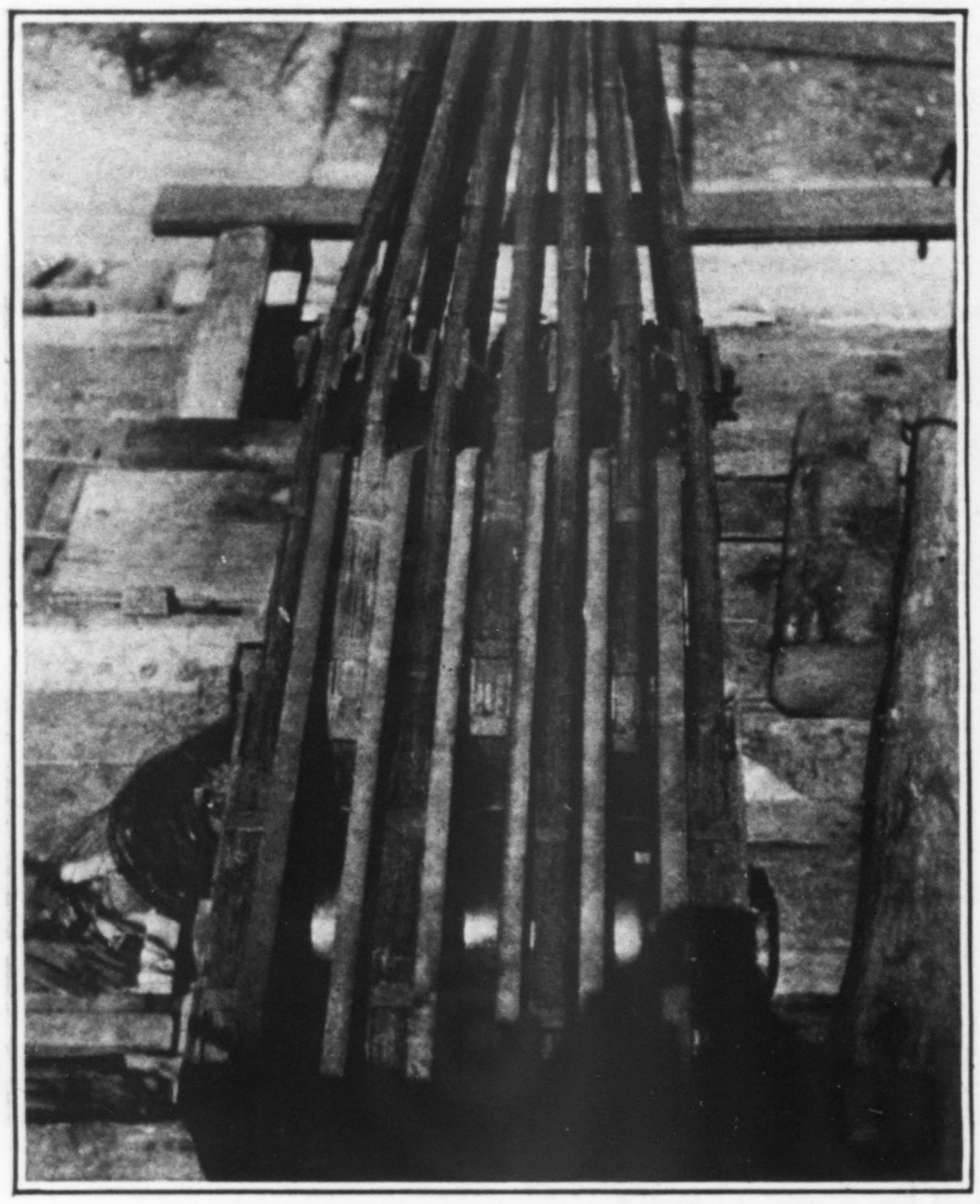

FIG. 6—CONNECTION OF WIRE CABLE TO EYEBARS
The shoes on the seven strands in the cable were placed on the river side of the cable bent. Two pins in steel yokes on the cable bent carried the strand shoes, three shoes attaching to the front pin and four to the rear pin as shown.

the messenger cables. In order to allow clearance of succeeding strands after the first strands were in position, the messenger cables were set about 5 ft. above the saddles at the main towers and 10 ft. above the pins at the tops of the cable bents. The $\frac{7}{8}$-in. messenger cables were carried down over the Ohio cable-bent tower and anchored to the eyebar back-stay, but on the West Virginia end they were carried back along the eyebar chains and equipped with separate take-ups consisting of a five-part $\frac{3}{4}$-in. line. The take-ups were inserted to adjust each messenger line independently in order to compensate for the variable stretch of the wire rope.

The gallows frames on the main towers carried a curved support consisting of two angles with 6-in. sheaves mounted to provide a support for the $\frac{7}{8}$-in. messenger cables, which would permit free movement of the messenger cable while the carriers rode over the curved support.

The carriers, shown in detail in Fig. 5, consisted of a two-roller carrier, with a third roller carried centrally on which the strand rested. The carriers were applied at the West Virginia approach about 90 ft. shoreward of the cable bent, the strands being hauled up the inclined approach to this point. Before starting across with a strand the $\frac{7}{8}$-in. messenger cables were adjusted as nearly equal as possible with about a 30-ft. main-span sag for the actual transfer. The $\frac{3}{4}$-in. hauling line was attached to the drum of a steam hoist located on the Ohio approach and was carried across the tops of the towers, resting in a temporary sheave on the main saddle and attached to the strand shoe of the strand being transferred. The back-hauling line was attached to the end of the hauling line by means of a loop around the strand shoe, and to this backhauling line the carriers were attached by means of a rope clamp. The two lines controlling the take-ups for the messenger cables were attached to the drums of a steam hoist located just riverward of the point of application of carriers, separate engines being used for the upstream and downstream systems; one of these engines was a three-drum hoist, the third drum carrying the backhauling line.

The transfer operation was started with the bottom strands of the upstream cable. As the strand was carried out the carriers were applied at about 40-ft. intervals. The messenger cables were kept sufficiently close to the same elevation with respect to each other without difficulty, and as the strands were carried across, the messenger cables were kept in constant adjustment to prevent interference of the strand being transferred with those already in position. As each strand was anchored at the two ends to the eyebar chains the strands were picked up by chain hoists on the gallows frames and raised about 5 ft. to allow returning carriers to clear the sheave on the main saddle.

Cable Attachment to Backstays—Since the eyebar backstays came up to the cable bent, it was necessary to place the strand shoes on the river side of the cable bent. The seven shoes were arranged in tandem formation, so that they were placed on two pins in steel yokes attached to the top of the cable bent. Three strands were attached to the front pin and four to the rear, so arranged as to prevent any crossing over of strands and to eliminate any difficulty of erection. All strand shoes had provision for an adjustment of $4\frac{1}{2}$ in. Since it was found convenient to do all adjusting on the West Virginia side and since the methods of spinning indicated that the strands would be nearly correct in length, all strand shoes were set on center at the Ohio cable bent and the adjustments of length were made at the opposite end. The correctness of the spinning was verified by the fact that the maximum adjustment needed was 3 in. and that some strands were within less than 1 in. of the correct length.

Strand Adjustment by Leveling—In order to eliminate the delays caused by field computations in adjusting cable strands, levels were used exclusively on this work.

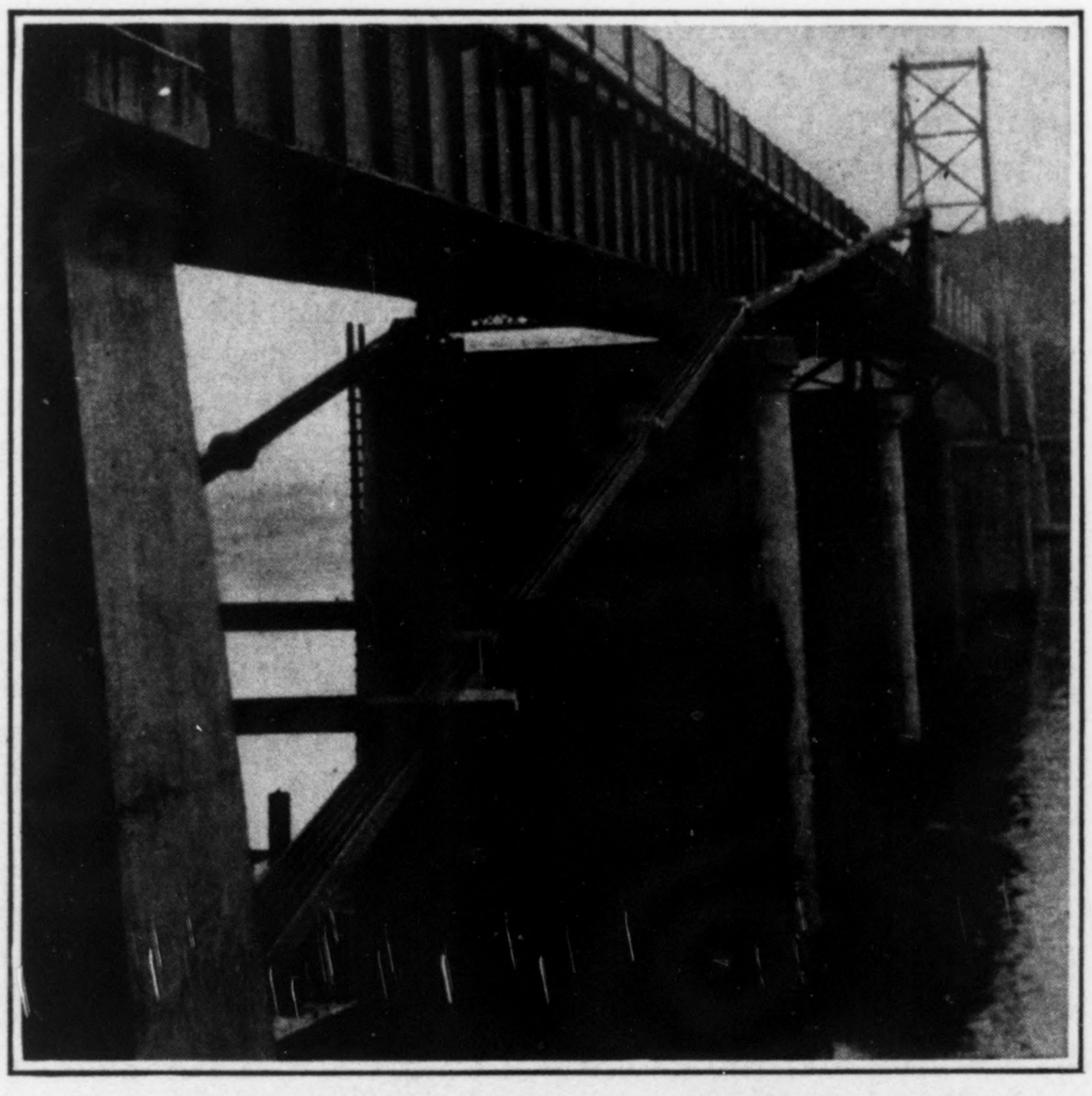

FIG. 7—EYEBAR CHAIN FROM CABLE BENT TO ANCHORAGE, WEST VIRGINIA APPROACH

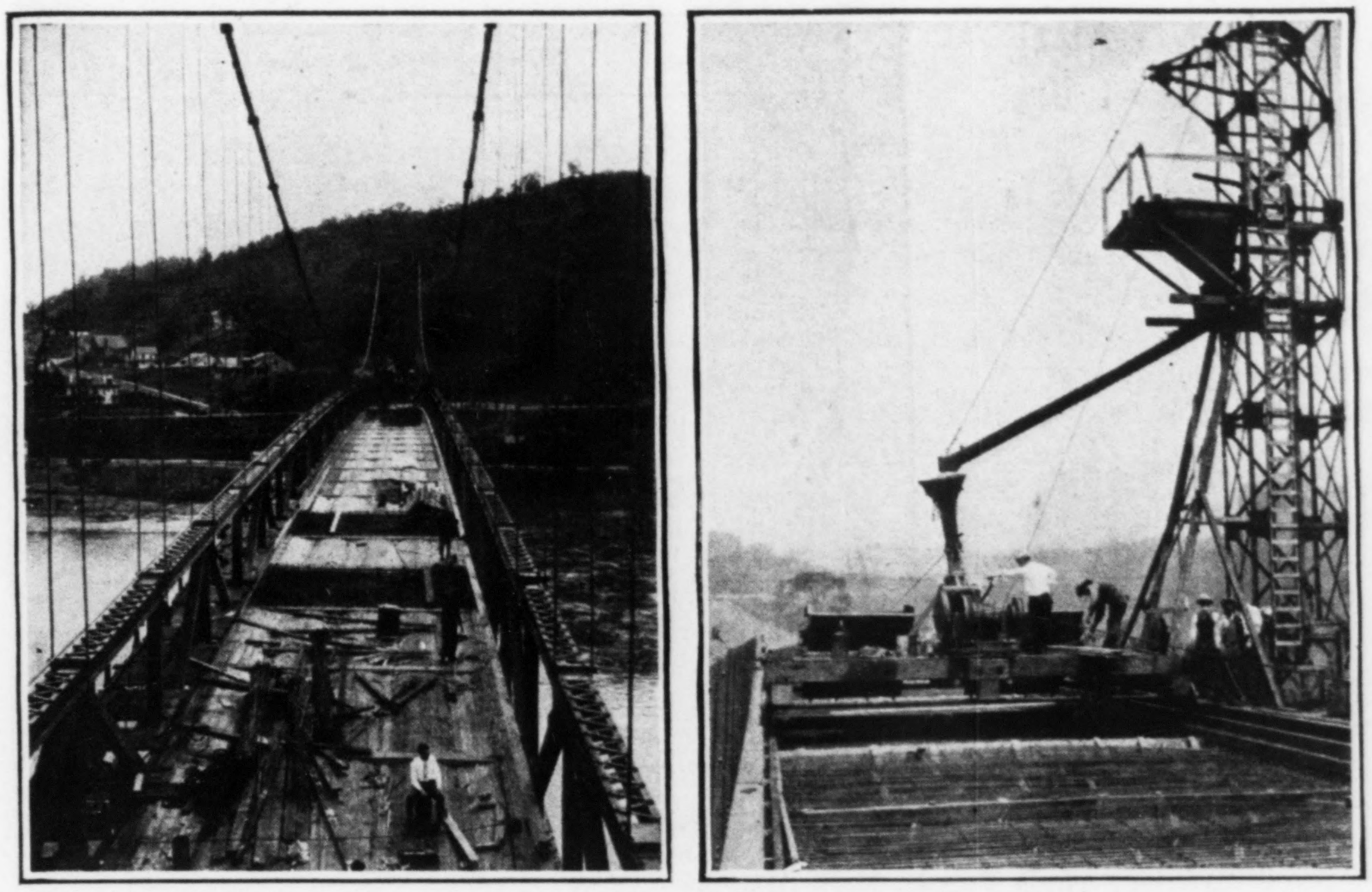

FIG. 8—FLOOR CONSTRUCTION ON THE STEUBENVILLE BRIDGE
At the left is shown a general view of the floor forms. At the right concrete is being poured from the tower to a buggy running on the roadway curb.

Hanging targets were placed at the center of the main and side spans, with the zero point of the scale on the center of the strand. With levels located on the top of the portal struts of the main towers, readings were taken on these targets, and from previously tabulated data the necessary adjustments were made at once. This method was so successful that all four bottom strands were adjusted in less than two working days.*

Stiffening Trusses—The stresses in the stiffening trusses were computed by considering the truss and cable as a redundant system. This method assumes that the cable retains a parabolic form under live loads and neglects certain deflections of the cable under such loads. Stresses secured by this method are in general slightly larger than the actual and are thus on the safe side. The trusses are continuous over three spans, and while they are attached at the main towers and at the cable bents to prevent vertical movement, all these joints are supplied with sliding joints to permit free horizontal movement.

The chords of the stiffening trusses are two 15-in. channels varying from 33.9 to 55 lb. per foot, with flanges turned out and top and bottom single laced. Where additional material was necessary, web plates were added. Full advantage was taken of I-beam construction, and all verticals and diagonals were made of 10-in. Carnegie beam sections. The resultant saving in shop work can best be shown by comparison with the Portsmouth bridge, which averaged 97 shop rivets per ton of steel, whereas the Steubenville bridge averaged 68; or, if expressed as a percentage, the shop riveting of the newer design is but 70 per cent of that of the former structure. The same percentage is true of the field riveting, this being due largely to the use of symmetrical chord sections in the stiffening trusses, which eliminated eccentric splices and thus reduced the number of rivets. Although the comparison of rivets is not the only consideration, it does indicate a considerable reduction of labor; and the use of beams in place of built-up members reduced the number of parts to be handled by a much greater percentage than the reduction in rivets. The I-beam construction offers surfaces easily accessible for painting and, combined with greater thicknesses of material, will decrease greatly the maintenance of the structure.

All stiffening trusses were fabricated in two panel lengths and weighed from 7 to 9 tons each. The Ohio side span was entirely over land, so erection progressed from the shore end, using a 10-ton jinniwink. The main span and West Virginia side span, being entirely over water, were erected with a standard derrick boat equipped with a special 130-ft. boom. The main-span steel was started at the center of the span and progressed both ways toward shore, while the West Virginia side span was erected from shore toward the main span. As all trusses had been shop-assembled and reamed, the fitters-up followed closely after the hoisting crews and pinned up all joints without difficulty. No riveting was done until all steel was in place, after which all floor steel was riveted as well as the bottom-chord joints of the stiffening trusses except at the main towers. Riveting was then stopped until all concrete was in place on the floor, after which the top-chord joints and the remaining bottom-chord joints were riveted.

Concrete Floor—The unusual type of floor design resulted from the decision to abandon provision for future addition of car tracks. It is an arched floor, but it was designed as a flat slab, the only effect of the arch being to lighten the bridge. In order to permit the proper distribution of loading, a steel curb was used which served as a track on which was run a concrete transfer car carrying two 1-yd. buckets, propelled by a gasoline engine-driven winch mounted on the car and attached to a fixed cable running from end to end of the bridge. All concrete was mixed at a plant on the West Virginia bank and delivered to the car by a hoisting tower. The method of placing concrete from a cable-operated buggy, also the position of the concrete tower, is shown in the right-hand cut in Fig. 8.

Cable Wrapping—The cable was squeezed down to about 8¼ in. diameter before wrapping. The wrapping, done immediately after the placing of the concrete floor, consisted of No. 9 double-galvanized steel wire applied under tension by a motor-driven wrapping machine. The work of squeezing and wrapping was done from cages suspended from trolleys running on the main cables and operated by means of lines from hoists located on the approaches.

Administration—The entire bridge was designed, constructed and erected by The Dravo Contracting Company, Pittsburgh, Pa. Clarence W. Hudson of New York acted as consulting engineer for the Steubenville-Weirton Bridge Company, the owner. The cable squeezing and wrapping equipment used was that developed and patented by H. D. Robinson, of the firm of Robinson & Steinman, New York.