New Mississippi River Bridge at Memphis

High Water Interfered with Erection of Structure Which Was Placed in Service July 15. Mayari Steel Used

The Two Memphis Bridges

ONE of the most advantageous opportunities for a study of the advancement in bridge design and construction during the last 24 years is afforded by a comparison between the new Harahan bridge just completed over the Mississippi river at Memphis, Tenn., and the Frisco bridge opened for traffic in 1892, which is located only 200 ft. down stream from the new bridge. Conditions are especially favorable for a comparison because the two bridges are of the same type and have almost exactly the same span lengths. Interest is added to such a comparison by the fact that Ralph Modjeski, consulting engineer, in charge of the new structure, was an assistant engineer on the construction of the older bridge. The weight of the last span of the new bridge was taken off the falsework on Friday, June 30, and the bridge was placed in service on July 15.

Aside from the attention merited by the details of the superstructure and substructure of a new bridge over the lower Mississippi, considerable interest attaches to the erection of the steel work because of the unusual flood conditions encountered. High water of unprecedented duration interfered materially with the progress of the work and resulted in a loss of considerable falsework and some structural material.

The new bridge, named after the late J. T. Harahan, was built by the Arkansas & Memphis Railway Bridge & Terminal Company, a corporation controlled jointly by the Chicago, Rock Island & Pacific, the St. Louis Southwestern and the St. Louis, Iron Mountain & Southern, all roads having lines terminating at Memphis. Until the new structure was opened for traffic, they used the old bridge owned by the St. Louis-San Francisco and were tenants of that road from the connections on the west side of the river to junctions with their own terminals in Memphis. In addition to the heavy traffic of the Frisco, between Birmingham and Kansas City, as well as that to St. Louis, the old bridge carried trains of the Rock Island between Memphis and Tucumcari, N. M., of the Iron Mountain from Memphis to Texarkana and St. Louis, and of the Cotton Belt to central Texas, the trains of the last named road running over Rock Island tracks as far as Brinkley, Ark.

General Description

As seen from the accompanying diagram the bridge consists of four spans of a cantilever arrangement having a total length of 2,201 ft. 10½ in., a simple 345-ft. deck span to the west, and west of that a steel viaduct, 2,363 ft. long. The bridge provides for two tracks 14 ft. center to center with a wide clearance of 8 ft. and a vertical clearance of 24 ft. above base of rail. Highway traffic is provided for by cantilever brackets outside of the trusses on either side, affording duplicate roadways, 14 ft. wide.

The tracks ascend from the east to pier 1 on a 1.1 per cent grade, continued on a level grade to pier 4 and then descend on a 1.126 per cent grade across the approach viaduct and an embankment three-quarters of a mile long at its western end. The highway deck is on the same grade as the tracks except on the viaduct, where it descends on a 3 per cent grade.

Commencing at the Tennessee end of the bridge there is an anchor arm of 186 ft. 3¾ in. from the anchorage to pier 1. The distance between piers 1 and 2 is 790 ft. 5¼ in., and is spanned by a suspended span of 417 ft. 9¾ in., carried by two cantilever arms of 186 ft. 3¾ in. each. Between piers 2 and 3 there is a fixed span of 621 ft., while the distance of 604 ft. 1½ in. between piers 3 and 4 is spanned by a semi-suspended span 417 ft. 9¾ in. long supported at its west end by pier 4 and at its east end by a cantilever arm 186 ft. 3¾ in. long. It will be noted that this arrangement permits of a number of duplications, i. e., two suspended spans of 417 ft. 9¾ in., and three cantilever arms of 186 ft. 3¾ in., this also being the length of the anchor arm at the east end of the bridge. The viaduct consists of a succession of 40 ft. towers with 80 ft. clear spans, the four lines of deck girders carrying the two railroad tracks being supported on cross girders at the tops of the bents. The highway decks are carried on brackets supported on the sides of the columns.

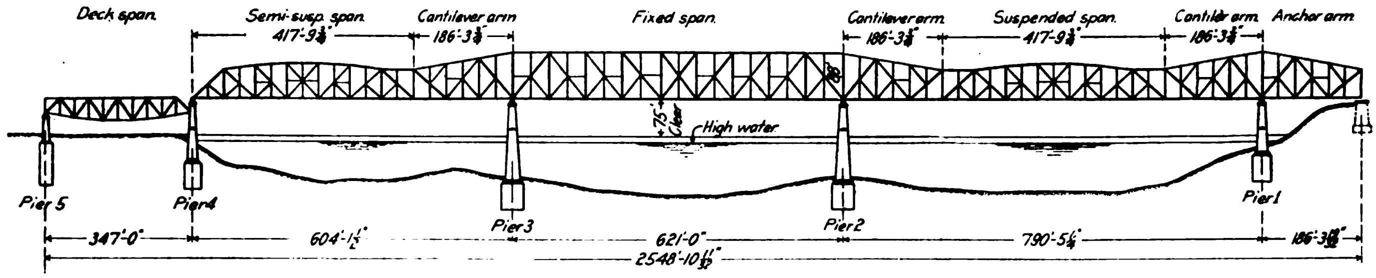
The total weight of the metal in the entire structure is about 21,400 tons, of which 14,700 tons is in the main cantilever structure, 1,400 tons in the deck span and 5,300 tons in the viaduct approach. One feature of note in this bridge is the use of an alloy steel (Mayari) to the extent of 8,900 tons. This material was used in all the main members of the trusses of the cantilever structure and in the pins and eye-bars of the deck span. A novel feature in this connection is the use of alloy steel for the bottom laterals of the main structure. The chemical requirements of this material are as follows:

	Rivet steel	All other steel
Manganese	.60	.80
Phosphorus (acid steel)	.04	.06
Phosphorus (basic steel)	.03	.04
Sulphur	.04	.04
Silicon	.15	.15
Carbon	.30	.40

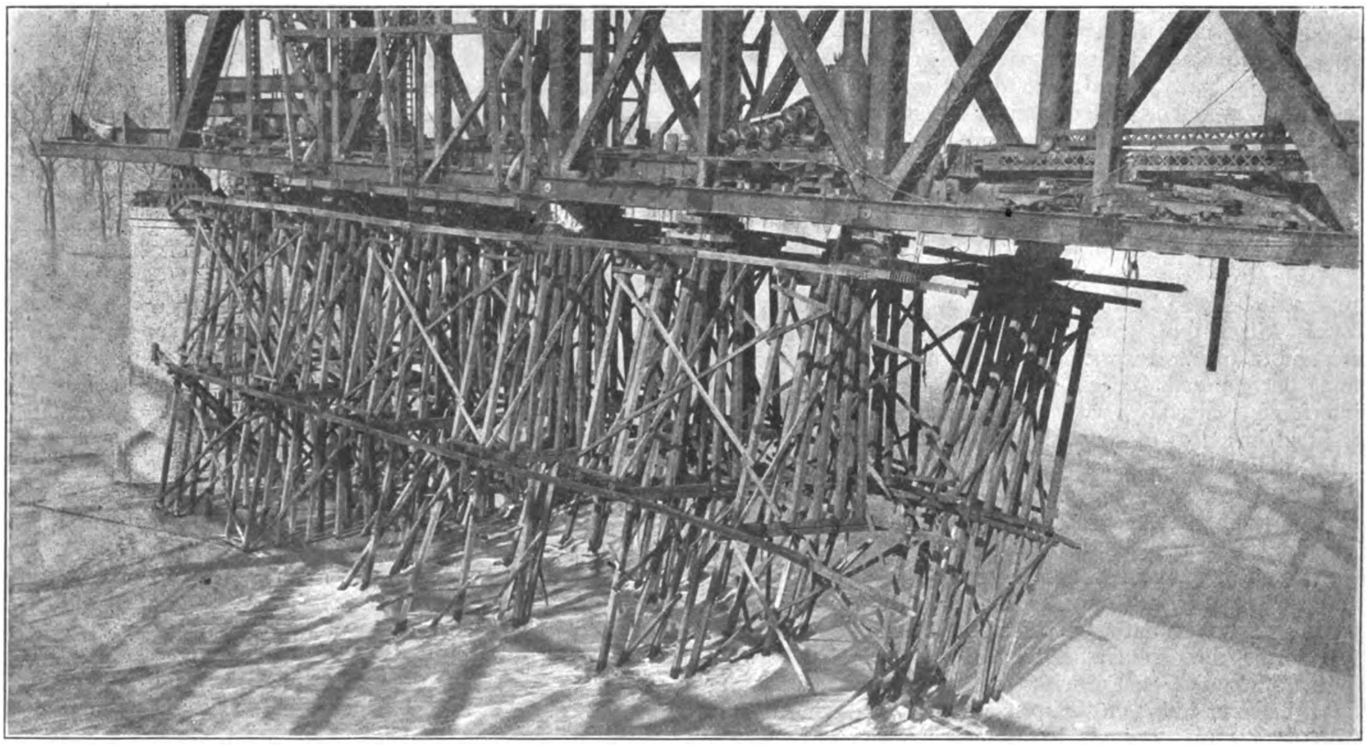
Aside from the limitations as shown above the alloy steel was required to contain not less than 1.2 per cent of nickel.

The alloy steel was divided into three classes as to physical requirements depending upon the purpose for which it was to be used. The required ultimate strength varied from 70,000 to 110,000 lb., the elastic limit from 45,000 to 55,000 lb. and the minimum reduction of area from 40 per cent to 25 per cent in the order named.

The piers are of granite with concrete backing. They are all supported on pneumatic caisson foundations resting on a very hard blue clay. Piers 2 and 3, with the deepest foundations, were carried 192 ft. and 195 ft. respectively below the elevation of the copings. The 76 pedestals supporting the viaduct contain 55 cu. yd. of concrete each, and are each supported on 16 concrete piles 30 ft. long. A complete account of the construction of the substructure was given in an article by M. B. Case in the *Railway Age Gazette,* April 23, 1915, page 877.



Elevation of New Mississippi Bridge at Memphis



Falsework for the Fixed Span Swinging in the Flood

Design and Details

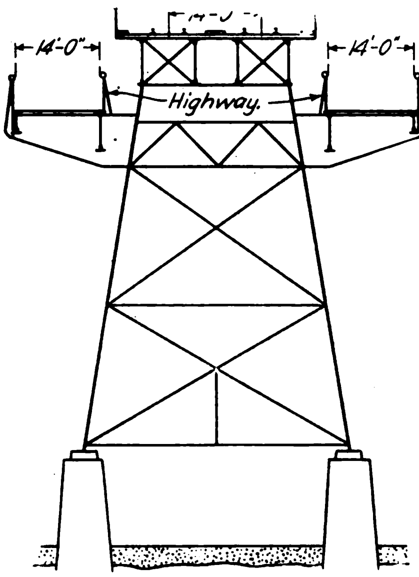
As the new bridge is only 200 ft. from the old one, the locations of the new piers were fixed by the position of the old ones, save that pier 4 was placed 17 ft. farther out in the river, thus shortening the span between piers 3 and 4 a sufficient amount to permit the duplication of the suspended spans previously mentioned. The anchor arm was made sufficiently short to insure an uplift on the anchorage under all conditions of loading. Otherwise the designers were permitted no latitude in the arrangement of the span lengths.

The maximum compression members are the bottom chords of the cantilever arms in the panels next to the piers and have sections of 319.3 sq. in., made up of four web plates 39 in. by 1 3-16 in. and eight angles 8 in. by 8 in. by 1⅛ in. The webs are vertical with heavy double angle lacing on the top and bottom and vertical diaphragms at frequent intervals. The maximum tension members are the top chords directly over the maximum compression members and consist of 10 eye-bars of which 6 are 16 in. by 2¼ in. and 4 are 16 in. by 2 3-16 in. As mentioned previously the bottom laterals are so heavy that alloy steel was found desirable. In the anchor arms these consist of a 24-in. by 13-16 in. plate and two angles 8 in. by 8 in. by ¾ in. maximum section.

The end of the anchor arm was given a vertical portal for the sake of appearance, but it is in reality a false portal because the two vertical members, being tension members under all conditions of loading, consist of eye-bars. To satisfy esthetics, they are enclosed in stiff box section members, cross-braced to give the appearance of heavy portal construction.

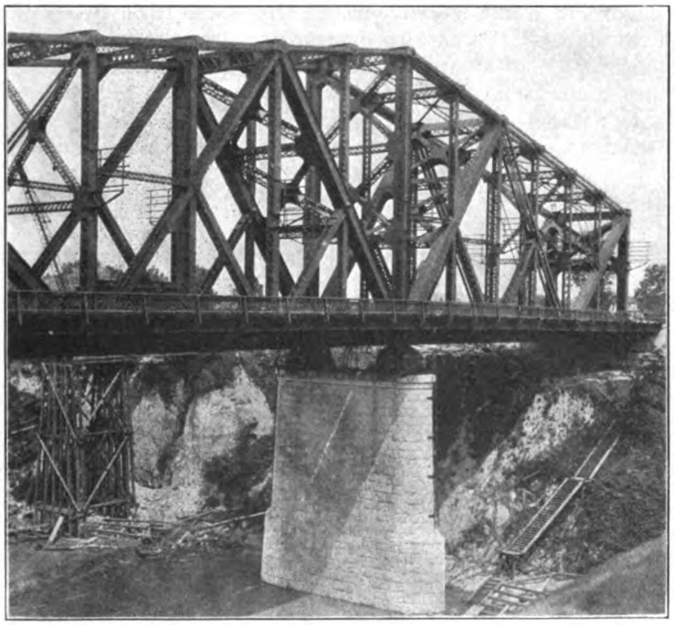
The uplift on the end of the anchor arm varies from 405,000 lb. to 6,892,000 lb. under the different conditions of loading. Consequently an anchorage of considerable size is necessary. As shown in one of the accompanying drawings this consists of a block or abutment of concrete 43 ft. high with a base 34 ft. by 80 ft., its weight of 10,900,000 lb. being sufficient to give a minimum bearing pressure of ¾ ton per sq. ft. under the condition of maximum uplift.

The uplift of the anchor arm is transmitted to the anchorage by means of two groups of eye-bars, each containing 6 bars 16 in. by 1¾ in., the load being transmitted to the bars by means of a structural steel grillage, consisting of 6 girders



Outline Section of West Approach

36 in. deep, assembled in a frame, which was equipped with columns to support it until it was imbedded in the concrete. To preclude the cracking of the concrete surrounding the eye-bars as they became extended under the anchorage stress, open wells were formed around the bars which were not filled with concrete until the uplift had assumed considerable proportions through the erection of the cantilever arm and the



Pier One and the Anchor Arm

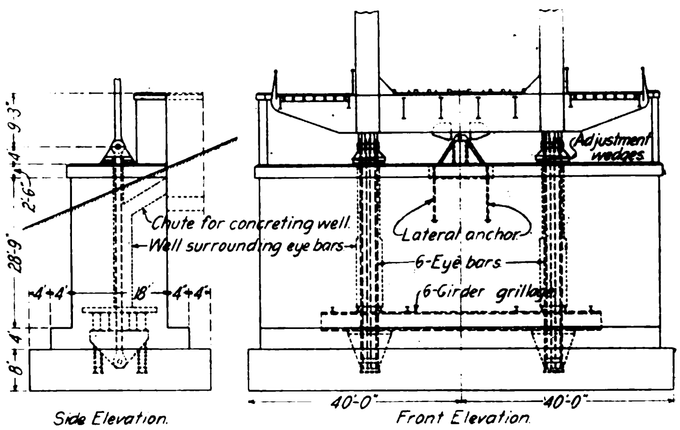
suspended span. The wedges shown in the drawing as forming a part of the shoes at the tops of these bars, were driven home at the same time to insure substantially uniform stress in the bars under all conditions.

On the bridge seat midway between the anchor shoes a bearing is provided to take the lateral forces. As the anchor arm must be left free to expand, this lateral bearing is designed to resist lateral movement only and does not interfere with either the longitudinal or vertical movement of the anchor arm.

Expansion Details

One of the accompanying photographs shows the connection of one end of the suspended span to the cantilever arm, the vertical hangers shown in the center of the picture serving as the supports for the suspended span. During the time that the cantilever arm and the suspended span were being erected, the top and bottom chords were continuous under the cantilever action. However, as soon as the suspended span was completed and supported from the cantilever arm by the hangers shown in the photograph, the panel of the top chord to the left of the hangers and the panel of the bottom chord to the right of the hangers became ineffective and carry no stress except as they are employed in preserving the continuity of the lateral systems. In fact these chords are broken, being provided with sliding joints to allow for the expansion and contraction of the trusses of both the suspended span and the cantilever arms.

This expansion amounts to 8 in. at each end of the suspended span and must be provided for also in the floor and lateral systems. As this is a greater movement than is allowable in any reasonable form of expansion pocket attached to



Details of the Anchorage, Reinforcing Bars Not Shown

the floor beams, the railway floor stringers at the expansion point are supported by a link arrangement as shown in one of the accompanying drawings. A similar arrangement is provided at the same point for the bottom lateral system.

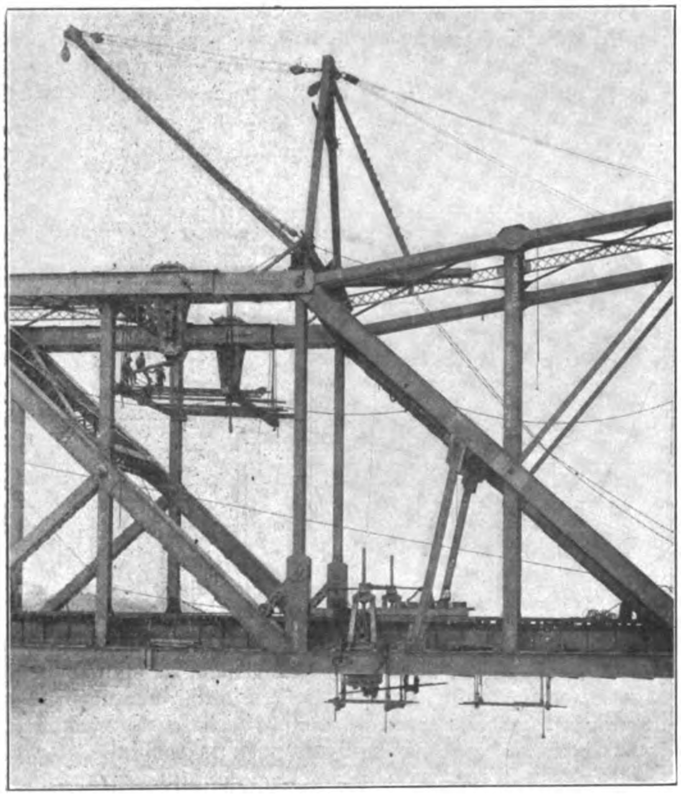
An expansion joint is also provided in the rails at these points as shown in one of the accompanying photographs, and is an application of the principle of the rail lock of the sliding-tongue type used on draw bridges. In this case, however, the tongues do not move but are secured to the rails on one side of the joint. The tongues are made of heat-treated alloy steel.

Falsework and Erection

Those portions of the bridge which were not erected by the cantilever method were carried on falsework consisting of towers of two bents each spaced 8 ft. center to center, at every main and sub-panel point. The upper portions of these bents consisted of two stories of frame bents having a total height of about 60 ft., each bent containing 12 posts at the main panel points and 10 posts at the sub-panel points. These frame bents were carried by pile bents of 26 and 22 piles respectively, which, owing to the great depth of water, required piles from 100 to 114 ft. in length, a total of 120,000 ft. of piles being used. The piles were Douglas fir, cut especially for this job. They were driven to about 30 ft. penetration with a marine driver having double leads 85 ft. high. The pile bents were cross-braced with timber from the caps to the water line, but as this left a considerable height unbraced, cables were clamped to the two outside piles on one side and to three outside piles on the other side at a point that brought the clamps to the river bed when full penetration had been obtained. As each bent was completed, the other ends of these cables were brought over and made fast to the opposite end of the bent at the cap, thus forming a cross-bracing of cables.

Stringers for the highway deck were used temporarily as falsework stringers. The superstructure was supported on the falsework on sand boxes consisting of drums 5 ft. in diameter, made of heavy steel plates with plungers cut from tight cribbings of 12 in. by 12 in. timbers.

In accordance with a provision of the specifications, the rivets for all tension splices were set with a pressure riveting machine. In erecting the two halves of the suspended spans by the cantilever method the junction at the mid-point was facilitated by keeping the meeting halves of the trusses a material distance above the final position, with the distance between adjacent panel points in the top chord at a somewhat



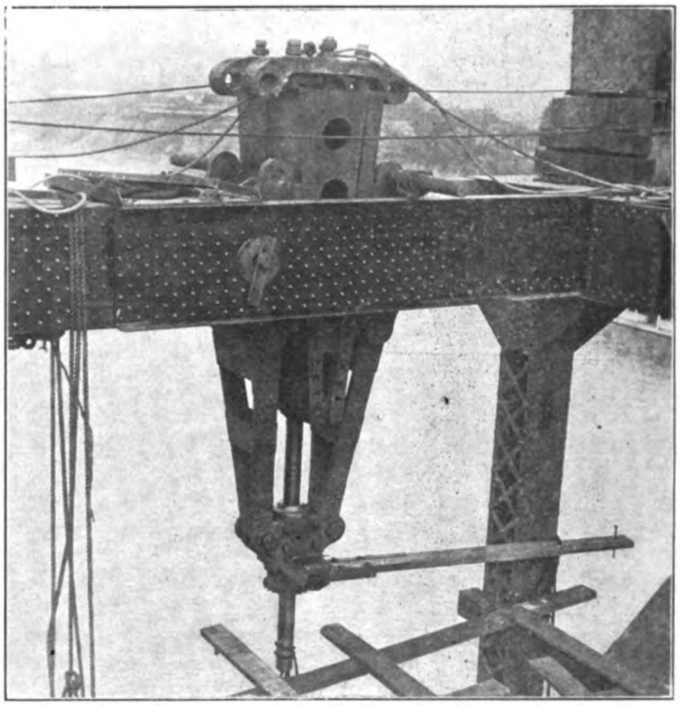
The Support for Suspended Span from Cantilever Arm

greater distance apart than the correct distance between these points, the reverse being the case between the panel points of the bottom chords. The complete assembling of the bottom chords across this panel was made possible by having slotted holes in the eye-bars of the center panel, while the splices in the top chords were left unriveted until the chords came together as the erection camber was taken out.

The camber of the suspended span and the length of the top and bottom chords were controlled during erection by wedges placed between pins in the broken sections of the top and bottom chords at each end of the suspended span as previously mentioned. These wedges, which weigh 50 tons each, are clearly shown in the photograph previously referred to. They were operated by a screw turned by a ratchet and a long lever. The pitch of the wedges is very flat and a delicate adjustment of the ends of the chord was possible. The wedges were used only for lowering the load and care was taken never to withdraw them further than was desired.

Erection Progress

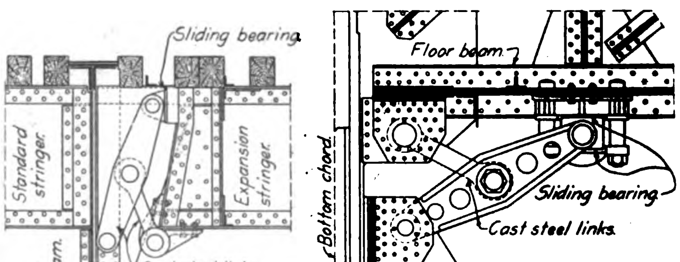
It was the intention to erect the anchor arm and all of the superstructure between piers 2 and 5 on falsework, the suspended span between piers 1 and 2, together with the two cantilever arms, to be erected by the cantilever method. In order to carry on any work on the pile driving or falsework construction, it was necessary that the stage of water in the



Wedge for Adjusting Chord Lengths

river be 20 ft. or less above standard low water level, while for security in the erection it was desirable that the water stage should not greatly exceed this level while work was in progress. It was also expected to time the work so that the erection of spans on falsework would take place late in the summer and in the fall when the river is ordinarily at a low stage.

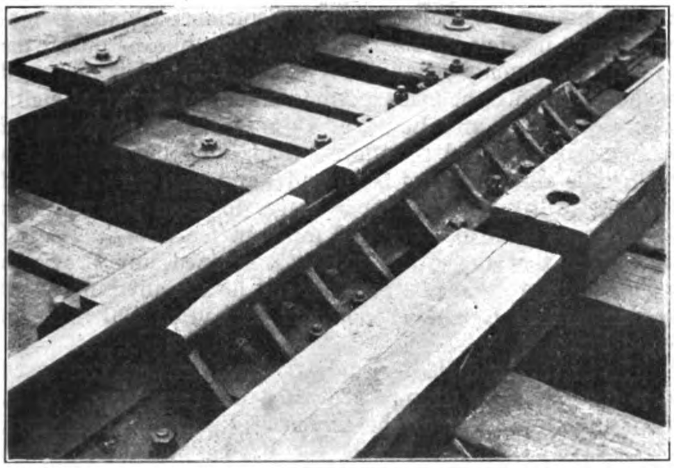
Accordingly the erection of the anchor arms and the



Details of Expansion Joints at the Ends of the Suspended Span

Arkansas viaduct, which was more or less independent of the water stage, was started in April, 1915, and carried to completion during the early summer. The deck span was started in August and finished in October and the east cantilever was finished October 1. Work on the falsework of the fixed span was started the latter part of May but progressed slowly on account of high water. On October 18 the water dropped below 20 ft. and work was rushed, the erection of the fixed span being started on October 15. The erection of this span was forced at a maximum rate in spite of a rise in the river occurring between November 18 and December 3, and the last pin was driven on December 22.

In the meantime the falsework between piers 3 and 4 had been completed and work had been commenced on the steel erection, but on December 23, the river rose to 28½ ft. and carried out all of the falsework between piers 3 and 4 except five tower bents adjacent to pier 3. In going out, this falsework carried with it the traveler, a mule derrick, the highway deck stringers which were being used in the falsework and four panels of the bottom chord and floor system.



Expansion Joint in the Rail Expansion

The river continued to rise, going to 43.5 ft. on February 9, and for a time caused grave concern for the safety of the fixed span, the flood having come so quickly that there had not been time to swing this span entirely clear of the falsework after driving the last pin. On December 29 the first bent of this falsework gave way, followed by others until February 2, when all but two pile bents had been washed away. However, the frame bents were not all lost, for by suspending a considerable portion of them from the steelwork it was possible to hold them until the water returned to a stage that made it possible to remove them. An accompanying photograph shows the conditions on February 2. A considerable number of the bents are seen swinging in the water.

Erection Progress on Semi-Suspended Span Showing Canvas Covers Over the Sand Boxes

On February 2, work was commenced on the creeper traveler to start the erection of the east cantilever from the fixed span, and the suspended span between piers 1 and 2 was completed on April 6. The west cantilever was started on April 27, it having been decided not to use the falsework between piers 3 and 4 except under the half of the suspended span adjacent to pier 4, as the rest of the span could be erected by cantilevering from pier 3. For this purpose the cantilever trusses were suitably reinforced. The falsework, therefore, consisted only of six towers, the one nearest the center of the span having four bents instead of two. The steel erection was started on this falsework on June 10 and the span was swung on June 30.

This bridge was designed and built under the direction of Ralph Modjeski, as consulting engineer in charge, with W. E. Angier as assistant chief engineer and M. B. Case as resident engineer. The substructure was built by the Union Bridge & Construction Company, Kansas City, Mo., and the superstructure was fabricated and erected by the Pennsylvania Steel Company, Philadelphia, Pa.

EIGHT-HOUR DAY COMMISSION APPOINTED

By H. F. Lane

WASHINGTON, D. C., October 10, 1916.

While politics played an important part in the passage of the Adamson eight-hour law, President Wilson has evidently not taken political considerations into account in appointing the commission which is to observe the operation and effects of the "eight-hour day" as provided for by the law. The President announced last week that the commission will be composed of Major General George W. Goethals, governor of the Panama Canal Zone and president of the Panama Railroad, who will act as chairman; Edgar E. Clark, of the Interstate Commerce Commission, and George Rublee, a member of the Federal Trade Commission. While none of these men have been active in politics, Mr. Goethals and Mr. Clark are reputed as Republicans and Mr. Rublee has been considered at various times as a Republican, later as a Progressive, and more recently as a Democrat, and the selection of such strong men for this commission seems to have been received with universal approbation.

General Goethals is a graduate of West Point Military Academy and his career has been that of an army officer in the engineering corps. He was chief engineer of the Panama Canal from 1907 until its completion in 1914, when he was appointed civil governor of the Canal Zone, and he has also been president of the Panama Railroad during that time. His prospective retirement from the canal work was announced on his recent return to the United States. Commissioner Clark was engaged in railway service from 1873 to 1889, when he was made Grand Senior Conductor of the Order of Railway Conductors. From 1890 to 1906 he was Grand Chief Conductor of the organization. In October, 1902, he was appointed by President Roosevelt a member of the commission to determine the issues involved in the strike of the anthracite coal operators. On August 28, 1906, he was appointed by President Roosevelt as a member of the Interstate Commerce Commission and he was reappointed by President Wilson on March 5, 1913. Mr. Rublee is a lawyer and was engaged in active practice in New York City for several years, and since March 5, 1916, has been serving a recess appointment as a member of the Federal Trade Commission.

Section 2 of the Adamson act provides for the appointment of this commission "which shall observe the operation and effects of the institution of the eight-hour standard work day, as above defined, and the facts and conditions affecting the relations between such common carriers and employees during the period of not less than six months nor more than nine months, in the discretion of the commission, and within 30 days thereafter such commission shall report its findings to the President and Congress." Members of the commission are to receive such compensation as may be fixed by the

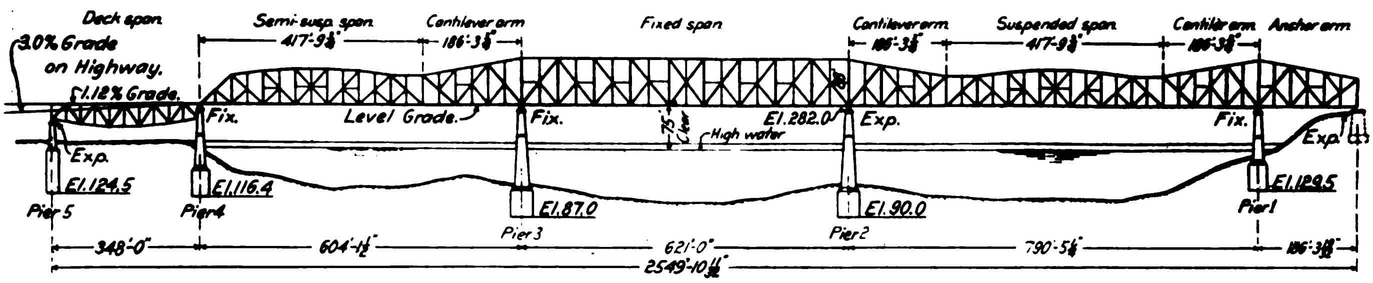
Substructure of the New "Harahan" Bridge at Memphis

Construction Methods Used to Build Piers for Mississippi River Bridge to Carry Three Roads and a Highway

By M. B. Case

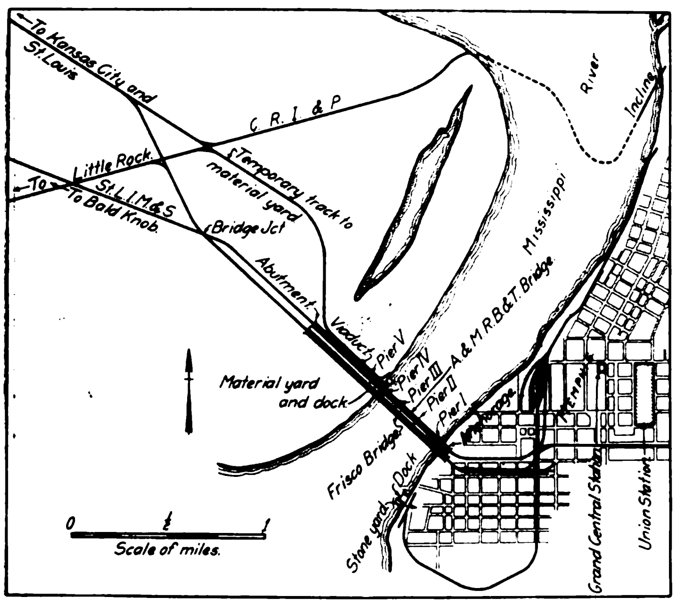
Resident Engineer, Arkansas & Memphis Railway Bridge & Terminal Co., Memphis, Tenn.

All traffic on the four roads extending west from Memphis, Tenn., must now pass over a single-track bridge completed in 1892 for the Kansas City & Memphis Railway & Bridge Company, which has since become a part of the Frisco system. In order to provide more adequate facilities, a new bridge is now being built by the Rock Island, the Iron Mountain and the Cotton Belt systems through a joint organization named the Arkansas & Memphis Railway Bridge & Terminal Company. Work was commenced in June, 1913, as mentioned in a preliminary description of the plans for this bridge in the *Railway Age Gazette* of October 31, 1913, and the substructure was entirely completed in January, 1915, slightly more than 18 months after the preliminary work was started at the site.



Elevation of New Mississippi River Bridge at Memphis

Active preparation for the erection of the superstructure of the main bridge is now under way. False work is being placed under one anchor arm, and derricks for unloading and storing the heavy truss members are being erected. The erection of the main bridge and the viaduct approach will be under way during the coming season.

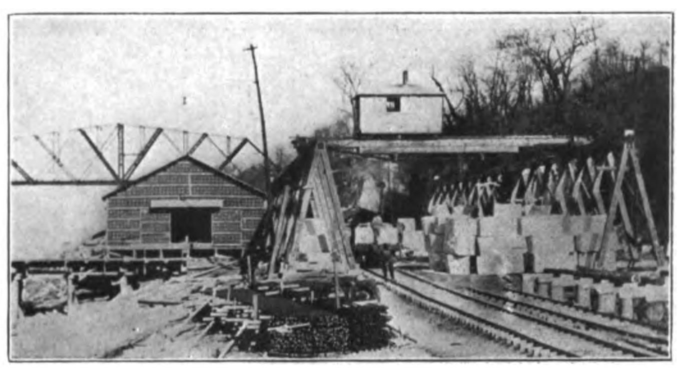


Sketch Map of Bridge Location Showing Material Yard, Stone Yard, Temporary Track, Etc.

THE NEW BRIDGE

The bridge will carry two railroad tracks spaced 14 ft. center to center located between trusses spaced 34 ft. 6 in., and two roadways 14 ft. wide on brackets outside of the trusses. The main bridge is 2,550 ft. long from the anchorage pier on the Tennessee bluff to Pier 5 located 345 ft. back from the low bank on the Arkansas side. Beyond this point a tower and girder viaduct continues over the bottom land for a distance of 2,363 ft. to the west abutment. The tracks are here carried onto an earth embankment 55 ft. high at the abutment, which extends westward on a tangent about ¾ miles to Bridge Junction, where the elevation is about 25 ft. above the general level of the bottom land.

The tracks ascend from the yards in Memphis on a 1.1 per cent grade to Pier 1, and run level to Pier 4, where they descend on a 1.126 per cent grade over the viaduct and the embankment, the necessary vertical curves being provided. The roadways start at Pier 4 to descend to the Arkansas bottoms on a 3 per cent grade along the viaduct until reaching an elevation above high water, about 23 ft. above the ground, when they run level for a short distance to the west abutment and then turn to the down stream side of the Frisco embankment on a single roadway structure to be provided by the county.

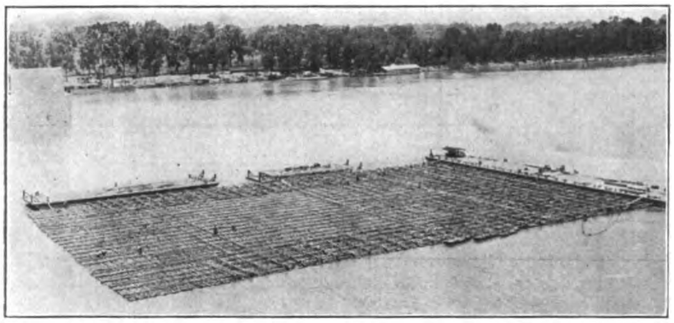


Stone Yard, Traveling Crane, Cement House and Dock on the Tennessee Shore

The center line of the new bridge is 200 ft. up stream, and parallel to the existing structure. Pier 1 on the Tennessee shore and Piers 2 and 3 in the river are directly above the corresponding piers of the old bridge, while Pier 4 on the Arkansas shore is 17 ft. toward the river from the center line of the old pier in order to permit the duplication between Piers 3 and 4 of the cantilever arm and suspended span used between Piers 1 and 2.

The piers are supported on pneumatic caisson foundations resting on a very hard blue clay over-laid by several softer strata of clay having slightly variable characteristics. Above this is a bed of sand covered with the shifting alluvial silt of the Mississippi river. The caissons for Piers 2 and 3 are 42 ft. by 90 ft. by 51 ft.; for Pier 1, 40 ft. by 80 ft. by 59 ft.; for Pier 4, 31 ft. by 77 ft. by 62 ft., and for Pier 5, 25 ft. by 46 ft. by 81 ft. The height from the bottom of the foundation to the coping of Pier 2 is 192 ft., and of Pier 3, 195 ft.

The shafts of Piers 1, 2 and 3, resting on the caisson foundations, are 42 ft. long between the shoulders with pointed noses extending up to the starling coping a short distance above high water elevation. The up-stream nose or cut-water is fine-pointed from the mud line to the starling coping, and above this level the piers have semi-circular ends, both of which have a quarry face. The piers are built of 1:2½:5 concrete, faced with a light gray granite with the exception

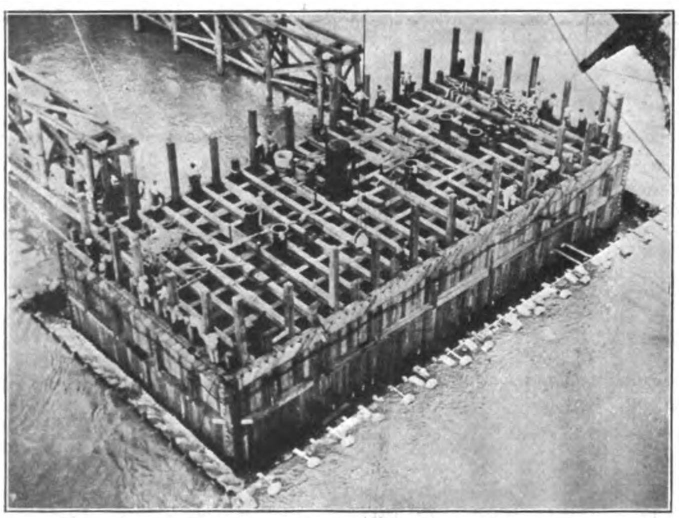


Laying a Willow Mat Over the Site of Pier II to Reduce the Tendency to Scour

of the three courses under the coping which have granite backing as well as facing. The stone was laid in Flemish bond with few exceptions, and the courses were 3 ft. thick up to the starling, with 30 stones in a course. Above this level the courses are reduced in thickness to a minimum of 2 ft. under the belting course.

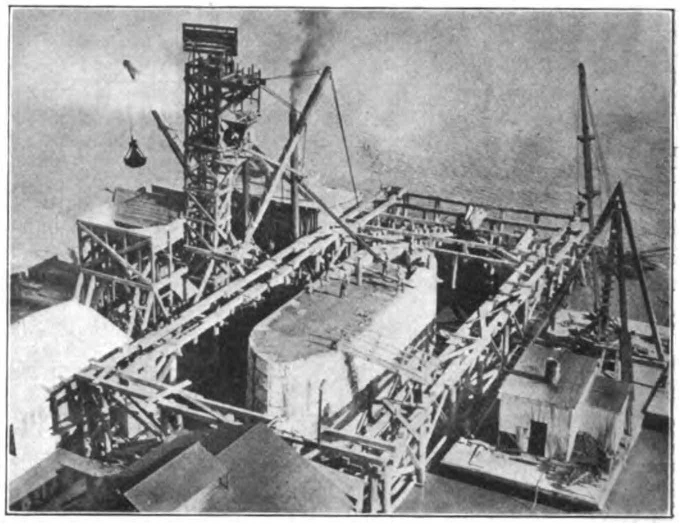
CONSTRUCTION PLANT

The most convenient ground available for the large storage and timber framing yard necessary was on the Arkansas



Launching the Timber Caisson at Pier III

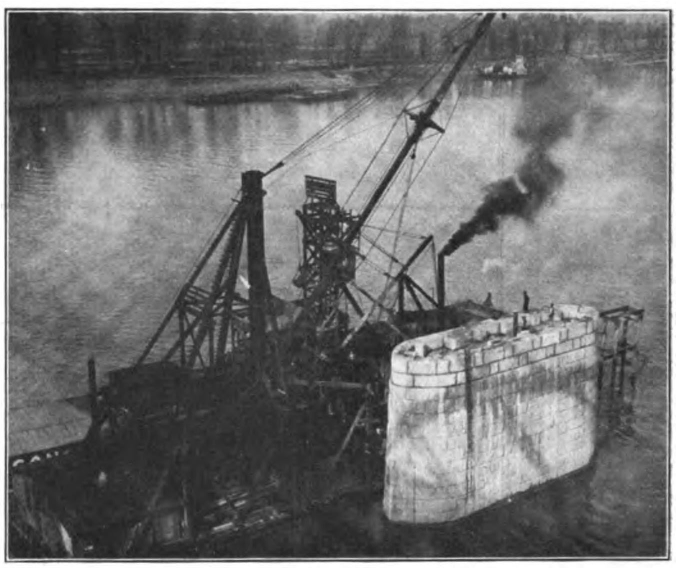
bottom land along the viaduct. This location furnished ample space at small expense, and permitted the quick and cheap delivery of material to barges for transportation to the piers. Although this ground was likely to be overflowed between February and June, a material yard on the high Memphis bluff would have caused considerable expense and delay in delivering material and supplies on the river, and did not furnish suitable ground for building the large number of barges required. The first preliminary construction consisted in building about two miles of track from the old Rock Island Hopefield line to the west bank of the river, as shown in the



The Concrete Mixing and Placing Outfit Working on Pier II

sketch map. This line connected with two tracks extending onto a dock equipped with a derrick for transferring material to boats.

The first three months were occupied almost entirely with the building of 15 barges, a part of which carried the various rigs needed in the construction and the rest were for use as cargo boats. In addition to these barges constructed on

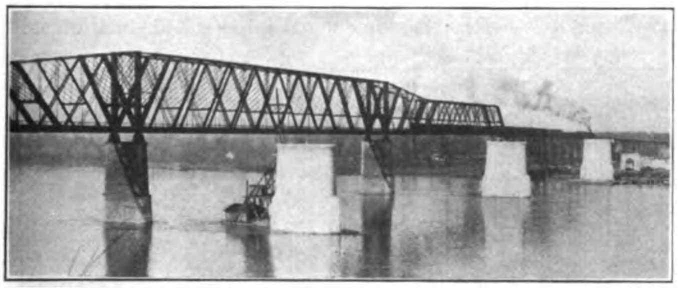


Placing the Upper Courses of Granite Facing on Pier II

the work six more were purchased second-hand, and several others and a small steam boat were chartered from time to time as required to keep the work going without delay. A screw propeller tug and two launches completed the marine equipment. The rigs built on these barges consisted of an air compressor plant, a concrete mixing and delivering plant, a pile driver, three derrick barges and two mat weaving outfits.

The granite for the piers was cut at the quarry and shipped from Stone Mountain, near Atlanta, Ga. This naturally called for storage on the east side of the river. A storage yard was obtained a short distance below the bridge on the

Tennessee side below the bluff but above high water. This yard was equipped with a traveling crane which unloaded the granite as received and later delivered it onto push cars which could be run out onto a dock with a derrick to lower it onto the barges by which it was delivered to the piers. A cement house of 3,000 bbl. capacity, for storage of a reserve supply, was also located on this ground next to the river. The greater part of the cement was delivered by

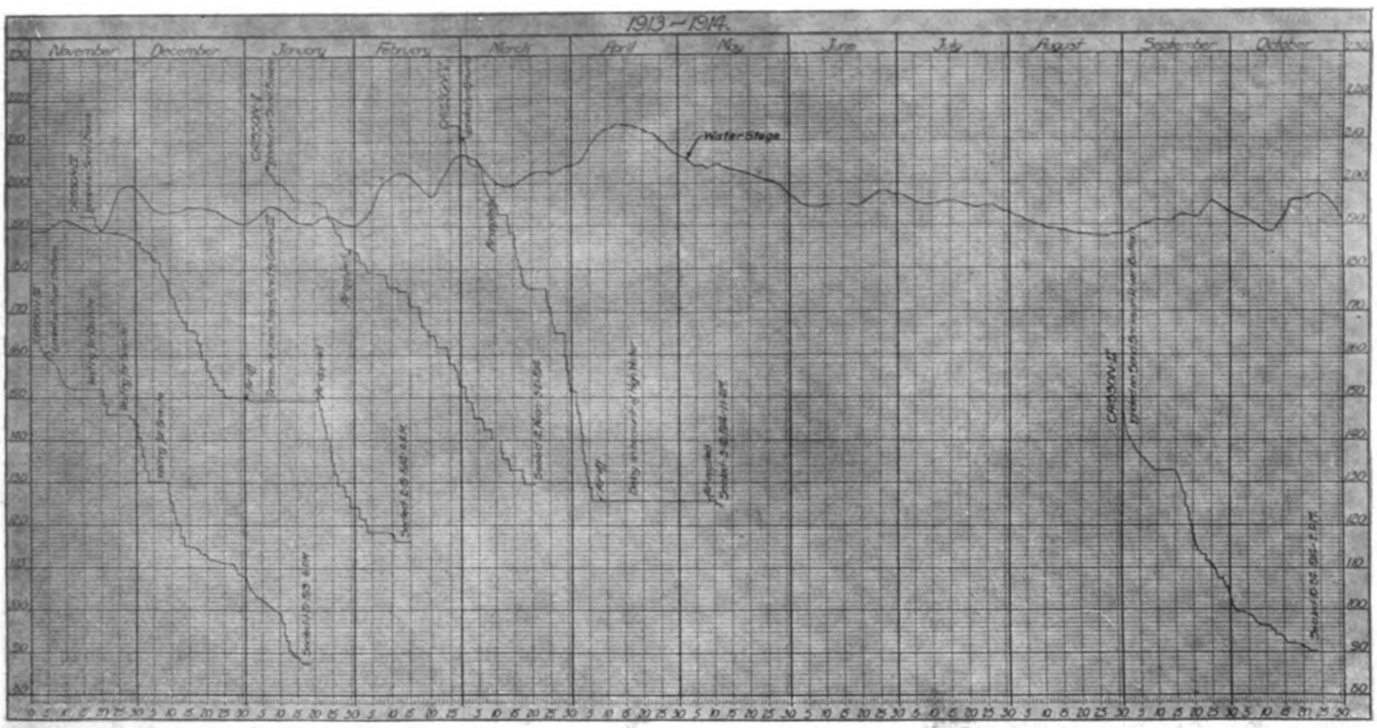


Piers II, III, IV and V Completed, Showing Also the Old Frisco Bridge

boat from St. Louis and unloaded into two covered barges of 1,500 bbl. capacity each. Cement intended for the storage house was shipped by rail, and used only when the deliveries by boat were delayed or suspended by the river conditions. This was but a small part of the 59,000 barrels used, and could be delivered directly into the barge houses by chuting down an incline.

The concrete mixing plant was carried on a barge 36 ft. x 100 ft. equipped with the familiar tower and chute for the delivery of concrete. Mississippi river washed sand and screened gravel were furnished by a local firm. This material was handled on the bridge company's barges of 275 cu. yd. capacity, and was raised into the hoppers over the mixer by a clamshell bucket and derrick located on the corner of the mixing plant barge opposite the mixer. These hoppers had a capacity of 50 cu. yd. of sand, and 70 cu. yd. of gravel. The material ran by gravity into a measuring hopper which discharged into a 1-cu. yd. mixer. Cement was elevated to the measuring hopper in a small car pulled up an inclined track by a line leading to a spool on the tower hoisting engine. The cement car ran back on a track extending under the roof of the cement barge which was moored below the mixing plant, thus reducing the handling of the cement and the loss and damage of sacks during wet weather. This barge carried a 60-hp. locomotive type boiler furnishing steam to the mixer engine and tower hoist. Ample steam was available for heating water and sand during chilly weather to hasten the setting action of the concrete, although low temperatures are not common at Memphis.

The compressor barge for the pneumatic caisson foundations carried four locomotive type boilers with a combined capacity of 300 hp., with the necessary pumps and feed water heaters. Three low pressure compressors with a capacity of 2,500 cu. ft. of free air per minute furnished air for the caissons, and one smaller machine furnished high pressure air for the boring tools and hammers used on the timber construction. A 25-kw. direct-connected generator furnished current for lights and for an elevator operated in the main shaft of the two deeper piers. The so-called hospital lock, for the use of the pressure men in relieving occasional cases of bends or after effects of the air pressure by recompression, was located on this barge. The compressors discharged directly into a small air receiver during cool weather, but during the warmer months the air passed through a series of cooling pipes before entering the caisson. These were submerged in the river and supported alongside the barge. This plant was used for Piers 3, 1 and 2 in the order named. Another compressor plant built on the Arkansas shore west of Pier 5 was used for Piers 4 and 5.



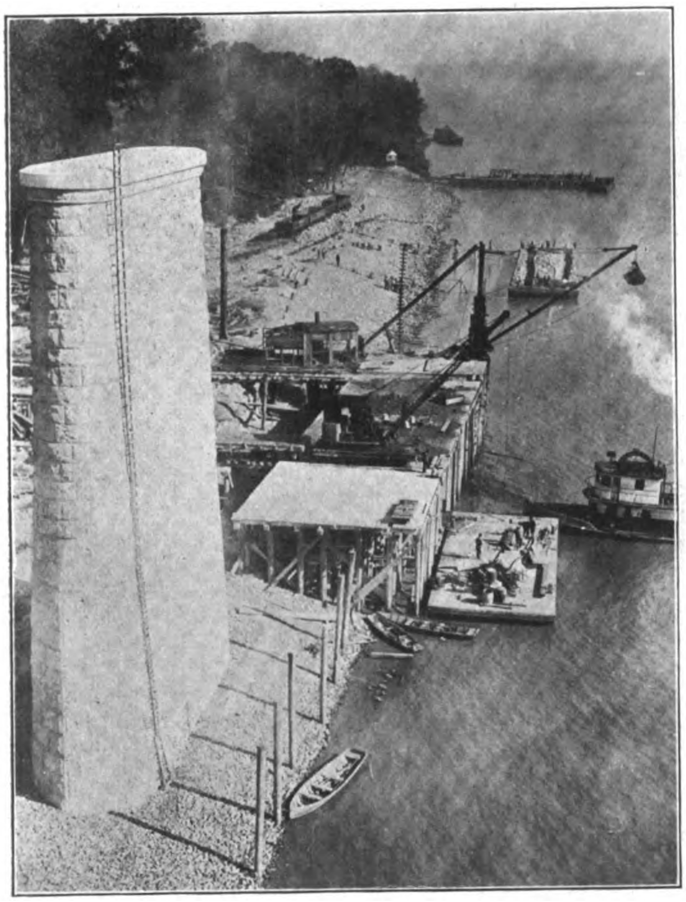
Progress Chart Showing Rates of Sinking Caissons at the Five Piers

SINKING CAISSON FOR PIER 3

Preliminary construction of barges and plant had advanced so that construction of the caisson for Pier 3 was started in September, 1913. This caisson was built up 14 ft. in a 54 ft. by 100 ft. by 11 ft. pontoon before launching. The weight of the caisson was distributed over the bottom of the pontoon by transverse loading beams consisting of two 12 in. by 12 in.

timbers well keyed and bolted together to act as a single beam 24 in. deep. These beams rested on longitudinal 12 in. by 12 in. timbers of the pontoon, and received the weight of the caisson at the cutting edge and center bulk-head. The pontoon was built with a longitudinal joint to provide a means of separating the two halves and withdrawing them from under the caisson after the pontoon had been flooded and the caisson floated. The bolts in this joint were removed just before flooding the pontoon. After the pontoon was submerged, the halves were pulled from under the caisson, the sliding surface being the top of the longitudinal timbers on the pontoon and the bottom of the transverse loading beams. The latter were afterwards pulled out by lines attached for that purpose before flooding the pontoon. The buoyancy of the timber in the pontoon was reduced very materially by loading it with pig iron immediately before flooding. The launching of this caisson was accomplished without trouble.

A well braced pile dock had been driven around three sides of the pier site previous to the launching of the caisson, which proved very satisfactory for holding it in position until well landed on the river bed and afforded a convenient and economical staging for the caulkers and the work of planking the sides of the crib during the sinking. It also furnished a location for a derrick on the upstream end of the pier, thus

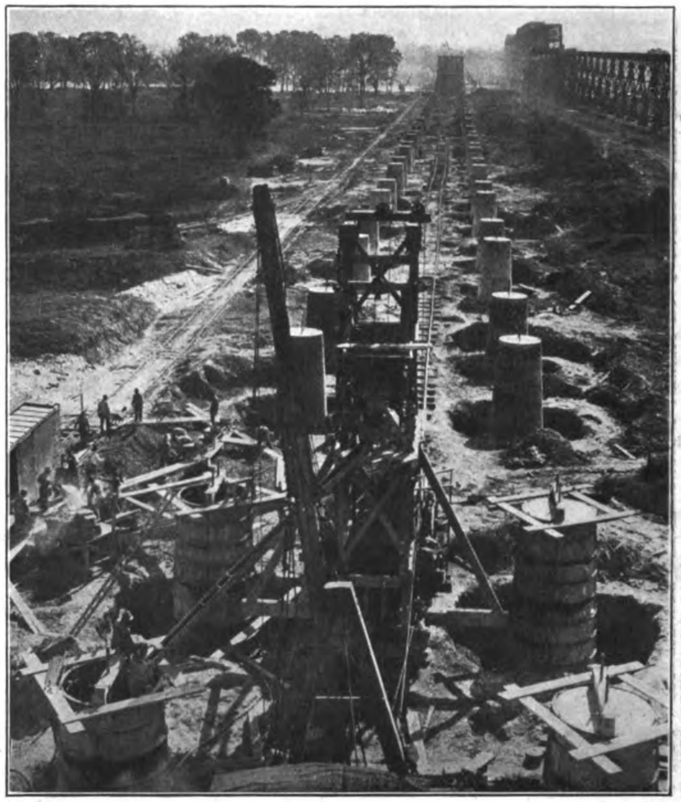


The Arkansas Shore Showing the Completed Pier IV, the Dock from Which Construction Material Was Handled to Barges and Shore Protection Extending Up Stream

getting a maximum amount of plant into position to work on the pier at one time.

A 6-ft. shaft, with a lock at the bottom a short distance above the roof of the caisson, was equipped with an electric elevator for handling the gangs in and out of the caisson, and in addition to this a 3-ft. shaft with a ladder and Morison lock was provided. Five 2-ft. material shafts were used for locking out the clay excavation and for passing in concrete when sealing the caisson. These material shafts were equipped with short vertical locks taking a bucket of 9 cu. ft. capacity handled by a derrick, the hoisting rope running through a packing gland in the top doors of the lock. These locks were very economical of air required for lockage.

While the sinking was in sand which was handled through 4-in. blow pipes, the rate of sinking nearly always depended upon the progress of building up on top, but when the clay excavation was reached sinking usually depended on the rate



Placing Concrete in Steel Pedestal Forms for Western Approach Viaduct

at which the locks could remove the spoil from the working chamber. After the harder clay was reached, the progress depended upon the rate of excavating the clay ready to be locked out. The accompanying diagram shows the rate at which the sinking proceeded on the various piers, as well as the immersion at various stages of the work. The highest air pressure required was 48 lb. on Pier 2, which continued for several days while the immersion was 107 ft. Pier 3 required 45 lb. just previous to sealing the working chamber.

In building up the piers, no difficulty was experienced in setting and backing one course each day. The water and sand were heated during chilly weather to hasten the setting action, so that the concrete was well hardened for the masons to work over on the following day.

OTHER PIERS AND THE APPROACH VIADUCT

The design of Pier 2 and the general construction methods followed differ but little from those described for Pier 3. Because of the much deeper water at Pier 2 (50 ft. as compared with 30 ft) it was necessary to use a removable cofferdam 15 ft. high as an extension to the crib. This was done to permit the landing of the caisson on the river bed, and to increase the buoyancy of the pier until sufficient friction and bearing was developed to carry the weight of the granite masonry. Because of the swifter current and consequent tendency to scour, the bed of the river was prepared to receive the caisson by sinking a willow brush mat 200 ft. by

300 ft. in size placed centrally over the site of the pier. The design and construction of this mat differed in no way from those placed by the Mississippi River Commission on other parts of the river. After the dock was driven through the mat 29,000 burlap sacks filed with sand were deposited at the pier site to reduce the depth of the water about 8 ft., and to give an even bearing on which to land the caisson.

Willow mats extending 150 ft. on both sides of the bridge axis were afterwards sunk and covered with rip rap for the entire distance between Piers 2 and 3 to protect the false work from scour during the erection of the 621 ft. fixed span, which also forms the anchorage for the 790 ft. cantilever span towards Pier 1, and for the cantilever arm and semi-suspended span towards Pier 4. After the completion of this channel mat work the same plant was used to place a mat along the Arkansas bank extending 1,000 ft. above the bridge.

The 76 pedestal foundations and the west abutment were built during the summer of 1914. The pedestals each contain 53 cu. yd. of concrete and rest on a 13 ft. by 13 ft. footing block supported by 16 30-ft. reinforced concrete piles of octagonal section, 16 in. between faces at the top, and tapering to 12 in. at the point. The reinforcement consists of 8 7/16-in. square twisted bars, spiral wound with No. 4 iron wire about 2½ pitch. The piles were cast on the Arkansas dock using 1:2:4 concrete from the river mixing plant, and were removed to the storage yard by a locomotive crane after 48 hours, where they were cured 30 days or more before driving. The concrete in the pedestals was made from crushed rock delivered on cars, and was mixed by a plant rigged on a flat car with tower and spout delivery. This car ran down the center line of the viaduct, and the four pedestals of a tower could be poured from one position of the plant. One of the accompanying illustrations shows the plant working on the last of the pedestals, and the steel forms used for the pedestal shafts.

Ralph Modjeski is the consulting engineer in charge of the design and construction of the bridge, and W. E. Angier is assistant chief engineer. The Union Bridge & Construction Company, Kansas City, Mo., were the contractors for the entire substructure, including the channel mats and bank protection work. They were represented in Memphis during the first season's work by H. K. Seltzer, vice-president and chief engineer, and later by J. F. Wilhelm, engineer of construction.

FRICTION SPRING DRAFT GEAR

On page 832 of the *Railway Age Gazette* for April 16, 1915, there was published an article with the heading given above, descriptive of the Slick friction draft gear. The first paragraph of this article read as follows: "The drawing below shows the plan and half-sectional elevation of the Slick friction spring draft rigging which was recently developed by the Carnegie Steel Company, Philadelphia, Pa." Through an unfortunate error, the name of the manufacturing company was given incorrectly; the Slick friction draft rigging was developed by the Cambria Steel Company, Philadelphia, Pa.

A New Railway for India.—The government of India has granted a concession to the Khoolna Bagirhat Light Railway to build a 20-mile, 2½-ft. gage line from the east bank of the Rupsa river, opposite Khoolna, the terminus of the central section of the Eastern Bengal Railway to Bagirhat, the headquarters of the most important subdivision of the Khoolna district and a place of considerable importance. The present communication between the two places is unsatisfactory, steamer service having been discontinued because of the silting of the River Bhairab, which runs parallel to the proposed railway. The country through which the line will pass is populous. The line will be operated by the Eastern Bengal Railway.

NEW ENGLAND AND THE NEW HAVEN ROAD*

By Howard Elliott

Chairman of the Board of Directors and President of New York, New Haven & Hartford

In discussing the railroad and public utility question the opinion is sometimes expressed that the public cannot be expected to pay a return upon any more capital than was originally invested in a prudent manner. But is this the whole story, and who is to decide today what was prudent 10, 20, 50, even 100 years ago, as in the case of the Norwich & Worcester road? Must we not, as long as we stick to the theory of private ownership of public utilities, allow those private owners to make their investments with the hope of a profit inasmuch as they have to assume the burdens that come with increased values and take all the risks of loss?

Prudence, if carried to an extreme, may stop all progress. What would be the conditions in America, in the United States today, if Christopher Columbus, Amerigo Vespucci, Vasco Nunez de Balboa, John and Sebastian Cabot and daring spirits like them had been prudent? Emigrants to the west who followed were not always prudent, but they helped to make an empire. Where would our great American manufacturing and transportation enterprises be if men of enterprise, ingenuity and resource throughout the whole period of wonderful development of the last 50 years had not had the courage to enter unknown and untried fields of human endeavor and really been imprudent on many occasions?

It is so easy to look back, criticize and point out the mistakes of others, and so hard to look ahead, do constructive work, and take the chance of failure in the hope of producing results that are to benefit a whole community and a whole country.

Under private ownership we have built up in this country a very remarkable system of railroads, public utilities and large industries. They furnish more of comfort and convenience to the people of the United States than are obtained anywhere else on the globe. In doing this great work, the private owners have made mistakes, of course, and a few men have made great fortunes—comparatively few, if you take the trouble to count up, when the vast number of men engaged in the constructive work of the last 50 years is considered. Only 357,598 persons in our population of 95,000,000 had an income of $4,000 or more, according to the report of the commissioner of internal revenue for 1913, and the greater proportion of these were in the $4,000 class. Because of these mistakes; because of a few great fortunes; because the growth of these great businesses has been very rapid and some of the men guiding them have not always grown as rapidly and considered carefully enough the rights of the public, there has been developed a system of regulation by state and national commissions. This is right and proper because human nature is such that people with power, unless checked, sometimes exercise that power unwisely. The regulators, however, given great power by the people, are human, too, and the business of regulating the public service corporations and the business enterprises is new, and men are trying to find out the best way to do it.

In the evolution of the regulatory system, mistakes are being made, and the absence of a check upon the vast powers of the various commissions has led to some arbitrary exercise of those powers and some harm has been done by this regulatory system. I am glad to say that some of the state and national commissioners, particularly in New England, realize the seriousness of the situation and the great responsibility that accompanies the unusual powers that have been delegated to them and that they are acting accordingly and are now trying to protect the public service corporations and business of the country.

VALUATION

A very important problem before the country today is that

*From an address to the members of the Eastern Connecticut Development Committee and of the Civic Associations of Norwich, New London, Willimantic, Putnam and Danielson, at Norwich, Conn., on April 8, 1915.

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THE HARAHAN BRIDGE AT MEMPHIS, TENNESSEE.*

BY

RALPH MODJESKI, D.Eng.,

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

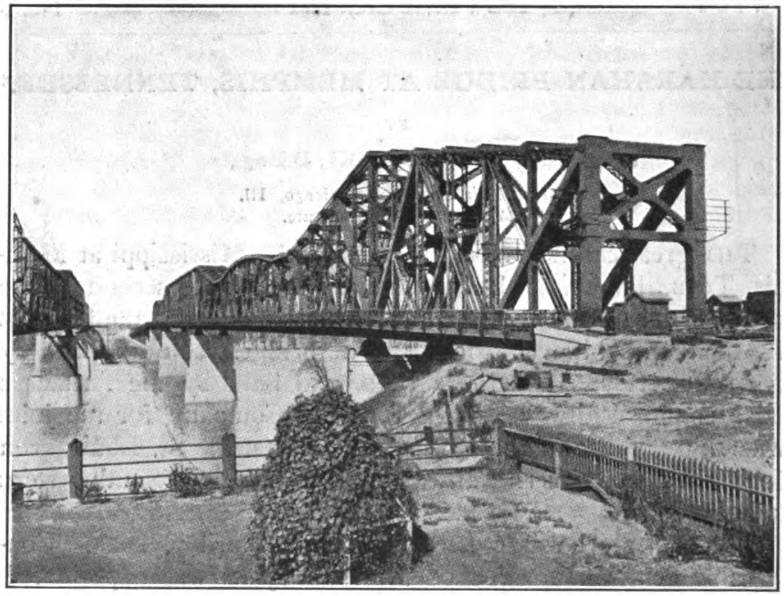
THE great cantilever bridge crossing the Mississippi at Memphis, Tenn., known as the Harahan Bridge, is the second bridge erected at that point and is an important addition to the long list of American cantilever bridges. The bridge was authorized by act of Congress, August 23, 1912, and built by the 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.

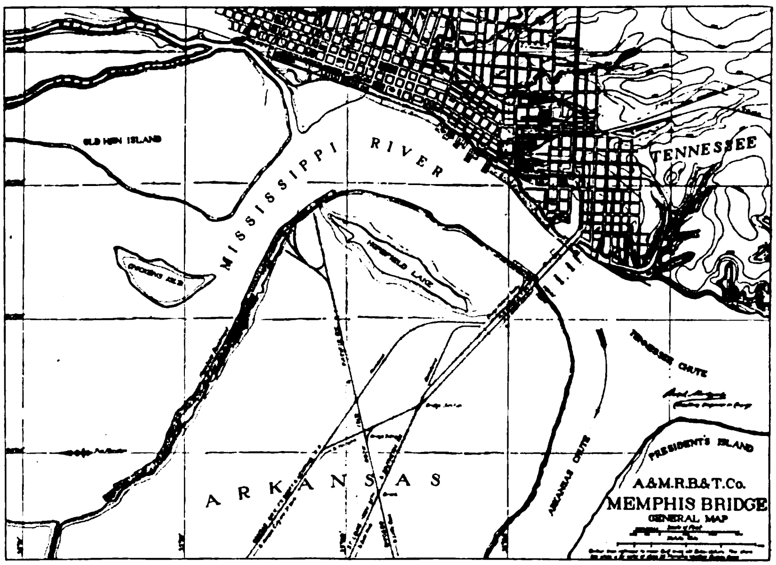
MAIN SUBSTRUCTURE.

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'

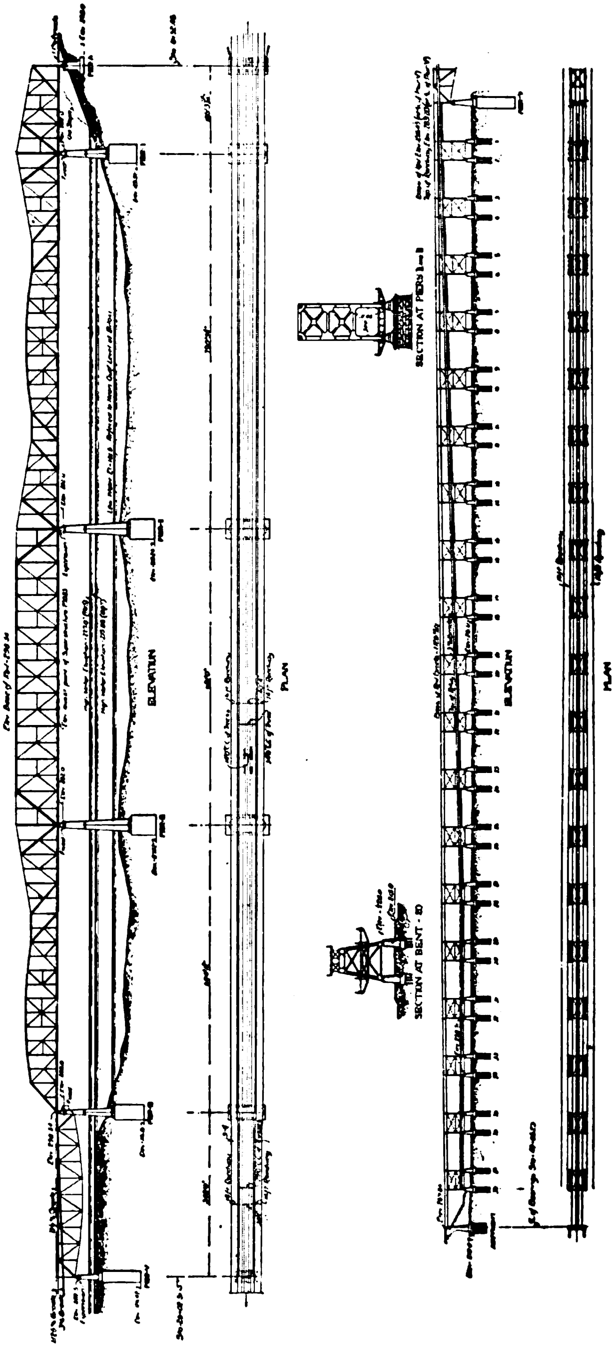
The deduction of 400 pounds per square foot for skin friction is conservative. As a matter of fact, while making the last drop in pier 4 conditions were such that a practically exact measurement of the skin friction could be taken, and this was found to be 800 pounds per square foot. It is probable that 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.

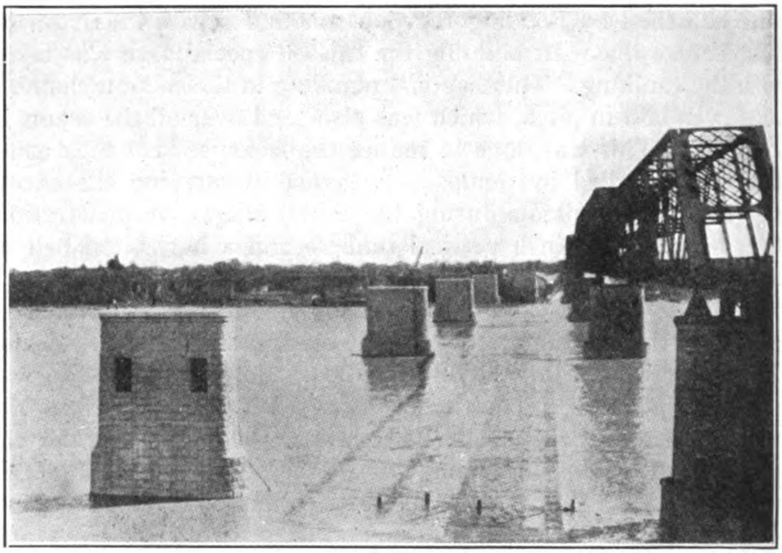


Arkansas and Memphis Railway Bridge and Terminal Company. The Memphis Bridge—General elevation and plan.

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 over-come 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.

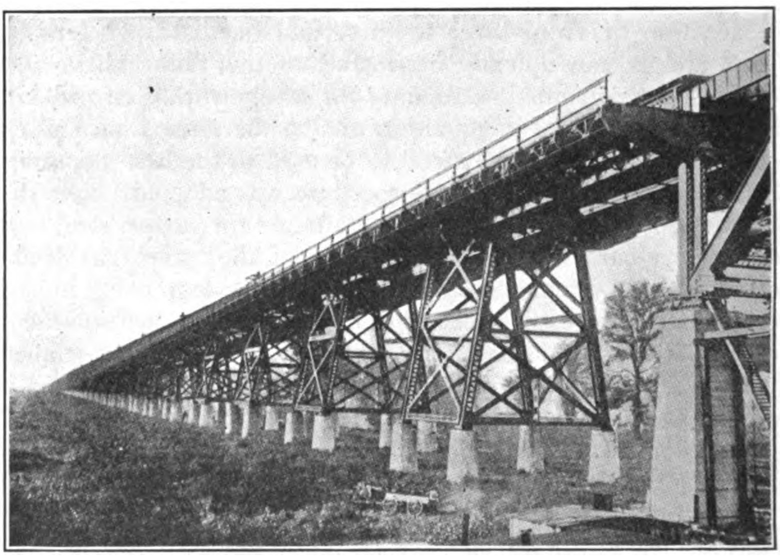
The main superstructure consists of a continuous cantilever system of four spans and one deck span, the lengths of which have been given elsewhere. It carries a double track for railway and two roadways, one on each side, supported on brackets outside of the trusses.

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