THE MEMPHIS BRIDGE.

The steel cantilever railway bridge recently completed across the Mississippi River at Memphis, Tenn., by the Kansas City & Memphis Railway & Bridge Co., was formally tested on May 12. The work of construction, which began in 1888, has been carried on so quietly that the structure has hardly received the attention, even from engineers, which its importance and magnitude demand, although its great length of span and depth of foundations place it well up among the largest bridges in the world. But aside from its engineering features its importance from a commercial standpoint is very great. It is the first bridge to be built across the Mississippi River below the mouth of the Ohio River, and its location is at the junction point of several of the most important of the southern railway systems both east and west of the river. The city of Memphis is entered by ten lines of railway; three from the west and seven from the east. These roads have heretofore been obliged to depend upon the slow and tedious operation of a transfer ferry for all interchange of traffic between the east and west sides of the river. While the bridge has been built principally in the interest of the allied companies, the Kansas City, Ft. Scott & Memphis and the Kansas City, Memphis & Birmingham, it will also serve the St. Louis, Iron Mountain & Southern and the Little Rock & Memphis railways, as well as the several lines entering the city from the east. Situated as it is on the line of great industrial and traffic development from Kansas City and the Southwest to the south Atlantic and Gulf coasts its importance is readily seen, and its chances as a paying enterprise seem good.

The construction of a bridge to replace the transfer at Memphis had been discussed for several years, but owing to the natural difficulties to be overcome and the great cost of such a structure nothing was done until 1885. During the winter of 1885 and 1886 an examination of the ground for the purpose of selecting a feasible site for the location of a bridge was made by Mr. Geo. S. Morison, M. Am. Soc. C. E., of Chicago, who afterward designed the bridge and superintended its erection. As a result of this investigation a charter for a bridge to be 75 ft. above high water, 22 ft. higher than is usually required, was secured at the next session of Congress. It was not until 1888, however, that the plans for the bridge were completed.

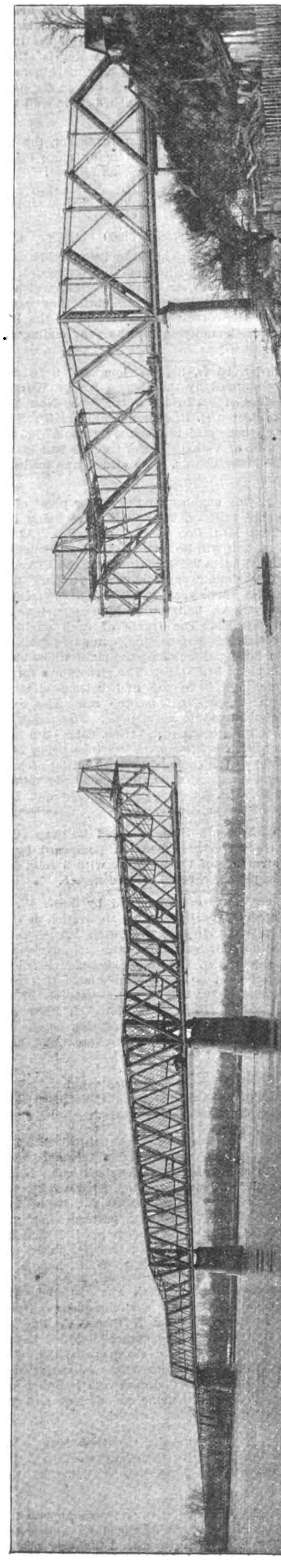
In brief, these plans called for a steel bridge across the river 2,597.12 ft. long, followed by an iron viaduct 2,290.6 ft. long and 3,097.5 ft. of timber trestle over the low swampy land on the west bank of the river, making the total length of the structure, including the eastern approach of 2,726 ft., a little over 2 miles. The bridge proper begins on the high bluff on the east side of the river known as the Chickasaw Bluff, and consists of five spans as follows:

	Feet.
Eastern shore span	225.83
Main span	790.42
Two river spans, each 621.06 ft.	1,242.12
Western shore span	338.75
Total length	2,597.12

The iron viaduct approach consists of 49 plate girder spans supported on Z-iron columns resting on small masonry piers on pile foundations.

From the west end of the trestle approach the bridge line is continued west by a high earth embankment to Sibley, Ark., where connection is made with the Kansas City, Ft. Scott & Memphis R. R. This embankment also crosses the St. Louis, Iron Mountain & Southern Ry., and the Little Rock & Memphis Ry., and has a connecting track to both roads. On the east or Tennessee side the bridge line connects with the Kansas City, Memphis & Birmingham R. R., by an approach consisting of three 23.8 ft. spans of iron viaduct and 2,641 ft. of trestle.

As the sinking of the caissons comprised the most important as well as the most difficult part of the work, the company decided to have the work done under the supervision of its own engineering staff, and accordingly headquarters were established at Memphis in the fall of 1888 and work commenced. The work was done under the immediate charge of the Resident Engineer, Mr. Alfred Noble, and under the supervision of the Chief Engineer, Mr. Geo. S. Morison. The accompanying profile shows the location of the several piers and the depths to which they were sunk. The caissons, which were five in number and unusually large, were sunk by the pneumatic process. Their dimensions were as follows:



THE MEMPHIS BRIDGE, OVER MISSISSIPPI RIVER AT MEMPHIS, TENN.: CONDITION OF WORK, MARCH 28, 1892.

No. pier.	Length, feet.	Width, feet.	Height, feet.
1	70	50	51
2	92	47	60
3	92	47	40
4	60	26	50
5	40	22	80

Three of the caissons were built on the east shore of the river and then towed into position and sunk, and two were built on the sites of the piers. The timber used in their construction was yellow pine from southern Mississippi. The table (page 471) gives the elevations of the several parts of the completed foundations and the record of the progress of work.

As will be seen from the table the deepest foundation is 130.8 ft. below high water and the deepest immersion during building was 108 ft. This, with the exception of the eastern abutment of the Eads bridge at St. Louis, Mo., where the greatest immersion was 109.7 ft., is the greatest depth at which the pneumatic process has ever been worked. The air pressure carried at the greatest immersion was 47 lbs. per sq. in. At this pressure the men worked in shifts of 45 minutes, each man working three shifts in the 24 hours. At this point it is interesting to note that there were but four deaths from the caisson disease or "bends," a very favorable showing considering the depth and pressure at which the work was carried on. The depths of this foundation compared with the deepest foundation of the Eads bridge are shown in the following table:

	Below low water, feet.	Below. high water, feet.	Greatest immersion, feet.
Memphis	96.2	130.8	108.
Eads, St. Louis	94.	135.5	109.7

The material penetrated consisted mainly of coarse sand and gravel to a depth of from 40 to 50 ft. with clay in some places. It was removed in the ordinary manner, by using the pressure of the compressed air to force the sand and mud out through the pipes for that purpose. The rate of sinking was limited by the progress made in building the masonry, and averaged about 2 ft. per day.

The river bed being of coarse sand and gravel at this point, its topography is, as at many other points along the river, subject to sudden and great changes from the action of the currents. To obviate as far as possible the disastrous effect of such changes upon the work a novel, and as far as we know an entirely new, expedient was used. Before each caisson was sunk a bed was prepared for it by sinking a willow mattress of the ordinary type used in the Mississippi River improvements by the government engineers. These mattresses were each 240 ft. wide and 400 ft. long, and were built from barges anchored over the pier sites, and sunk by being loaded with stone. The process of sinking the mattresses was as follows: When the weaving was completed, the mattress was loaded with stone until only a few points projected above the surface of the water. The barges carrying rock were then hauled across the upper edge of the mattress, stone being thrown from them so as to depress this edge below the surface of the water. To prevent the mattress from wholly sinking it was attached by lines to the mooring barges. After being placed in position the barges of stone were allowed to float slowly down over the mattresses, stone being thrown from them by a large force of men. When the upper half of the mattress had been sunk below the surface the lines connecting its upper edge with the mooring barges were cast off and this portion of the mattress sunk to the bottom. The upper edge of the mattress was attached to anchors a few hundred feet upstream.

The caissons were sunk on the carpets so prepared, the mattress and stone being cut through in the excavation. The object sought was to prevent the scour of the sandy bottom both during the sinking of the caissons and after completion of the masonry, and thus prevent the delay and possible disaster arising from any tilting of the caisson, and insure the stability of the completed pier. The success in sinking the caissons, which were unusually large, and the rapid progress of the foundation work is attributed largely to the use of these mattresses. In addition to preventing the scour of the river bed during the progress of the work the mattresses will be covered with riprap and will afford protection to the completed piers.

The five piers as well as the eastern abutment are of granite and limestone masonry. The facing is of granite from the quarries at Lithonia, Ga., and the backing is of Bedford, Ind., limestone. All masonry, including the backing, is of dimension stone. The contract for the masonry, including the east abutment, was let to L. Ross, of Rochester, N. Y. This east abutment is located on dry land and thus afforded few difficulties of construction as compared with the pier foundations. The bottom of its foundation is 50 ft. below the surface, and as it is an anchorage for the eastern cantilever span, it is of solid masonry and weighs 2,500 tons. The anchor rods pass entirely through the masonry and are connected at the bottom with a network of iron I-beams.

As will be seen by the table the last masonry was completed on pier 2 on April 25, 1891, 2 years and 5 months after the date of beginning the construction of the first caisson. During the entire work very little trouble was experienced from bad weather or high water, and with the exception of a few unimportant delays work was carried on continuously from the beginning.

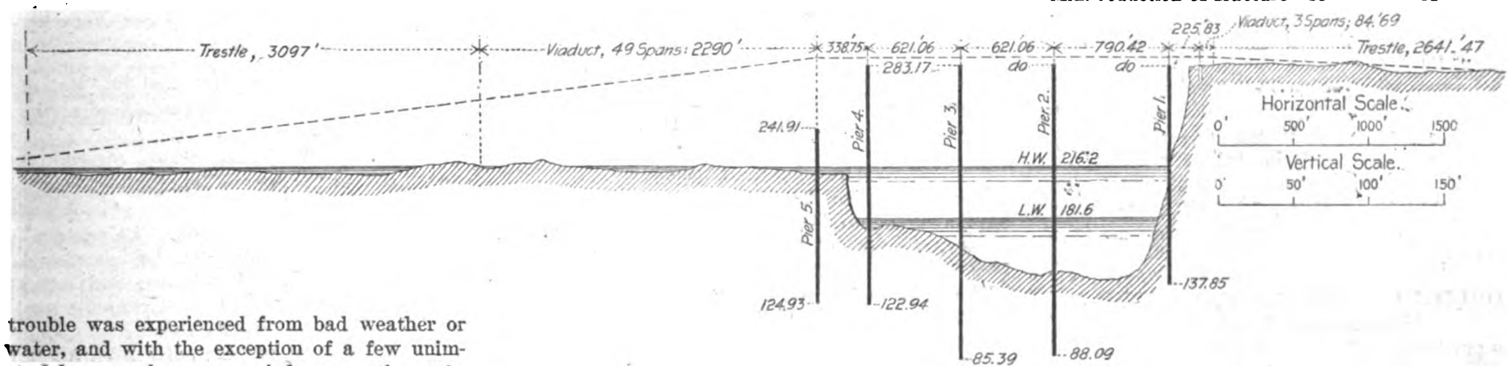
As before stated, the bridge proper is of the cantilever type and consists of five spans. Beginning at the east end the spans are as follows: East abutment to pier 1, one cantilever arm, 225.83 ft.; pier 1 to pier 2, two cantilever arms each 169.38 ft., and an intermediate truss 451.66 ft.; pier 2 to pier 3, continuous truss 621.06 ft; pier 3 to pier 4, one cantilever arm 169.38 ft., and a parallel chord truss, 451.66 ft., with one end hung to the cantilever arm and the other supported on pier 4, and pier 4 to pier 5, one deck span, 338.75 ft. The longest span, from pier 1 to pier 2, is 790.42 ft. There are but two bridges in the world having longer trussed spans than this, and so far as we call to mind there are only seven bridges of any type in the world having longer spans. The following table shows the length of span of some of the more important bridges now existing as compared with the Memphis bridge.

The continuous superstructure is rigidly fastened to piers 1, 2 and 3, and rests on expansion rollers on pier 4. Slip joints provide for expansion at the suspended ends of the independent spans. The trusses are 30 ft. c. to c. and are divided into panels 28 ft. 2¾ ins. long. The trusses of the deck span are 22 ft. c. to c. The east end of this span is carried in nitches on pier 4, and the west end has roller bearings resting on pier 5. The estimated approximate weight of the continuous superstructure is 13,000,000 lbs., and that of the deck span 1,000,000 lbs., making the total estimated weight of the superstructure of the bridge proper 14,000,000 lbs., or 7,000 tons.

The first work on the superstructure began about Feb. 21, 1891, and consisted in placing the castings on pier 1. In July, 1891, the building of the false works for the center span began, and the erection of the iron work was commenced in September, 1891, and on Oct. 15 it was swung clear of the false works. The building of the false works for the span between piers 3 and 4, and the erection of that span followed next, and were completed in December, 1891. The deck span between piers 4 and 5 was completed in January, 1892, and work was then begun on the main span between piers 1 and 2 without false works. This span was swung on April 23, 1892.

	Pier 1.	Pier 2.	Pier 3.	Pier 4.	Pier 5.
Began building	Dec. 21, '89	May 17, '89	July 30, '89	Nov. 24, '88	April 25, '90
Launched	Built in place	July 29, '89	Oct. 26, '89	Dec. 15, '88	Built in place
Placed at pier site	Dec. 21, '89	Sept. 23, '89	Oct. 28, '89	Dec. 17, '88	April 25, '90
Began filling with concrete	Jan. 1, '90	Sept. 25, '89	Nov. 5, '89	Dec. 23, '88	May 8, '90
Building completed	Mar. 8, '90	Oct. 21, '89	Dec. 11, '89	Jan. 10, '89	May 27, '90
Filling completed	Mar. 9, '90	Oct. 11, '89	Nov. 27, '89	Jan. 10, '89	May 30, '90
Sinking commenced	Jan. 10, '90	Oct. 10, '89	Dec. 16, '89	Dec. 27, '88	May 8, '90
Sinking completed	Ap'l. 18, '90	Oct. 16, '90	Aug. 21, '90	Feb. 6, '89	June 8, '90
Sealing commenced	Ap'l. 18, '90	Oct. 16, '90	Aug. 18, '90	Feb. 6, '89	June 8, '90
Sealing completed	Ap'l. 22, '90	Oct. 24, '90	Sept. 4, '90	Feb. 10, '90	June 12, '90
Masonry commenced	Mar. 10, '90	Oct. 23, '89	Dec. 12, '89	Aug. 27, '89	No masonry. Cyls. May 28, '90.
Masonry completed	June 23, '90	Ap'l. 25, '91	Jan. 24, '91	Sept. 3, '90	Set coping. May 15, '91
Elevation cutting edge of caisson	137.85	88.09	85.39	122.91	124.93
Elevation top of caisson	190.69	147.29	125.01	173.38	204.93
Elevation top of masonry	283.17	283.17	283.17	283.17	241.91

Elevation of high water, 216.2. Elevation of low water, 181.6.



PROFILE SHOWING LOCATION OF PIERS, ETC., MEMPHIS BRIDGE; Geo. S. Morison, Chief Engineer

Name.	Country.	Purpose.	Type.	Spans, feet.
Forth	Scotland	Double track railway	Cantilever	Two, 1,710; Two, 690
Brooklyn	United States	Wagon and double track railway	Suspension	One, 1,595; Two, 930
Cincinnati	" "	Wagon	"	One, 1,057
Fribourg	Switzerland		"	One, 870
Niagara	United States	Wagon and double track railway	"	One, 821
Sukkur	India	Double track railway	Cantilever	One, 820
Pittsburg	United States	Wagon	Suspension	One, 800
Memphis	" "	Single track railway	Cantilever	One, 790.4; Two, 621
Red Rock	" "	" " "	"	One, 660
Louis I	Spain	Double deck wagon	Seg. arch	One, 566
Cincinnati	United States	Double track railway, wagon and street railway	Truss	One, 550; Two, 490
Poughkeepsie	" "	Single track railway	Cantilever	Three, 548; Two, 525
Ohio River	" "	Double track railway and wagon	Truss	One, 543; Two, 486
Garabit	France	Single track railway	Seg. arch	One, 541
Douro	Portugal	" " "	" "	One, 525
Merchants	United States	Double track railway	Truss	One, 524; Two, 522
Henderson	" "	Single track railway	"	One, 522
Cairo	" "	" " "	"	Two, 520; Seven, 408
St. Louis	" "	Double track railway and wagon	Seg. arch	One, 520; Two, 502
Havre de Grace	" "	Single track railway	Truss	Two, 515; Four, 476
Washington	" "	Wagon	Seg. arch	Two, 510

The steel of the bridge proper was furnished by the Union Bridge Co., of New York City, and A. P. Roberts & Co., of Philadelphia, Pa. The order to the Union Bridge Co. was given in January, 1890, and to A. P. Roberts & Co. in 1891. The general requirements are given in the following abstract from the specifications, which were very elaborate and complete:

All parts, except nuts, swivels, clevises and wall pedestal plates, will be of steel. The nuts, swivels, and clevises may be of wrought iron, but shall have sufficient strength to break the bodies of the members to which they are attached. The pedestal plates will be of cast iron.

The steel will be divided into three classes: (1) high grade steel, which will be used in all the principal truss members; (2) medium steel, which will be used in the floor system, laterals, portals, transverse bracing and the lacing of the truss members; (3) soft steel, which will be used only for rivets, and at the option of the contractor where wrought iron is permitted. The bolsters which carry the large pin bearings on piers 1, 2 and 3, will be of cast steel. In any case where it seems doubtful what quality of steel is required, high grade steel may be used.

Steel may be made by the open hearth or by the Bessemer process, but no steel shall be made at works which have not been in successful operation for at least one year. In the finished product of open-hearth steel the amount of phosphorus shall not average more than 0.08 of one per cent., and never exceed 0.1 of one per cent. In the Bessemer steel, the amount of phosphorus shall not average more than 0.04 of one per cent., and never exceed 0.05 of one per cent.

The laboratory test shall meet the following requirements:

	High't grade. Steel, lbs. per sq. in.	Medium Steel, lbs. per sq. in.	Soft Steel, lbs. per sq. in.
Max. ultimate strength	78,500	72,500	63,000
Min. ultimate strength	69,000	64,000	55,000
Min. elastic limit	40,000	37,000	30,000
	p. c.	p. c.	p. c.
Min. elongation in 8 ins.	18	22	28
Min. reduction of fracture	38	44	50

Steel for pins shall be sound and entirely free from piping and all pins in the main trusses shall be drilled through the axis.

The laboratory tests of the cast steel shall show an ultimate strength of at least 70,000 lbs., an elastic limit of at least 40,000 lbs., and an elongation of at least 15 per cent. in 8 ins. and a reduction of 18 per cent. at point of fracture.

All riveted members which are made of high-grade steel and all other pieces connecting with such members shall be solid drilled, no punching whatever being allowed, excepting lacing bars, which may be punched and reamed. Where bolts passing through the metal are used the holes shall be drilled in all metal more than ¾ in. thick, the diameter of the drilled hole to be at least ⅛ in. less than the diameter of the finished hole. In metal not more than ¾ in. thick punched holes may be used for fitting up, the diameter of the punched hole not to be more than three-quarters the diameter of the finished hole; and the number of punched holes never to exceed eight in any one plate or four in one flange of any one angle. After the drilling is completed a special reamer shall be run over both edges of every hole, so as to remove the sharp edges and make a fillet of at least 1-16 in. under each rivet head. In general, all holes which are to pass through several thicknesses of metal shall be drilled with all those pieces of metal assembled in the exact relative position they are to hold in the bridge. All rivets shall be driven by power wherever this is possible. Tightening by calking or recupping will not be allowed. This applies to both power-driven and hand-driven rivets. All pin holes and holes for turned bolts passing through the whole width of a riveted member shall be bored or drilled after all other work is completed. All riveted members which are composed entirely of medium steel may be punched and reamed; but this does not apply to the connections between such members and high grade steel members, which connections shall be solid drilled throughout.

The heads of eye-bars shall be formed by upsetting and forging. No welds will be allowed. After the working is completed the bars shall be annealed in a suitable annealing furnace by heating them to a uniform dark red heat and allowing them to cool slowly. The thickness of the head shall not be more than 1-16 in. greater than that of the body of the bar, and the heads shall be of sufficient strength to break the body of the bar. Nuts, swivels and clevises, if made of steel shall be forged without welds, and whether made of steel or wrought iron, one of each size shall be tested and be of sufficient strength to break the bars to which they are attached. Twenty full-sized steel eye-bars shall be selected from time to time from the bars made for the bridge by the inspector for testing.

The tests of full-sized eye-bars shall be made in the large testing machine at Athens. These bars will be required to develop an average stretch of 12 per cent. and a minimum stretch of 10 per cent. before breaking. The elongation shall be measured on a length of not less than 20 ft., including the fracture. The bars will be required to break in the body. They shall also show an elastic limit of not less than 32,000 lbs. and an ultimate strength of not less than 62,000 lbs., as indicated by the registering gages of the testing machine at Athens. In the case of bars too long for the machine, the bars shall be cut in two, each half reheaded, and both halves tested in the machine, the two tests, however, to count as a single test bar. If the capacity of the machine (estimated at 1,200,000 lbs.) is reached before the bar is broken, the bar shall be taken out of the machine and the edges shall be planed off for a length of 10 ft. at the center until the section is reduced to the equivalent of 16 sq. in. of section of the original bar. The bar shall then be placed in the machine and broken; when this is done, the elongation shall be measured on a length of 8 ft. and an ultimate strength of 60,000 lbs. computed on the 16 in. of original section will be considered satisfactory.

The contracts for furnishing the metal for the 2,300 ft. of the viaduct approach on the west side of the river were given to the Pennsylvania Steel Co., of Steelton, Pa., and Cofrode & Saylor, of Pottstown, Pa.

The accompanying engraving showing the condition of work on March 28, 1892, also gives a very fair idea of the bridge as it will appear when completed. Partial views of the bridge showing the progress of work have also been published in our issues of Feb. 27 and March 12, 1892. We expect to publish complete details of the structure in a future issue.

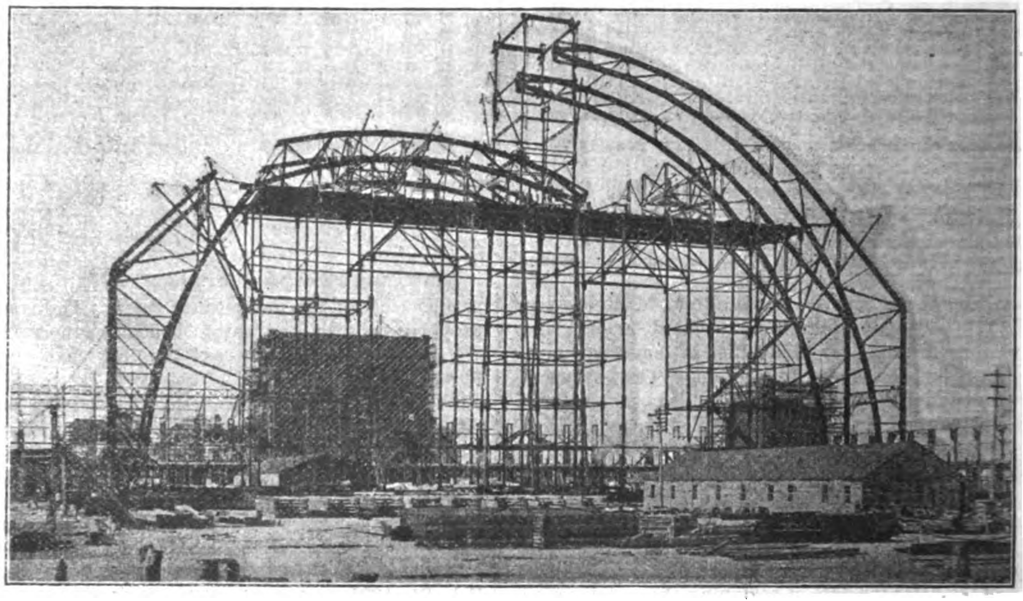
WORLD'S COLUMBIAN EXPOSITION.

Manufactures Building.

Some particulars of the great arch trusses for this building, and the method of erecting them, were given in our issue of April 21. From Mr. John Worcester, who is superintendent of the erection for the Exposition management, we have received the view of the work which we reproduce herewith, together with the following notes of progress. The first pair of arches was erected in 11½ days, the average number of men being 147. The total weight was 640,000 lbs., an average of 380 lbs. per man per day. The traveler was moved 100 ft. in three hours. The second pair of arches was erected in nine days, with an average of 148 men. The total weight was 694,000 lbs., the difference from the weight of the first pair being in the number of purlins set, and the average weight per man per day was 520 lbs. The second move of the traveler for 100 ft. was made in 45 minutes, and the third pair of arches was up to the traveler platform by April 30. The method of erection was designed by Mr. S. Mitchell, Assistant Manager of the Edge Moor Bridge Works, and in a later issue we shall give further details of the building and its erection.

Boiler Plant.

In our issues of March 5 and April 9 we have given particulars of the boiler plant and the fuel for power purposes. The fuel is to be oil, and the contract has been awarded to the Standard Oil Co., as already noted. The contracts for boilers have been distributed among six firms and are all for water-tube boilers. The successful bidders and the amount of power each will furnish are as follows: Heine Safety Boiler Co., St. Louis, Mo., boilers to have a capacity of evaporating 112,500 lbs. of water per hour; Campbell & Zell Co., Baltimore, Md., 112,500 lbs.; Mills Patent Sectional Boiler Co., Manchester, England, 90,000 lbs.; Stearns Mfg. Co., Erie, Pa., 45,000 lbs.; Abendroth & Root Mfg. Co., New York, 45,000 lbs., and the National Water Tube Boiler Co., New York, 45,000 lbs. The kinds of burners, injectors and other appliances for the use of oil fuel are left to the selection of the boiler makers, but none of the makers are yet prepared to give information on this point. The Heine Safety Boiler Co. states that it will put in eight Heine boilers, rated at 375 HP. each. The company has now in use in this country about 1,600 boilers aggregating 325,000 HP. The Campbell & Zell Co. states that the number of boilers has not been determined, but that they will aggregate 2,500 HP.; they will be of the Zell pattern. The Stearns Mfg. Co. will use Gill's patent water-tube boilers. Mr. F. Sargent is the Mechanical and Electrical Engineer.



ERECTION OF ARCH TRUSSES FOR THE MANUFACTURES BUILDING, WORLD'S COLUMBIAN EXPOSITION; SPAN, 328 FT.

Dredging the Lagoons.

The contract for dredging the interior lagoons has been awarded to MacMahon & Montgomery, at a price varying from 10 to 18 cts. per cu. yd.

Mining Exhibits.

The scope and extent of the exhibits in the Mines and Mining Department were described in our issue of May 5. One of the notable exhibits will be a model of the entire plant of the H. C. Frick Coke Co., of Scottdale, Pa. The company has a capital of about $40,000,000, and is said to be the largest of its kind in the world. The model will cost between $3,000 and $4,000, and the contract for making it has been awarded to the Jones Bros. Electric Co., of Cincinnati, O. It will be on a scale of 1-20 of an inch to the foot, covering a space of about 20x50 ft., and will be an exact representation of the works, including engines, boilers, piping, elevated tracks, hoists, cupolas, ovens, cars and all other machinery. The machinery will be in operation, the motive power being electricity, with gas for the ovens, the coke therein being represented by asbestos. The model will represent a section of one of the shafts, extending from the floor to the top of the stand, with tipple, self-acting rams, bins, cages, winding apparatus, engine and boiler houses with their machinery, workshop and electric light plant. There will also be shown several tenement houses and a block of ovens with the charging engines, lorries, railway tracks, etc. The company will also exhibit samples of its products, and a topographical chart of the Connellsville district, showing the location of the company's property and plants.

TORPEDO VESSEL FOR THE U. S. NAVY.

(With inset.)

Upon our inset sheet this week we show the designs made by the Bureau of Steam Engineering for the machinery of a vessel which, with but 750 tons displacement, is intended to carry engines developing 6,000 I. HP., or 8 HP. per ton.

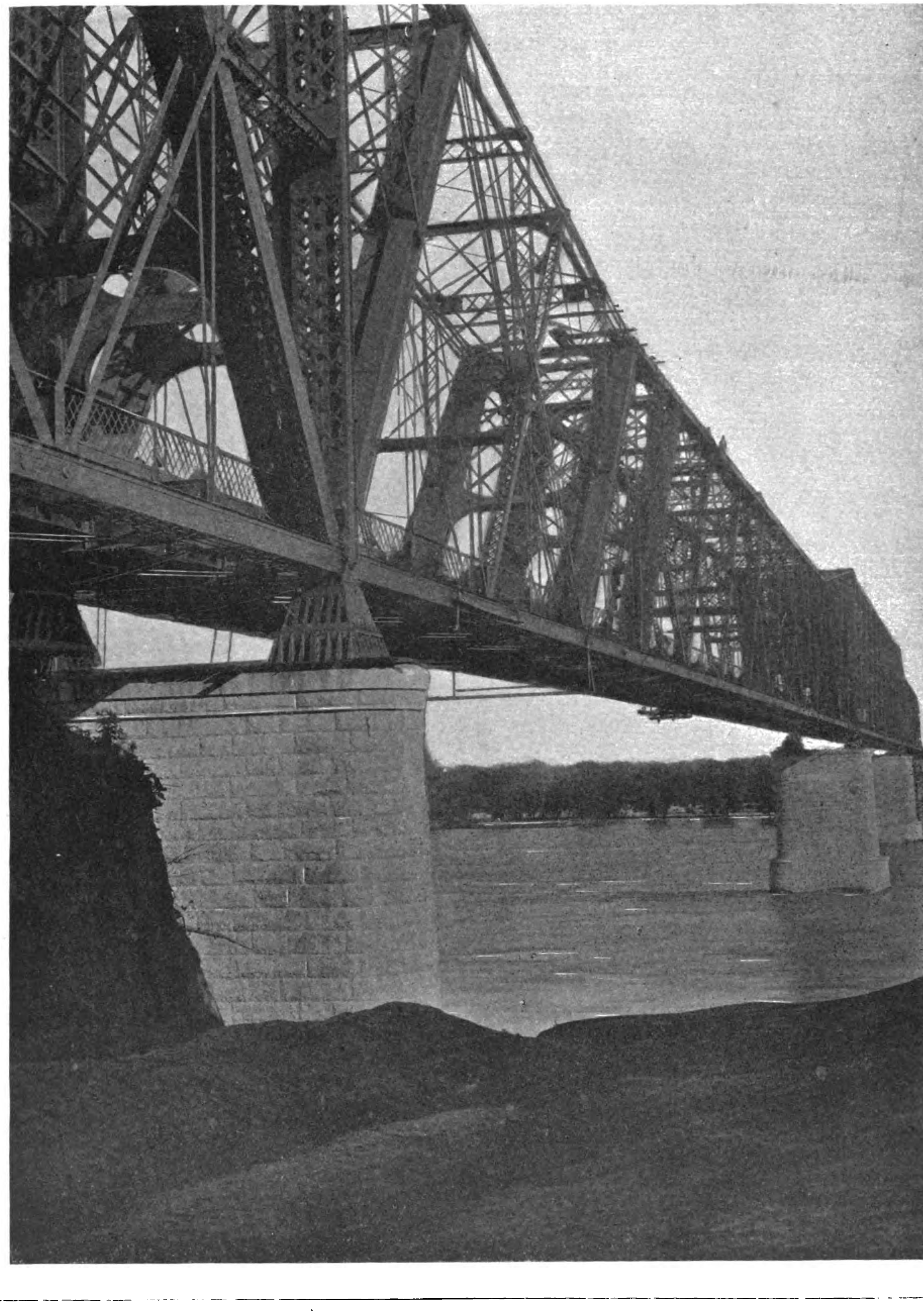
Chief Engineer Geo. W. Melville, in his report, says that so far as is known this is the greatest power ever proposed for this displacement. While this is quite true, vessels of smaller displacement have been built with even a larger power in proportion to size. Torpedo boats are especially noted for their combination of high power with small speed. The "Cushing" in some high speed tests last year showed 1,336 I. HP. with 125 tons displacement, or 10.7 HP. per ton. A Spanish seagoing torpedo vessel, the "Destructor," built in 1886 by Thompson, of England, showed 3,829 I. HP. with a displacement of 385 tons, or a little less than 10 HP. per ton. Her average speed on a 3-hour trial was 22.6 knots per hour, and a maximum of 23¾ knots was reached. The vessel has proven herself thoroughly seaworthy, and in "Recent Naval Progress" for 1887 was characterized as the fastest vessel afloat.

The proposed United States torpedo vessel is about double the size of the Spanish boat, and the only approach to her power in vessels of similar size is the Italian torpedo vessel "Partenope," which, with 859 tons displacement, has developed nearly 4,300 HP., or 5 HP. per ton, and has attained a 20-knot speed. The United States vessel is expected to show at least 23 knots.

The problem of placing engines of 6,000 I. HP. in a hull only 25 ft. wide on the water line at the engine rooms was no easy one, and the drawing of the general arrangement of machinery shows how every available bit of space between the bunkers has been utilized by the designer. Triple expansion engines were adopted, but space has been saved by the use of two low pressure cylinders instead of one. The following description of the machinery is given in the official report of Chief Engineer Geo. W. Melville:

There are twin-screw, triple-expansion engines of the vertical, inverted cylinder, direct acting type for the main engines, fitted as rights and lefts and in a common compartment. There is one high pressure cylinder 23¾ ins. diameter, one intermediate, 34¼ ins. diameter, and two low pressure, each 38 ins. diameter, the common stroke being 18 ins. The working steam pressure is 200 lbs., and the revolutions of the propelling engines 333 per minute, giving a piston speed of 1,000 ft. per minute. The main valves are all of the piston type, one for the high pressure, two for the intermediate, and two for each low pressure cylinder, all worked from Stephenson double bar links. The valves for the high pressure and intermediate cylinders are each a single casting turned to a neat fit and without packing rings; the low pressure valves are fitted with packing rings and followers. The point of cut-off, in full gear, is at 7-10 of the stroke. The engine framing consists of forged steel columns, trussed by forged steel stays. The bed plates are of cast steel, supported on plate steel keelsons built in the vessel. The crank shafts form a single hollow forging.

There is only one condenser for both engines, of composition and rolled brass. The cooling surface is 8,400 sq. ft. There are four vertical single acting air pumps: two worked from the low pressure cross-heads of each engine; the diameter is 19 ins. and the stroke 6 ins. There are two centrifugal circulating pumps, each driven by an independent single cylinder engine; each



THE GREAT BRIDGE AT MEMPHIS, FROM THE TENNESSEE SHORE.

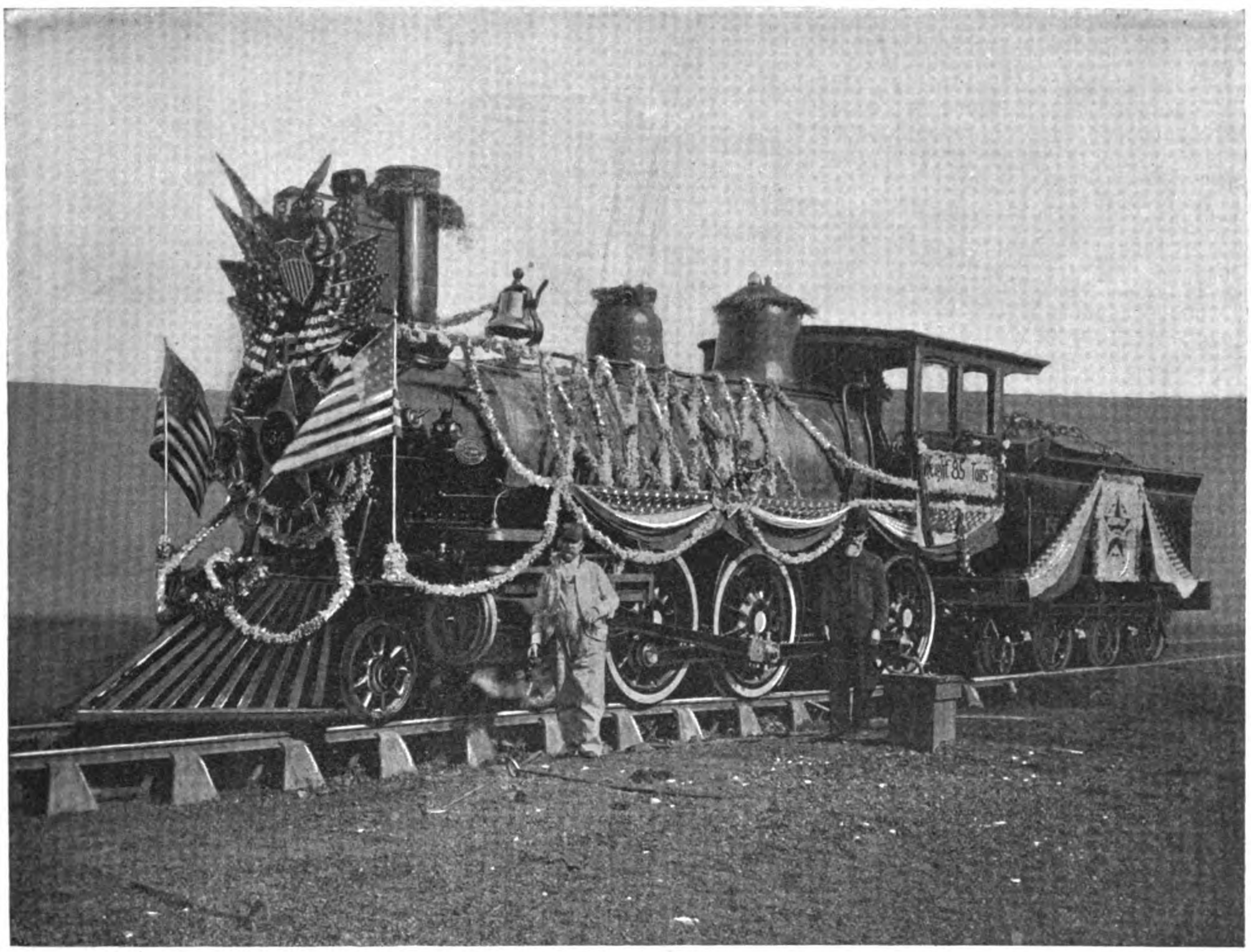
THE LENGTH OF THE MAIN TRUSS IS 790.42 FEET, MAKING IT THE THIRD LONGEST OF THE KIND IN THE WORLD.

MEMPHIS' MIGHTY BRIDGE.

MEMPHIS, Tenn., can boast to-day of one of the greatest bridges in the world. It has the longest spans of any truss bridge in the New World, and only two in the Old—the Forth Bridge in Scotland, and the Lansdowne Bridge at Sukkin, in India—surpass it in this respect.

the great States west of the river, and had no direct railroad communication with them. The new bridge now connects her with these States. The result is that Memphis becomes the railroad centre of the lines joining the States east and west of her, and of those lying north and south. What an enormous advantage this must be to the city, a glance at the map of the United States will show. It is no wonder that her citizens foresee in the opening of the bridge an era of prosperity denied to Memphis as long as she was cut off from direct communication with the Arkansas side of the river.

The building of the bridge had been agitated for many years, and the charter granted some time before work was commenced upon it late in 1888. The plans were drawn up by Mr. George S. Morrison of Chicago, and he has acted as superintending engineer of the whole work.



THE LOCOMOTIVE THAT LED THE FIRST TRAIN.

This great bridge, which, with its approaches, is about a mile and a half long, was built by the Kansas City, Memphis and Birmingham Railroad Company, and was opened on May 12th with considerable ceremony.

Over three hundred and fifty years ago Fernando de Soto and his company of Spaniards, lured on by the hope of finding gold somewhere in the interior, reached the eastern bank of the Mississippi. They first looked down upon the Great River, to whose waters De Soto's body was afterward to be consigned, from the Chickasaw bluff. From that bluff the bridge starts, and stretching across the river to the Arkansas side, continues through the forest, in the form of a viaduct, high above the low, swampy ground which during the spring is generally overflowed by the waters of the Mississippi.

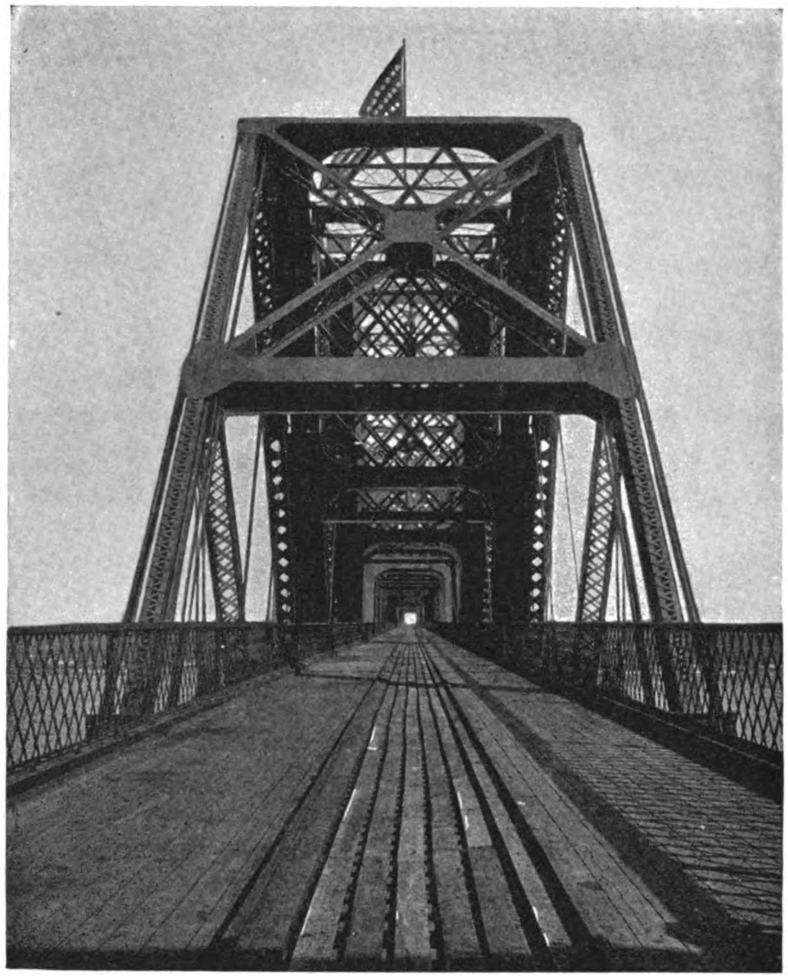
The advantage that Memphis has of being the geographical centre of the Southwest has been hitherto nullified to a great extent because she was cut off by the Mississippi from

The greatest difficulty encountered by the engineers was the placing of the caissons, and in the work of sinking and settling them in the bed of the river four lives were lost. This work was begun in December, 1889, and the coping of the last pier was laid May 15, 1891.

A caisson or chest used in laying the foundation of piers consists of a strong platform of timber or of metal plates. The site of the pier having been levelled by dredging, the caisson is moored over the spot. Two or three of the lower courses of masonry are then built upon the platform of the caisson, and the water is slowly admitted by means of a sluice in order to cause it to settle in its place. There is a metal column in the caisson, at the bottom of which is a chamber for the workmen employed in excavating. The column is open at the bottom, but the water is prevented from occupying the working-chamber by means of compressed air. Communication between this chamber and the atmosphere is effected by means of an air-lock, which serves as a means of exit and entrance for the workmen and the material they have to use. Before men or materials are admitted the air in the lock is raised to the pressure of the air in the working chamber; on the contrary, before the chamber is opened to admit their coming out, the air in the lock is lowered to the pressure of the atmosphere.

The caissons used in the building of the Memphis bridge were from forty to ninety-two feet long. There are five piers to the bridge, not including the anchor pier, and there are five spans. The east shore or cantilever span is 225.83 feet; the main span, consisting of two cantilever arms and one intermediate span, is 790.42 feet; there are two continuous spans 621.06 feet long, and one deck span 338.75 feet, making a total of 2,597.12 feet in the bridge proper. The viaduct, which stretches into the forest on the Arkansas side of the river, is 2,500 feet in length, and is followed by a timber trestle 3,100 feet long, and nearly a mile of embankment, to a junction with the track of the Kansas City, Fort Scott and Memphis Railway.

In July, 1891, the building of the false work for the central span was commenced, and in the following September was commenced the erection of the superstructure. On October 15th the central span was swung clear of the false work. The building of the false work for the span between piers 3 and 4 and the erection of that span followed next in succession, and were completed in December, 1891. The span between piers 4 and 5 was raised in January, and after that work was pushed on the cantilever span between piers 1 and 2 without false work, all the remainder of the bridge having been completed superficially. The two sides were joined in and the complete chain formed between Arkansas and Tennessee on April 6, 1892.



TENNESSEE END OF THE BRIDGE.

The following table gives the longest trussed spans now in existence or in the course of construction:

	Feet.
Forth, two spans, each	1,710
Lansdowne, one span	820
Memphis, one span	790.42
Memphis, two spans, each	621
Colorado River, one span	660

The principle of the cantilever used in the Memphis bridge has for centuries been practised by the Japanese bridge builders. A cantilever is the name of the bracket used in architecture for supporting balconies, cornices, and sometimes staircases. It is a structure overhung from a fixed base. The old Japanese bridge builders, when they wished to span a stream of considerable width, would imbed a great beam of timber on each bank with the ends projecting over the stream. These formed the cantilevers. A centre beam was then stretched across from one to the other, and there you had the crude idea of the cantilever bridge. In India there is one of these ancient bridges across the Sutlej, the side beams of which, a hundred feet in length, are imbedded to the extent of fifty feet in the masonry of vertical abutments, leaving fifty feet projecting. On their ends rests a centre-beam with which the span is made up to about two hundred feet.

At the opening of the Memphis bridge, before the dedicatory exercises began, eighteen great locomotives were sent across to test its strength. Upon a signal being given by the chief engineer, Mr. Morrison, the throttles of the locomotives were simultaneously opened, and the engines began to move slowly across the bridge, keeping close together in order to concentrate the weight as much as possible. When they reached the Arkansas side a tremendous cheer arose from the thousands gathered upon the Memphis side. It sounded like an expression of relief over the engines not having broken through and dived into the Mississippi.

The orator of the day was Senator Daniel Voorhees of Indiana, and he paid to the South all the tribute it could well stand in one afternoon for its recuperative power. "You have," he said, "removed the rubbish left by the most destructive tornado that ever swept the earth, and on their old foundations you have rebuilt States, now more powerful, progressive, and full of present and future greatness than ever before. You have risen superior to the most unjust and injurious system of National legislation that ever cursed a people, not excepting English laws for Ireland; and that system has totally perished, leaving only its memory, despised alike throughout the North as it is throughout the South. It is not a new South; it is the old South moving in connection with the revolution that has taken place. The old blood and brain power of the South, transmitted from generation to generation, are now aroused and working out the problem of her destiny. The old South is young again; she has renewed her mighty youth, and henceforth she will tower in her pride of place, regardless of the mousing owls that may hawk at and seek to destroy her. The world is looking in these closing years of the nineteenth century at the American Republic. The enemies of free government have made loud predictions that one section of the Union has been ruined by the other; that chronic aversion, strained relations, and ill-disguised hostility between the United States and the people of the States would follow the close of the war, never to be superseded by mutual esteem, affection, and a common prosperity. These predictions have been already proven false."

Memphis is expecting great things as a result of the enterprise she has shown in building her bridge. Among other things she hopes to have an open waterway to the sea, and become a port for transatlantic and other steamers.

["ENGINEERING SERIES."]

A RECORD

OF

THE TRANSPORTATION EXHIBITS

AT THE

WORLD'S COLUMBIAN EXPOSITION OF 1893.

BY

JAMES DREDGE.

Partly reprinted from "ENGINEERING."

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1894.

thick, with 5½ in. of hard wood behind. The vertical post is 12 in. thick, and a 2½-in. spindle runs horizontally through the post and the rubber disc to support the latter from falling sideways. Behind the post is a heavy mount on a timber column, and tied to the track by two rails, which embrace it on either side. To prevent the track rising, tie bolts are carried down to a sleeper buried at a depth of some feet. Further, the rails are bound together by an iron cross tie.

248.—THE EXHIBIT OF MR. G. S. MORISON.

The Bridge over the Mississippi at Memphis, Tennessee.

(Plate CLXXXIX.)

The fine bridge across the Mississippi at Memphis, Tennessee, which was built to the designs of Mr. George S. Morison, of Chicago, has a total length of 4988 ft. 9 in., of which 2290 ft. 7½ in. consists of an approach viaduct on the western shore of the river. The principal spans, however, are the cantilever channel span of 790 ft. 5 in., and two ordinary truss spans of 621 ft. each to the west of the cantilever span. In addition there are two smaller spans of 338 ft. 9 in., and 225 ft. 10 in., respectively, which, with an approach of 101 ft. on the east of the anchorage, make up the total. The structure ranks in point of size as the third of its type in the world, its greatest span being 790 ft. 5 in., as compared with 820 ft. in the Sukkur Bridge, India, and 1700 ft. in the case of the Forth. The following Table shows some of the principal particulars of the bridge:—

Table No. CIV.—General Particulars of Memphis Bridge.

Span.	Length.		Weight of Iron and Steel.	Height.		
	ft.	in.	lb.		ft.	in.
East of anchorage	101	0	66,700	Highest point to bottom		
Anchorage span ...	225	10	1,603,000	of lower chord ...	80	6
Channel ,, ...	790	5	4,699,300	Lowest chord to high		
Central ,, ...	621	0¾	5,274,300	water	75	4
West ,, ...	621	0¾	3,518.800	High water to low water	34	7
Deck ,, ...	338	9	1,073,000	Deepest foundation be-		
West viaduct ...	2290	7½	3,306,600	low water	96	3
Total ...	4988	9	19,541,700		286	8

The eastern end of the bridge, where there is an anchor span for the cantilever, rests on a rocky bluff, which is said to be that from which De Soto, the discoverer of the Mississippi, first gazed on its mighty waters. The western approach is over low-lying marshy ground, requiring, as shown in the above Table, a viaduct 2290 ft. long. The cantilever span is over the deepest part of the stream, and is the second in order from the eastern shore. The whole of the river piers were sunk by the pneumatic process, the depth of the bottom of the curb varying, in different cases, from 43½ ft. to 96¼ ft. below low-water mark, the latter being 34 ft. 7 in. below high water. The caissons, five in number, were, as usual in American practice, built of timber, every stick used being cut to drawings furnished to the timber merchants, and the work of construction was thus greatly lightened. The following figures show the dimensions of these caissons:—

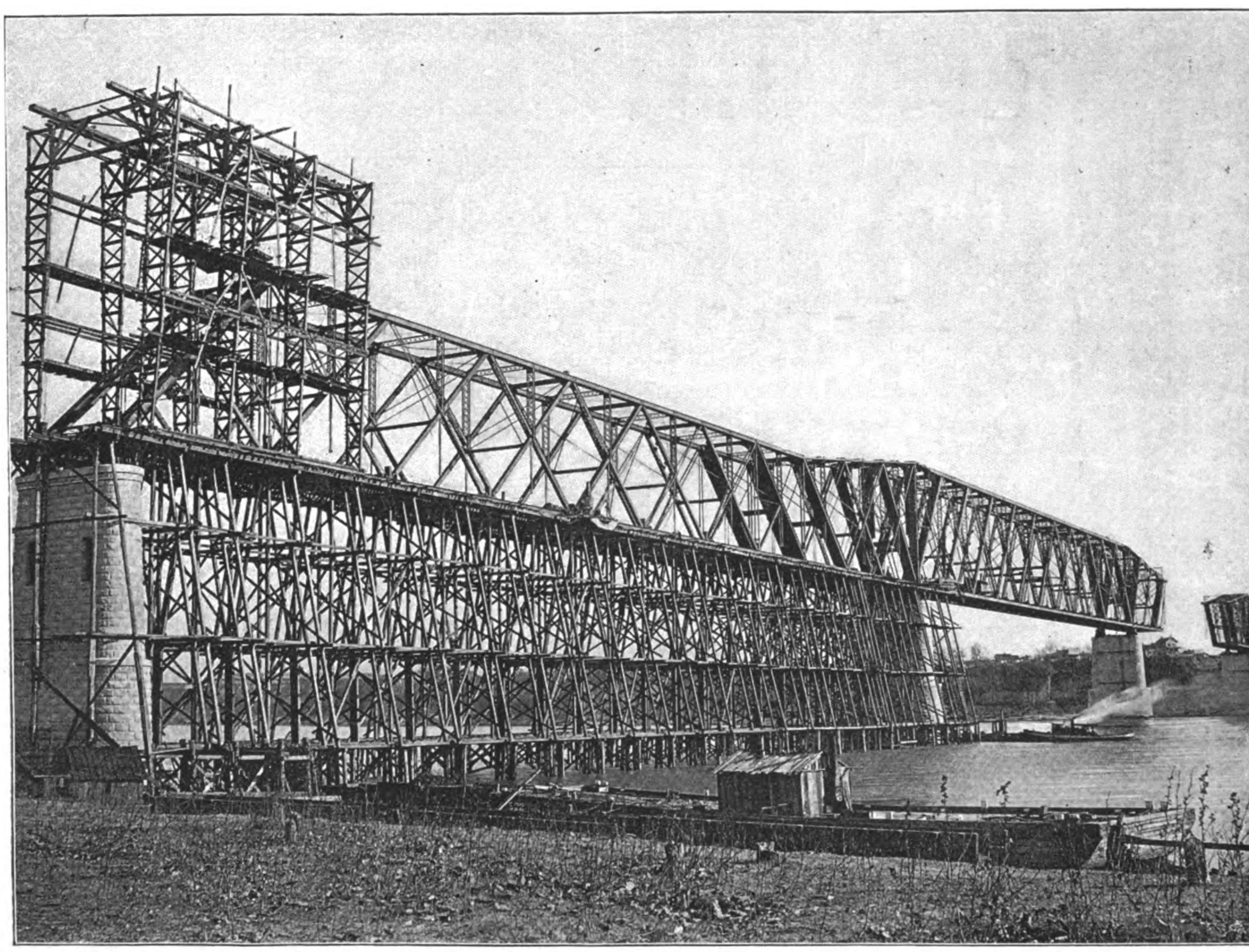
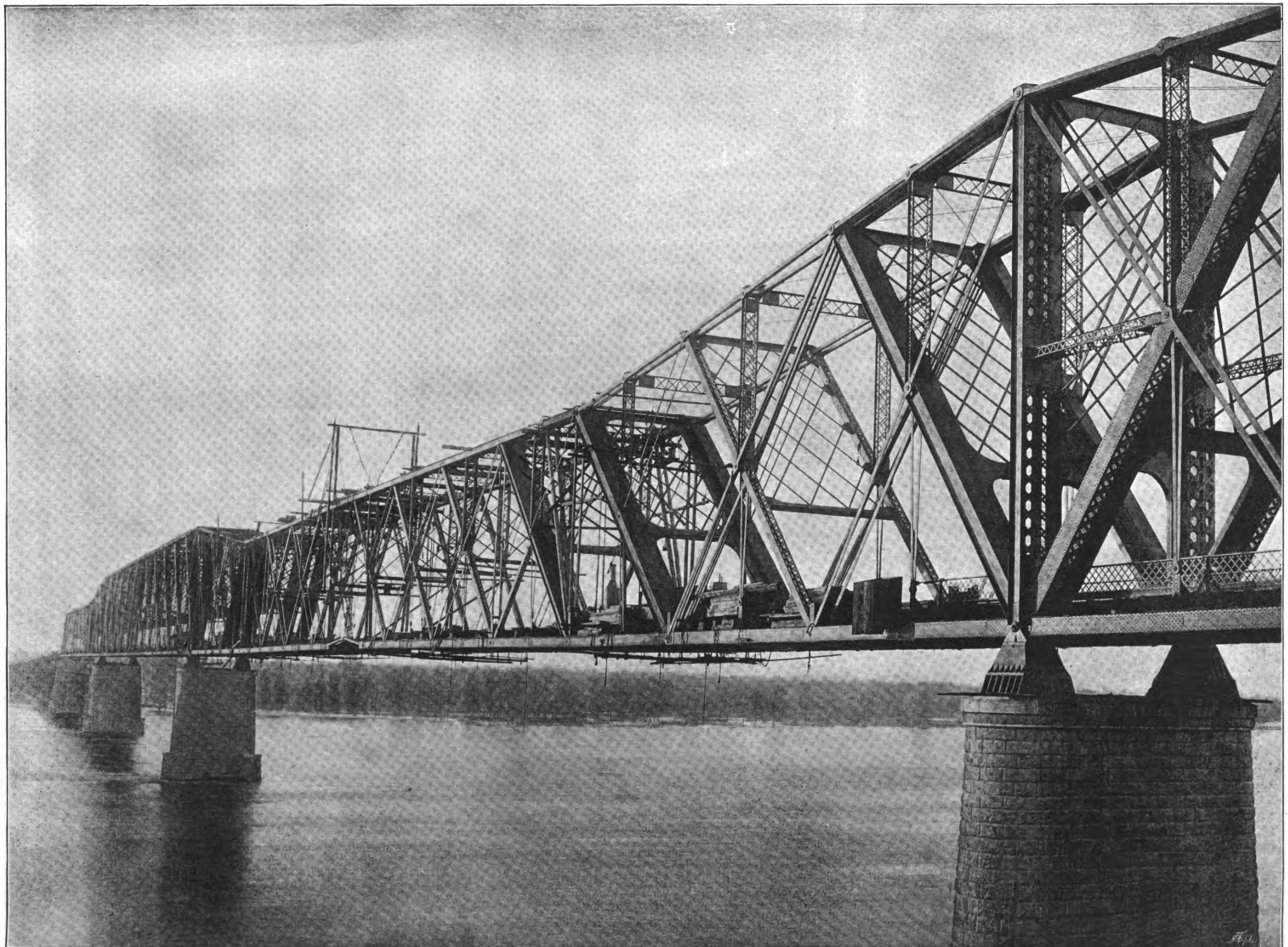


Fig. 338. Bridge over the River Mississippi at Memphis, Tennessee.

BRIDGE OVER THE RIVER MISSISSIPPI AT MEMPHIS, TENNESSEE.

MR. GEORGE S. MORISON, ENGINEER, CHICAGO.



Pier 1.	Caisson 70 ft. long,	30 ft. wide,	51 ft. high.
,, 2.	,, 92 ,,	47 ,,	60 ,,
,, 3.	,, 92 ,,	47 ,,	40 ,,
,, 5.	,, 40 ,,	22 ,,	80 ,,

The bed of the river at the point where the bridge crosses consists of 40 ft. to 50 ft. of coarse sand, which is very subject to scour. To prevent this taking place round the caissons whilst they were being sunk, mattresses of willow and brush were first made and sunk on the site of the future pier. The caissons were then sunk on the bed thus formed, and the water being expelled from the air chambers, men were sent down who cut through the mattresses and began the work of sinking. The mattresses formed a perfect protection to the river bed, and no trouble was experienced from tilting of the caissons, which would otherwise have been likely to arise owing to scour. When the sinking was completed, the mattresses were not removed, but left in position, rip-rap being thrown on them to form a further protection to the pier. The spoil from the working chamber was removed by forcing it up pipes. The greatest air pressure used was 47 lb. per square inch, at which the men worked in shifts of 45 minutes only, there being three shifts in the 24 hours. In spite of the care taken, four men died from caisson disease during the progress of the works. The whole of this work was done under the direct supervision of Mr. Morison and his representative, Mr. A. Noble, without the intervention of a contractor. The work was done very rapidly, as the following progress Table shows:—

TABLE No. CV.—PROGRESS OF WORKS ON MEMPHIS BRIDGE.

	Pier 1.	Pier 2.	Pier 3.	Pier 4.	Pier 5.
Began building	December 1, 1889.	May 17, 1889.	July 30, 1889.	November 24, 1888.	April 25, 1890.
Launched	Built in place.	July 29, ,,	October 26, ,,	December 15, ,,	Built in place.
Placed at pier site	December 21, 1889.	September 23, ,,	,, 28, ,,	,, 17, ,,	April 25, 1890.
Began filling with concrete ...	January 1, 1890.	,, 25, ,,	November 5, ,,	,, 23, ,,	May 8, ,,
Building completed	March 8, ,,	October 24, ,,	December 11, ,,	January 10, 1889.	,, 27, ,,
Filling ,, ...	,, 9, ,,	,, 11, ,,	November 27, ,,	,, 10, ,,	,, 30, ,,
Sinking commenced	January 10, ,,	,, 10, ,,	December 16, ,,	December 27, 1888.	,, 8, ,,
,, completed	April 18, ,,	,, 16, ,,	August 24, 1890.	February 6, 1889.	June 8, ,,
Sealing commenced	,, 18, ,,	,, 16, ,,	,, 18, ,,	,, 6, ,,	,, 8, ,,
,, completed	,, 22, ,,	,, 24, ,,	September 4, ,,	,, 10, ,,	,, 12, ,,
Masonry commenced	March 10, ,,	,, 26, ,,	December 12, 1889.	August 27, ,,	No masonry, cylinders May 28, 1890.
,, completed	June 23, ,,	April 25, 1891.	January 24, 1891.	September 3, 1890.	Set coping, May 15, 1891.

The masonry portion of the piers varies in different cases from 93 ft. to 158 ft. in height. The masonry consists of a limestone backing faced with granite, dimension stone being used throughout. The east abutment, to which the anchor arm of the cantilever is attached, is founded at a depth of 50 ft. below ground level, and contains 2500 tons of masonry. The following are the levels of various points of the piers, high-water mark being 216.2 ft., and low-water mark 181.6 ft.:—

TABLE No. CVI.—LEVELS OF PIERS, MEMPHIS BRIDGE.

	Pier 1.	Pier 2.	Pier 3.	Pier 4.	Pier 5.
Elevation cutting edge of caisson	137.85	88.09	85.39	122.94	124.93
Elevation top of caisson ...	190.69	147.29	125.01	173.38	204.93
Elevation top of masonry ...	283.17	283.17	283.17	283.17	241.91

Coming to the ironwork, it will be noted that the structure is pin-connected throughout. The trusses are spaced 30 ft. centre to centre, and the maximum height at any point is 77 ft. $7\frac{13}{16}$ in. between centres of pins. Steel was used almost exclusively, the exceptions being nuts, swivels, and wall pedestal plates, for the former of which wrought iron was used, whilst the pedestal plates were of cast iron. Three different grades of steel were used, viz.:—1. High grade steel in all the principal truss members. 2. Medium steel in the floor system, laterals, portals, transverse bracing, and the latticing of the truss members. 3. Soft steel used only for rivets, or at the option of the contractors in place of wrought iron, where the latter was specified. The steel had to satisfy the following laboratory tests:—

TABLE No. CVII.—STEEL SPECIFICATION, MEMPHIS BRIDGE.

	High Grade Steel.	Medium Steel	Soft Steel.
	lb. per sq. in.	lb. per sq. in.	lb. per sq. in.
Tensile strength, maximum ...	78,500	72,500	63,000
,, ,, minimum ...	69,000	64,000	55,000
Minimum elastic limit	40,000	37,000	30,000
	per cent.	per cent.	per cent.
,, elongation in 8 in. ...	18	22	28
,, reduction at fracture ...	38	44	50

No punching was allowed in the case of the principal truss members, save as regards the lattice bars. In the case of the members of medium steel, punching was allowed, provided the holes were punched less than their finished size and reamed out afterwards. The eye bars were specified to have their heads formed by upsetting. No welds were allowed. The heads were not to be more than $\frac{1}{16}$ in. thicker than the body of the bar, and on test the bar was to break always in the shank, and not in the head. Twenty full-sized bars were to be selected from time to time and tested to destruction in the large testing machine, Athens, Pa. Under these tests the bars were specified to develop an average stretch of 12 per cent. and a minimum of 10 per cent. before breaking, the stretch to be measured on a 20-ft. length, including the fracture. The elastic limit was specified to be not less than 32,000 lb., and the ultimate strength not less than 62,000 lb. The total amount of steel used, as shown by the Table, was about 8724 tons. The steel rivetting amounted, it is estimated, to about 100,000, which is, of course, a mere fraction of what it would have been in a rivetted structure. With the exception of the cantilever span, all the spans were erected on false work. The cantilever arms are 169 ft. $4\frac{1}{2}$ in. long, thus making the intermediate span 451 ft. 8 in. long. The expansion appliances are based on a range of temperature of 140 deg. Fahr. This important work was illustrated by a very beautiful model.

FIFTH ANNUAL REPORT.

Office of the

Kansas City, Fort Scott & Memphis Railroad Company,

50 STATE STREET, BOSTON, OCTOBER 26, 1892.

The directors of this company submit the following statement for the year ending June 30, 1892: —

	1892.	1891.
GROSS EARNINGS	$4,991,277 70	$4,703,141 82
(Increase, $288,135 88).		
OPERATING EXPENSES	3,634,674 47	3,389,217 89
(Increase, $245,456 58).		
Expenses, per cent. of Earnings	(72.82)	(72.06)
NET EARNINGS	$1,356,603 23	$1,313,923 93
(Increase, $42,679 30).		
MISCELLANEOUS INCOME	26,527 94 (Paid)	11,803 34 (Rec'd)
	$1,330,075 29	$1,325,727 27
CHARGES: —		
Interest on Bonded Debt (inc. coupon notes)	$1,043,726 22	
Sinking Funds		
Bonds former Ft. Scott branches	7,230 00	
Bonds Kansas Equipment Co.	12,000 00	
Traffic Contract (K. C., M. & B. R. R. Co.)	22,159 80	
TOTAL CHARGES	$1,085,116 02	$1,068,846 53
(Increase, $16,269,49).		
SURPLUS	$244,959 27	$256,880 74
(Decrease, $11,921 47).		

MEMPHIS BRIDGE.

The bridge over the Mississippi River at Memphis was opened for passage of trains on the evening of May 12th, 1892. It is now used for the passage of all of the trains of the St. Louis, Iron Mountain & Southern Railway Company, the Kansas City, Fort Scott & Memphis Railroad Company, and the passenger trains of the Little Rock & Memphis Railroad Company.

For future reference the following complete narrative of the progress of the work of building the bridge from the beginning, together with table of weights and heights, is given: —

The work on the bridge was commenced in October, 1888, with the building of a service track on the west side of the river. The building of the caisson for Pier 4, which was the first one undertaken, was commenced Nov. 7th, 1888. It was launched Dec. 15th and finished Jan. 12th, 1889; the sinking continued after this date until Feb. 5th, when the full depth was reached. The filling of the working chamber with concrete was completed Feb. 10th, 1889, this finishing the foundation of that pier. The masonry of the bridge was commenced with Pier 4, August 27th, 1889, and completed Sept. 2d, 1890. The foundation of this pier is 58.7 ft. below extreme low water at the bridge site. Height of coping above top of caisson 109.8 ft.; above cutting edge of caisson 160.3 ft.

The next caisson commenced was that for Pier 2 on April 18th, 1889; when partially built it was launched and placed at the pier site and there completed. The caisson was completed October 24th, 1889; the sinking was completed Oct. 16th, 1890, there having been a delay of several months during the season of high water in the winter, spring and summer of 1889 and 1890. The working chamber was filled with concrete and the foundation completed Oct. 24th, 1890. The base of the foundation is 93.7 ft. below extreme low water at the bridge site. Height of coping above top of caisson 135.9 ft.; above cutting edge of caisson 195.1 ft.

The framing of the caisson for Pier 3 was commenced July 30th, 1889, and the completed caisson was finished Dec. 11th, 1889. The sinking of this pier was commenced in the fall of 1889, was suspended during the season of high water, and was finally completed August 22d, 1890. The working chamber was filled with concrete Sept. 4th, 1890, finishing the foundation, the base of which is 96.2 ft. below extreme low water at the bridge site. Height of coping above top of caisson 158.2 ft.; above cutting edge of caisson 197.8 ft.

The building of the caisson for Pier 1 was commenced Dec. 4th, 1889, and completed March 8th, 1890. The sinking was completed April 18th, 1890, and the filling of the working chamber completed April 22d, 1890. The base of the foundation is 43.7 ft. below extreme low water. Height of coping above top of caisson 92.48 ft.; above cutting edge of caisson 145.3 ft.

The building of the caisson for Pier 5, which is about 150 ft. west of the bank of the river in Arkansas, was commenced March 4th, 1890, and completed May 30th, 1890. The sinking was completed June 8th, 1890, and the filling of the working chamber was completed June 12th, 1890. The base of the foundation is 56.7 ft. below extreme high water. Height of coping above top of caisson 37 ft.; above cutting edge of caisson 117 ft.

The masonry of the piers of the main bridge, which, as before stated, was commenced August 27th, 1889, was completed June 23d, 1891. These piers contain approximately 16,000 cubic yards of first-class masonry.

The length of the main bridge extending from the East Abutment to Pier 5 is 2681.81 ft., comprising three spans each 28.23 ft., making together 84.69 ft.; the Anchorage span 225.83 ft.; span from Pier 1 to 2, 790.42 ft.; from Pier 2 to 3, 621.06 ft.; Pier 3 to 4, 621.06 ft., and Pier 4 to 5, 338.75 ft. Following this on the west side of the river is an iron viaduct 2290.63 ft. long. This consists of twenty-three spans 29.5 ft.; twenty-two spans 59 ft. each; two spans 59.75 ft. each; two spans 86.25 ft. each; and one span 22.13 ft. In general the viaduct consists of spans alternately of 59 ft. and 29.5 ft. The bridge track is carried over the tracks of the Kansas City, Fort Scott & Memphis Railroad, and the St. Louis, Iron Mountain and Southern Ry., in the West Memphis yard on two spans 86.25 ft. each. West of the viaduct is a timber trestle about 3100 ft in length. This brings us to within 650 ft. of the crossing of the St. L., I. M. & S. Ry. The track is carried on an embankment from the west end of the timber trestle before referred to, across the St. L., I. M. & S. Ry. as above mentioned, and the Little Rock & Memphis R. R., to a junction with the K. C., F. S. & M. R. R., there being a trestle, however, of 300 ft., between the Little Rock & Memphis crossing and the junction.

The grade of the west approach is at the rate of 66 feet to the mile, from a point on the span between Piers 4 and 5 to a point 400 feet west of the end of the timber trestle where we reach the level of the tracks in that vicinity.

The east approach is in the limits of the City of Memphis, and provision has been made for the several street crossings. They are all grade crossings except the one at Delaware Avenue, which is about 170 feet east of the east end of the main bridge; there the tracks are carried over the street on a bridge of forty feet span. The grade of the east approach is sixty-nine feet per mile for the greatest part of the distance.

The erection of the superstructure was commenced February 21st, 1890, and was practically finished May 3d, 1892.

By the requirements of the charter, provision has to be made for the passage across the bridge of animals and vehicles. This traffic will be carried on the main floor of the bridge, from the Tennessee to the Arkansas shore; it will be diverted from the bridge on the east side at the East Abutment and at the west side at Pier V. It will thus be carried on the main bridge only, and not on the approaches or viaduct.

All the foundation work, as well as some other of minor importance, was done by the Company's own force. The masonry was built by Lewis M. Loss, of Rochester, N. Y., under contract. The material for the superstructure has been furnished by several companies, principally by the Union Bridge Company, The Pencoyd Iron Works, The Pennsylvania Steel Company, and Coffrode & Saylor. The erection of the superstructure of the main bridge has been done by Baird Brothers, of Pittsburgh, Penn., under contract; the erection of the viaduct by the Company's own force; the erection of the timber trestle by James Saguin, of Council Bluffs, Iowa. A number of smaller contracts have been carried out for grading and other small work.

The foundations of the main piers rest, in every case, on clay. This is generally a very tough material, which will support a great load per unit of surface, and will resist scour for a long time.

The face stone for the portion of the piers which will show above extreme low water is of granite from the Lithonia quarries in Georgia; the remainder of the piers of limestone from Bedford, Ind.

The material for the superstructure of the main bridge is almost wholly steel; of the viaduct, steel and iron. The whole structure is calculated to carry a load of 4,000 pounds per lineal foot.

WEIGHTS OF IRON AND STEEL.

East of Anchorage	66,700 pounds.
Anchorage Span	1,603,000 "
Channel "	4,699,300 "
Central "	5,274,300 "
West "	3,518,800 "
Deck "	1,073,000 "
West Viaduct	3,306,600 "
	19,541,700 pounds.

HEIGHTS.

Highest point to bottom of lower chord	80 ft. 6 in.
Lower chord to high water	75 " 4 "
High water to low water	34 " 7 "
Deepest foundation below low water	96 " 3 "
	286 ft. 8 in.

There are yet unfinished, the highway approach on the west side; additional mat and rip-rap work around piers II. and III., and grading and paving for shore protection on the east side of the river; but it is expected that everything will be completed before the end of November next.

Accompanying this are the reports of the Comptroller showing details of construction and operating expenses for the fiscal year.

GEO. H. NETTLETON,

President and General Manager.

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CXIV.

EDITED BY

JAMES FORREST, Assoc. Inst. C.E., Secretary.

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1893.

(*Paper No. 2647.*)

"The River Piers of the Memphis Bridge."

By GEORGE SHATTUCK MORISON, M. Inst. C.E.

THE Memphis Bridge crosses the Mississippi near the southern limits of the city of Memphis, in latitude 35° 8′ north, and longitude 90° 5′ west, and is situated 232 miles below the junction of the Ohio and the Mississippi rivers at Cairo, Illinois. The authority for its construction was conferred by an Act of Congress, approved April 24th, 1888.

It is the first bridge across the real Mississippi. The Ohio and the Mississippi, though of about equal magnitude where they unite, are streams of very different character. The former river, with its great tributary the Tennessee, comes from a stable country, but is subject to extreme floods early in the year. The Mississippi, whose features are controlled by its greater tributary the Missouri, is subject to less violent floods than the Ohio, but possesses all the uncertain elements of a silt-bearing river; its greatest flood generally comes in June. At Memphis, the river feels the floods of both the Mississippi and the Ohio, though those contributed by the latter river are the more dangerous. The two sets of floods generally result in high water for about one-half the year. The rainfall in this part of the Mississippi valley is abundant, and the climate of Memphis is rather damp. Whilst some snow falls nearly every winter, the amount of frost is insufficient to exercise any essential influence on building operations. During three of four winters while the bridge was under construction, no ice was seen in the river. The position of the river has remained unchanged for a long series of years at the site of the bridge, and, as always happens in such cases with silt-bearing rivers, has become narrow and deep. The low-water width is about 2,000 feet, though the west shoreline has been somewhat variable. Low water, which is of rare occurrence, is 181·76 feet above mean tide-level in the Gulf of Mexico, at the Government gauge 2 miles above the bridge site. At the bridge site it is 181·6 feet, as nearly as could be determined. The highest water-level that has been observed at Memphis occurred on March 25th, 1890, and was 216·2 feet above datum at the bridge site. All elevations given in the Paper refer to this tide-level datum.

The requirements of the Government charter fixed the minimum span at 600 feet in the clear, with a channel span of 700 feet. The Secretary of War required the long span to be next to the Tennessee shore, and indicated a preference for a span of 770 feet in the clear. The bridge as built, crosses the river with one span of 790 feet 5 inches and two spans of 621 feet $\frac{3}{4}$ inch between centres of piers.

The three bridge-spans rest upon four masonry piers. Two of these are near the low-water shore lines, and may be properly termed shore piers. The other two are in deep water, and are properly called river piers, and of these the Paper treats. The east pier is known as Pier II, and the west pier as Pier III. The plans of the two piers were prepared in January, 1889. The data from which their character was decided upon were a set of borings which had been made two years previously, and such information as had been obtained during the sinking of the caisson of the west shore-pier. Soundings had shown the bottom of the river to be 145 feet above datum at the site of Pier II, and 160 feet at the site of Pier III. The borings had found clean river sand to 98 feet above datum, near the site of Pier II, and to 108 feet at the site of Pier III. At these levels clay was encountered, which, at the higher levels was somewhat variable in quality, but into which one boring was made down to 61 feet above datum. This clay forms part of an immense deposit known as the La Grange formation, which is about 150 feet thick, and perfectly water-tight. Under this clay lies water-bearing sand or gravel, the outcrop of which is perhaps 50 miles east of Memphis, and at a somewhat greater distance west of that city. The water-supply of the city is derived from artesian wells passing through the La Grange clay into the underlying water-bearing sand, and the wells which have now been driven afford valuable data as to the thickness of the clay. Ten of the wells sunk at Memphis have found the bottom of the clay at depths varying between 6 feet and 93 feet below the datum. A well situated $1\frac{1}{2}$ mile west of the bridge found the top of the clay at 85 feet, and the bottom at 58 feet below datum. A cross-section of the river, showing the material found by the borings and in the caissons, is given in Fig. 1, Plate 6.

It was evident that the foundations must be sunk through the sand and into the clay, and that, whilst it was important to secure a thorough bearing everywhere on this clay, it was probably so compact that difficulty would be experienced in any attempt to dredge it. Plans were therefore made to meet the four requirements:—(1) The weight of the piers to be limited as much as possible; (2) Provision to limit the scour, at least during the construction of the work; (3) The base of the foundation to be large enough to keep the pressure within safe limits, even on a compressible clay. (4) The method of sinking selected to be the 'plenum' pneumatic process.

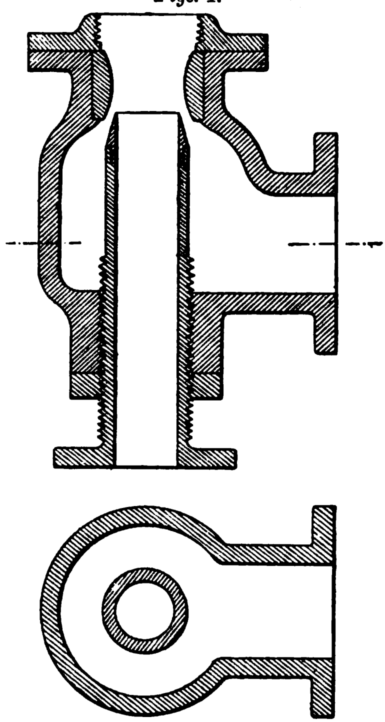
To keep down the weights, it was determined to build a high quality of masonry, to diminish the dimensions of the piers to a minimum, and to build the lower portions of the piers hollow, a device which, objectionable in cold climates, seemed prudent here. The method of limiting scour was to carpet the bottom of the river with a woven willow mat, built floating on the surface of the water and then sunk in position by loading it with rip-rap. This device, which is believed to have been originated by the Author, proved successful. When the plans were prepared, it was thought that a satisfactory bearing for Pier II could not be found higher than 83 feet above datum, but that a safe foundation for Pier III would be found 20 feet higher, or at 103 feet above datum. It was also thought that the bottom of the river could be maintained at the site of the piers at about 140 feet above datum. The general rule followed in determining the size of the foundations was to make the caissons of such construction that the weight of material below the bottom of the river should not be greater than that of the sand which they displaced; and that, after deducting 400 lbs. per square foot for friction on the sides of the caissons, the weight placed on top of the latter should not produce a pressure on the foundation exceeding 2 tons to a square foot. The base required for such foundations was 92 feet long by 47 feet wide, and it was thought best to build the caissons with vertical sides below the bottom of the river.

The caisson for Pier II, with its upper works, was made 59·4 feet high, and that for Pier III, 39·6 feet high, both being alike in all respects, except in vertical dimensions. This was an error of judgment. It would have been wiser to have made them exactly alike, and each 50 feet high. Good material was found at the site of Pier II, a few feet higher than was expected, and the square foundation projects above the bed of the river. It was necessary to go deeper with Pier III than with Pier II, and the masonry of this pier begins 10 feet lower than had been desired. The caissons are illustrated in Figs. 2. They are built of southern pine timber, most of which came from the State of Mississippi. The cutting-edge is iron, of a form used by the Author at other bridges; this shape is preferred because it at once permits access to the actual edge when obstacles are encountered, and provides a shoulder on which the caisson can bear when sinking through sand, the edge that projects below this shoulder preventing an influx of sand from without. The V-shaped walls surrounding the working-chamber, and the entire space between the timbers for a height of 17·3 feet above the bottom, were filled with concrete after the caisson was placed in position. Above this concrete filling, for a height of 26·7 feet in Pier II, and 11·9 feet in Pier III, the interior portion only of the structure was filled with concrete, the outer parts being left empty. The upper 15·4 feet in Pier II, and the upper 10·4 feet in Pier III, are of solid timber.

The vertical side-walls are bound together by fifty-four 2-inch rods, the lower lengths of which pass through the timbers—the nuts being screwed against the under side of the shoulder of the cutting-edge and against washers on the top; in the upper part of the work, these rods are placed immediately inside the timbers. There are also twenty-four 2-inch rods similarly placed in the cross-walls, and connected with 1½-inch rods extending through the concrete. Besides these, 112 rods of the latter size extend from the roof of the caisson to the top of the concrete, near the timber intersections; and the inclined walls of the caisson are tied to the outside vertical walls with 96 rods of similar section passing across the V-shaped space. The sides of each cross-wall are tied together by thirty-six 1-inch bolts, and the timbers of the roof are tied together by three hundred and ninety 1-inch bolts. The successive courses of timber in the outer walls are fastened together with 1-inch round drift-bolts 34 inches long, spaced 5 feet apart; and as these bolts alternate in successive courses, the actual distance between them is only 30 inches. The timbers of the inclined walls of the working-chamber are fastened with drift-bolts 30 inches long spaced 3 feet apart; and the cross-walls are fastened with drift-bolts in the same manner as the outer vertical walls. The timbers of the solid filling above the concrete are fastened with thirty-four 1-inch drift-bolts spaced 8 feet apart in every stick, thus making the actual distance between the bolts 4 feet. The outside planking is secured by two 7-inch by ½-inch boat-spikes to each square foot of plank, and all other planking is fastened with two 7-inch by ⅜-inch boat-spikes to each square foot. The corners are rounded and plated with ⅜-inch iron. The larger caisson, for Pier II, contains 1,548 M.B.M. of timber and 424,000 lbs. of iron. That for Pier III contains 1,078 M.B.M. of timber, and 340,000 lbs. of iron.

The great depth to which the foundations were sunk, as well as the fact that a considerable amount of clay had to be penetrated, made it important to provide special machinery for passing the men up and down, and for removing the clay. Each caisson was provided with four 24-inch shafts for the removal of material, and these shafts were used to send in the concrete with which the working chamber was finally filled. Besides this there was one 36-inch shaft with a double air-lock at the bottom, of the pattern used on the piers of other works built by the Author; and one 6-foot shaft with a special air-lock at the bottom, and fitted with an elevator cage for the use of the men. Besides this, the usual provision was made of pipes for air- and water-supply, and for the removal of sand.

Figs. 4.



Scale $\frac{1}{4}$.

The device selected for the removal of the clay was what is known as a "clay hoist." It was originally designed by the Author for use on the Rulo Bridge, and had been used at Sioux City and Riparia. This arrangement is shown in detail in Figs. 3. It consists of an air-lock at the top of the shaft, behind which is placed a cylinder and piston; the speed of the piston is multiplied by two sets of sheaves, so that the stroke of the piston will lift a bucket from the bottom of the caisson to the air-lock on top; the air-lock is provided with two doors, one of which opening into the shaft below is closed by a lever with a balance weight on the outside, and the other opening into the open air is worked by the attendant outside. The only power used is the air-pressure of the caissons. The bucket carried $6\frac{1}{2}$ cubic feet, and twelve buckets have been passed out by a single hoist in an hour. Four hoists were provided, but no more than two were ever used at a time. *Figs. 4* show the form of sand-pump used in the caisson to remove sand by a column of water. It is the same in principle as the Eads pump used at the St. Louis Bridge, but is much simpler in construction. The special air-lock and shaft are illustrated in Figs. 5. The passenger-hoist is simply a hoisting-engine placed on the top of the working shaft, and so arranged as to be taken off with a derrick and quickly replaced when it was necessary to add a section to the shaft. The engine has large cylinders, and instead of being driven by steam, is driven by air from the caisson. The upper shaft through which the elevator-cage runs, is a cylinder 6 feet in diameter, the air-lock is 6 feet in diameter, and the shaft leading to the caisson is 4 feet in diameter. These three cylinders are side by side, the shells being connected by cast-iron door-frames carrying doors; while a fourth door opening outwards is placed at the bottom of the lower shaft; in working, the door between the two shafts was always kept closed, and the door at the bottom of the bottom shaft was always left open. It would have been possible, however, if an emergency had arisen, to use the lower section of the shaft as an air-lock by itself. When the filling of the working-chamber was completed the bottom door was permanently closed. The only power used to raise either men or material was the air of the caisson; and while this arrangement may not be as economical of power as the direct use of steam, it had the advantages of convenience and of improving the ventilation of the caissons.

It was hoped that the two foundations might be completed during the low-water season of the autumn of 1889, a hope destined to be disappointed. The first timber for the caissons was received on the 1st April, 1889, and framing was begun on the 18th of that month. The timber was received in a yard on the east side of the river, about 2,000 feet below the bridge line. A Daniels planing-machine was used to size the timber in the yard, the 12-inch timber being thus reduced to $11\frac{3}{4}$ inches; this reduction explains the slight irregularity in vertical dimensions. All other work was done by hand with ordinary carpenters' tools. The caissons were put together on launching-ways; being built directly in front of the framing-yard, and at the edge of the water. The foundation of these ways was of cypress piles driven about 25 feet into the ground. The piles were cut off and capped with 12-inch square timbers running parallel with the river, and on these were placed the ways proper; which were drift-bolted to the caps and inclined at 1 in 4 for a length of 48 feet, and at 1 in 3·43 for the remainder. The launching-shoes, which were simply transverse timbers, were placed on these ways, the cutting-edge was set up on the shoes, and the caisson was built up to a height of 17·8 feet from the lower edge of the iron in this position.

The building of the caisson and the construction of the lower portion of the ways proceeded simultaneously. The ways were completed on the 27th of July, and two days later the caisson for Pier II was successfully launched. The caisson was fitted with a false bottom, which, however, was simply intended to prevent the lower edge from settling too rapidly in the water, and was not made tight. When the caisson was launched it drew about 12 feet. It was then kept near the bank until the condition of the river admitted of its being put in position. The caisson for Pier III was meantime constructed, and was launched on the 26th of October.

The plant for handling the work in the river comprised:—

Two steam-boats with pneumatic plant complete; one tug-boat; two anchor barges; one derrick-boat; one pile-driver boat, used also as a derrick-boat; one boat carrying a concrete-mixer; one house-boat for workmen; two barges with weaving-ways for mattresses; seven material-barges. The two steam-boats were built originally to serve as transfer boats on the Missouri. They were side-wheel boats of the type common on western rivers, each having four high-pressure boilers and two long-stroke poppet-valve engines with independent wheels. The nine barges were ordinary coal barges, such as are used on the Mississippi, 25 feet by 130 feet, and 7 feet deep; they were decked over to fit them for this work. This plant was exclusive of that used by the masonry contractor.

Before the caissons could be placed in position, the mats which were to protect the pier sites from scour had to be placed. Two barges were fitted with ways for weaving the mats, and two mooring-barges were anchored above the site of the pier, across the stream. The weaving-barges were then placed below the mooring-barges, and the material-barges were brought to the lower side of the latter. The mat was then woven on the ways, and the upper end of it was fastened to the mooring-barges and to the anchors which held them—each anchor having one line leading to one of the mooring-barges, and another line leading under the mooring-barge to the mat. As the weaving proceeded, the weaving-barges dropped down stream, so that when the mat was entirely completed, they were at the lower end, and the whole mat, 240 feet wide and 400 feet long, was floating on the water. It was then loaded with stone until it barely floated, and the upper end was submerged, but held near the surface by the lines leading from the mooring-barges. Two barges loaded with stone were then brought to the upper end of the mat, and stone was thrown from them upon it; as it sank the barges were dropped down stream until the mat settled on the bottom. When these barges had passed over about one-half the length of the mat, the mooring-lines were cast off, and the upper end was allowed to sink to the bottom. The time required to sink the mat did not exceed ten minutes. In the case of the first mat sunk, soon after the upper end had been dropped on the bottom, the anchors dragged and the mat took a position about 120 feet further down stream than had been intended. Two mats were placed at the site of Pier II, each one containing 1,000 cords of brush and poles, 900 tons of rip-rap, and 10,000 lbs. of wire.

To facilitate handling the caisson in position, two special barges were anchored above the pier site, the lines by which the caisson was held were fastened to these barges, and a double-drum winding-engine on one of them was employed to haul the lines. The anchors used were of the pattern known as box-anchors, consisting of timber cribs, each 10 feet cube inside the timbers, filled with stone. They were built on barges, thrown overboard at the place where they were wanted, and were never recovered. Each barge was held by six steel-wire ropes 1¼ inch in diameter, leading to separate anchors, so that twelve anchors and twelve wire cables were used for one caisson. On the 23rd of September, these anchorage arrangements having been completed, the caisson for Pier II was brought into position, and was held at first by two wire ropes leading to the anchor-barges. It was also anchored laterally by a 4½-inch Manilla rope passing from each of two anchors situated about 500 feet distant on either side of it, through snatch-blocks, to one of the anchor-barges above. This method of anchoring and handling the caisson was devised and carried out by Mr. Noble, the Resident Engineer.

Fortunately, the current in the river was slight at this time, and no special difficulties were experienced in placing the caisson. After it was securely anchored, the concrete filling of the spaces above the working-chamber was begun, and the building of the upper works was carried on at the same time. As this proceeded, the number of anchor-lines leading from the caisson to the barges was increased until their strength was about the same as that of the lines from the barges to the anchors. On the 7th of October, the caisson grounded at 151·6 feet above datum, in 36 feet of water. Air-pressure was applied on the 10th, and fourteen days were spent in cutting away and removing the two thicknesses of mat underneath the caisson. Meanwhile the concrete filling was completed, and sinking proceeded regularly from this time, the sand being excavated by columns of water driven through sand-pumps. On the 23rd of October, the laying of masonry was begun; but, on the 30th of November all work was suspended for ten months, the water having risen to such a height that it was considered inexpedient to do more at present. The shoulders under the cutting-edge were blocked, and the foundation was abandoned until the low-water season of the following year.

The situation of Pier III was considered to be less exposed than that of Pier II, and one mat only was woven for this pier. The caisson was brought into position without serious trouble, and the concrete filling was begun on the 5th of November. The river had already begun to rise, and it continued to do so until the 25th. These three weeks formed the most critical time of the entire work. During the rise of the water, the current in the river made an angle of about ten degrees with the axis of the pier, and tended to move the caisson towards the west; on the 19th of November, the caisson was 20 feet out of place; by the aid of two tugs and of five lines leading to Pier II, it was brought within 5 feet east of its true position; four days later, all the lines leading east and one of the north-eastern lines parted, and the caisson was carried 50 feet west of its true position. Five coils of wire-rope were brought from St. Louis—350 miles—in one night; and anchors were added, until the caisson was held by eighteen wire-ropes up-stream, and five leading eastward. With these lines the caisson was brought into correct position and held there until it was completely sunk on the 10th of December, in 44 feet of water; on the following day the caisson and upper works were completed. It had been necessary to build up the sides of the caissons before putting in the solid timber, and to carry it up 4 to 6 feet above its intended height by false sides. The caisson had been saved, and no serious loss experienced. Its safety may be ascribed to: first, the mat which prevented the deepening of the bottom; and second, the strength of the anchorages. Air-pressure was applied, the mat was cut through, and sinking was conducted in the same manner as at Pier II, until the clay was reached on the 7th of February, 1890; one week later, work was suspended until the river should be in a condition more favourable to the work. Before stopping work, borings had been made below the edge of the caisson and a well sunk into the clay, which proved to be of a less substantial character than had been expected; and it became evident that the foundation must be carried lower than was originally intended.

By the middle of June the water had fallen sufficiently for work to be resumed, and on the 4th of September the foundation was completed at a depth of 18 feet lower than had been originally intended. The masonry was completed on the 23rd of January, 1891. The increased height of the pier was made entirely in the masonry, the batter being correspondingly reduced.

In September, 1890, work was resumed on Pier II; no work had been done on it for eight months, and for more than three months the entire work had been submerged. Early in the morning of the 10th of February, the steamer "Port Eads," going down the river with a tow of barges, struck the submerged pier and sank, an accident which unfortunately resulted in the loss of five lives. The cutting-edge of the caisson reached its final level on the 16th of October. An experimental well was sunk to 86·0 feet above datum, and a boring was made from the bottom of this well 10 feet lower. The whole pier, including the masonry, was finished on the 25th of April, 1891. This foundation had been sunk 6 feet less than had been expected, and the difference required for correct dimensions was obtained by a slight offset in the masonry.

The entire work on the foundations was done by men employed by the bridge company, under the direction of the Resident Engineer, the number of men worked on one foundation sometimes amounting to one hundred and sixty. When the work was begun, the caisson force was divided into three gangs, each of which worked eight hours in four-hour shifts; but as the depth increased, the working hours were shortened until, at the maximum depth, the actual working time in the caisson was reduced to two hours per day, divided into three shifts of forty minutes each, the same men going in at intervals of four hours. Good accommodation was provided for the men on the house-boat, with facilities for bathing and drying clothing. During twenty-five days the work on Pier III, and during twenty-eight days the work on Pier II, was carried on in over 100 feet of water. The actual maximum depth at which the men worked was about 108 feet.

The concrete used was composed of crushed limestone, sand, and cement. The sand was dredged from the bottom of the Mississippi river, and was of excellent quality. The cement used was manufactured near Louisville, Kentucky. In special portions of the work, German Portland cement was used. The concrete was generally made in a mechanical mixer, the capacity of which was about 20 cubic yards per hour. The mixer, together with a derrick and hoisting-engine were carried on a barge 90 feet long, 30 feet wide, and 5½ feet deep. A platform, large enough to handle three batches of concrete, was built on the barge about 5 feet above the deck, and the mixer was placed under this platform. The cement and sand were first thoroughly mixed together, spread over the crushed rock, and shovelled whilst dry into the mixer where the water was added. The mixer discharged the concrete directly into buckets which were delivered by the derrick where required. The concrete above the working-chamber was generally gauged one barrel of cement to 7½ cubic feet of sand and 13¾ cubic feet of crushed rock. In the lower portion of the V-shaped walls, where some leakage existed, the proportion of crushed rock was reduced nearly one-half. The concrete used to fill the working-chamber was generally mixed similarly to that used above, but the amount of crushed rock was reduced in all places difficult of access; the lowest 2 feet of concrete was made with Portland cement, and the 6 inches of filling under the shoulder of the cutting-edge, the cross walls and the flat surface of the roof were Portland cement mortar, three parts of sand to one of cement; all other parts of the filling were Louisville cement concrete.

The masonry of Pier III is shown in Figs. 6. That of Pier II is very similar, with the slight differences before mentioned. The form of pier is substantially the same as that designed by the Author for the Plattsmouth Bridge, and used subsequently on the B. C., Omaha, Rulo, Nebraska City, Sioux City, Cairo, and St. Louis Merchants' Bridges. It is a form which passes the water with little disturbance, and affords a convenient shape for the superstructure.

The cost of the two piers is given in the Tables below:—

PIER II.

—	Material.	Labour.	Total.	—
Launching-ways	$1,792·31	$1,824·51	$3,616·82	
Caisson	45,850·47	24,168·05	70,018·52	
Concrete above chamber	10,528·76	3,847·05	14,375·81	
Concrete in chamber	3,814·66	1,310·46	5,125·12	$93,136·27
Mattress	12,362·57	5,634·31	17,996·88	
Anchoring caisson	4,619·63	2,087·55	6,707·18	
Sinking caisson	17,215·52	50,826·11	68,041·63	
Lighting pier	260·70	2,398·71	2,659·41	
Insurance	552·51	..	552·51	
Placing, sinking, &c.	..	..		$95,957·61
Total foundation	..	..	..	$189,093·88
Masonry (4,197 cubic yards)	..	..	..	$108,669·14
Total cost	..	..	..	$297,763·02

PIER III.

—	Material.	Labour.	Total.	—
Launching-ways . . .	$1,885·50	$1,788·07	$3,673·57	
Caisson	33,117·46	17,976·84	51,094·30	
Concrete above chamber .	7,393·20	2,448·66	9,841·86	
Concrete in chamber . .	6,383·15	2,174·86	8,558·01	$73,167·74
Mattress	4,543·43	2,127·85	6,671·28	
Anchoring caisson . .	7,557·02	3,778·95	11,335·97	
Lighting pier	55·81	178·69	234·50	
Sinking caisson . . .	19,432·91	59,534·01	78,966·92	
Insurance	394·81	..	394·81	
Protecting foundation .	562·55	101·28	663·83	
Placing, sinking, &c. .	..	..		$98,267·31
Total foundation . .	..	..	..	$171,435·05
Masonry (4,870 cubic yards)	..	..	..	$124,442·67
Total cost	..	..	..	$295,877·72

The protection mat-work which still remains to be done will bring the cost of each pier up to about $300,000. The first cost of the plant is not included in the above Tables.

Both the foundations rest on clay, Pier II being sunk 13 feet into the clay, and Pier III 21 feet. In the case of Pier III the last 9 feet were of a very sandy character, so that the foundation of the former is the better of the two. Both piers, however, rest on an entirely solid clay, free from sand. Special tests were made to determine the bearing strength of this clay. The method adopted was to cut out a large block of it, and, without giving time for it to dry or slack, to trim it so as to make a 2-inch cube protruding from a large mass of clay below; pressure was then applied to the top of the 2-inch cube. Four samples, which were taken from the chamber of Pier II, about 1 foot above the final position of the cutting-edge, were tested, with the following results:—

No. 1 broke under 423 lbs. pressure. As the weight was applied it compressed gradually. When compressed $\frac{1}{32}$ inch it gave way suddenly at the bottom, two-thirds of the top being uninjured. No. 2 broke under 343 lbs. pressure. This sample compressed $\frac{1}{32}$ inch, and then broke suddenly into several pieces. No. 3 broke under 303 lbs. pressure. It did not yield gradually, but broke suddenly along dry cracks. No. 4 broke under 343 lbs. pressure. No compression appeared to take place. The top slipped off suddenly along a joint in the clay, and it broke in two nearly equal pieces.

Three samples tested were taken from the clay on which Pier III rests, with the following results:—

No. 1	broke	under	503	lbs. pressure.
No. 2	,,	,,	503	,, ,,
No. 3	,,	,,	603	,, ,,

The first and second samples had small cracks in them, the third sample appeared to be sound.

In behaviour, the clay resembles rock rather than an ordinary clay, and is capable of withstanding much greater pressures than the piers put upon it. It is also well adapted to resist scour. It is important to compare the strength of the clay as thus tested with the actual weights put upon it. The four tests made of clay from Pier II show an average strength of 13,400 lbs. per square foot when entirely unsupported at the sides. The three samples tested from Pier III gave an average strength of 19,300 lbs. per square foot.

		Lbs. per Square Foot of Foundation.
The actual weight above the foundation of Pier II is, with the live load on the bridge.		10,410
Deduct for buoyancy below 182 feet above datum .	3,722	
It is expected that at least 40 feet of this foundation will be perpetually buried in the sand; and, to obtain the increased pressure on this area of foundation, deduct the weight of this sand in water	2,320	
Deduct the skin-friction on 40 vertical feet of caisson, assumed to be 400 lbs. per square foot	1,029	
		7,071
Actual probable pressure		3,339

It would therefore appear that, making no allowance for buoyancy, the intensity of pressure on the foundation is less than that borne by the unsupported cubes experimented upon without material compression or deformation of shape; while the actual pressure, without allowance for skin-friction, is less than one-half that borne by those cubes. Further, it must be remembered that this foundation is 40 feet below the bed of the river, and that the mats around the piers will probably prevent scour near to the latter.

The pressures for Pier III are:—

		Lbs. per Square Foot of Foundation.
Actual weight		9,934
Deduct for buoyancy below 182 feet above datum .	3,075	
Deduct for sand displaced.	2,320	
Deduct skin-friction	1,036	
		6,431
Actual probable pressure		3,503

The pressure on this foundation is a little greater than that on Pier II. As already stated, it would have been wiser to make both caissons alike and both 50 feet high, instead of 40 and 60 feet.

During the progress of the work, the river at the site of the bridge showed a gradual tendency to become deeper. This is illustrated by the seven different sections of the river bottom in Fig. 7. It will be observed that this tendency has been more marked in the western than in the eastern half of the river, and it will also be noted that the probable limit of scour is about 40 feet above the bottom of the foundation. Of course this scour may be greatly increased by local disturbances, but it is hardly conceivable that, even if greatly neglected, the bottom of the river should ever be less than 20 feet above the bottom of the foundations. Should this deep scour occur, the value of the breadth of the foundations will be evident.

The soundings show the effects of the mats around the piers. Their work has been so satisfactory that it has been thought well to reinforce them with additional mats, and to cover these with a heavy layer of stone. This will be done during the low-water season of 1892, the plan being to sink a mat 240 feet by 400 feet around each pier, and to cover these mats with from 2 to 4 feet of large rip-rap. When this is done it is believed that these piers will be as secure as any on a clay foundation.[1]

The Paper is accompanied by eleven photographs and fourteen sheets of drawings. From a selection of the latter Plate 6 has been prepared.

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[1] In a letter dated 3 October, 1892, the Author states that these additional mats have been duly placed.