Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 184 — NOVEMBER, 1917 — No. 5

THE HARAHAN BRIDGE AT MEMPHIS, TENNESSEE.*

BY

RALPH MODJESKI, D.Eng.,

Consulting Engineer, Chicago, Ill.
Member of the Institute.

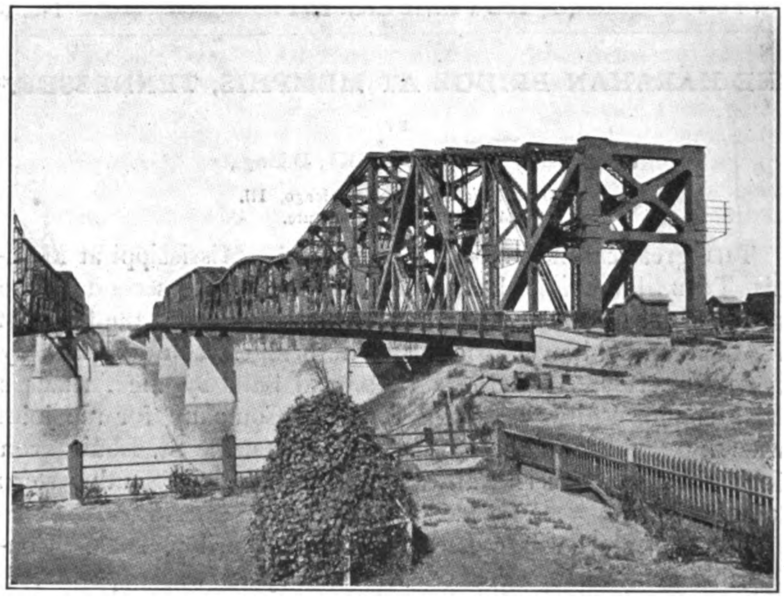
THE great cantilever bridge crossing the Mississippi at Memphis, Tenn., known as the Harahan Bridge, is the second bridge erected at that point and is an important addition to the long list of American cantilever bridges. The bridge was authorized by act of Congress, August 23, 1912, and built by the Arkansas and Memphis Railway Bridge Terminal Company for the joint ownership and use of the Rock Island Lines, the St. Louis, Iron Mountain and Southern Railway, and the St. Louis Southwestern Railway.

The first steel was erected on Pier 1, April 7, 1915. Considerable delay in erection of the river spans was experienced, owing to the almost unprecedented high stage of the river during the summer months, when a low stage may usually be looked for. This prevented commencement of erection when expected. Later, again, when the erection of spans 3 and 4 was barely commenced, the river rose to a stage of 26.6 feet on December 23, 1915, carrying away the falsework between piers 3 and 4, and some five hundred tons of steel beams, stringers and other material, which had been deposited or assembled on the falsework during the initial stage of erection of this span. In order to insure an early

* Communicated by the Author.

[Note.—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.]

completion of the bridge, a supplemental agreement was entered into between the bridge company and the contractors by which this span would be erected partly without falsework and without waiting for the summer low water. This involved some changes in the plans and the payment of a premium for quick delivery of material. It also became expedient to protect the contractors against loss by high water of such falsework as would still be required for this span. These arrangements permitted the completion of the bridge several months sooner than could have been



The Harahan Bridge at Memphis.

done had the course of waiting for the low water been carried out. The last pin was driven in this span on June 28, 1916. The first train was run over the bridge on July 14, 1916, and the bridge opened to railway traffic on the day following.

GENERAL DESCRIPTION.

The bridge crosses the Mississippi River two hundred feet upstream from, and parallel to, the old bridge now owned by the St. Louis and San Francisco Railroad, and which in this report will be called the Frisco Bridge. The eastern end of both bridges is within the city limits of Memphis, Tenn., while the western end lands in Crittenden County of the State of Arkansas. At ordinary low water the Mississippi River at this point is about 1900 feet wide between banks, while at bank-full stage it is about 2050 feet wide. At extreme high-water stages the river overflows the low land in Arkansas for several miles inland on the bridge line. This made it necessary to construct a long, open viaduct approach and thus provide a large cross-section to take care of flood waters, as required by the War Department. The Tennessee shore is formed by bluffs on which the city is built. The top of these bluffs is nearly at the same elevation as the bridge deck, so that no long approaches were required at the east end of the bridge. The structure covered by this report consists of two main portions—the main bridge and the Arkansas viaduct. The main bridge comprises from east to west one anchor arm 186 feet 3¾ inches long, one channel span 790 feet 5¼ inches long, one fixed or centre span, 621 feet long, one shore span 604 feet 1½ inches long, and one deck span 345 feet long. These rest on six piers, the easterly one being an anchor pier acting both as an anchorage and as an abutment. The total length of the main bridge, counting between centres of extreme end pins of the spans, is 2548 feet 10½ inches, including a distance of 2 feet between centres of end pins at pier 4. Owing to the proximity to the Frisco Bridge, the river piers were necessarily located exactly opposite those in the Frisco Bridge, but, for reasons explained further in this report, pier 4, which is placed on the west bank of the river, was moved 17 feet towards the river, thus making the shore span shorter than the corresponding span in the Frisco Bridge. Permission to do so was received from the War Department. The main bridge is built to provide a vertical clearance of 75 feet above high water of 1887. This high water corresponds to elevation 215.85 of the U. S. Government gauge or to 33,14 of the Weather Bureau datum. The viaduct is composed of plate girder spans placed on steel towers, which in turn rest on concrete piers. There are twenty 80-foot and nineteen 40-foot spans, making the total length of the viaduct 2360 feet. The total length of the bridge between centres of extreme end bearings is 4912 feet 9½ inches. The superstructure of the main bridge was designed as a four-span cantilever system continuous over five piers, the deck span being independent. This is a very similar disposition to the one followed in the Frisco Bridge, the difference being: first, that the anchor arm has been made shorter to obviate any reversal of stress in the anchor bars, which will thus always be in tension; and, second, in the length of the suspended spans, which are shorter than in the Frisco Bridge. These two modifications resulted not only in greater economy of material, but also in reducing the difficulties of cantilever erection by reducing the stresses on adjusting devices at the juncture of the suspended spans and the cantilever arms. The shifting of pier four 17 feet toward the river permitted to shorten the suspended spans by 34 feet, and still have the three cantilever arms and the two suspended spans respectively alike. Both the main bridge and the viaduct are double-track structures, two wagon roadways being also provided on brackets outside of the railway deck. The distance centre to centre of tracks is 14 feet. A horizontal clearance of 30 feet and a vertical clearance of 24 feet above base of rail have been provided. The clear width of each wagon roadway is 14 feet.

Starting at the Memphis end on the railway deck, there is an ascending grade on the anchor or easterly span of 1.1 per cent.; the grade then becomes level and remains so over the three main river spans, and becomes 0.6 descending over the deck span and 1.126 per cent. descending over the entire viaduct. The wagon roadways follow the same grades until pier 4 is reached, and then descend with a 3 per cent. grade for a distance of 2030 feet 11 inches, and then continue level until they reach the county road.

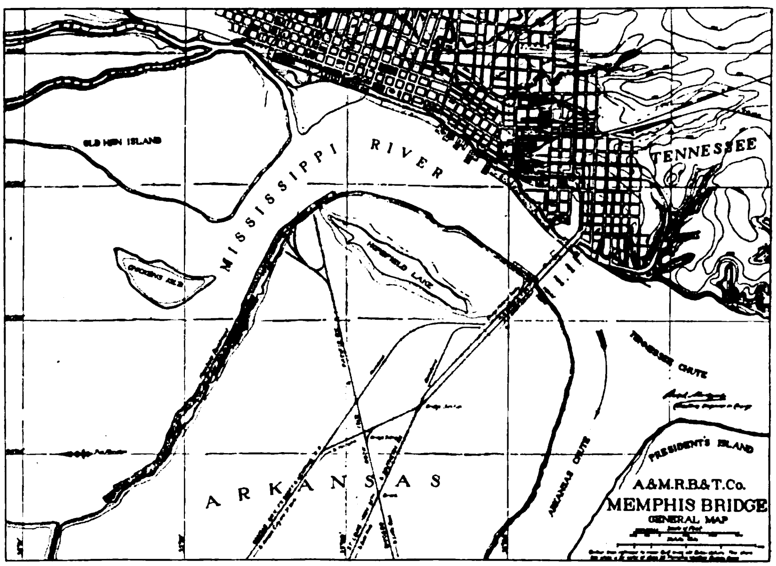
MAIN SUBSTRUCTURE.

Description.

The substructure of the main bridge consists of five piers, numbered consecutively from 1 to 5, pier 1 being placed on the east shore, and one combined anchor pier and abutment. The foundations for piers 1 to 5 were built by sinking caissons by pneumatic process. The foundation for the anchor pier was built in open excavation.

Borings taken before work was commenced revealed very much the same character of materials as were found in the Frisco

Bridge; namely, fine to coarse sand, thin strata of gravel and clay, and a heavy stratum of hard blue clay, which carries the foundations of the Frisco Bridge. No bed rock was found, although the borings extended 200 feet below low-water level. It was therefore decided to sink the foundations to the same stratum of hard blue clay. Experience in the Frisco Bridge with this hard clay taken out of the caissons showed that cubes with two-inch sides, unsupported laterally, could, with one exception, withstand a pressure of at least 100 pounds per square inch, or



Site of the Memphis Bridge, Memphis, Tennessee.

7.2 tons per square foot. It is fair to assume that in case of material supported on all sides the resistance would be greater. Crude experiments made in the caisson working chambers of this bridge by Resident Engineer Case seem to justify that assumption. It was therefore decided that a net pressure of 5 tons per square foot on the clay would be a safe load to impose, and the dimensions of the caissons were determined accordingly. The following table shows the various pressures on the foundations of piers 1 to 5, including full live load:

PRESSURES ON FOUNDATIONS.

Weights in Tons of 2000 Pounds.

	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5
Timber, iron, and concrete in foundations	10110	9330	9470	7800	5190
Concrete in working chamber and shafts	1180	1390	1500	1620	390
Granite masonry concrete backing, except pier 5, which is all concrete	7780	13730	14030	6770	1170
Total weight of pier	19070	24450	25000	16190	6750
Superimposed earth	1810	0	2830	1180	80
Superimposed water to zero gauge	0	2740	1310	0	0
Superstructure dead load	5670	5600	5600	1140	850
Superstructure live load	3870	3900	3900	1910	1070
Total downward pressure	30420	36690	38640	20420	8750
Deduct for water reaction at zero gauge	5310	10920	11250	4950	2090
Deduct for earth displaced	8110	4000	6950	5450	3450
Deduct for skin friction at 400 pounds per square foot	2850 16270	2320 17240	2710 20910	2660 13060	2300 7840
Net weight on foundation	14150	19450	17730	7360	910
Pressure on foundation in tons per square foot	4.4	5.1	4.7	3.1	0.8
Horizontal dimensions of caissons	40'x80'	42'x90'	42'x90'	31'x77'	25'x46'

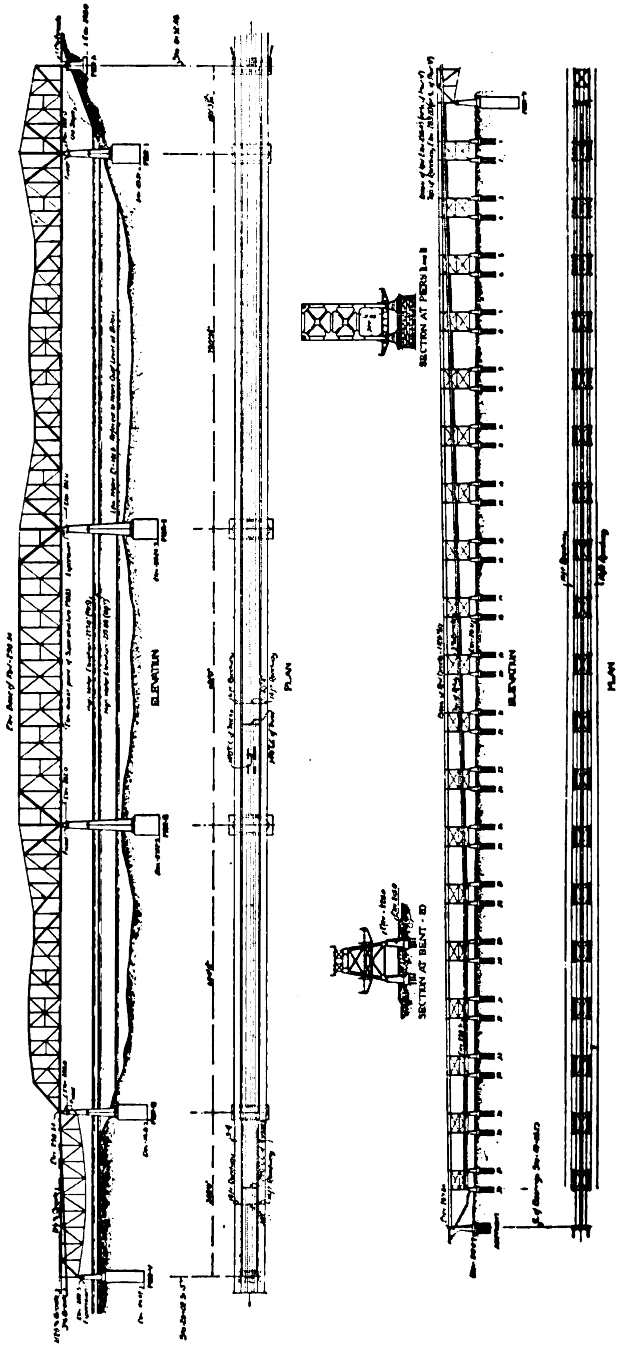
The deduction of 400 pounds per square foot for skin friction is conservative. As a matter of fact, while making the last drop in pier 4 conditions were such that a practically exact measurement of the skin friction could be taken, and this was found to be 800 pounds per square foot. It is probable that this friction will not be less than 1000 pounds per square foot after the materials are well settled around the piers. The above table also gives the horizontal dimensions of each caisson. The caissons were built of timber with steel cutting edges. They were filled with concrete made of Portland cement mortar and gravel. A small quantity of crushed rock was used in pier 2 when gravel could not be obtained in time. In piers 1, 2, and 3 steel rods were imbedded in the concrete just above the roof of the caisson working chamber to secure additional strength during the first stages of sinking. The general method of sinking was that usually followed in similar cases. The wet "blow out" was used for excavating sand or silty clay, and buckets through air-lock for clay. Elevators were provided in piers 2 and 3 for the use of men in going in and out. The method of sealing the working chamber differed from that used in the Frisco Bridge, and which was generally used at the time that bridge was constructed:

instead of using dry concrete for the entire volume of the chamber, which required men for ramming it in benches, and consumed considerable time, dry concrete was used only to support the edges of the caisson and the crossbeams, under which it was rammed in, and then wet concrete was poured in until the chamber was filled. By that method the time required for sealing a chamber was generally under 48 hours, meaning that the rate of placing concrete in the chamber was about 15 cubic yards an hour. The piers above the caissons, except pier 5, are of granite backed with concrete, except the belting courses and two courses below, which are backed with granite stones of same thickness as the face stones. The coping of these piers is entirely of granite. The bearing surfaces under the steel pedestals have been carefully dressed after the stones were set. The thickest course in the piers is 36 inches. The face stones have a rock or quarry face with projections not exceeding three inches, except the copings, beltings, and starlings. The copings are laid with close joints and are bush-hammered throughout. A four-inch draft line is cut around the lower edge of the belting course and on each side of each nose line. The curved faces of the upstream cutwater and the surfaces over the pointed ends of each pier are fine pointed, with no projections greater than one-half inch; the projecting portion of the lower bed of the coping and belting courses are bush-hammered.

Reinforcing rods 1¼ inches square were used in the concrete backing of the first seven courses, and every seventh course above that, and in the four top concrete-backed courses.

Pier 5 was built entirely of concrete reinforced by steel rods.

PIER 1.—The caisson for this pier was built on shore in place. It was supported on the sand and gravel of the bank. Work was begun on setting the cutting edge on November 23, 1913. The cutting edge was placed 6 inches nearer shore than the desired final position, to provide for the crowding effect of the bank. The caisson was lowered 20 feet, of which 5 feet were below the level of the water, before the air-pressure was applied. Its final position was correct, showing that the 6-inch allowance for crowding was right. The upper eight feet of the crib were of light construction and built of 3-inch vertical planking to act as a form for the concrete. Compressed air and water for sinking were supplied from the floating compressor plant moored near by.

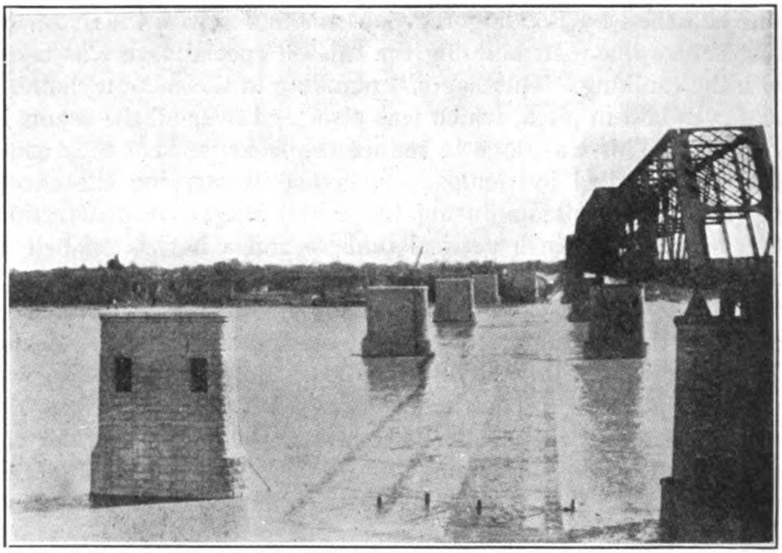


Arkansas and Memphis Railway Bridge and Terminal Company. The Memphis Bridge—General elevation and plan.

PIER 2.—This pier is located in the deepest portion of the river, and because of the great depth of water at this place precautions had to be taken which were considered unnecessary for the other piers. To protect the river bottom from scouring before the landing of the caisson, and also after the work is done, a willow mat 200 feet wide and 300 feet long was sunk at the site of this pier, the long dimension being parallel with the stream and the mat placed so that it extends 200 feet upstream and 100 feet downstream from the centre line of the bridge. The caisson for this pier, as well as for pier 3, was built on a floating pontoon and launched by flooding the pontoon and separating it on its long centre line. In building the caisson special care was taken with the caulking. The diagonal planking in the caisson chamber roof was laid in pitch, which was also used over all the seams in the roof. This was done to reduce the leaks, so that they could easily be handled by pumps. To assist in carrying the excess weight of the caisson during the initial stages of penetration, 24 12-inch by 12-inch vertical timbers and a horizontal belt of 12-inch by 12-inch timbers were bolted to the caisson walls on the outside and just above the caisson chamber. These timbers increased the sinking friction of the caisson sufficiently to enable the excess weight to be easily handled. Before the caisson was placed in position a quantity of sacks filled with sand were deposited on top of the mat so as to reduce the depth of water for the purpose of easier landing of the caisson. About 6 feet in height was thus gained, reducing the depth of water from 51 feet to 45 feet at the time of landing. The greatest head of water during compressed-air work occurred in this pier. It reached 107 feet during the sealing of the working chamber, while the air-pressure was 48 pounds per square inch.

PIER 3.—A small amount of sand sacks were used to level up the river bottom before the caisson was landed. The depth of water at the time of landing was 30 feet. The mat and riprap placed during the construction of the Frisco pier were found over the downstream half of the caisson.

PIER 4.—The caisson for this pier was built in place. The cutting edge was located 18 inches toward shore to compensate for the crowding effect of the bank. The river side of the caisson was supported during construction by a series of boxes filled with sand and sunk about 8 feet into the silt before the cutting edge was assembled. The caisson was carefully lowered and all necessary precautions taken for keeping it level. In spite of that, the plane of the cutting edge developed a warp of 2 inches before sufficient friction on the sides was attained and sufficient air-pressure applied to assist in lowering the caisson. The air plant for this caisson, as well as for caisson 5, was located 400 feet inshore on an old dike above ordinary high water. The allowance of 18 inches for the crowding effect of the bank proved



General view of completed piers, looking east.

to be too great, and it was with considerable difficulty that the caisson was finally brought to within 3 inches of its true position. After the cutting edge reached a depth of 65.5 feet below low water, or elevation 116.1, the excavation was carried down 3 feet below the cutting edge to a stratum of rock a few inches in thickness overlying the hard blue clay.

PIER 5.—The caisson was built in place. The material traversed was almost entirely sand, very little being removed through the bucket locks. On the morning of April 9 a deplorable accident occurred in which 9 men lost their lives. The men of the gang going in to relieve the crew in the working chamber were overcome by gas as they were about to lock in, and apparently instantly killed. No definite evidence as to the nature or origin of the gas which had accumulated at the bottom of the main shaft above the lock has been obtained, but the probability is that the accident was due to carbon monoxide formed by the ignition and combustion of methane (CH_4). The men in the working chamber felt no ill effects whatever, and were taken out one by one through the material locks.

ANCHORAGE PIER.—The anchorage pier was built in open excavation 48 feet deep, and, although the clay through which this excavation was made stands well on a vertical face when dry, it was deemed necessary, in view of the considerable depth, to use heavy timbering. The pier was built of concrete faced with granite above the ground line and reinforced by steel rods. The anchor girders were entirely imbedded in the concrete. Wells were left around the anchor bars and filled in later, after the bars had been stretched by subjecting them to a stress, as explained in the chapter on superstructure.

QUANTITIES AND COMPARATIVE UNIT COSTS OF PIERS.

The substructure of the Frisco Bridge was built with the railway company's forces; that of the new bridge was built under contract based on cost and percentage. In both cases, therefore, an accurate account of cost was possible. The design and character of the piers in both bridges are very similar. In both, the piers have been sunk by pneumatic process to about the same elevations, through very similar materials; in both, the face stones are of granite, except that in the Frisco Bridge some limestone facing was used below low water. Because of this similarity it was deemed of interest to prepare unit costs of the various portions of the piers and compare the results with the Frisco Bridge, as given in Morison's report.

VOLUME OF PIERS IN CUBIC FEET.

	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5
Foundation	189,440	192,780	193,725	147,278	93,150
Sinking (actual volume sunk)	243,616	195,642	281,666	182,772	98,088
Masonry	101,986	173,632	180,074	86,282	19,062

UNIT COST IN DOLLARS PER CUBIC FOOT.

	Pier 1	Pier 2	Pier 3	Pier 4	Pier 5
			All concrete		
Sinking (to actual volume sunk)	0.141	0.310	0.206	0.139	0.109
Foundation (excluding sinking)	0.469	0.759	0.631	0.509	0.494
Foundation (including sinking) (to total volume foundation)	0.649	1.074	0.931	0.682	0.508
Masonry (to total volume shaft)	0.785	0.721	0.757	0.889	0.371
Foundation, sinking, and masonry (to total volume of pier)	0.697	0.906	0.847	0.758	0.568

Morison's report on the old Memphis Bridge gives unit costs, which are on a comparative basis, with the following exceptions: Morison's figures do not include concrete below cutting edge or clay left in chamber above cutting edge, and there are included credits from sale of plant which are not included in the figures for the new bridge. Morison's report also includes the volume of the voids, or wells in the body of the piers. The unit costs which compare with the last line of the former table are as follows:

UNIT COST IN DOLLARS PER CUBIC FOOT OF PIERS OF THE FRISCO BRIDGE.

	Pier 1	Pier 2	Pier 3	Pier 4
Foundation, sinking, and masonry (to total volume of pier)	0.787	0.832	0.999	0.801

MAIN SUPERSTRUCTURE.

Description.

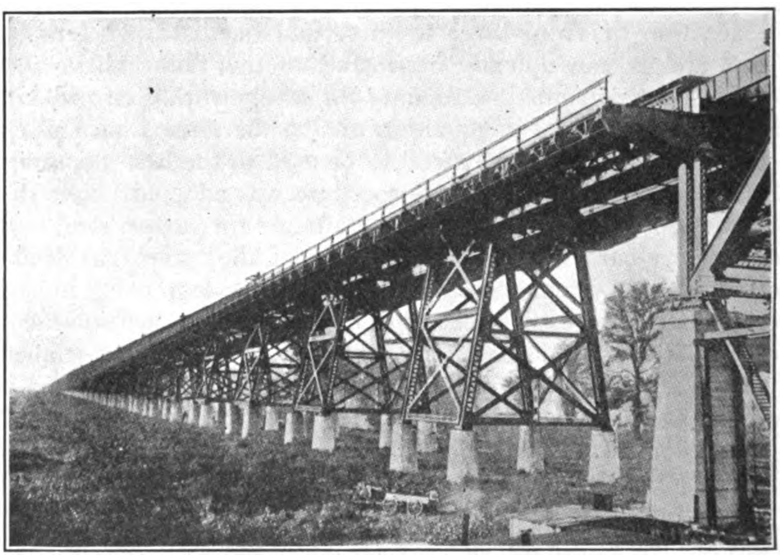
The main superstructure consists of a continuous cantilever system of four spans and one deck span, the lengths of which have been given elsewhere. It carries a double track for railway and two roadways, one on each side, supported on brackets outside of the trusses.

The principal reason for adopting the cantilever system for the river spans was that it enabled the channel span between piers 1 and 2, which is placed over the deepest portion of the river, to be erected without falsework. It would have been extremely hazardous, if not impossible, to erect the 790-foot channel span on falsework. It has been suggested that a fixed or simple span of that length could be erected by cantilever method, but a fixed span of that length has not yet been built, and if built by cantilever method would require a large addition of metal near the ends in the top and bottom cords, to take care of erection stresses. But, even without that addition, a system of fixed spans would weigh considerably more than the one used. It was originally planned to use falsework in all spans except the channel span, but, owing to high water, as already described, the cantilever arm projecting from pier 3 and the east half of the semi-suspended span between piers 3 and 4 were erected by cantilever method, and only the west half of the latter on falsework.

The superstructure is built partly of carbon steel and partly of a nickel-chrome alloy, known under the name of "Mayari" steel, which is manufactured from Cuban ores containing both nickel and chrome very nearly in right proportions to produce proper bridge material of excellent quality. Nickel steel had been used a short time previous to the construction of this bridge in at least two large bridges where strength of the metal became a source of economy. That alloy was artificially produced by the addition of from three to three and one-half per cent. of nickel and is consequently expensive. Other alloys have also been suggested from time to time for bridgework. In order to receive the benefit of competition and at the same time make a decision possible as to the metal to be used to the best advantage in the structure, the following procedure was adopted: Two distinct designs were worked out in detail, one for carbon steel with only the eye-bars of alloy steel, and one of alloy steel trusses and bottom lateral system and carbon steel floor system, using in both designs unit stresses fifty per cent. higher for alloy tension members and forty per cent. higher for alloy compression members than for carbon steel. The specifications were then prepared in such a way as not to exclude any alloy of nickel and other metals which the manufacturers might desire to submit for use, provided it met the physical requirements, and provided their composition did not contain an excess of injurious elements. Tenders were received on both the carbon and the alloy designs, and the alloy design, costing approximately $68,000 less than the carbon design, was adopted.

Expansion for the trusses was provided on pier 2 by means of specially designed segmental roller bearings. Expansion is also taken care of at the junction of each cantilever arm with the corresponding suspended span and at the shore end of the anchor arm. Anchorage is provided by means of eye-bars attached to steel girders which are placed near the bottom of the anchorage pier. Both the girders and the anchor bars are imbedded in concrete, but wells were left open around the anchor bars until these bars were stretched to correspond to the greatest stress which they will be expected to carry under a moving live load. This was accomplished by a special device, consisting of bearing blocks and wedges placed on the anchor pier coping. By means of these wedges a requisite tension stress was introduced into the bars, and while they were thus stretched the wells were filled with concrete packed tightly around the bars. In this manner there will be no variation of length in the imbedded anchor bars due to varying loads. The expansion is taken care of by the oscillation of the vertical bars leading from the anchorage to the top chord.

The superstructure was designed to carry a loading of



Arkansas approach viaduct, October 1, 1915.

Cooper's E 55 on both tracks, and in addition thereto 600 pounds per foot of roadway on suspended spans, and 500 pounds on the remainder of the bridge. Members subject to concentrated panel loading were calculated for E 55 locomotives on both tracks with 1120 pounds per lineal foot of the nearest roadway. The stresses in the entire bridge have also been calculated on the assumption of a loading of Cooper's E 75 on each track and 1000 pounds per foot of truss for roadways. Under this "test load," the stresses will not exceed six-tenths of the elastic limit of material in any member, which means that such a loading could be operated over the bridge with perfect safety at moderate speeds.

The weights of metal in the completed superstructure are given in the following table:

	Alloy steel	Carbon Steel	Total
Anchor arm—			
Chords and end posts	927,370	115,620	1,042,990
Web system	261,862	842,206	1,104,068
Railway floor system		364,088	364,088
Wind and sway bracing		272,473	272,473
End bearings on pier		312,001	312,001
Roadway floor system		160,428	160,428
Railing		43,500	43,500
	1,189,232	2,110,316	3,299,548
Anchorage material	58,028	181,594	239,622
Three cantilever arms—			
Chords and end posts	3,749,668	37,500	3,787,168
Web system	644,372	496,494	1,140,866
Railway floor system		905,712	905,712
Wind and sway bracing	162,420	402,383	564,803
Roadway floor system		402,868	402,868
Railing		130,800	130,800
	4,556,460	2,375,757	6,932,217
Suspended and semi-suspended spans—			
Chords and end posts	3,678,332	48,240	3,726,572
Web system	1,307,833	589,678	1,897,511
Railway floor system		1,515,848	1,515,848
Wind and sway bracing	86,390	396,040	482,430
End bearings on pier 4		58,699	58,699
Roadway floor system		635,840	635,840
Expansion devices		57,005	57,005
Railing		195,800	195,800
	5,072,555	3,497,150	8,569,705
One fixed span—			
Chords and end posts	4,640,577	53,900	4,694,477
Web system	2,105,649	762,871	2,868,520
Railway floor system		1,161,260	1,161,260
Wind and sway bracing	80,650	539,480	620,130
End bearings, piers 2 and 3		681,195	681,195
Roadway floor system		459,601	459,601
Railing		145,769	145,769
	6,826,876	3,804,076	10,630,952
One deck span—			
Chords and end posts	327,522	716,873	1,044,395
Web system		539,700	539,700
Railway floor system		600.654	600,654
Wind and sway bracing		200,121	200,121
End bearings piers 4 and 5		82,110	82,110
Roadway floor system		301,031	301,031
Railing		81,000	81,000
	327,522	2,521,489	2,849,011
Railway guard angles, floor bolts, wire supports, and pier ladders		331,809	331,809
Total—Main Bridge	18,030,673	14,822,191	32,852,864
Adjusting devices	61,174	351,390	412,564
Grand total—Main bridge	18.091,847	15,173,580	33,265,428

The railway and roadway decks are built of creosoted timber. In view of the considerable depth of water between piers 2 and 3 and the necessity of erecting the fixed span on falsework, it was decided to protect the river bottom by sinking woven willow mats over the entire space between the piers and on a width of 200 feet. Special weaving barges were leased for that purpose, and the mats were woven and sunk in place by means of riprap. It is believed that without this precaution the unusual high water in December, 1915, would have endangered this span very seriously. As it was, great pressure was being exerted against the falsework by the accumulated drift, which caused the span to deflect downstream approximately eight inches. Owing to the fact that the lateral system was completely bolted, no damage was done.

It was intended to proceed with the erection of the cantilever arm and semi-suspended span between piers 3 and 4 as soon as the fixed span was erected. To that end, falsework had been placed between these piers and some steel work assembled on top of the falsework and a gantry traveller built to handle the steel. On December 23, as already described, the falsework between piers 3 and 4 went out, due to high water. It was then decided to complete the channel span between piers 1 and 2 while arrangements were being made for replacing the steel lost with the falsework and modifying the details of the span, so as to adapt it to cantilever erection.

The first train, carrying the officials of the bridge company, ran over the bridge on July 14, 1916, and the bridge was opened for traffic the following day.

ARKANSAS APPROACH VIADUCT.

This viaduct is 2363 feet 11 inches long between centre of end bearings, and consists of an alternating series of 40- and 80-foot plate girders, 40-foot spans forming towers. The piers for the towers are of concrete and built on concrete piles. The steel was manufactured under the writer's standard specifications for bridges of 1911. No other steel was to be used in the viaduct, and, as the work is of a simple nature, these specifications were deemed sufficient. The weights of steel are given in the following table:

	Carbon steel, pounds
Railway floor	4,824,900
Roadway floor	2,752,440
Towers	4,131,810
Railing, guard angles, and refuge platforms	445,910
Total	12,155,060

The total quantities of the principal materials in the main bridge and approaches are as follows: Timber in foundation, 3270 M.B.M.; concrete in piers and foundations, 43,000 cubic yards; granite masonry in piers, 9467 cubic yards; steel in superstructure, 45,420,488 pounds; creosoted timber in railway and roadway decks, 2090 M.B.M.

The Liberty Motor. ANON. (*Aerial Age*, vol. vi, No. 2, p. 53, September 24, 1917.)—One of the first problems which confronted the War Department and the Aircraft Production Board after the declaration of hostilities was to produce quickly a dependable aviation motor. Two courses were open. One was to encourage manufacturers to develop their own types; the other to bring the best of all types together and develop them. The necessity for speed and quantity production resulted in the choice of the latter course. By the inspiring coöperation of consulting engineers and motor manufacturers, who gave up trade secrets under the emergency of war needs, a new motor, designated by the Signal Service as the "liberty motor," has been developed for the use of the United States air service, and is the country's main reliance for the rapid production of this important component of high-powered battle planes.

In power, speed, service ability, and minimum weight the new engine invites comparison with the best the European war has produced. One of the chief rules adopted at the beginning of the designing work was that no engineer should be permitted to introduce construction which had not been tried out: there was no time for theorizing. The new engine is successful because it embodies the best thought of engineering experience to date. Not only did consulting engineers of this country furnish ideas, but representatives in the United States of England, France, and Italy contributed to the development of this motor.

While it is not deemed expedient to set forth in detail the satisfactory performances and the mechanics of the new motor, it may be said that standardization is a chief factor in the development of the