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The St. Louis Municipal Bridge

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The St. Louis Municipal Bridge, now being built across the Mississippi River, connects the cities of St. Louis, Mo., and East St. Louis, Ill., and is being constructed by the city of St. Louis as a combined railway and highway structure. The superstructure of the river crossing consists of three simple truss spans of the Petit type, each having a length of 668 ft. c. to c. of end pins. The substructure has been described in a previous article (Engineering News, Mar. 16, 1911).

The position of the shore piers, the minimum span length and the clearance above high water were all made to conform to the requirements of the Secretary of War.

The original plans submitted to the War Department called for three spans each of about 500 ft. clear between piers at low-water line. The vertical clearances were 50 ft. at the shore piers, and 53.4 ft. at the center of the middle span, above the high-water line of 1844. These spans are about the same as for the Merchants and McKinley bridges, the two structures spanning the Mississippi at St. Louis, just above the Eads Bridge. The vertical clearances are somewhat greater than for the above-named bridges. On these plans the shore piers were placed just inside of the outer harbor lines, or at the foot of the levee slope on the Missouri side, and opposite the end of the Pittsburg dike on the Illinois side.

The War Department, however, ruled that the Eads Bridge was the dividing line between the upper and lower river, and that therefore, the spans and clearances of the Municipal Bridge must conform, in general, to those of the first existing crossing south of the Eads Bridge, which is at Thebes, Ill., about 200 miles below St. Louis. In addition to this, the shore piers were required to be placed inside of the inner harbor lines. The central span of the Thebes Bridge is 650 ft. in the clear, with a vertical clearance of 65 ft. above the high-water line of 1844.

New plans showing three approximately equal spans of about 650 ft. in the clear, with a clear height of 65 ft. above the high-water line of 1903, were then submitted, and finally approved by the Secretary of War. These changes increased the length of the river crossing 500 ft. and the elevation of the clearance line some 12 ft., thus increasing very materially the cost of the river spans

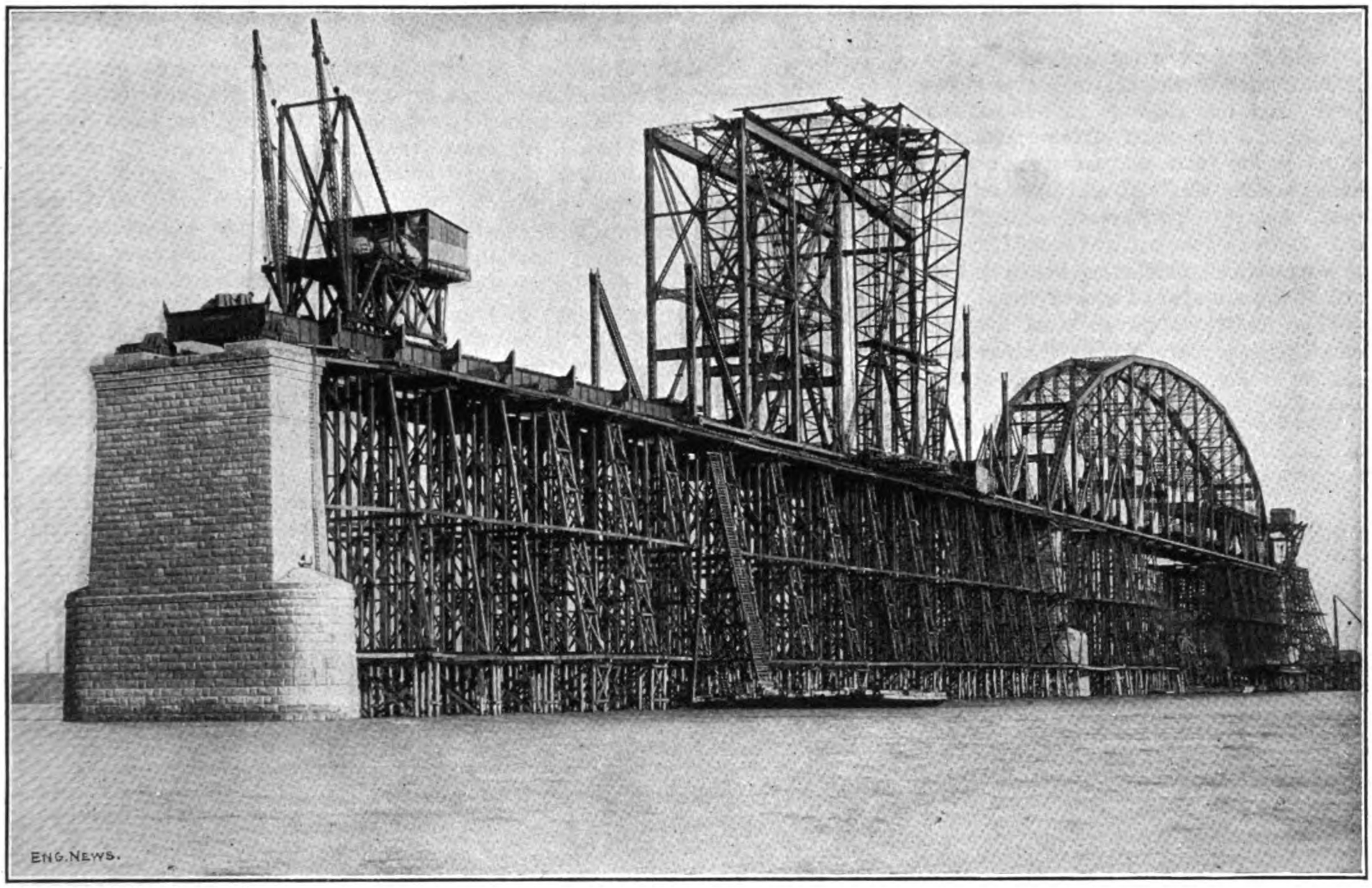

Fig. 1. Erection of the Municipal Bridge Over the Mississippi River at St. Louis, Mo.

(From a photograph taken in November. The east span was then completed, except a part of the upper deck, and the falsework was being removed. The middle or second span had the floor system in place and the main traveler was erecting the trusses. The smaller traveler at the left was used for erecting the falsework and the floor system.)

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and approaches. The spans and clearances, as well as the general dimensions of the structure, are shown on the profile elevation.†

Fig. 1 shows the completed east span on the falsework, and erection commenced on the second or middle span.

Design of Superstructure

The structure has two decks; the lower of these carries two steam-railway tracks, while the upper supports two tracks for an electric interurban railway on a 30-ft. paved roadway. Two 6-ft. sidewalks at the level of the upper deck are carried on cantilever brackets outside of the trusses. The roadway is paved with creosoted wood blocks on a reinforced-concrete slab supported on the stringers; the sidewalk slabs are also of reinforced concrete. The cross-section of the span, Fig. 2, shows the arrangement of tracks, etc., as well as the construction.

On the stress sheet, Fig. 3, shown herewith, are given the loading and the stresses used in the design of the steelwork, and the makeup of the various members. All main truss members, both tension and compression, are of nickel steel. Carbon steel is used for the secondary truss members, railway and highway-floor systems, and for all bracing. Such details as batten plates and lacing are also of carbon steel.

[The live loads for the floor systems and the secondary truss members are shown in Fig. 4. For the trusses they are as follows: (1) On each railway track, 5000 lb. per lin.ft., with two concentrations of 130,000 lb. each, placed one panel apart; (2) on each trolley track, 1400 lb. per lin.ft.; (3) on the roadway, 75 lb. per sq.ft., 10 ft. wide, 750 lb. per lin.ft.; (4) on the sidewalks, 60 lb. per sq.ft., 12 ft. wide (two walks, 6 ft. wide), 720 lb. per lin.ft. Wind loads: Upper laterals, 300 lb. per lin.ft.; lower laterals, 300 lb. per lin.ft. moving and 300 lb. fixed, 600 lb. per lin. ft. The unit stresses are given in Table I.—Editor.]

A novel feature of the design is the construction of the top chords and end posts. In all of these members, three webs are used, composed of plates and angles. These webs are connected together along the neutral axis by means of continuous longitudinal diaphragms of plates and angles. The flanges of the webs are stayed by lacing composed of 5-in. 11.5-lb. channels. At intervals of about 10 ft. transverse diaphragms are introduced to prevent the member from becoming distorted while being handled. This type of cross-section is well adapted to withstand high unit-stresses, as the longitudinal diaphragms support the webs at the middle of their depth and tend to prevent them from distorting laterally, while the lacing systems prevent the distortion of the flanges and edges of the webs. As the longitudinal diaphragms are counted in as stress-carrying material and act also as lacing, the member is lighter than would be the case if only lacing were used to stay the webs and flanges. At the ends of the members where the longitudinal diaphragms stop, the necessary cross-sectional area is supplied by means of pin plates.

Fig. 5 shows the size and makeup of one of the end posts. This member (a view of which is shown in Fig. 6) is about 85 ft. long c. to c. of pins and weighs about 70 tons. The heaviest member in the structure is the middle section of the top chord, which is 96 ft. long c. to c. of pins and weighs about 83 tons. The cross-sectional area of this chord is 441.11 sq.in. The ends of the top-chord members are faced to bear on each other, the pins and pin plates merely transferring the components parallel to the chords of the stress in the diagonal members. The one exception to this rule is the joint at U2, which has a full pin bearing. No hinge plates are used on any top chords or end posts, and only on the diagonal web members where they are required for structural reasons, or to provide for reversal of stress. This arrangement greatly facilitated the erection, as the members could be placed much more easily than would have been possible had all members been built with full holes. The last pin could also be driven without the members being in exact position relative to each other and to the pin.

The contractor was given the option of splicing the top chords and end posts at the subpanel points, or of making them in full panel lengths, and he chose the latter method.

Riveted members capable of taking either compression or tension, are used when reversal of stress occurs, except in the case of members M5-L6. Here the ruling stress is tension and is very much in excess of the compression. This member is therefore made to take care of the stresses independently, the compression being taken by a latticed built member of plates and angles, and the tension by four eyebars, two placed outside and two inside of the compression member.

The pins range in size from 10 to 15 in. diameter and are all bored with 2-in. axial holes, through which 1⅞-in. rods pass to secure the cast-steel caps in place. The main shoes are of cast steel and rest on granite bridge seats. These seats were bush-hammered to a water level, and the shoes set on a thin bed of cement grout. The shoes are secured to the bridge seats by means of anchor bolts grouted into holes drilled into the granite after the shoes are placed. Segmental expansion rollers, 15x8 in., are used on the shoes at the east end of each span.

The contract for furnishing and erecting the steelwork was awarded to the American Bridge Co. Bids were taken on the "nickel-steel" design shown on the stress sheet, as well as on an alternative design in which all members except

†Engineering News, March 16, 1911.

TABLE I. UNIT-STRESSES FOR THE RIVER SPANS OF THE MUNICIPAL BRIDGE AT ST. LOUIS, MO.

		Live	Dead
(A) Carbon steel:			
Flanges of railway stringers and floorbeams		10,000	10,000
Flanges of highway stringers and floorbeams		12,500	12,500
(B) Nickel steel:			
Bottom chord and main diagonals	(eyebars)	16,000	32,000
Main diagonals	(riveted)	13,000	26,000
Long verticals		12,000	24,000
Outside fibers of pins		36,000	36,000
Power-driven rivets and pins	(shearing)	14,000	14,000
Hand-driven rivets	(shearing)	11,200	11,200
Power-driven rivets	(bearing)	22,000	22,000
Hand-driven rivets	(bearing)	17,600	17,600
Pins	(bearing)	24,000	24,000
Compression members having $l+r$ less than 40		15,000	30,000
For lengths over $40 \times r$		$17{,}000 - 55 \frac{}{r}$	$34{,}000 - 110 \frac{l}{r}$
Inclined posts		$14{,}000 - 45 \frac{l}{r}$	$28{,}000 - 90 \frac{l}{r}$
(C) Carbon steel:			
Wind bracing	(compression)	$15{,}750 - 60 \frac{l}{r}$	$15{,}750 - 60 \frac{l}{r}$
Wind bracing	(tension)	13,500	13,500
Power-driven rivets	(shearing)	10,000	10,000
Hand-driven rivets	(shearing)	8,000	8,000
Power-driven rivets	(bearing)	16,000	16,000
Hand-driven rivets	(bearing)	12,800	12,800
Rivets for bracing	(shearing)	15,000	15,000
Rivets for bracing	(bearing)	24,000	24,000
Vertical sub-posts			$24{,}000 - 80 \frac{l}{r}$

TABLE II. WEIGHT OF MATERIAL IN THE RIVER SPANS OF THE MUNICIPAL BRIDGE AT ST. LOUIS

	Cast Steel, Pounds	Carbon Steel, Pounds	Nickel Steel, Pounds	Total	Per Cent.
Pedestals and shoes	510,000	....	....	510,000	1.85
Pins and nuts	....	19,000	458,000	477,000	1.73
Rollers	....	126,000	....	126,000	0.46
Railway floor	....	3,791,000	....	3,791,000	13.70
Highway floor	....	4,107,000	....	4,107,000	14.90
Laterals and trans. br	....	1,067,000	....	1,067,000	3.86
Trusses; bars	....	....	6,753,000	6,753,000	24.50
Trusses; b'lt. mems	....	1,810,000	8,959,000	10,769,000	39.00
Totals	510,000	10,920,000	16,170,000	27,600,000	100.00

eye-bars and pins were to be of carbon steel, the bars and pins to be of nickel steel. The low bid on each of these designs was $1,393,931, or 4.28c. per lb., for the "carbon-steel" design, and 5.05c. per lb. for the "nickel-steel" design. A pound price for extras was also specified; this was 5.6c. for nickel steel and 3.95c. for carbon steel. As the general preference was for nickel steel, this design was adopted. The material was fabricated at the Ambridge plant.

In addition to the regular shop inspection, all work was inspected by Robert W. Hunt & Co., who were employed by the consulting engineers to do this work.

Aside from the usual diffifficulties in manipulating nickel steel, the shop had no great trouble with the fabrication of the work, although some of the members were of unusual size.

The shop work was remarkably good and the number of shop errors found and corrected in the field was very small.

The total shipping weight of the three spans is about 13,935 tons, while the weight as estimated by the engineers from their plans was about 13,800 tons. This weight was divided as shown by Table II. The weight of the steelwork used in computing the final dead-load stresses exceeds the actual shipping weight by less than 2%. These loads are distributed to the various panel points according to the estimated weights of the various members. There are approximately 109,000 field rivets required for the three spans, of which about 8% are of nickel steel, the remainder being of carbon steel. The number of rivets per ton of material is about eight.

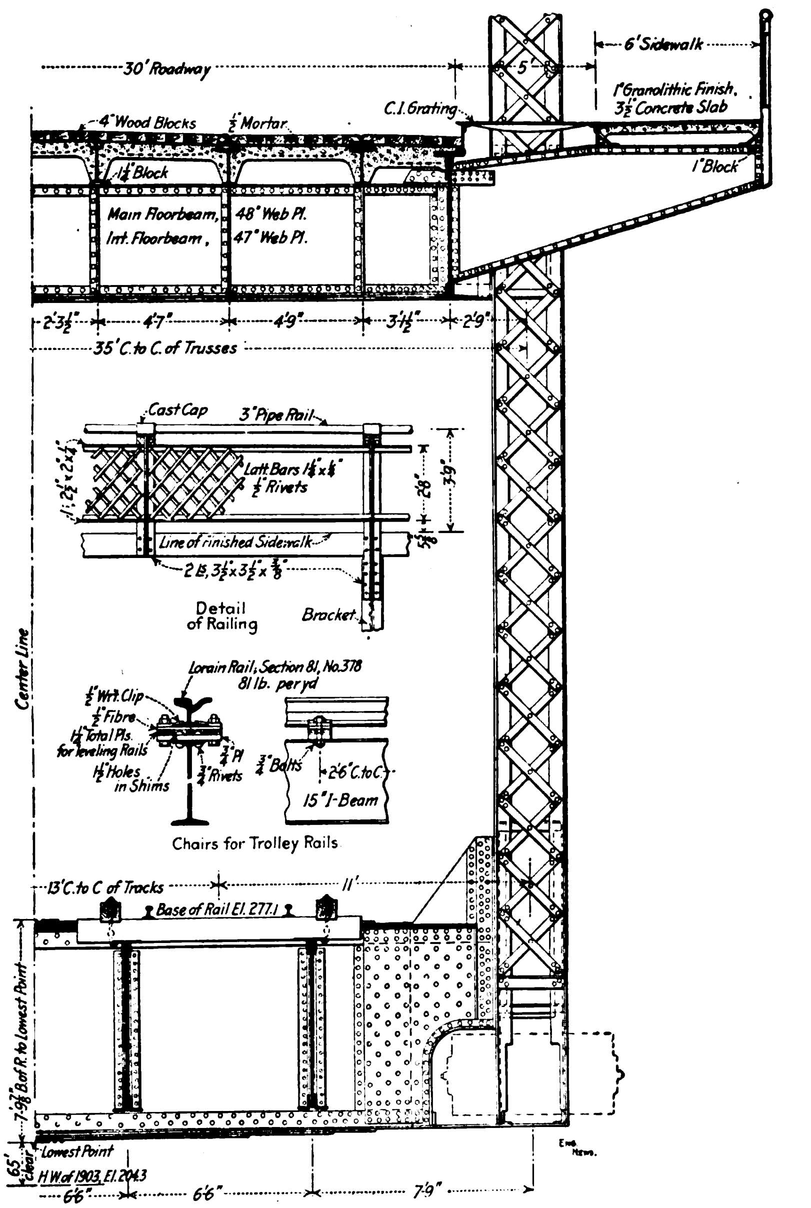

FIG. 2. HALF CROSS-SECTION OF THE MUNICIPAL BRIDGE AT ST. LOUIS, MO.

ERECTION PLANT AND METHODS

The storage yard was located on the east side of the river for two reasons: (1) Lack of sufficiently large unoccupied space on the St. Louis side, near the bridge site, and (2) the avoidance of the transfer of material across the river, the material being shipped in from the east.

The ground in the immediate vicinity of the east end of the bridge being too low to serve as a site for the storage yard, it was found necessary to go about ¼ mile south, where a tract of land was found of sufficient size and above the average high-water stage. Tracks were laid out on this property, and the steel stored as it arrived, in accordance with a prearranged plan. Each class of members was assigned to a certain place, as shown on a plan of the yard, so that any member could be readily located. A woodworking mill was built for framing the falsework and traveler timbers, and a bunk house and commissary building was put up to provide for the men employed in the yard.

The program of erection provided for erecting the three spans in order, beginning at the east end of the structure. Permission was obtained from the War Department to close two spans with falsework at the same time, provided that the third span be kept perfectly clear. The scheme of erection is, in general, as follows: The framed falsework bents are erected in place on the pile foundation bents, by means of a double-boom steam viaduct traveler, running on the railway floor. This is shown at the left in Fig. 1. This traveler, after placing the bents, places the camber blocking and the stringers, floor beams and bracing of the railway floor system. The main trusses and truss bracing are erected by the gantry or main traveler, which is equipped with electric power. The highway-floor system is placed by a small, single-boom steam traveler, running on the stringers of the upper deck.

The viaduct traveler or "mule" is built of timber, with the exception of the two masts and booms at the front end. The booms are operated by two steam hoisting engines, which are located on a raised deck. The traveler is so constructed that there is sufficient clearance between the bridge floor and the engine deck to allow cars of material to pass through, so as to be picked up by the booms. The entire machine is mounted on wheels and travels on two lines of single rails, one over each outside railway stringer. The small traveler used for placing the highway-floor system is also constructed of timber, with the exception of the boom, and is operated by a single steam hoisting engine. This traveler is mounted on wheels, and travels on two lines of rails, supported on the I-beam stringers.

The main traveler (Fig. 7) consists of three gantry bents, supported on sills, which are mounted on wheels and run on standard-gage tracks, one on each side of the falsework. The bents are braced together with timber struts and steel diagonal rods. The legs of the bents and the chords of the trusses are of 12x12-in. timbers, the sills 8x16 in., and the bracing 4x8 in. All connections are bolted. The splices of the legs are of four angles, inclosing the sticks, and heavy steel gusset plates are used at all principal points. The loading beams are steel I-beams. The traveler is equipped with eight sets of falls, four on each side, composed of six-sheave steel blocks reeved with wire rope. In addition to this, there are 16 single manila lines or runners, eight on each side, for handling the lighter pieces and holding them in position while connections are being made. The working platforms are raised and lowered by means of tackle, so that the pins at the various points can be readily driven. Power for operating the traveler

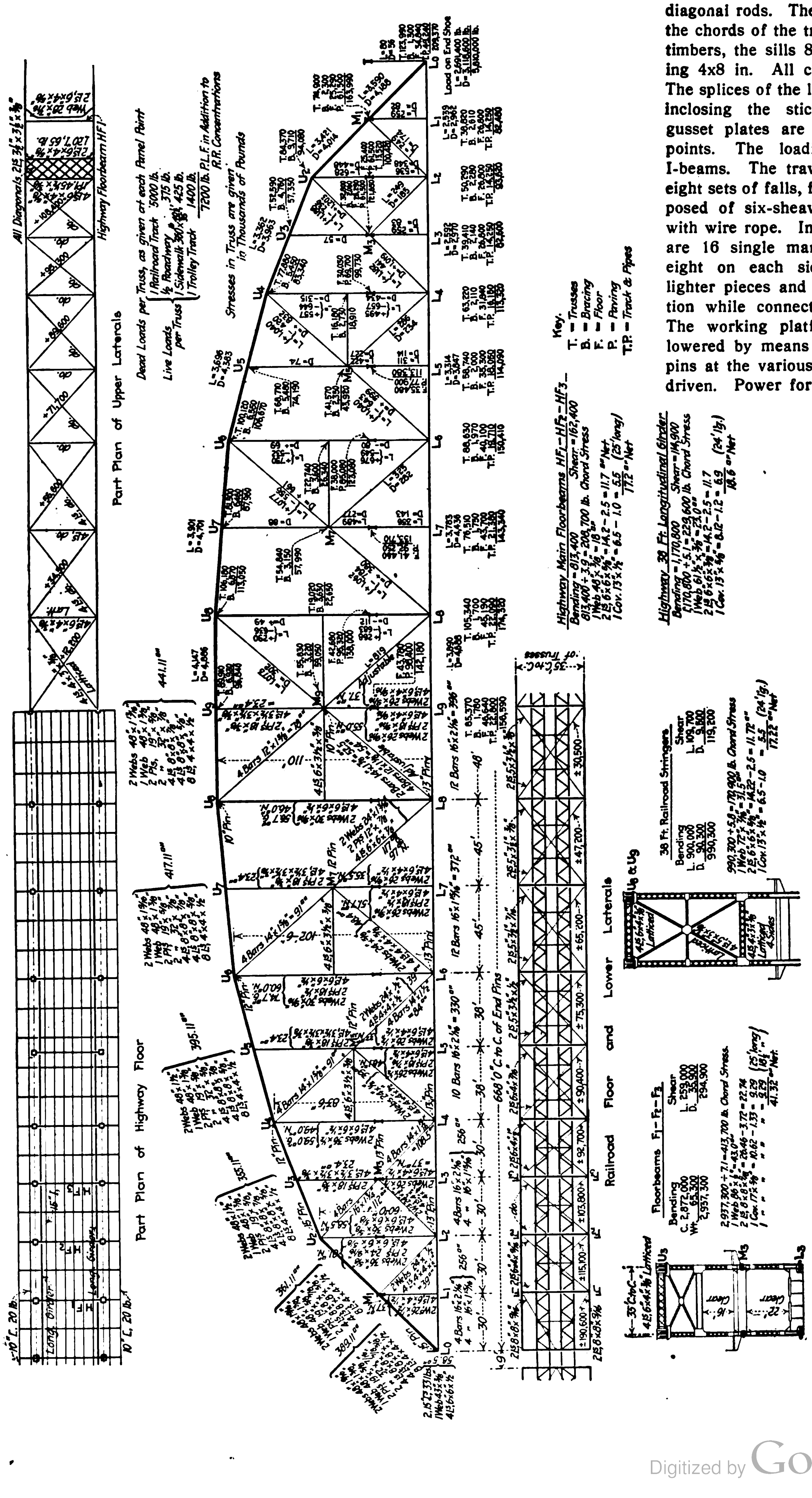

FIG. 3. STRESS SHEET OF THE MUNICIPAL BRIDGE, AT ST. LOUIS, MO.

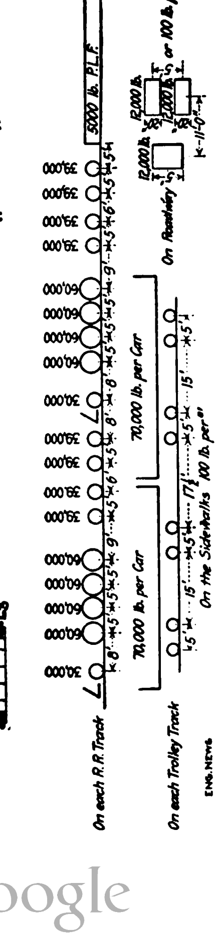

FIG. 4. LIVE LOADS FOR FLOOR SYSTEMS AND SECONDARY TRUSS MEMBERS

is furnished by two 100-hp. direct-current electric hoists, each having 4 drums and 8 spools. These hoists are mounted on trucks and run on the traveler tracks, one being attached to each sill of the traveler like a trailer.

In order to get material from the surface track on which it is received from the storage yard, to the track on the level of the bridge floor, a double hoisting trestle was constructed just east of Pier IV, as shown in Fig. 8. The low-level track runs between these two trestles, while the high-level track is supported on the upstream trestle. Spanning these two tracks and supported on the two trestles are two 83 hp. alternating-current electric gantry cranes, one of which is stationary, and the other travels on tracks laid on the trestles. The members are loaded on cars at the yard, by locomotive cranes or stationary derricks, depending on the weight of the member, hauled to the bridge site, raised by the gantry hoists, and deposited on cars on the high-level track. These cars are then pushed out to the traveler by means of a small locomotive. In the case of short members carried on single cars, car and contents are hoisted together, thus avoiding several lifts and the transfer of members from car to car. These gantries are shown in Fig. 8.

The electric current for operating the two material hoists and the main traveler is obtained from East St. Louis, and is reduced in voltage in the power house at the bridge site. The power house also contains two boilers, which supply steam to the two air compressors. The compressors furnish air for the wood-boring machines and riveters, as well as for an engine on the diver's barge, which handles bracing and staging for the divers. A 4-in. pipe leads from the compressors out along the falsework, with valves and connections at convenient intervals, and another pipe of the same size leads to the lower deck of the bridge and out along the bridge floor. With the exceptions noted above, steam power is used for all derricks and cranes.

Work was started on the hoisting trestles on May 1, 1911. Piles were driven by means of a pair of leads suspended from the 60-ft. boom of a locomotive crane. This rig proved to be very efficient, and piles could be driven at any desired batter. On top of these hoisting trestles a temporary floor was laid, supported on I-beams. On this floor the "mule" was erected. While this work was going on, the falsework piles were being driven, capped and braced.

The falsework (Figs. 9 and 10) consists of pile bents surmounted by two-story framed-timber bents. The piles supporting the framed falsework bents are of yellow pine and range in length from 60 to 100 ft. Each bent consists of a double row of piles; the total number per bent varying from 28 to 40, depending on the load to be supported. The total number of piles per span is 608. Piles were arranged to take a maximum load of about 20 tons, and were driven by means of a No. 1 Vulcan steam hammer, until at least 20 blows were required to drive 1 ft. The piles of each bent were braced together in both directions above the water line, and where the depth of the water exceeded about 20 ft. below zero of the gage, submarine bracing was put on by divers. The piles were capped at about a 25-ft. stage of water, which is the average high-water line. Two floating drivers were used the greater part of the time, although the work was started with one driver.

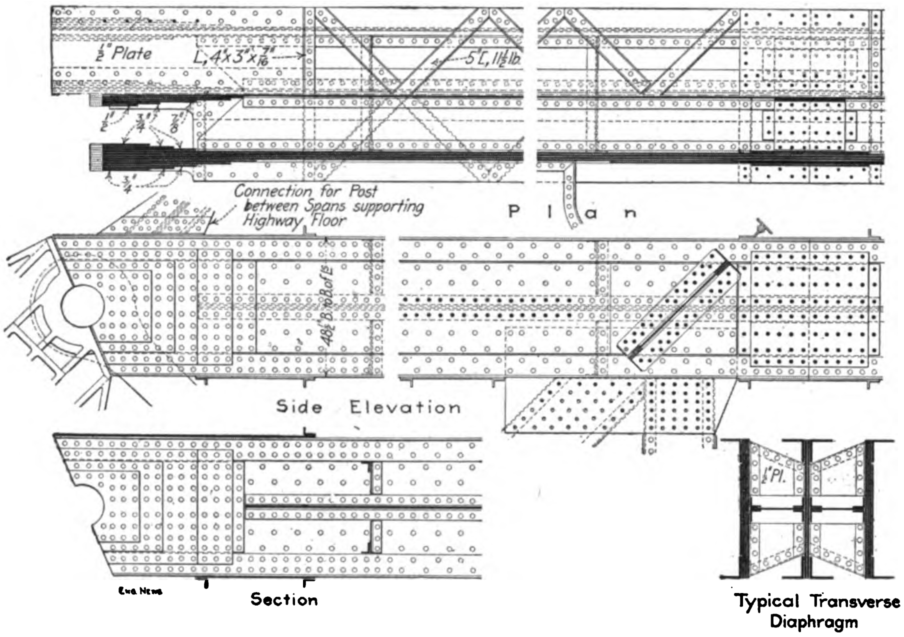

FIG. 5. DETAILS OF END POST

The framed-timber bents, surmounting the pile foundations, are constructed with 12x12-in. posts, caps and sills. Longitudinal struts are 8x12 in.; transverse bracing, 4x8 in., and the sway bracing between bents is of 1¼-in. round rods. All timber is yellow pine. No drifts are used as in permanent timber structures, but the posts are connected to the caps and sills, and to each other by means of flat steel scabs. Some of these scabs also serve to connect the sway rods to the bents. As all connections are bolted, the bents can be readily dismantled.

The timbers were framed in the material yard; one bent being first framed and assembled complete, to guard against mistakes. All sticks were framed from templates. The traveler tracks and camber blocking are supported on lines of steel I-beams. There are four lines of 20-in. 65-lb. I-beams under each traveler track, and four lines of 15-in. 42-lb. I-beams under each truss, to support the camber blocking. These beams lap 11 ft. at each panel point. All these beams are perfectly plain, and can be put back in stock when the job is finished.

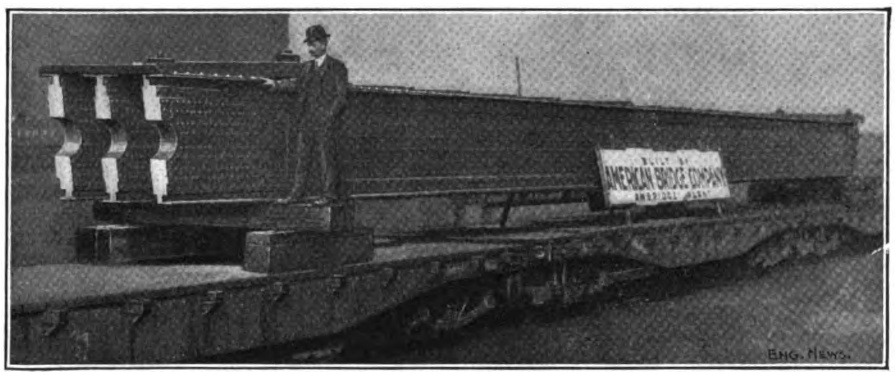

FIG. 6. TRANSPORTATION OF 70-FT. SECTION OF END POST FOR THE MUNICIPAL BRIDGE, ST. LOUIS, MO.

The timbers for each bent of falsework were loaded on cars as needed and hauled to the bridge site, where they were run out on a trestle at the downstream side of the falsework. They were then assembled on barges by means of a stationary derrick, and bolted together to

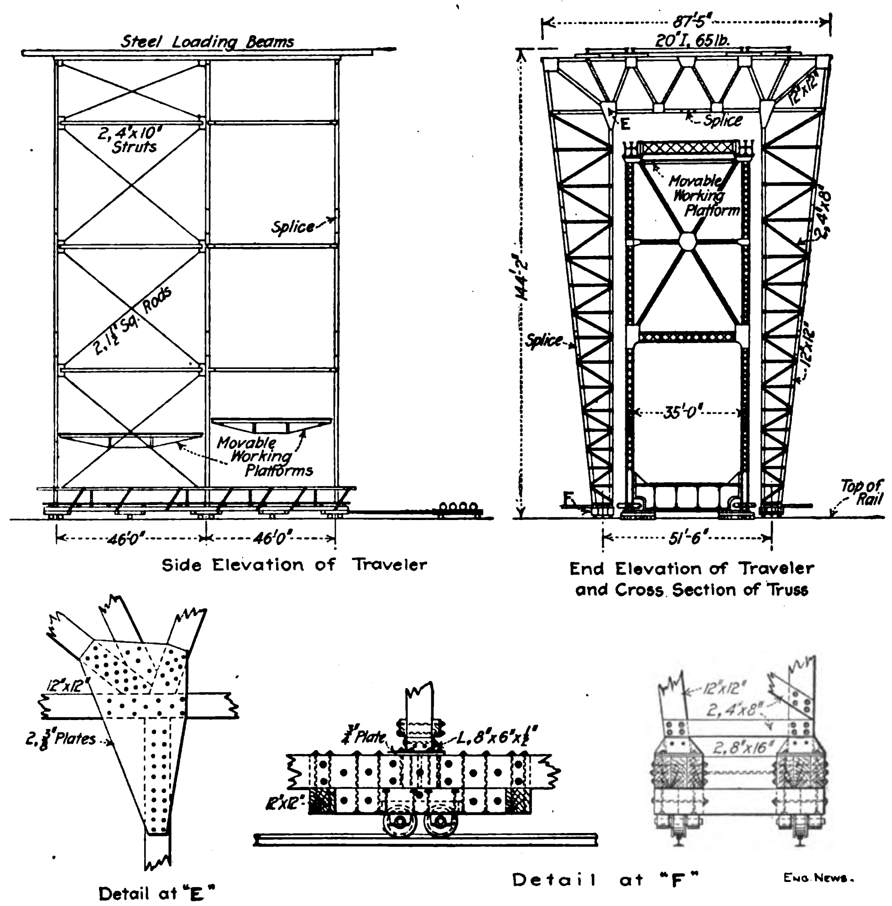

FIG. 7. MAIN TRAVELER FOR ERECTING THE TRUSSES OF THE MUNICIPAL BRIDGE

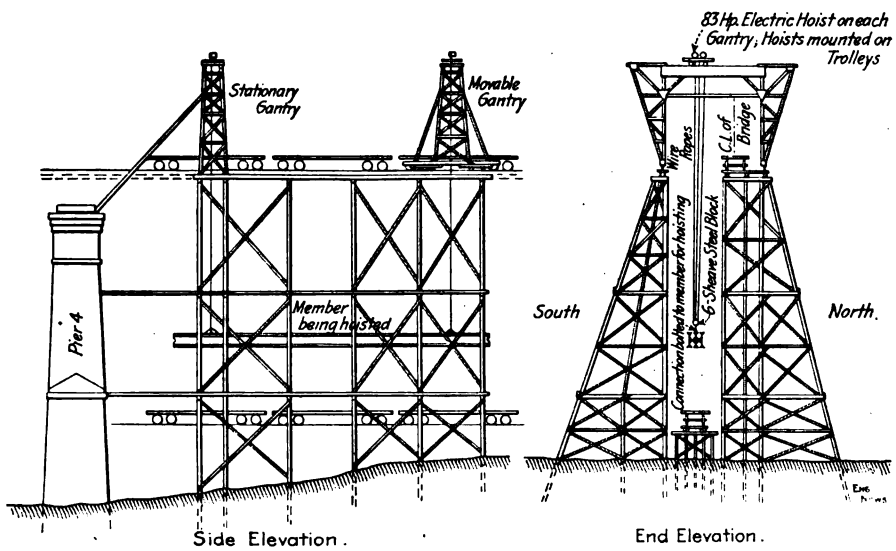

FIG. 8. GANTRY CRANES FOR HOISTING STEELWORK FROM SUPPLY TRACK TO THE FALSEWORK

form each story of the bent. The two stories forming a complete bent were assembled on top of each other on one barge. These barges were then towed alongside the falsework and the bents were picked up by the "mule" and placed in position. Each one was handled in four sections.

By the time the "mule" was ready for use, the first timber-falsework bents had been assembled. They were then picked up and placed in position by the "mule," together with the I-beam stringers and camber blocking. The main shoes and the first panel of floor system was then set, a temporary track laid on the stringers, and the "mule" advanced one panel length and placed the next bent of falsework. This process was repeated until the center of the east span was reached, when the material for the gantry traveler was brought to the bridge site and hoisted to the top of the falsework, where it was assembled by the "mule," in position to raise.

The gantry traveler had been framed and assembled in the material yard and was knocked down for shipment to the bridge site. Each of the bents of the traveler was knocked down in eight pieces; the sills were handled in one piece. The bents were bolted together on blocking, the lower ends resting on the sills, which had been placed in position on the traveler tracks, the bents overlapping each other. In raising them, a tipper bent was attached to the lower end of the first one, the blocks and lines being arranged as shown in Fig. 11. The bent was then tipped up into position, the power being furnished by two electric hoisting engines belonging to the traveler. One engine was located on each side of the falsework on the traveler tracks. The other two bents were raised in the same manner. As soon as the three traveler bents were raised and braced, the "mule" moved forward, through the gantry traveler, and after clearing up the blocking on which the bents had rested, resumed the work of building falsework. Meanwhile the gantry was being rigged and preparation made to begin the erection of the trusses.

The erection of the main trusses of the east span was started on Sept. 11. The posts were first placed and bolted to the floor beams and bottom laterals, then the bottom-chord bars, diagonals, etc., were placed in position and the bottom-chord pins driven as each joint was packed. When the middle of the span was reached, the middle panel (8-8) was erected complete and all bracing bolted up. The traveler then completed the next panel toward the west, in order to distribute the load onto the bents to the west, as the center bent had been somewhat weakened by the scouring of the river bed at the center of the span.

After this, the traveler moved back toward the east and completed each panel as it went, until the east end of the span was finished. Later the west end of the span was erected and the traveler then moved on and began the erection of the middle span. All lifts, wherever possible, were made simultaneously on both sides. The top-chord sections were handled by means of heavy bent plates bolted to the flange angles of the middle web. These plates were in pairs and were connected to the falls by means of pins passing through them.

The spans are cambered for dead load only. The camber at the center of the span, for the unstrained position of the truss, amounts to about 7 in. In order to provide for compression in the various joints of the falsework, and a possible settlement of the piles, under the weight of the steelwork and traveler, an arbitrary camber of about 6 in. was added. This proved to be sufficient to keep the points above the line of no stress until the blocking was lowered and the span swung.

No riveting was done until the span was free of the blocking. Work was then started on the railway-floor system and bottom laterals. All rivets were driven with pneumatic hammers and pneumatic dollies were used wherever possible.

Although no unusual difficulties were encountered in getting good carbon-steel field rivets, the nickel-steel rivets were exceedingly hard to drive. A great many had to be cut out and re-driven, and this frequently loosened the adjoining rivets, which were apparently tight originally. Wherever the clearances permitted, these rivets were driven with two pneumatic hammers, one on each head. This gave much better work than when only one hammer was used, but was not always entirely satisfactory. These rivets cool very fast, and it is difficult to start them hot enough, without burning. This accounts, to some extent, for the difficulty of getting them tight, although the high elastic limit and consequent stiffness of the sheets has something to do with it.

Before any of the steel work was placed is position, the distances c. to c. of piers were measured with a long tape furnished by the American Bridge Co. The pier centers, which had previously been established by triangulation, consisted of brass tacks set in the concrete.

A base line was first laid out, 672 ft. 6 in. long, which is the plan distance c. to c. of piers, of the side spans. The length of this line was established by repeated measurements with a 100-ft. base-line tape. After all corrections had been made and the position of the end tacks established beyond question, the long tape was stretched out and supported at the two ends of the base line. Each end of the tape was supported on a pair of light timber shears, guyed back to a stake; the tape had metal tags at each 100-ft. point, and was provided with clamps, turnbuckles, plumb-bobs and a heavy spring balance. This latter was not graduated in pounds, but had divisions corresponding to the unsupported length of the tape. The zero end of the tape was first adjusted approximately over one end of the base line, a plumb-bob being hung from the marker on the tape.

Tension was then applied by taking in the slack on the guy lines, until the tape hung clear, and the spring balance at the head end read approximately 700 ft. The turnbuckles were then brought into play and the zero point carefully adjusted over the end base-line tack, while the spring balance was brought to the 700-ft. mark. A small marking clamp was then slid along the tape until a plumb-bob suspended from it, hung directly over the tack at the head end of the base line. The position of the marking clamp was then marked on the tape and the temperature noted. As a check on the accuracy of the work, the tension was relaxed and then applied again, correction being made for the change of temperature that had occurred. It was found that the marker could be reset within $\frac{1}{16}$ in. of the original position. After this preliminary work was finished, the tape was taken down, stretched from pier to pier and supported on the piers under exactly the same tension as before. By making the proper temperature correction, the distance c. to c. of piers was determined.

As the effect of the wind on the long tape produced some horizontal deflection, a second measurement was made, as soon as the falsework was completed. The tape in this case was supported on the caps of the falsework bents. In order to calibrate the tape for this second measurement, it was stretched out on the base line, and supported on stakes driven into the ground at intervals, corresponding to the spacing of the falsework bents, the tops of the stakes being level. Owing to the accidental breaking of the long tape, a piano wire was used in making the second measurement. A pull of 50 lb. was used on the wire when supported on the stakes, as described above. The results of the measurements made to date are given in Table III.

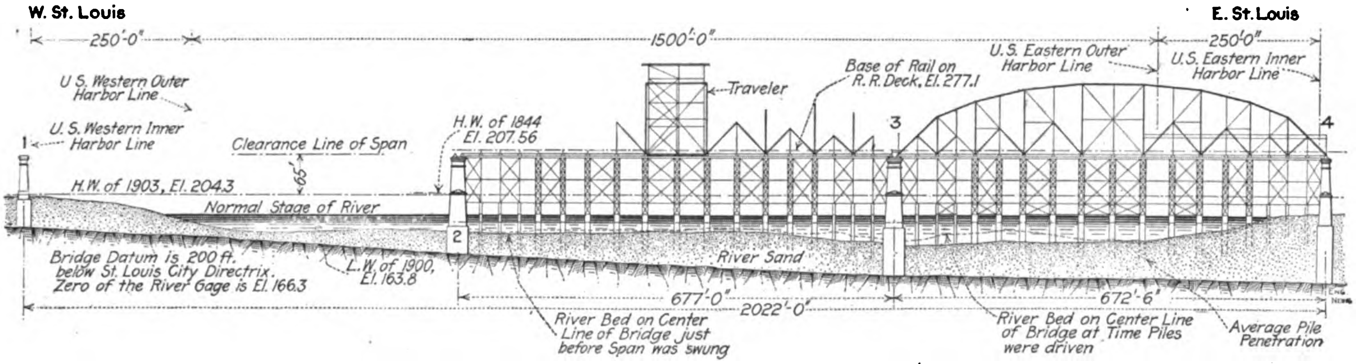

FIG. 9. FALSEWORK FOR THE RIVER SPANS OF THE MUNICIPAL BRIDGE, ST. LOUIS, MO.

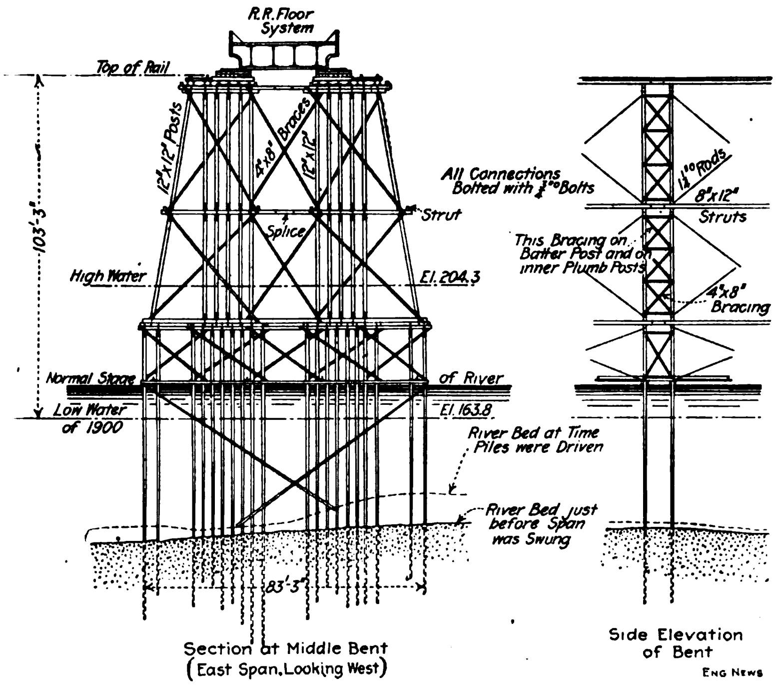

FIG. 10. CROSS-SECTION OF FALSEWORK

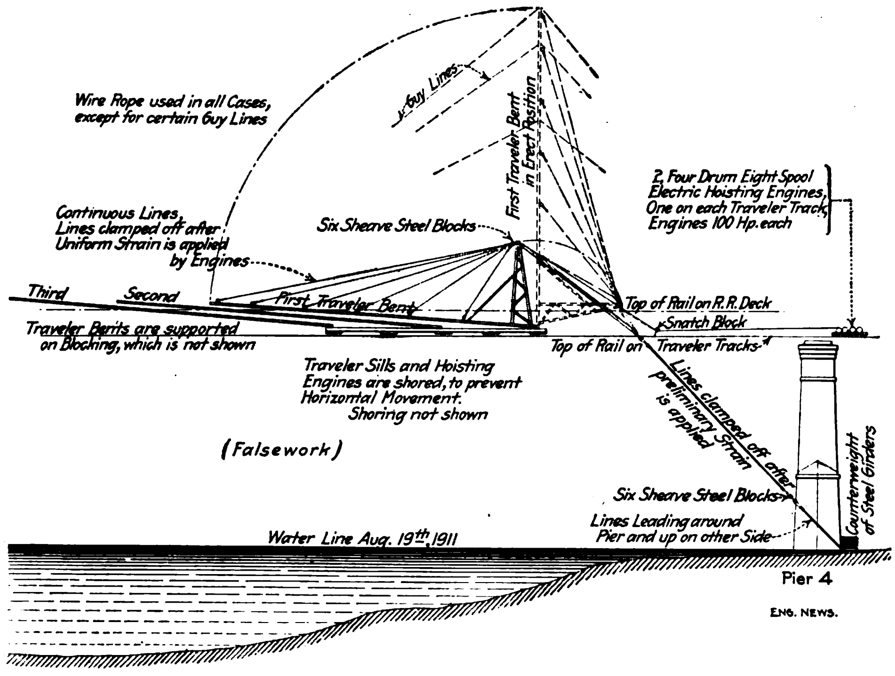

FIG. 11. METHOD OF ERECTING THE BENTS OF THE MAIN TRAVELER

TABLE III. MEASUREMENTS FOR THE ERECTION OF THE MUNICIPAL BRIDGE AT ST. LOUIS, MO.

Span	Plan Dimension*		Sag Measurement		Supported Measurement	
	Ft.	In.	Ft.	In.	Ft.	In.
East	672	6	672	6 5/16	672	6
Middle	677	0	676	10 3/16	676	10
West	672	6	672	7 1/4	...	..
Total	2022	0	2021	11 3/4	...	..

*Centers of piers.

In order to detect and keep track of any movement of the falsework, lines and levels were taken on same at frequent intervals. The center of each bent was established with a transit, shortly after the bent was placed in position, and these centers were referred to the bridge tangent or center line of bridge at least once a week, and daily when occasion demanded it. Any movement of the falsework, either up or down stream could thus be detected. At the same time levels were run on the ends of the railway-floor beams, in order to detect any settlement which might occur. This movement might be caused by the force of the current on the bents, or by the scouring of the river bed.

The bed of the Mississippi is composed of fine sand and silt, which is constantly shifting, due to the action of the current. The piles of the falsework were driven as deep into the river bed as circumstances would permit, but there was always danger that they might be undermined and washed out by the action of the current, which at this point sometimes reaches a velocity of 8 m.p.h. In order to guard against such a disaster, soundings were taken at least once a week (and daily in the east span) during periods of comparatively high water. These soundings were taken at the two ends and middle of each bent; they were plotted on a tracing which shows a cross-section at each bent, the position of the river bed and the penetration of each pile at the time of driving.

The penetration of any pile at any particular time was thus shown graphically, as well as the fill or scour at any bent since the preceding soundings were made. It was not at all unusual to find a fill or scour of 5 or 6 ft. within 24 hours. These soundings were usually made with an ordinary sounding line and lead. But during a rise of the river, when the depth in the east span exceeded 60 ft. at some points, this method was found to be inadequate, owing to the swiftness of the current. In place of the sounding line, an annealed wire was then used. This wire was wound on a reel and had markers at 5-ft. intervals. A piece of wrought-iron pipe filled with lead and weighing about 30 lb. was used as a weight. This apparatus required two or more men to handle it, but gave reliable results. Much trouble was experienced from the line or weight fouling on submerged drift or on the submarine bracing.

During the erection of the east span and after the middle panel was erected, the river began to rise, bringing down large quantities of drift, ranging in size from brush to logs 2 ft. or more in diameter and 50 ft. or so in length. This drift lodged against the falsework and accumulated in spite of the effects of the river crew to dislodge it. The force of men employed on this work was then increased and night and day shifts were employed. The larger snags were handled by means of a floating derrick and by runner lines leading from the pile-driver barges and from the "mule" on top of the falsework. The accumulated mass of drift was gradually disposed of and the new drift was kept under control. The river meanwhile continued to rise until a stage of 19 ft. was reached. Daily soundings showed that the deep water was gradually shifting toward the west. The river bed in the west half of the east span and for about 100 ft. west of Pier III scoured to such an extent that some of the shorter piles worked loose and washed out. The bents were temporarily braced with timber-sash braces until more piles could be driven.

The vibration of the falsework at this time was very marked. The tops of some of the bents near Pier III were pushed

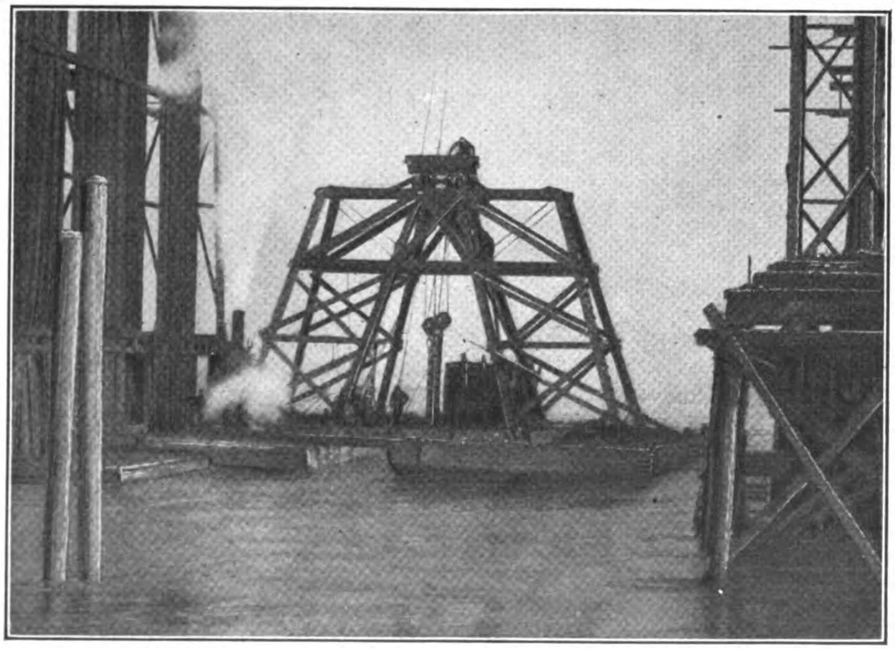

FIG. 12. PILE-PULLING BOAT USED IN REMOVING THE FALSEWORK

downstream over a foot by the pressure of the current. In order to stop the scouring of the river bed and prevent the possible loss of the falsework and partially erected span, rip-rap and sacks of sand were then dumped between the two rows of piles forming the bent. This material was wheeled from barges and dumped near the upstream side of the falsework, with the expectation that it would reach the bottom at or near the downstream side of same. It was found by tests that single sacks would not come to rest on the river bed within a reasonable distance, but would roll down stream almost indefinitely. Several sacks were, therefore, tied together and dumped at the same time. The rock was thrown in loose. In all, about a dozen barge loads of rip-rap and 7000 or 8000 sacks of sand were used. In spite of this, the scour continued for some time, and was barely held in check until a fortunate fall of the river relieved the situation.

During the first part of this period of high water, the east half of the span was being erected. This part of the work was completed and bolted up, at about the time the crest of the rise was reached. In view of the condition of the west half of the falsework, it was not thought safe to erect the remainder of the span until the water fell sufficiently to allow additional piles to be driven at the weak points and the falsework generally reinforced. As the water fell, the falsework came partly back to proper line. The railway-floor system was then jacked back the remainder of the way, so as to be in the proper position, and erection was resumed after a delay of about two weeks. No trouble was experienced in completing the span, and the last pin of the east span was driven on Oct. 26.

The work of lowering the camber blocking was immediately begun, and continued for several days. The blocking was bored out by means of pneumatic boring machines and split out by chisel bars and sledges. The blocking at the sub-panel points was first lowered, then the No. 2 and No. 4 points at the west end of the span were let down, so as to hold the fixed shoes in position. The remainder of the blocking was then lowered, beginning at the east, so as to cause the camber movement to take place in that direction.

The segmental expansion rollers which are at the east end of each span were adjusted just before the span was lowered onto them. These rollers were adjusted to stand vertically under dead load at normal temperature, 62° F. Owing to the great weight of the span, some of the camber blocking was exceedingly difficult to remove, and heavy pressures were thrown on some of the last points to be lowered. As a result of this pressure, the bottom lateral plates at these points became badly dished and were straightened later with considerable difficulty, by means of jacks and wedges. In view of this fact, a different arrangement of the camber blocking was used at the secondary points of the next span and sand jacks were placed under the principal points so as to control the lowering of the span more readily.

As soon as the span was swung, the work of removing the falsework was started. The timber bents were disconnected and lowered into the water in quarter sections, by a stationary hoisting engine on the railway deck of the bridge. These sections were then towed downstream and beached just south of the Pittsburg dike, where they were left until used again in the west span. For pulling the piles, a heavy timber tower formed of two bents battered in both directions, was constructed on two barges, as shown in Fig. 12. These barges were placed about 10 ft. apart in the clear so as to straddle the double line of piles forming the bent. Two sets of falls, composed of 4-sheave steel blocks, reeved with wire rope, were used and attached to the pile by means of chains. After the pile was lifted about 20 ft. by the main falls, they were disconnected and the pile lifted clear by means of a runner passing through a snatch block attached to the lower chord of the span. From 30 to 45 piles per day of 9 hours were pulled with this rig.

After the piles were pulled, the channel was dragged to be sure that no obstructions were left that might interfere with navigation. For this purpose two pile drivers were lashed together, with space between for a tug. In the leads of each driver, a pile was suspended and a heavy timber was bolted to the bottom of each pile, thus connecting them to each other. The piles with the horizontal connecting timber were then lowered to the desired depth below the water surface, and the tug towed the drivers up and down stream over the site of each bent. Any broken piles found were removed by dynamite. The work of dragging the channel was done in the presence of a representative of the local office of the War Department.

The work of erecting the west and last span was rendered difficult and dangerous by the cold weather and the heavy ice in the river.

In order to protect the west span falsework from floating ice, clumps of three piles each were driven about 50 ft. c. to c. arranged on a line running from the nose of Pier II upstream and toward the west bank of the river. This line of pile clusters made an angle of about 60° with the center line of the bridge. A boom, composed of two piles lashed side by side was attached to the pile clusters by means of wire ropes, so that the boom could rise or fall with the river. The first floating ice appeared in the river late in November, but was not heavy enough to cause trouble. As the weather grew colder, the water between the boom and the falsework froze over, and a belt of ice formed outside of the boom. This served to deflect the floating ice into the middle span, through which it passed without doing any harm.

Fig. 13. Completed East Spans of Municipal Bridge, at St. Louis
(From a photograph taken about the middle of January.)

In order to provide for the possibility of the falsework between the pier and the shore being swept out, bent No. 6 west was made sufficiently strong to carry the weight of the span from Pier II to this bent. The dead load stresses in the trusses were computed, assuming the span to be supported on Pier II and Bent No. 6 west. Under these conditions, members U6-M7 east, composed of eye-bars, were in compression. The eye-bars were accordingly stiffened by means of timbers bolted between them, and the members were braced together by diagonal rods and transverse timber struts. As soon as the trusses and bracing were completed to panel point No. 6 west, the camber blocking at the sub-panel points 1, 3, 5, 7, etc., was removed, and the weight of the span carried on the sand jacks at the principal panel points 2, 4, 6, 8, etc. With this arrangement, in case

TABLE IV. PROGRESS RECORD OF ERECTION OF THE RIVER SPANS OF THE MUNICIPAL BRIDGE AT ST. LOUIS; 1911-'12

	East span	Middle span	West span
Began pile driving	May 9, 1911	July 18, 1911	Nov. 23, 1911
Finished pile driving	June 22, 1911	Aug. 5, 1911	Dec. 31, 1911
Finished falsework	Sept. 13, 1911	Oct. 26, 1911	Jan. 20, 1911
Began erecting trusses	Sept. 11, 1911	Oct. 28, 1911	Dec. 20, 1911
Finished erecting trusses and bracing	Oct. 27, 1911	Dec. 6, 1911	Jan. 24, 1912
Channel cleared	Nov. 21, 1911		

of any danger to the falsework in the river the span could be swung between Pier II and bent No. 6 west in a short time. Bent No. 6 west was on the shore above any ordinary stage of the river.

Early in January very cold weather occurred, which lasted about two weeks. During this time the river at the bridge site froze entirely over. This cold spell was followed by a thaw and on Jan. 20 the ice immediately below the bridge went out and that above moved sufficiently to destroy the fender, break about twenty piles of the west-span falsework; and take out four bents of piles just west of Pier III, which had not been pulled because of the ice. After this the ice held for several days.

The sand jacks at points No. 2, at the east end of the span were lowered, leaving points 1, 2 and 3 clear of the blocking; the falsework near Pier II was unbolted and work was pushed on the steelwork for the west end of the span, which at that time was incomplete from panel point No. 6 west to Pier I.

The last pin was driven a few minutes before midnight of Jan. 23, and the last of the bracing for the truss steel was placed the following morning, Jan. 24. The remainder of the camber blocking was then removed, the sand jacks lowered and the span finally swung on Jan. 25, shortly before midnight. On the following day, Jan. 26, the ice was broken up by the tugs in the harbor, and the greater part of it between the Municipal and Eads bridges went out, passing between the east and middle spans, without doing any damage worth mentioning.

The floe above the west span fortunately pivoted on Pier II and swung over against the west bank, where it remained.

The progress of the work on the span is shown in Table IV. It is to be remembered that about two weeks' time was lost in the erection of the steelwork of the east span, and of the falsework of the middle span, due to the rise of the river, mentioned above. The east span has been cleared of falsework, leaving a clear channel. The middle span is practically cleared, and the work of removing the falsework of the west span has begun. The east and middle spans are being riveted, and the highway-floor system of these two spans is nearly all in place.

The falsework, hoisting trestles and travelers were designed and built by the American Bridge Co., the superstructure contractor, which also devised the general scheme of erection and the erection methods. This company was represented in the field by W. H. Radcliffe, erecting engineer, and Chas. Webster, general foreman.

The bridge and approaches were designed by and are under the supervision of Boller & Hodge (now Boller, Hodge & Baird), consulting engineers, of New York. Local matters are looked after by Brenneke & Fay, resident engineers, of St. Louis, while the writer is engineer-in-charge, representing the last-named firm.

A Fire in a Concrete Building under Constuction

The accompanying halftone is a view of the second floor of the Swift-Canadian Co.'s building at Fort William, Ont., taken after a fire, on Dec. 15, 1911, that completely burned out the centering and falsework supporting the second and third floors of the building, then under construction. The concreting was being carried on through the very cold weather common in that part of Canada in December and the usual precautions for heating the interior of the building and the concrete were observed. On Dec. 7 the columns supporting the top floor, shown in the view, and the top floor slab were cast, this being the last concrete work to be done. Salamanders were kept lighted in the two floors thereafter to preserve a high temperature for the setting concrete, and on Dec. 15, eight days after the last concrete was laid, a pot of pitch caught fire from one of these salamanders and the whole timbering was soon destroyed.

A FLOOR OF A CONCRETE BUILDING AFTER A FIRE WHICH BURNED OUT ALL OF THE FALSEWORK

The concrete was damaged only by a slight surface spalling and the slabs and columns stood up under their load without any apparent crack or sag, although the concrete had had only about eight days' set in very cold weather.

The building was designed by C. A. P. Turner, using the Turner system of "mushroom" flat-slab construction, and was built by J. & W. A. Elliott Co.

A Radical View of the Sewage Works question was expressed in a paper recently read before the Manchester section of the Society of Chemical Industry (England) by Dr. Grossman, of Manchester. After speaking of the enormous (theoretical) value of the manurial constituents of sewage works, which he claims total about $200,000,000 (presumably for all of Great Britain), the author of the paper expresses the belief that sewage sludge, unless disposed of by "sound hygienic" methods, is a source of danger to the community. He also said that no process of sludge disposal can be considered satisfactory which does not make it possible to return to the soil the manurial constituents of the original sewage in a thoroughly sterilized condition. Sludge cannot be used as a valuable fertilizer unless it is free from the greasy matter which it contains, for greasy matter prevents the assimilation by plants of the manurial constituents of the sewage sludge.

Problems Overcome in Building Approach to St. Louis Municipal Bridge

Railroad Tracks Beneath the Structure Were Continually Occupied With Cars, Which Taxed the Ingenuity of the Surveyors—Complex Steel Construction Necessary

By M. H. Doyne
Chief Engineer, C. E. Smith & Company, St. Louis, Mo.

The St. Louis municipal bridge is notable as an effort to regulate railway traffic in the city's interests. For many years all railway movements across the Mississippi River at this point have been over two bridges controlled by the Terminal Railroad Association of St. Louis, which thus controls all transfer movements between the numerous trunk lines on the east and west sides of the river. In order to provide competitive communication, the city planned a municipally owned bridge having both railway and highway facilities. But although the roadway of this bridge was opened for traffic in 1917, the track deck has never been used, since the city has been unable to get the railways to agree to relinquish or relieve the older facilities of the Eads bridge and the Merchants bridge.

The river spans of the municipal bridge were completed in 1912 and the west railway approach in 1913, but it was not until 1917 that the highway approaches and the eastern railway approach were finished. If the necessary traffic arrangements were made, the west approach would give access to the union station, the freight stations and the industrial district of Mill Creek Valley. But all these western connections are operated by the Terminal Railway Association, whose lines on the east side of the river have no direct connection with the bridge approach.

A southern approach to the west end of the bridge is the latest development, as described in the accompanying article. Until additional approaches are made on the east side to enable the Terminal Railroad Association to reach the bridge, the only railroad traffic expected to cross the municipal bridge is the freight and coal that moves between various trunk lines by way of the belt line of the Alton & Southern Railway on the east side and the Manufacturers Railway (a local terminal line) and the St. Louis Transfer Railway on the west side. This last-named road is a riverfront line owned by the city and operated by the Terminal Railroad Association, but under the terms of an ordinance of 1917 it may be used by any railway. Both the Alton & Southern Railway and the Manufacturers Railway have applied to the city for permission to operate over the Transfer Railway track for about a mile between the former road and the new bridge approach. Besides this, the construction of additional railway approaches on the east and an improved connection with the Mill Creek Valley district on the west are now under consideration by the city authorities and the Terminal Railroad Association.

—Editor.

Many interesting and complicated problems entered into the design and construction of the new southern approach to the railway deck of the municipal bridge across the Mississippi River at St. Louis, as the approach passes through a closely built-up industrial district. This approach, completed recently and consisting mainly of a steel viaduct incline, connects the west end of the city's bridge with the Manufacturers Railway (a local line), the St. Louis Transfer Railway (a riverfront line owned by the city and operated by the Terminal Railroad Association) and also with the Missouri Pacific Railroad in its Lesperance St. yard. Fig. 1 is a plan of the bridge and its several approaches, while viaduct construction on the curved connection to the bridge is shown in Fig. 2.

Starting at the pier on the west bank, this southern approach swings to the left for 1,600 ft.; thence it continues for about 110 ft. on tangent and then along a 6½ deg. curve to the right for about 270 ft., beyond which it is on tangent to the foot of the approach incline. A compound curve at the upper end (Fig. 3) begins at 12 deg. and changes to 8 deg. and then to 5 deg. The 12 deg. curve was fixed by limiting side clearances and by provisions made in the existing steel of the west approach for this connection. Industrial plants, railroad tracks and other physical obstacles governed the general alignment of the remainder of the approach. Its total length is 4,700 ft., with a ruling grade of 2.1 per cent on the tangent, this grade being controlled by the connection to the yard tracks of the Missouri Pacific Railroad.

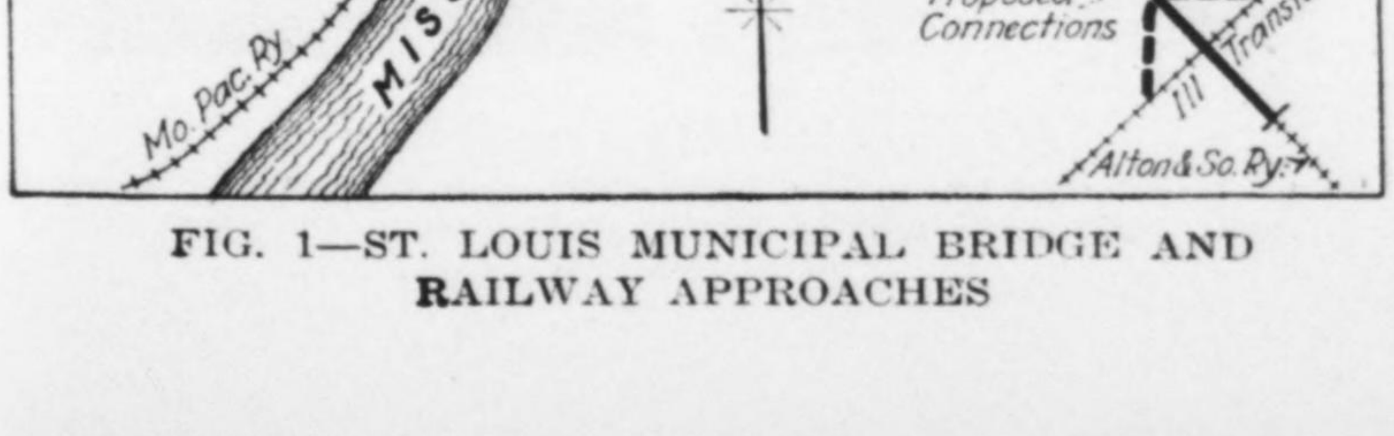

FIG. 1—ST. LOUIS MUNICIPAL BRIDGE AND RAILWAY APPROACHES

Difficult Survey Work—Much preliminary surveying was necessary before the final alignment was selected. Arrangement of supports to clear buildings and private property was a controlling element in the ultimate location, as may be seen from Fig. 3. Staking out the center line presented many surveying problems and taxed the ingenuity of the field party. On account of the freight houses and tracks constantly occupied with cars, and also on account of the many buildings and other obstacles, very few points could be located directly by running out the center line. It was necessary to set the points on the curved portion of the alignment from offset lines. Many small auxiliary traverses had to be run in order to check the accuracy of the work and to get the correct relationship between the various portions of the structure where direct measurements could not be made. This extra care in locating the supports was fully justified by results, as the steelwork fitted in place without any difficulty de-

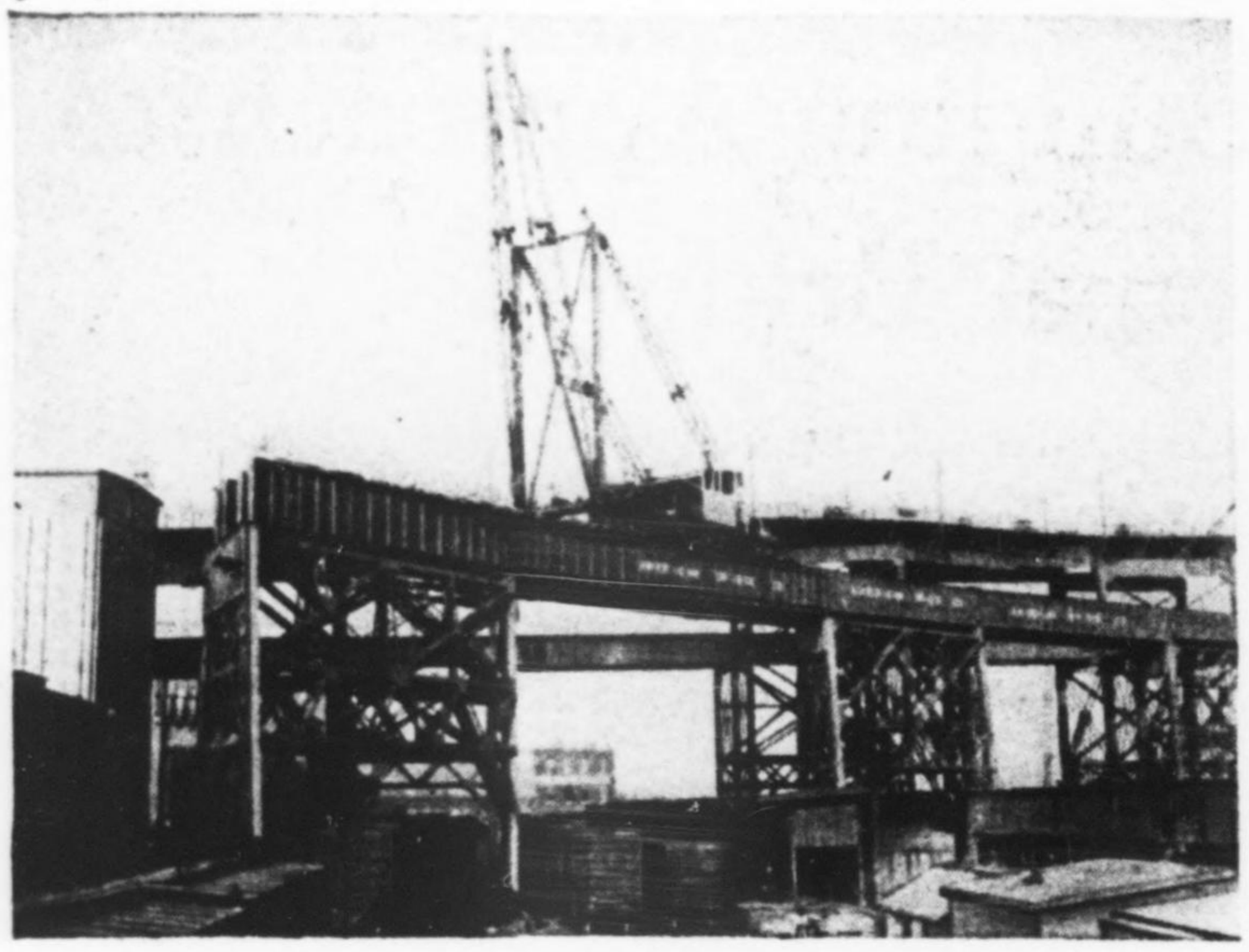

FIG. 2—NEW SOUTHERN APPROACH TO ST. LOUIS MUNICIPAL BRIDGE
Bridge in background has railway on lower deck and highway on upper deck.

spite the badly skewed bents and towers. Most of the approach was on property of the Missouri Pacific Railroad and considerable rearrangement of tracks was necessary.

Foundations and Concrete Work—Except for the interference due to railroad traffic, no unusual difficulties were encountered in the construction of the foundations. All column footings were supported on reinforced-concrete piles with a penetration of 25 to 30 ft. Three special bents 50 ft. high were constructed of reinforced concrete on account of their location in a large coal storage pile. One of these bents, with its structural steel core, is shown in Fig. 4. About 600 ft. of embankment is retained on one side by a crib wall built of precast reinforced-concrete units, this wall having a height of 3 to 20 ft. above the ground and extending about 3 ft. below the surface. Its toe is supported on a concrete block, no piling being used for the wall. The wall units and piles were cast at the site by the foundation contractor. Concrete mixed at a central plant and trucked to the site was used for all column footings and for the abutment. Concrete for the wall units, piles and concrete bents was supplied by the contractor's mixing plant at the pile-casting yard.

Special Steel Construction—The northern half of the structure includes deck-plate girders, deck trusses and through-plate girders. Its spans vary from 25 ft. to 117 ft. and are all skewed. Several bents with pin connections at top and bottom had to be used because of inability to get sufficient tower bracing at critical points, as shown by Fig. 5. In the right-hand view, the bent (No. 25 in Fig. 3) supports four girders at the north side and two through-girders at the south side. Limited side clearance made it necessary to cantilever the ends of the cross-girder to carry the through-girders. The southern end of the structure (on the tangent) adapted itself to standard viaduct construction with 70-ft. spans and 30-ft. towers.

An example of one of the special problems encountered is illustrated by the bent, No. 21, in the upper view of Fig. 6, which carries a 100-ft. through span and a 68-ft. deck span. Because of the surface tracks on which a locomotive crane must operate with top of boom 42 ft. above the ground, the columns had to be spread 40 ft. c. to c. With the very tall columns, it was necessary to brace the bent in the manner shown to provide for both lateral and longitudinal stability against traction and centrifugal forces in addition to wind and sway. The next bent, No. 22, also shown in the upper view of Fig. 6, is a badly skewed A-frame to permit a roadway to pass under the structure.

Immediately south is an almost square tower, shown by the lower view in Fig. 6, consisting of two bents (23 and 24 in Fig. 3) spaced 55 ft. c. to c. and having their columns 57.5 ft. c. to c. These bents span four busy tracks of the Missouri Pacific Railroad. The tower forms a table on which rest the $61\frac{1}{2}$-ft. girders that carry the deck, these girders lying diagonally across the tower and the span being partly on tangent and partly on curve. A deck-truss span (Fig. 7) was found advisable in passing diagonally over a foundry building in which no supports could be placed. At the north end, the span is supported on a pin-connected bent at the curb line. One truss is 10 ft. longer than the other. Because of limited headroom, the depth of the trusses could not exceed

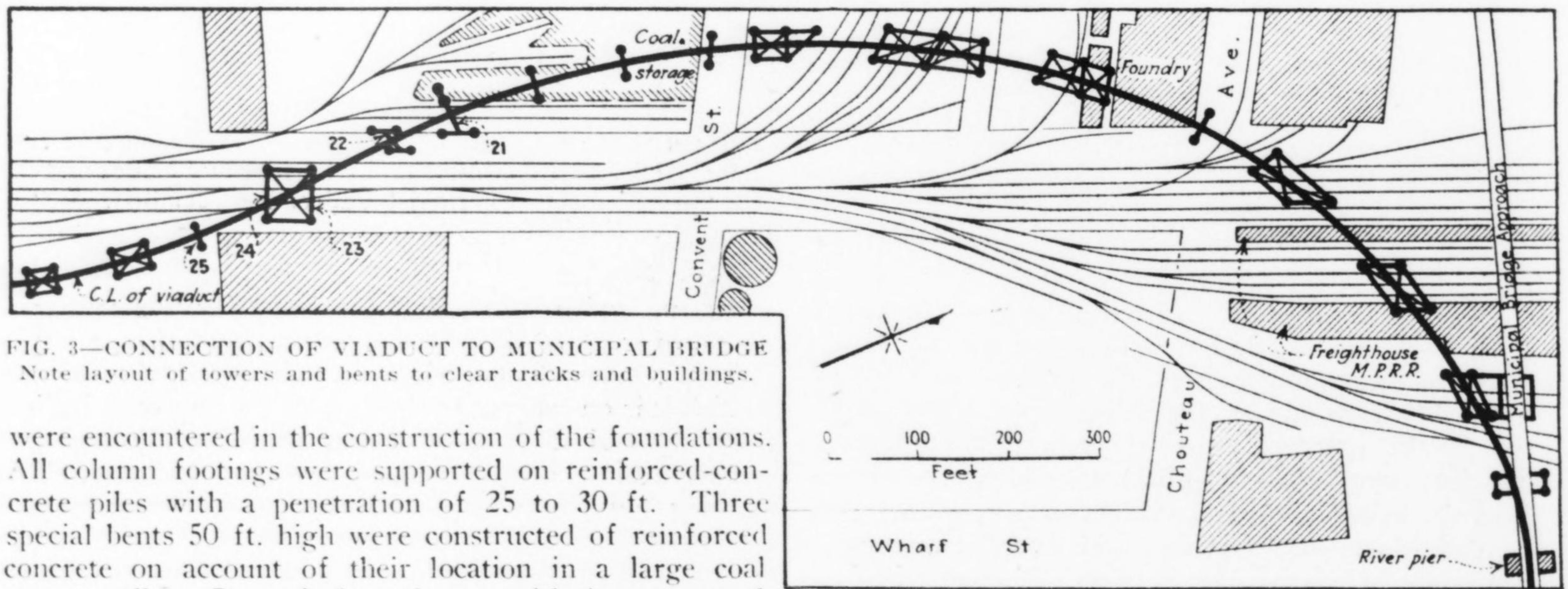

FIG. 3—CONNECTION OF VIADUCT TO MUNICIPAL BRIDGE
Note layout of towers and bents to clear tracks and buildings.

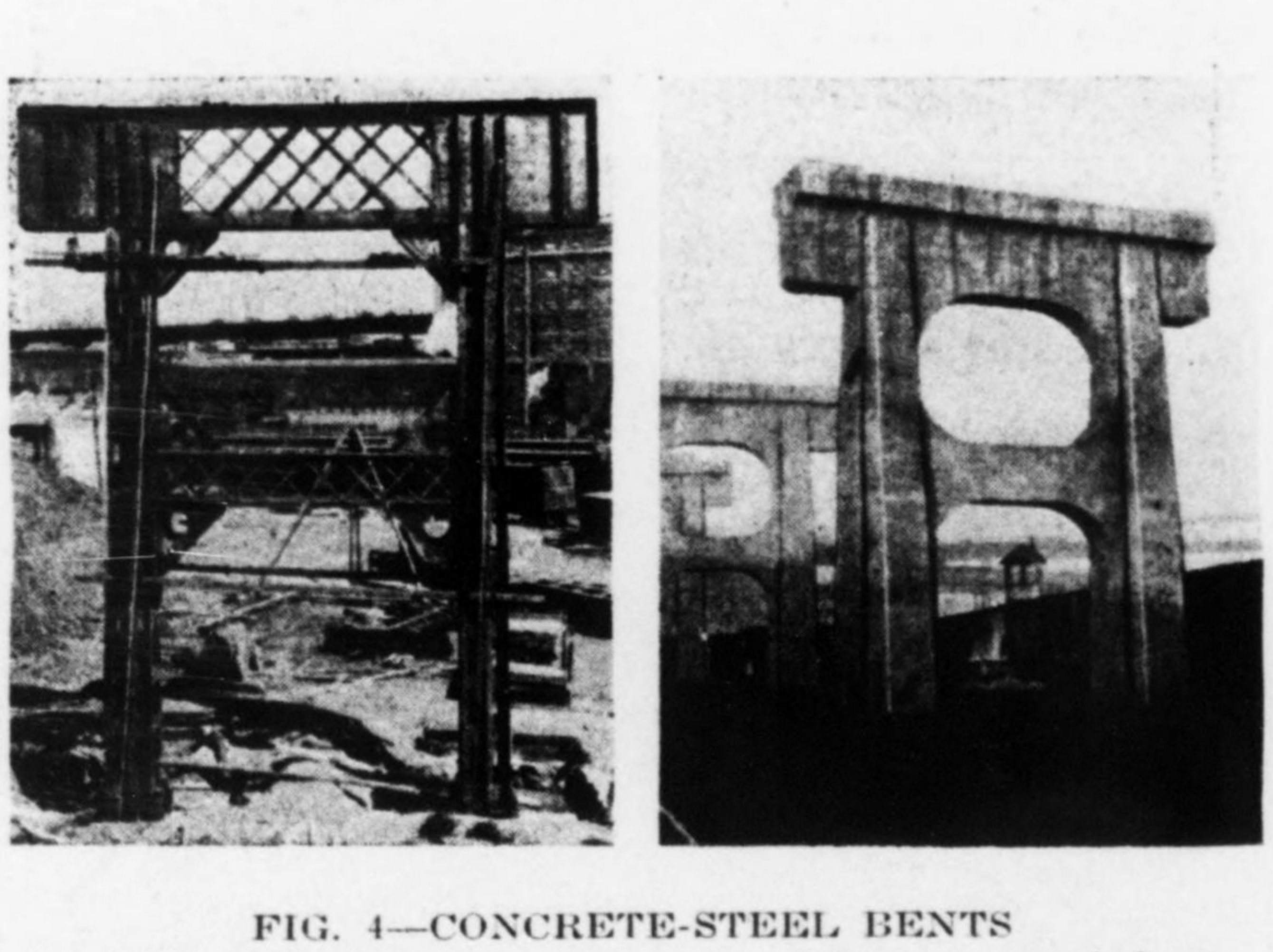

FIG. 4—CONCRETE-STEEL BENTS
At left—steel frame or core. At right—concreted bent. Three such bents will be partly embedded in the stock pile of a coal yard.

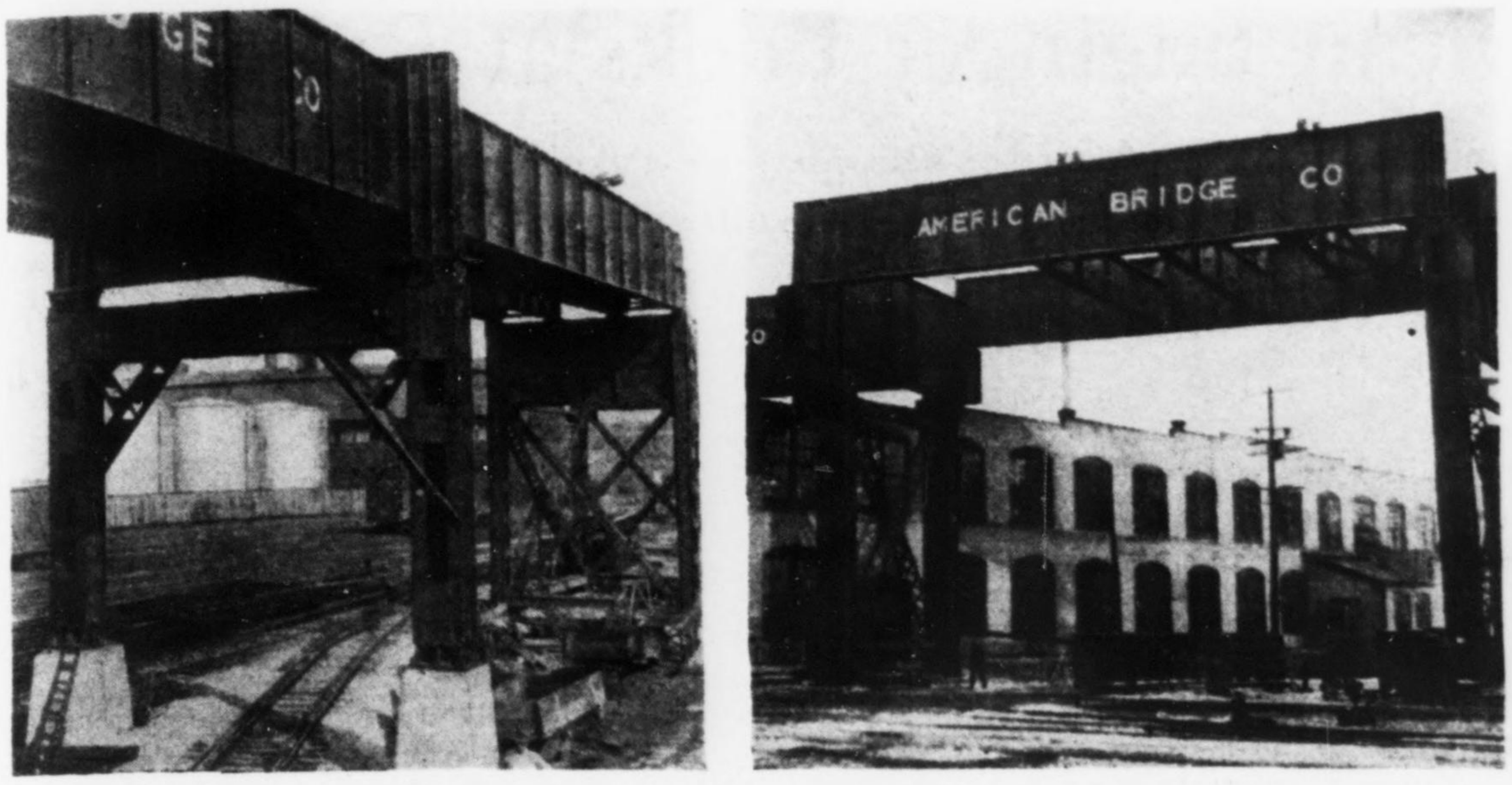

FIG. 5—PIN-CONNECTED VIADUCT BENTS
Note cantilever ends of cross-girders.

15½ ft. Temporary brackets on the columns, as shown, were used to assist the steel erection.

Treated Timber Deck—Tracks are laid with 100-lb. rails on open-deck construction consisting of ties and timbers of longleaf Southern yellow pine treated with mineralith or Wolman salts. About 1,000,000 ft. of lumber was required for the deck, walkways and hand railing. As the specifications required all timbers to be framed before treatment, framing details were prepared for all timbers along the tangent. But to follow this method for the curved portion of the approach was considered unwise, on account of the maze of detail due to curvatures, skews and grades.

To avoid the great expense of shipping those timbers to the job, framing them there, shipping them 125 miles to the treating plant and then returning them to the job, it was decided to reproduce the top flanges of the stringers for each span at the treating plant. This was done with timbers, two adjacent spans being laid out at one time to proper line and grade, making the necessary provisions for the variations in elevations of girder flanges due to variation in length of cover plates. Then the timber decking was laid out according to the track plans and was marked, framed, stamped for identification and treated. When these timbers arrived at the site they were assembled upon their respective spans in the order indicated by the numbers stamped upon their ends at the timber-treating plant. This method of determining the proper framing before treatment produced very satisfactory results, very little trimming being necessary in the field to make the timbers fit the steelwork.

Contractors and Cost—Foundation work and the approach fill were let to the Dunham Construction Company, St. Louis; steel fabrication to the American Bridge Company, and its erection to the Ben Hur Erection Company, St. Louis. The deck and track were installed by the Frazier-Davis Construction Company, St. Louis. A summary of cost is as follows: Foundations and filled approach, $162,000; structural steel erected, $720,000; deck and track, $190,000; rearrangement of surface tracks, $160,000; total construction, $1,232,000; right-of-way, $158,000; grand total, $1,390,000. Other incidental costs and engineering fees made the total cost of the project $1,500,000. Changes in surface tracks were carried out by the Missouri Pacific Railroad with its own forces at such times as the progress of work on the viaduct required.

Engineers—This project was handled under the direction of E. R. Kinsey, president of the Board of Public Service, St. Louis, with C. E. Smith, then head of C. E. Smith & Company (and now vice-president of the New York, New Haven & Hartford Railroad), as consulting engineer. The work was carried out under the personal supervision of the writer, with S. B. May in charge of surveys and design and F. R. Nohl resident engineer on construction.

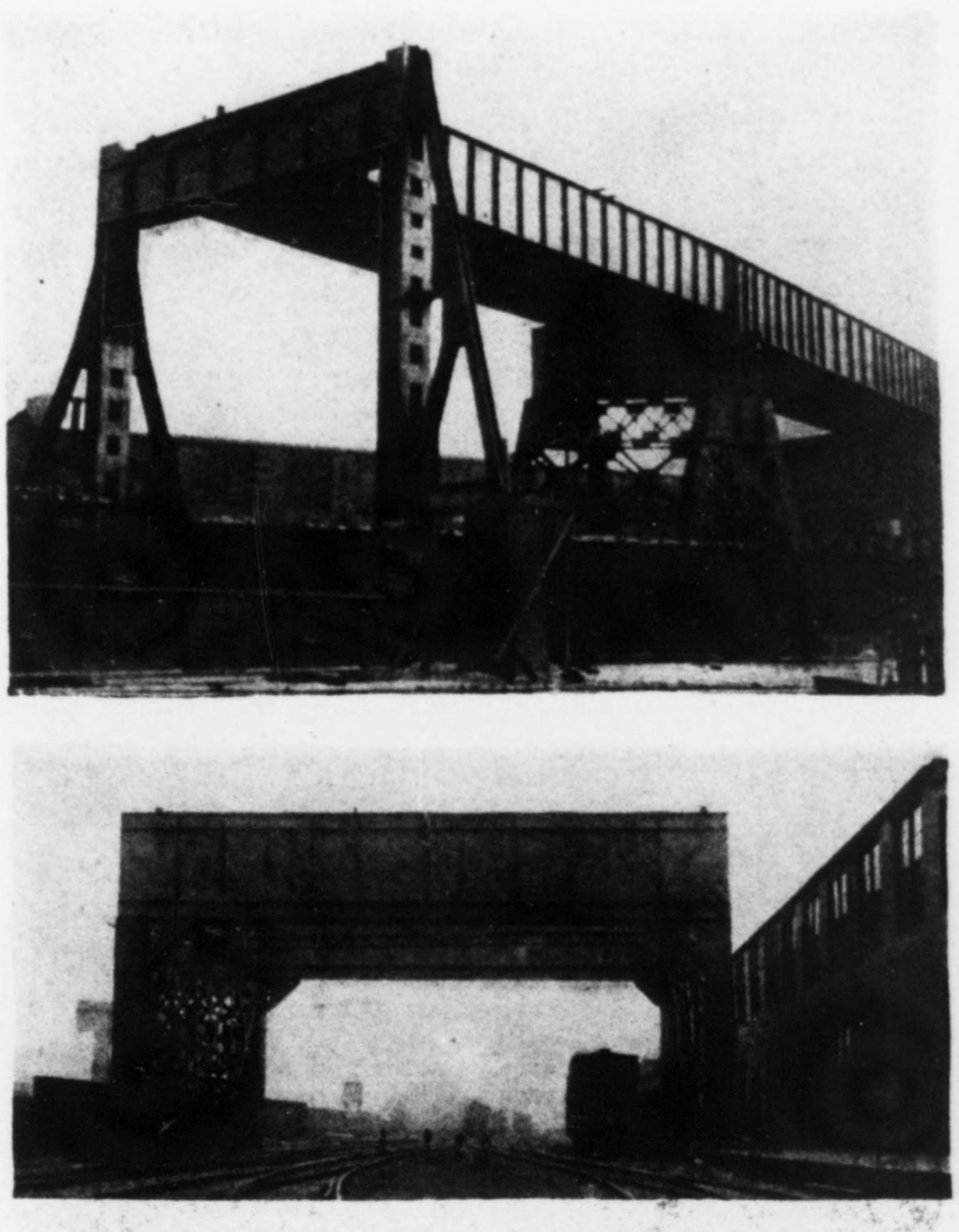

FIG. 6—SPECIAL VIADUCT CONSTRUCTION
Above—Bent at left has farther column braced longitudinally and bent at right is braced laterally; the next bent is skewed and two A-frames carry the cross-girder. Below—Two bents form square tower, across which the track stringers run diagonally.

FIG. 7—DECK TRUSS SPAN
Brackets on bent at left are for erection purposes.