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Engineering News-Record

Fort Snelling-Mendota Bridge Across the Minnesota River

..."And Far Away": The observations of a civil engineer's wife— Concrete Arch Bridge over the Minnesota River—Los Angeles Plant Disposes of Non-Combustible Rubbish—Waterproofing the Upstream Face of the Mountain Dell Dam

Long Concrete-Arch Road Bridge Over Minnesota River

Thirteen Two-Rib Spans Carry Highway 120 Ft. Above Water—Steel Centers—Caissons Sunk 55 to 90 Ft. by Dredging—Grouting Foundation — Design and Construction Features

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THE Fort Snelling-Mendota bridge and the new highways which connect it with important centers and with the main trunk highways of Minnesota constitute a major highway development and one of the most important links in a system of paved highways having Minneapolis and St. Paul as its center. This bridge shortens the distance between Minneapolis and points south and east of Minneapolis by about five miles and correspondingly shortens the distance for through traffic on some of the heavily traveled trunk highways. By avoiding congested districts it reduces running time about half an hour.

This bridge was financed by Hennepin County. Before engaging to undertake the engineering of this project for the county, the writer stipulated that the county board should agree to keep politics and individual interests out of it and allow the engineer a free hand to secure the desired results at the least cost and with the maximum efficiency. It is to the credit of the board that it quickly agreed to that program.

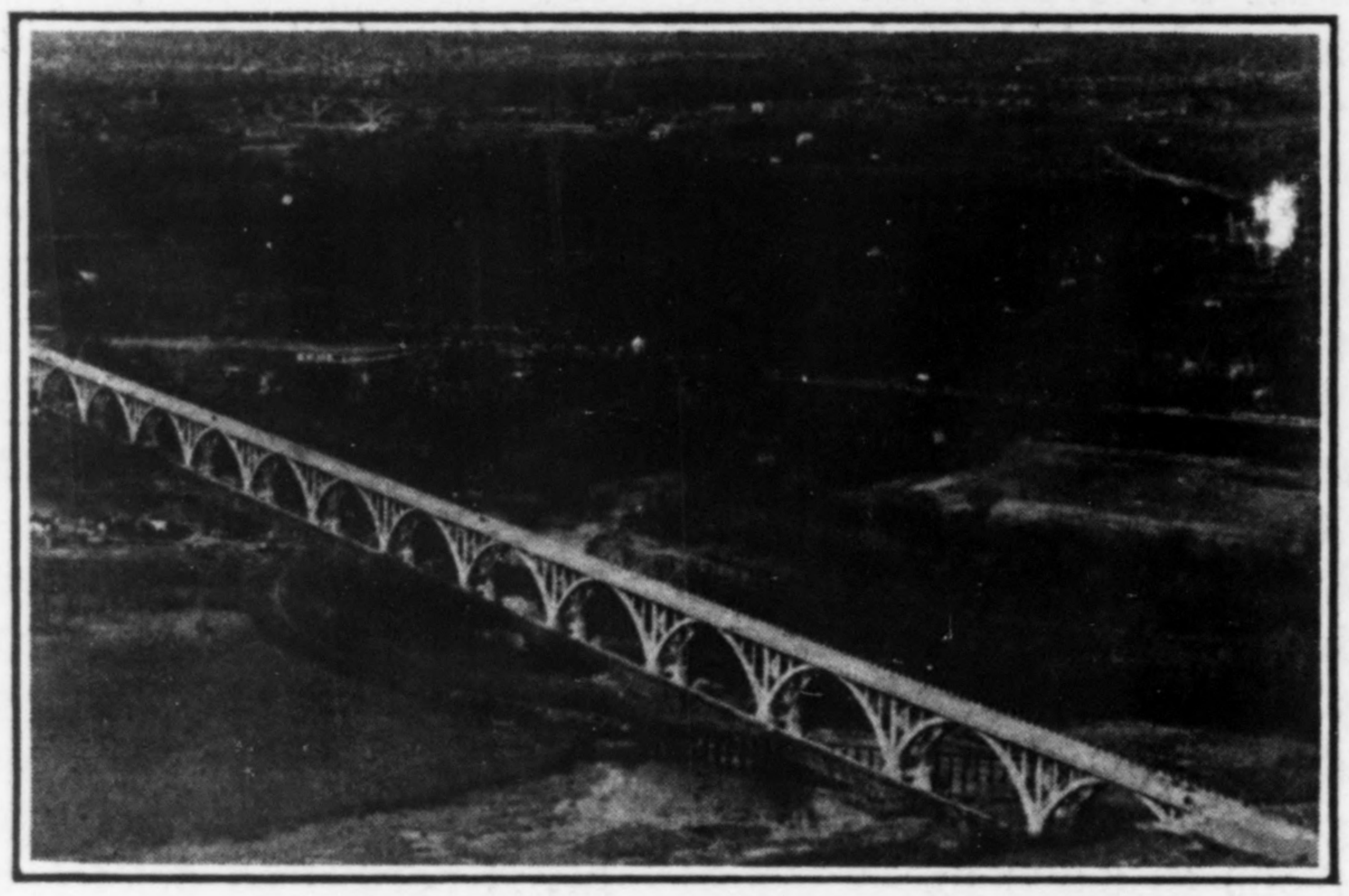


FIG. 1—FORT SNELLING-MENDOTA BRIDGE

Fig. 1 is a general view of the completed bridge and Fig. 2 shows the completed ribs of one span on the steel centers. Fig. 3 shows further details of the completed structure.

Geological and Topographical Conditions—According to the geologists, the Minnesota River meanders through a gorge cut by a great glacial river, known as River Warren, of which the Mississippi River was a branch. The Falls of St. Anthony, at Minneapolis, were cut back along this river to the confluence of the Warren and the Mississippi, thence up the Mississippi to their present location and up River Warren about 2½ miles, leaving a gorge some 200 ft. deep. A later ice flow ground off the layer of shale which overlay the surrounding country rock and filled the gorge with glacial mud to a depth of 70 to 80 ft. The old gorge in the vicinity of Fort Snelling is from 4,000 to 5,000 ft. wide, while the main channel of the Minnesota River is 300 to 400 ft. wide and 10 to 40 ft. deep. On both sides of the channel are lakes and marshes. At times of extreme high water the low lands are covered with 4 to 6 ft. of water for practically the full width of the old gorge.

Test drilling showed that the foundation conditions in the gorge are substantially the same at all points below the old falls, namely, 70 to 80 ft. of mud over sandstone or limestone bedrock, with a few feet of sand and gravel on top of the bedrock in some places. At the mouth of the Minnesota this condition changes and more gravel and boulders are found. The banks of the old river rise abruptly on each side of the gorge. There is a capping of about 20 ft. of Trenton limestone on top of 160 to 170 ft. of soft St. Peter sandstone; below is hard Shakopee limestone. The sandstone becomes quite hard near the contact with the limestone and some of the sandstone remains in places overlying the limestone at the bottom of the old gorge. In excavating one caisson a section of a vertebra was brought up from 60 ft. down in the mud which was identified as that of a pre-glacial buffalo.

As the Minnesota River is considered by the War Department to be a navigable stream, the same clearance for navigation is required as on the Mississippi River. The Chicago, St. Paul, Minneapolis & Omaha line of the Chicago & Northwestern Ry. is at the foot of the bluff on the Mendota side of the river. The Chicago, Milwaukee & St. Paul R.R. crosses the Minnesota on a swing bridge and has another line on top of the bluff on the Mendota side. The Fort Snelling military reservation is on the Minneapolis side, and the War Department would only permit crossing the reservation with a road at certain points, complicating the bridge location problem.

Bridge Location and Type—Four locations were made for a low-level bridge with draw span and long grades on fills and trestles up the bluff on either side of the river, and two locations for a high-level bridge. It was desired to eliminate all grade crossings and also the draw span if possible. Due to the foundation conditions and other limiting factors it was found that while a high-level bridge would be somewhat more expensive in first cost, the lower upkeep and its greater value to the users of the highway by eliminating grades and curves and shortening distances made it the best investment for the county.

On the ngineer's recommendation, the county first adopted the high-level bridge on location No. 1, because the length of bridge was about 100 ft. less than on No. 2 and the bridge would cost $50,000 to $100,000 less. Serious complications, which seemed insurmountable, developed in securing right-of-way, and on the recommendation of the engineer the county board then adopted location No. 2, some 400 ft. upstream.

Four types of design were considered: (1) Reinforced-concrete rib arches on concrete piers with caisson foundations; (2) steel arches with concrete piers and caisson foundations; (3) steel deck trusses on concrete piers and caisson foundations; (4) steel deck trusses on steel towers with pile foundations. The estimated cost of the various designs was in the order

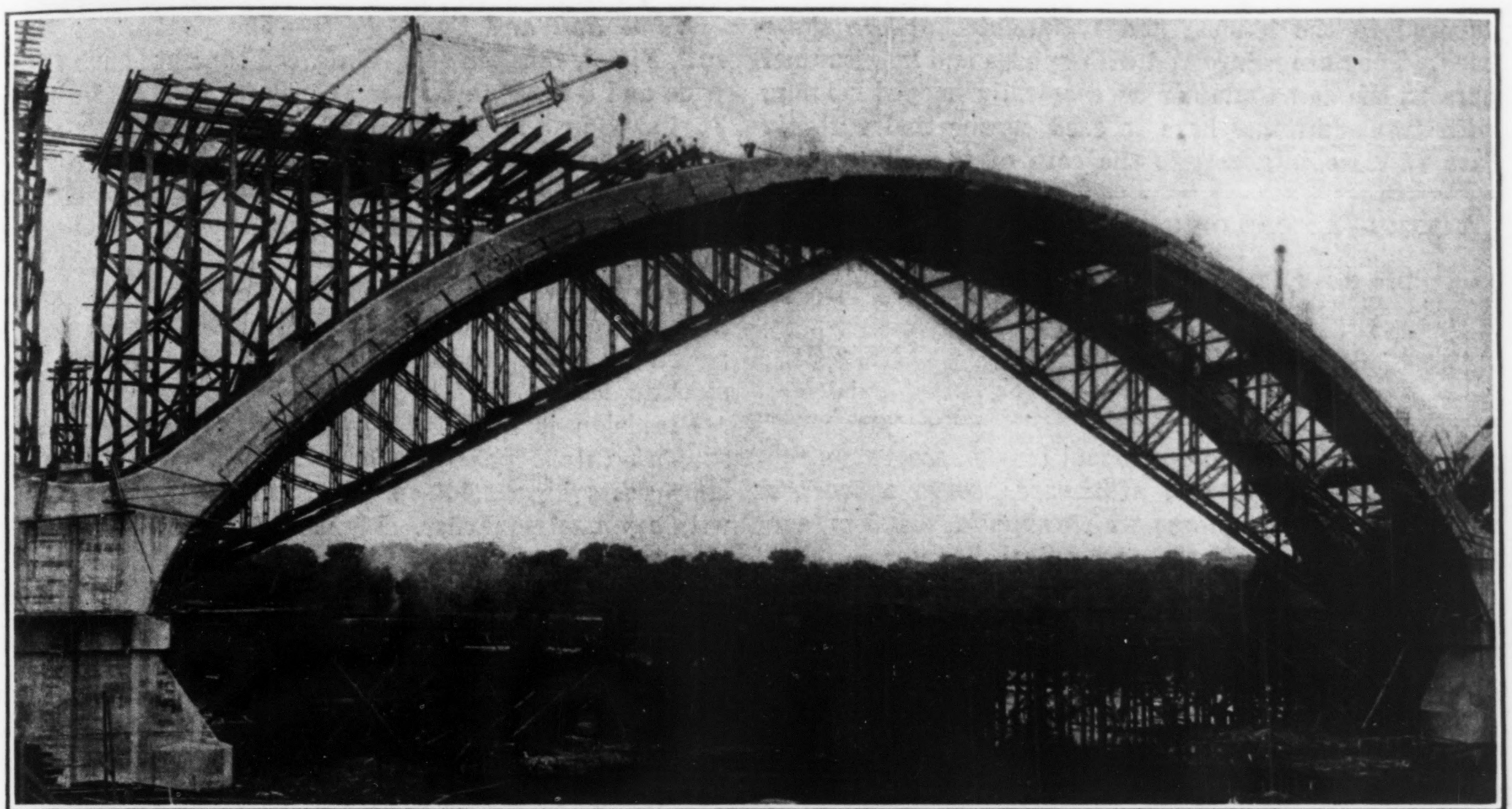


FIG. 2—COMPLETED ARCH RIBS ON STEEL CENTERS

given, type 1 being the most expensive. After going into the matter very fully the engineer recommended type 3, but because of the strong preference of the board for a concrete bridge he agreed to prepare working plans and specifications and to receive bids for types 1 and 3.

Bids were received in February, 1924. The low bid on the reinforced-concrete arch bridge, complete, was $1,870,000, with 30 months for construction. The lowest formal bid on the steel bridge complete with buckle plate floor, was $1,766,000; and 22 months time. An alternate bid on the steel design, with I-beam and concrete slab floor, was $1,713,807, with 28 months time, but this bid was informal and could not be considered.

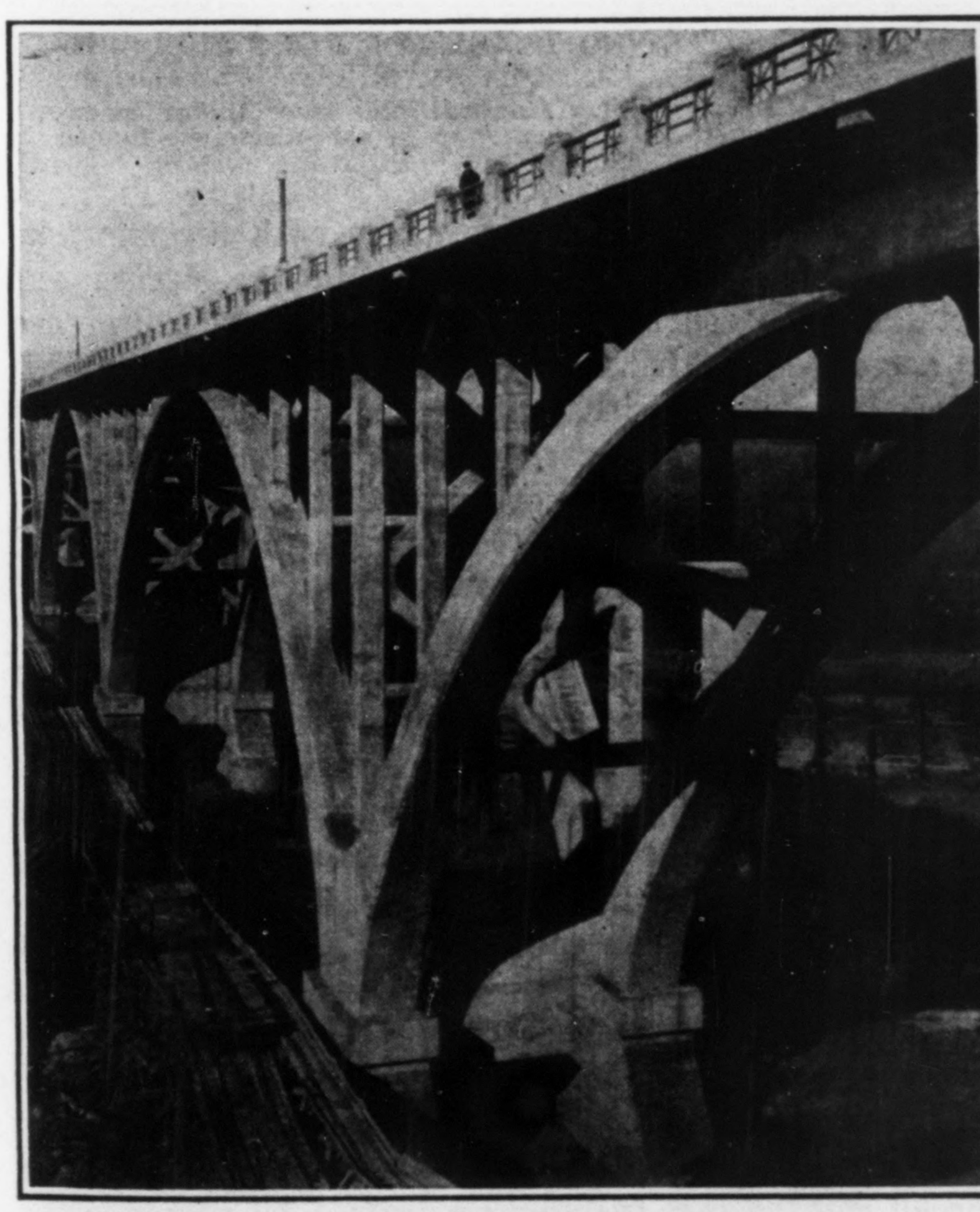


FIG. 3—PORTION OF FINISHED BRIDGE
Sidewalks cantilevered over arch ribs. Metal parapet between concrete posts. Construction trestle at left.

The engineer had estimated difference in cost between the steel bridge and reinforced-concrete bridge at approximately $250,000, but the only two bids for the steel bridge complete were disappointing, while the concrete bridge was preferred by the county board. After carefully weighing the various phases of the problem, the low bid on the concrete bridge was accepted. The contract was executed in February, 1924, and the date of completion was fixed at Sept. 26, 1926.

Description of Structure—The bridge is 4,066 ft. long between abutments, or 4,119 ft. including the end abutments. It has a roadway 45 ft. wide between steel-nosed curbs 11 in. high, with a 6-ft. sidewalk on each side, the width overall being 60 ft. 8 in. The roadway is paved for 41 ft. with 2 in. of asphaltic concrete, while concrete gutters 2 ft. wide, have 4-in. drains spaced 30 ft. 6 in. c. to c. Provision is made in the floor for a future double-track street car line. The roadway is designed to carry 25-ton tractors and the sidewalk for 100-lb. live-load.

The superstructure consists of twelve two-rib arch spans 304 ft. c. to c. of piers (283 ft. 4 in. clear), one three-fourths arch span at the Mendota end and five trestle spans at the Fort Snelling end. The floor is of flat-slab construction reinforced four ways, with depressed panels and bracketed column capitals. The columns are supported on the arch ribs. Expansion joints are provided in the floor of the bridge at each end abutment and over all piers, except piers 5 and 17, and are covered by double steel angles. Over the piers at expansion joints are double columns and double sets of sway bracing. Over the end piers are single columns with single sway bracing. Between arch ribs are struts located at points of column support.

In section, the arch ribs are square at the crown, tapered to the haunch and rectangular at the skewback. They are reinforced with spirals and longitudinal bars in the same manner as a spirally hooped column, with two additional bars in each corner tied with tie bars at close intervals to the core of the rib. These corner bars supply the additional tension steel required during construction, and afterwards serve as corner reinforcing. The columns which support the floor are reinforced with verticals and spiral hooping, except over the piers. Pier columns which are rectangular instead of square are reinforced with verticals and ties. The corners of arch ribs and columns are chamfered. Octagonal struts between the piers are reinforced with longitudinal bars and spiral hooping.

TABLE I—RECORD OF CENTERING: FORT SNELLING-MENDOTA BRIDGE

Span	Date Raised	Date Struck	Span	Date Raised	Date Struck
16–17	5/21/25	9/30/25	10–11	4/21/26	6/29/26
15–16	6/25/25	11/19/25	9–10	5/19/26	7/22/26
14–15	9/ 8/25	1/ 6/26	8– 9	6/14/26	8/12/26
13–14	10/28/25	4/12/26	7– 9	7/ 8/26	9/ 1/26
12–13	12/ 7/25	5/10/26	6– 7	7/29/26	9/27/26
11–12	2/ 1/26	6/ 5/26	5– 6	8/19/26	10/11/26

Abutments are of the hollow box type, and the end piers of the two end arches are built into the rock in the sides of the gorge. Twelve of the piers of the main arches are each supported on four cylindrical caissons sunk to bedrock at 55 ft. to 90 ft. and averaging about 70 ft. below the surface of ground or water. The shoe of each caisson, of reinforced concrete built into a structural steel frame, is 22 ft. in diameter and 11 ft. high, with a steel cutting edge. At the top of the shoe there is a 4-ft. offset made in two stages to the barrel of the caisson cylinder, which is 14 ft. in outside diameter. The shells of the caissons were built up in sections 5 ft. and 10 ft. high and 2 ft. thick, leaving a 10-ft. shaft through which the dredging was done. After sinking, the caissons were sealed with rich concrete and filled with 1:3:5 concrete in which rubble stone was embedded.

TABLE II—ARCH DEFLECTIONS: FORT SNELLING-MENDOTA BRIDGE

	Deflection At Crown		Deflection At ¼-Point		
Span	Center Line, Ft.	Edge of Sidewalk, Ft.	Center Line, Ft.	Edge of Sidewalk, Ft.	Date
		A. Deflections when centers were struck			
17–18	—.040	......	......	......	8/ 3/25
16–17	—.031	......	+.005	......	9/30/25
15–16	—.021	......	+.006	......	11/19/25
14–15	—.01	......	+.005	......	1/ 6/26
13–14	—.034	......	.00	......	4/12/26
12–13	—.008	......	—.003	......	5/10/26
11–12	—.008	......	.00	......	6/ 5/26
10–11	—.015	—.017	—.003	—.003	6/29/26
9–10	—.013	—.012	—.002	—.002	7/22/26
8/ 9	—.011	—.013	—.006	—.006	8/12/26
7– 8	—.012	—.012	.00	—.003	9/ 1/26
6– 7	—.011	—.011	.00	.00	9/27/26
5– 6	—.009	—.009	.00	.00	10/11/26
		B. Deflections During Lowering of Centers			
17–18	Centers of this span not lowered from deck				....
16–17	—.01	......	.00	......	10/ 5/25
15–16	.01	......	.00	......	11/20/25
14 15	—.01	......	+.001	......	1/14/26
13–14	—.005	......	.00	......	4/14/26
12–13	—.008	......	+.002	......	5/11/26
11–12	—.007	......	.00	......	6/ 7/26
10–11	—.011	—.011	—.002	—.002	6/30/26
9–10	—.002	—.007	.00	.00	7/23/26
8– 9	—.005	—.007	.00	.00	8/13/26
7– 8	—.007	—.007	.00	.00	9/ 4/26
6– 7	—.008	—.008	+.002	+.002	9/29/26
5– 6	—.008	—.007	+.002	+001	10/13/26

All piers except the end piers are designed to permit construction of the bridge with three sets of centers and to take the unbalanced loads of construction with that system of centering. The end piers are designed as abutment piers.

Hand Rail and Lamp Posts—The parapet or hand rail, Fig. 3, consists of a reinforced-concrete curb 10 in. wide and 8 in. high between concrete posts 51 in. high, 36 in. wide and 14 in. thick, paneled on both sides. The end posts and posts supporting lamp standards are 4½ ft. wide. Between posts, the rail is 3 ft. 3 in. high and consists of built-up steel panels with top member of 4-in. steel pipe having the ends let into cast-iron flanges in the concrete posts, but left free for expansion and contraction movements. Cast steel panels bolted to the pipe and to the curb are connected by steel angles.

Provision is made in posts at suitable intervals to support future poles for a street railway. Cast-iron lamp posts have 1,000-cp. lamps in ripple-glass globes with asymmetric domes. Lighting is controlled by time clocks and also by a key switch at each light. Electric conduit to supply the lights is carried in the sidewalk slab under the hand rails. Two 4-in. fiber conduits for telephone wires, with one 3-cell and one 6-cell tile conduit are buried in one sidewalk, with manholes at intervals. One 6-cell tile conduit is buried in the opposite sidewalk, with provision for installing manholes when required.

Materials and Construction—The steel centers for the arches were designed in accordance with recommendations of the engineer, who checked the design and details. The concrete mixing plant was also designed in accordance with his requirements and subject to his approval. The engineer furnished center line, grade and bench marks at each end of the bridge and the contractor laid out his work from these points.

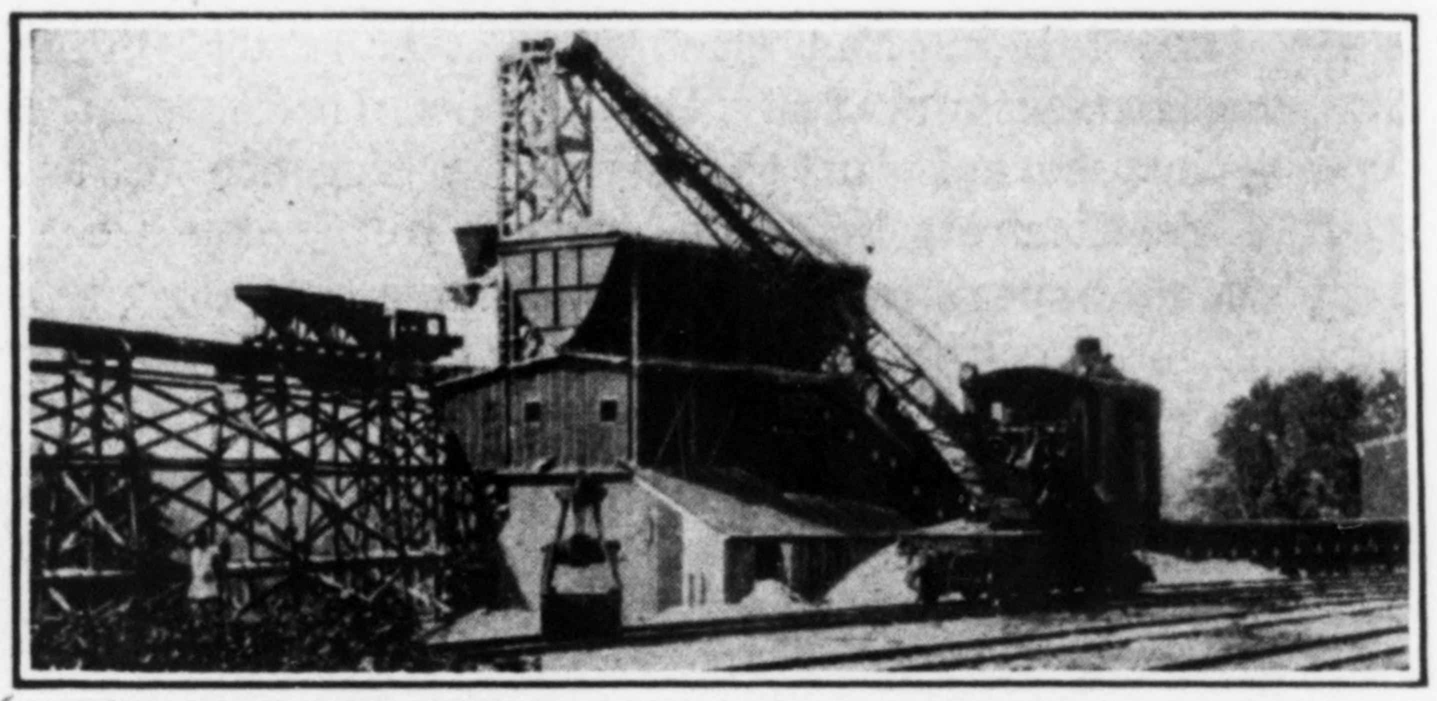


FIG. 4—CONCRETING PLANT FOR FORT SNELLING-MENDOTA BRIDGE

Cement shed at right. Material bins over mixer house. Elevator bucket delivers concrete to side-discharge hopper cars.

A minimum mix of 1:2:4, using gravel or crushed rock, was specified, except for the caisson filling and the hand railing. Control of water ratio and a minimum strength of 2,400 lb. per sq.in. on concrete test cylinders at the age of 28 days were also specified. The sizing and quality of aggregates were particularly specified, including hardness, toughness and water absorption for the coarse aggregate, thus eliminating materials known to disintegrate rapidly by frost action and weathering. The specifications also provided that sand and gravel must be washed and that if crushed rock was used it must be free from dust. Gravel aggregate was used throughout, with the exception of a small amount of caisson concrete made with crushed rock. Structural and intermediate grades of steel were used for all reinforcing, including spirals. All vertical surfaces of the concrete above ground level were ground dry with carborundum stones by electrically driven machines, except that the hand-rail posts were rubbed with carborundum blocks and water.

The concreting plant, Fig. 4, was set up at the Mendota end of the bridge and a railroad yard built from a spur of the C., M. & St. P. R.R. at the top of the bluff. At the foot of the bluff, the C., St. P., M. & O. R.R. had a passing track which the contractor arranged to use for unloading and loading equipment and materials and to which the working trestle was connected by a switch which permitted the locomotive cranes to operate on this passing track when necessary. A cement shed with capacity for several thousand barrels was served by a belt conveyor which delivered the cement sacks to the charging floor. Four steel storage bins for fine and coarse aggregates, with batchers, were above the mixer hoppers.

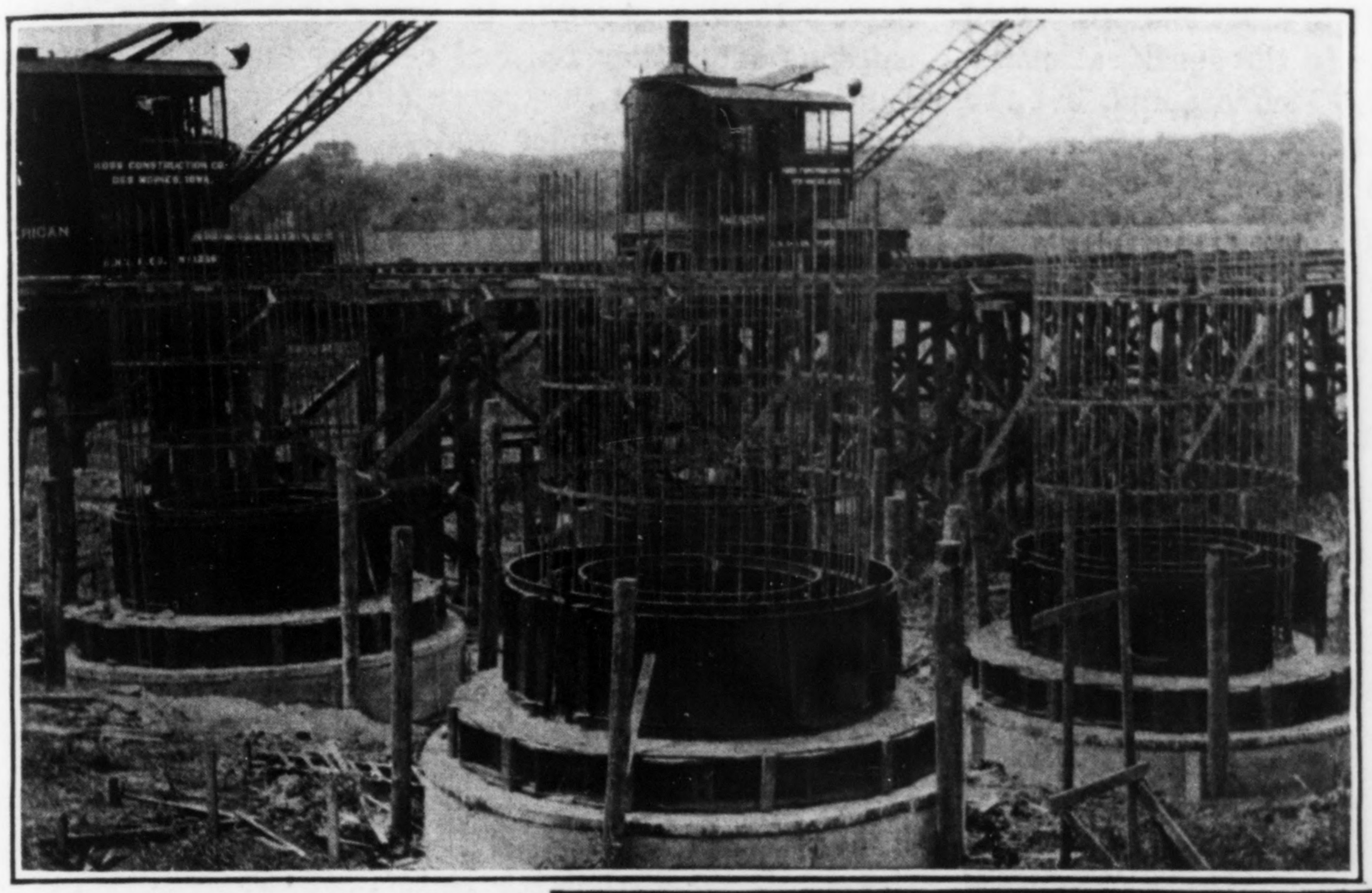


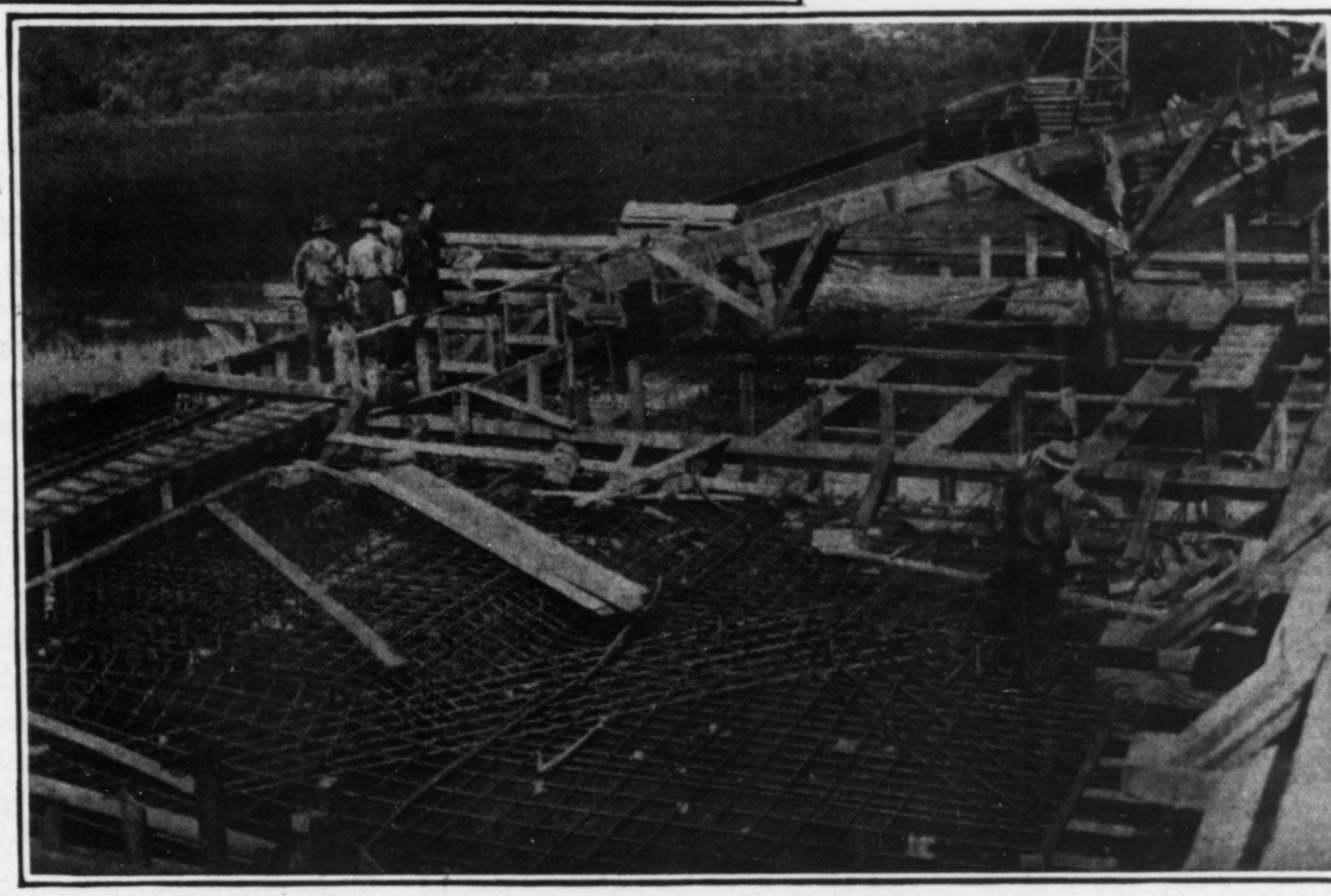
FIG. 5—(ABOVE) SINKING PIER CAISSONS
Locomotive cranes on construction trestle handled grab buckets, placed steel forms and poured concrete.

Two ¾-yd. mixers driven by electric motors dumped into metal-lined wood spouts arranged to discharge into a hoisting bucket to deliver the concrete to a steel hopper. This hopper discharged to side-dump cars on an elevated track and also into a steel chute which delivered the concrete to a large steel hopper set over an industrial track below to discharge into bottom-dump cars. This track was laid out on the working trestle beside the standard-gage track on which the cranes operated. All concrete, except that used in columns and floor slab, was hauled out on the lower track in trains of four to six cars by gasoline locomotives and was deposited by locomotive cranes. On the upper track, the concrete was hauled in trains of three and four cars by gasoline locomotives and dumped into wooden chutes which delivered the concrete in place.

Concreting—During construction of the arch ribs, the order of pouring concrete on each pier was checked by the contractor's engineer and by the bridge engineer. The same order of pouring the sections of each arch rib was maintained throughout and at least 48 hours elapsed after all other concrete was poured before the key sections were poured. The arch rings were poured in nine sections, including key sections. The floor was poured in alternate sections. Fig. 6 shows the floor reinforcement and concreting chute with drop pipes.

Sand inundators were installed in 1925, although good and uniform concrete had been secured previously by careful handling. The total amount of water in the concrete per sack of cement ranged from 6½ to 6¾ gal. This was reduced to 6¼ gal. after the inundators were installed, without decreasing the workability of the mix, while a more uniform consistency was obtained. The strength of concrete, as determined by 28-day test cylinders 6x12 in. had an extreme range of 2,413 to 2,825 lb. per sq.in. for all cylinders taken before installing the inundators. Those taken with the inundators in use showed higher strength, ranging from 2,672 to 3,521 lb.

FIG. 6—(BELOW) CONCRETING THE FLOOR SLAB
Wood chute with drop pipes delivers concrete in place. Note heavy reinforcement.



Work on the piers progressed continuously through the winter of 1924-25, the water and aggregates being heated so that the concrete reached the forms at 100 to 110 deg. F. The fresh concrete was enclosed in canvas and kept warm by salamanders under this covering. In the winter of 1925-26, work on the superstructure was stopped from Dec. 22 to March 3, but before closing down some of the work was done at temperatures ranging down to 10 deg. below zero, even lower temperatures being reached while the concrete was still green. Here the arch ribs were enclosed in canvas and the floor in board sheds and canvas, and the concrete was kept warm for a week after pouring. No difficulty was experienced in keeping the concrete warm and no concrete was frozen. These precautions for cold weather work were provided for in the specifications.

Construction was begun at the Mendota end, but the abutment and trestle at the Fort Snelling end were constructed separately during the progress of the work. The working trestle 4,000 ft. long was of standard railroad type, 20 ft. above low-water level, built along one side of the bridge. Piles 70 ft. long were required. For the bents opposite the piers, where the cranes worked while sinking the caissons, the piles were driven flush and capped at the ground or water line to carry trestle bents. Work was carried on at several piers at one time. Four locomotive cranes were employed, one unloading sand and gravel and other material in the yard at the top of the bluff to keep the aggregate bins above the mixing plant filled, and the other three cranes on the foundation work; when that was completed, one crane was released while the others finished the work.

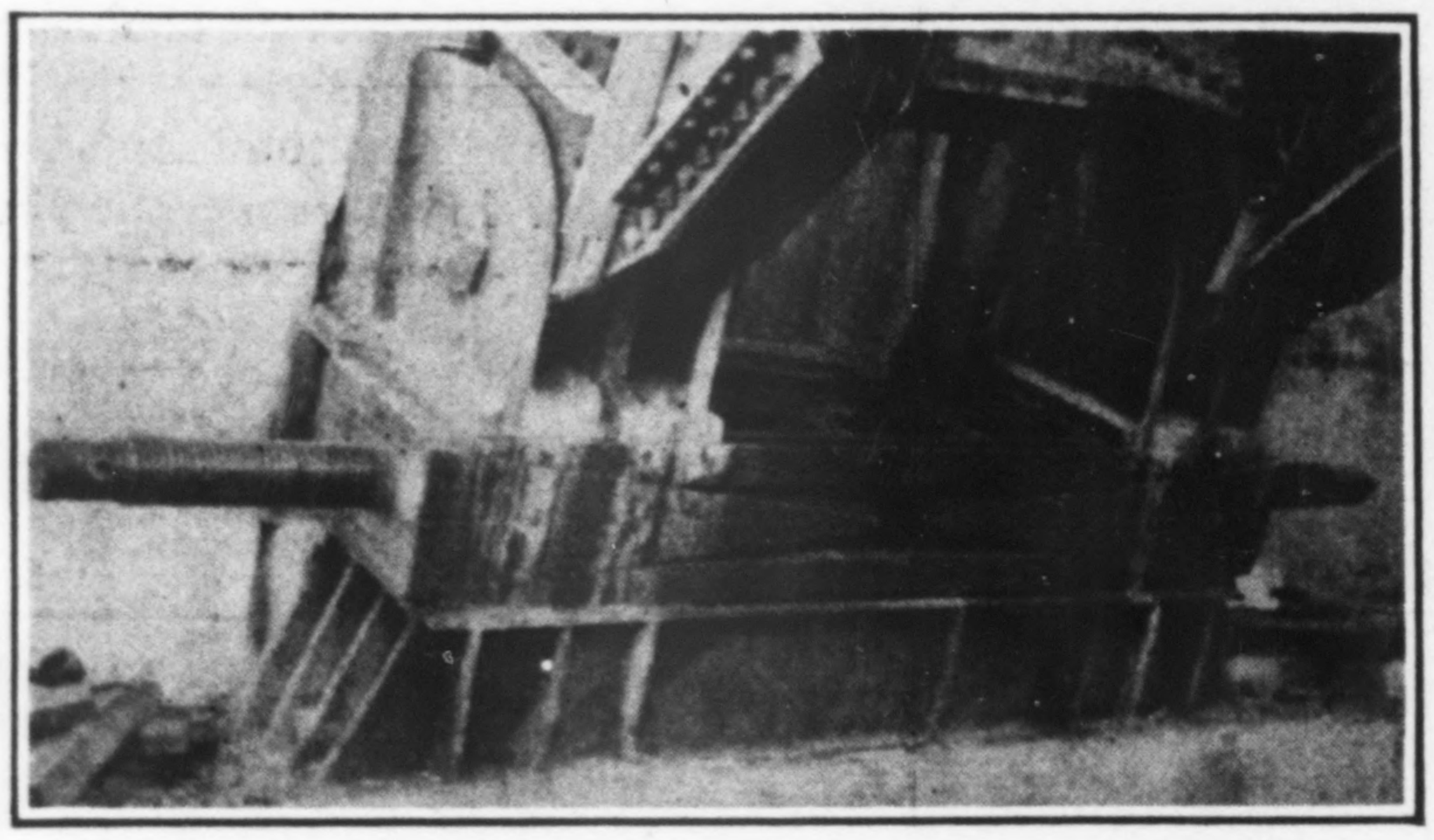


FIG. 7—WEDGES FOR LOWERING ARCH CENTERS

Caisson Work—Preliminary soundings showed the bedrock to be nearly level across the full width of the gorge, sloping slightly at the two caisson piers nearest each end. At pier 12, one caisson landed in a pothole in the rock with the edge of the caisson toward the Fort Snelling end resting on the sloping side of the hole. Prospecting with a drill showed that the pothole was filled with sand and gravel and was only 6 or 7 ft. below the bottom of the caisson. To use compressed air and cut out a seat in the rock for the caisson would have been expensive. The writer decided to try grouting the sand and gravel in the pothole, and prepared a sketch of the grouting machine from which it was built by the contractor. This machine was tested first in similar material to see what penetration could be expected (illustrated in *Engineering News-Record* Oct. 14, 1926, p. 621).

Five grout pipes were sunk to bedrock and grouting begun early in the morning was carried on until the work was complete, the pipes being pulled gradually as grouting progressed. This work was done under 90 ft. of water. After the grout had set, drill holes showed that the grouting had succeeded. The total cost of the operation was less than \$3,000, as compared with an estimated cost of \$30,000 to \$35,000 with air locks.

Caissons were required to be centered correctly and plumb within 9 in. and these requirements were closely adhered to. One caisson slipped out of plumb about 3 ft. when it had nearly reached bedrock, due to too rapid digging on the inside, but was forced into place by using hydraulic jacks against the thick ice and jetting on the opposite side. The pressure applied was about 300 tons and the caisson was straightened up in a few days. It was possible to unwater a number of the caissons after they reached bedrock and clean them by hand, after which they were allowed to fill with water and were sealed under water. The majority of the caissons could not be unwatered. These were cleaned by jetting and inspected by a diver who also assisted in the final cleaning up.

Steel Arch Centers—Handling the steel centers, Fig. 2, was one of the problems of the work which the contractor solved very well. As described in *Engineering News-Record,* Oct. 14, 1926, p. 621, the centers were assembled in a horizontal position in four sections on skids; then the wind bracing was put in and the centers were raised in two halves, each half weighing about 205 tons. The forms for the center three panels of the floor in each span were supported on I-beams which in turn were carried on the steel centers. The rest of the floor forms were supported on bents from the arch ribs and steel I-beams across these bents.

The time of striking the steel centers was determined by the age and hardness of the concrete in the three middle spans of the floor, since the forms for this part of the floor were necessarily struck with the steel centers. The dates on which centers were raised and struck for each span are given in Table I. This omits the first or three-fourths arch span, as its centers had to be erected on falsework and taken apart for removing. As centers were removed they were shifted ahead three spans and raised again, until the last span was reached. Fig. 7 shows the steel wedges and shoes, with operating screws, for striking the centers.

As the arch centers were struck and lowered, readings were taken of the deflections in the arch ribs and floor, as given in Table II. A minus reading is a deflection downward and a plus reading is a deflection upward. In lowering the centers, the load of the free ends of the centers and of the lowering machinery, or a total of about 210 tons, was carried on the floor of the bridge at the middle of the arch span.

When the centers were struck, the floor had not been poured on the whole of the span. In some cases two panels were not poured on each half of the arch span. This condition produced tension on the top of the arch rib at the quarter point and a slight rise at the quarter points resulted when centers were struck. On other spans only one floor panel on each half of the arch span remained to be poured but the resulting tension did not produce a rise at the arch rib quarter point.

General Information—Remarkably fast progress was made on the construction of the superstructure during the spring and summer of 1926. Centers for an entire span on the last four or five spans of the bridge were struck, lowered, moved ahead 900 ft. and raised again in $5\frac{1}{2}$ to 6 days. Only about $3\frac{1}{2}$ weeks was required to strike, lower, move and raise centers, build forms and pour concrete for each of the last six spans, including arch ribs and floor complete for a 304-ft. span. During the summer of 1926 the concrete mix for 90 ft. of floor at the crown, which was supported on forms from arch centers, was changed by the contractor to $1:1\frac{3}{4}:3\frac{1}{2}$ in order to shorten the time the forms were left in place, with the result that test cylinders showed that forms could be removed in 12 to 13 instead of 16 to 17 days.

Fire and tornado insurance was carried by the county on completed work and on materials which had been delivered to the site and paid for in monthly estimates, and the contractor was required to carry insurance on his equipment and forms.

The approach roads were completed in 1926, so that when the bridge was ready to open to traffic on Nov. 8, 1926, the entire project was complete. The bridge was dedicated to the 151st Field Artillery, U. S. A. In all, twelve contracts were let on the entire project, all to the low bidder on first advertisement.

Engineers and Contractors—Walter H. Wheeler and the C. A. P. Turner Co., Associated, were designers and engineers of the bridge. M. G. Hyde was chief office engineer. F. A. Camp was resident engineer until January, 1926, when he asked to be relieved because of advancing years. W. C. Jorgenson was resident engineer for the rest of the job, and E. M. Beal was inspector. The Koss Construction Co., Des Moines, Iowa, had the general contract, with Frank Kratoska as general superintendent and William De Butts as engineer.

Power Requirements of Industrial Plants and Steel Mills

Use of Steam or Electric Power, Produced in Plant or Purchased, Depends Upon Economic Factors and Individual Plant Processes

ABSTRACTS of two of the papers read at the recent Midwest Power Conference in Chicago, relative to power requirements of industrial plants and steel mills follow:

Industrial Power Plants (By Samuel G. Neiler, consulting engineer, Chicago)—In relation to the development of industrial power plants it may be said that engineers thoroughly versed in individual branches such as construction, furnace design, heating or refrigeration may not be capable of visualizing and correlating all the items which enter into the engineering field of industrial work. It is only within the past few years that concentrated effort has been made to analyze plant conditions with the idea of increasing economy in production not only as to the power plant but, which is most important, in the manufacturing departments of the industry. Many advances have been made in the economical production of power, utilization of byproducts, higher machine speeds and improvements in handling and factory routing of manufactured products. A summary of some power-plant functions is:

Electricity: For light and power, ovens, laboratory heating units, welding.

Steam: For heating buildings or water; for dry kilns and process work.

Compressed Air: For drills and other tools or machines; hoists; oil or pulverized-coal furnaces; foundry molding machines and special equipment.

Water: For domestic and fire purposes and for process work; refrigerated water for drinking; high-pressure water for riveters and other machines.

Miscellaneous: Dust-collecting systems are required for foundries, wood-working mills and other industries. In foundries there is also sand handling and conditioning apparatus. In manufacturing plants, transportation methods have to be considered for handling materials and products, also arrangements for storage and shipping facilities.

The modern industrial plant of 2,500 to 20,000 kw. is almost invariably complicated on account of demands for steam in processes or for the utilization of by-products, so that the electric power becomes more or less of a by-product and in many cases is developed at a cost with which a service supply company cannot compete. The mere fact that a large central station develops electrical energy at a very low cost does not determine the decision in connection with an industrial plant. The only consideration is what advantage there is in purchased power as compared with the isolated plant. Mr. Low, past-president of the American Society of Mechanical Engineers, had an editorial in *Power* which was a plea for industrial power plants to keep up with modern development and to design for economy in fuel production.

Where there is any by-product, there is the chance for maximum return, and engineering along this line has progressed steadily. Thus cement plants utilize waste gases to generate sufficient steam to operate their entire electrical equipment and provide for compressed-air requirements, the kilns using no more coal than before, and coal for the boilers being used only after a shut-down for annual repairs. A decided advance has been made also in collecting and recovering cement dust that was formerly discharged into the atmosphere. As much as 13 tons per stack per day has been thus recovered. Marked development has been made in the economical burning of wood waste, from sawdust with 15 per cent moisture to kiln-dried lumber, and this has been due mainly to analysis of the various types of furnaces.

In foundry work, mechanical molding has resulted in a more uniform product at lower cost. A recent foundry of this type has a continuous uninterrupted production of one car-wheel per minute throughout the 8-hour day. In high-pressure hydraulic machinery the problem of interruptions due to breakage of supply lines to the valves on account of vibration has been solved by spiral pipe connections designed to suit the different sizes of pipes. In all such cases, the engineer must realize the necessity of analyzing every problem, as each problem distinctly stands by itself.

Power for Steel Mills (By Wilfred Sykes, consulting engineer, Inland Steel Co., Chicago)—Probably the most important item in the development of the steel industry has been the availability of power which can be substituted for human effort, giving increased production coupled with improved working conditions and standard of living. This has been accompanied usually by a reduction in cost and selling price of the product. Figures at one plant indicate an increase in production per man of about 35 per cent in the past ten years, in spite of the elimination of the 12-hour day.

At the present time the steel industry is largely electrified. This power is used even for driving the main rolls in a large proportion of the mills and is universal for auxiliary devices. Approximately 75 per cent of the power in 1926 was generated in the mills and 25 per cent supplied from outside sources, mainly central station plants. The aggregate rating of motors in steel mills is about 3,500,000 hp., of which 1,000,000 hp. are driven by purchased power. The largest continuously rated rolling-mill motor is 9,000 hp., but where several motors drive different units of the mill the total power may be much higher. Many of the continuously running mills have constant-speed motors, but there is increasing use of adjustable-speed motors.

A characteristic of steel-mill load is considerable fluctuation in the demand for power and little correlation between the operation of the blast furnace and the power requirement. The load factor on week days will average 60 to 65 per cent, based on the maximum load, or 45 to 50 per cent when spread over a year. This is not an ideal load for internal-combustion engines, which should be operated near their rated capacity and without rapid load changes. Where gas engines have been used, therefore it has become regular practice to install about 30 per cent of the total capacity in turbo-generators to carry the peak load and regulate the system. But the overall efficiency of such a combined plant is not much in excess of that of a turbo-generating plant, while in addition to its complications the former costs much more than an all-steam plant. With boilers heated by waste gas from the open-hearth furnaces, steam generated averages 1,200 to 1,500 lb. per ton of steel produced, and usually all the steam available is used.

Future development at steel plants having blast furnaces will be in installing steam turbo-blowers and turbo-generators and in connecting these plants with central station plants, so that excess power can be delivered to or additional power taken from the latter as conditions require. For steel plants which have no blast furnaces and have central-station power available it is better to purchase power.