THE ENGINEERING SUPERVISION OF THE NEW MEMPHIS BRIDGE

BY

HARRY ANTHONY WIERSEMA

B. S. University of Illinois, 1913

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

CIVIL ENGINEER

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1919

1919
W63

UNIVERSITY OF ILLINOIS

THE GRADUATE SCHOOL

March 6, 1919

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Harry Anthony Wiersema

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Note.

The writer was associated with the consulting engineer in charge during the entire construction of the New Memphis Bridge, for the most part as assistant to the Resident Engineer, M.B.Case, also in charge of the shop inspection on the approach viaduct, and for the last several months, in sole charge of the construction work in the field.

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THE ENGINEERING SUPERVISION OF THE NEW MEMPHIS BRIDGE.

INTRODUCTION

I. General Description.

1. Economic features.-- The building of the New Memphis Bridge during the years 1914 to 1917 was brought about primarily by the inadequacy of the Old Memphis Bridge, in conjunction with an economic condition that made the new project feasible several years before the physical necessity would have forced its adoption.

Ever since the expansion of the railway lines to the west of the Mississippi river, the crossing of that stream has been one of the greatest of problems, towards the solution of which the construction of the Eads Bridge at St.Louis was the first great attempt. For many years thereafter, however, all traffic below St. Louis was carried across the river by means of ferry boats, which were fairly successful for the small amount of traffic carried; until in 1892 the Kansas City and Memphis Railway and Bridge Co. completed the construction of the Old Memphis Bridge, a single track structure, long known as the Memphis High Bridge, which still remains the lowest crossing of the Mississippi. This bridge was first used by the St.Louis and SanFransisco Railway-the Frisco- and the St.Louis Iron Mountain and Southern Railway-the Iron Mountain- and later by the St.Louis Southwestern-or Cotton Belt- the latter running over the Iron Mountain rails; but the Little Rock and Memphis Railway- part of the Rock Island system- continued to operate their transfer boat for freight traffic until 1912, when

the formation of a sand bar on the Tennessee shore, and the wash-out of terminal facilities on the Arkansas shore due to erosion of the bank, made it necessary for the entire traffic of this line to use the old bridge also.

This increase in traffic over a single track structure a mile in length necessarily caused a congestion that resulted in frequent delays, aggravated by the fact that the steep approach on the Arkansas side, a 1.25 % grade, made it necessary to reduce the tonnage drawn by one locomotive, and also greatly reduced the running time, even of passenger trains. The bridge had been designed for wheel loads that obtained in 1890, hence heavier locomotives could not be used; the piers were not wide enough to permit of double tracking the structure, and as there was no bridge other than this below the conflux of the Mississippi and the Ohio rivers at Cairo, little traffic could be diverted to other crossings. Obviously another crossing at Memphis was the ultimate solution of the problem.

This solution was hastened, however, by the economic status of the old bridge. The stock of the Kansas City Fort Scott and Memphis Bridge Company was controlled by the Frisco Railway, which in effect, therefore, received the tolls of the other three roads. The greater proportion of the traffic was over the Rock Island, and the amount paid in tolls by this road alone more than equalled both the interest and operating charges of a new bridge. This was true even after a reduction in tolls of 25 per cent, when for the fiscal year ending June 30, 1913, the total of the tolls paid by the three tenant companies was $ 640,000.

The initiative was taken by the Rock Island Railway, and

preliminary steps were taken for the project of a New Memphis Bridge. It very soon appeared that the most advantageous organization for this purpose would be a separate corporation, and consequently the Arkansas and Memphis Railway Bridge and Terminal Company was incorporated, stock being taken by all three of the tenant companies of the old bridge, the Rock Island, Iron Mountain and Cotton Belt. Officials of these three roads became officers of the new Bridge Company. Bonds were issued and guaranteed by a New York bonding house, and credit thus obtained for the immediate commencement of construction operations. A prominent bridge engineer, Ralph Modjeski, was appointed consulting engineer in charge, and to him was given the task of carrying out the project.

2. Engineering features.- The physical conditions of the river channel in the vicinity of Memphis are such that no better location could be found for the new structure than in the immediate vicinity of the old. At this point the channel width at usual stages is about 2000 feet, less than half a mile, while very few points exist below Cairo at which the width is less than three-quarters of a mile. Moreover, a high bluff on the Tennessee side of the river makes an ideal approach, and government revetment work an the Arkansas side eliminates the possibility of a wash-out on that side. It was decided therefore to build the new structure just 200 feet upstream and parallel to the old; and this condition in itself decided several other features of design, since the War Department decreed that on account of the proximity, all the clearances of the old bridge must be maintained. The five masonry piers were therefore located opposite the five old piers, thus determining the main span lengths of 790, 621, 604 and 345

feet; the height of 75 feet clear above the previous highest water mark was maintained, and the length of the Arkansas approach viaduct,made necessary to provide for the free passage of water at flood stages,was also kept the same as on the old bridge, about 2400 feet. The main features of this location are clearly shown on the accompanying map, Plate I.

The river at this point is about 50 feet in depth at ordinary stages, and frequently over 100 feet at flood stages. On account of the character of the river bottom, the pneumatic caisson process was the most feasible for securing foundations for the river piers, and was used on all five of these foundations, the lowest of which was sunk to a depth of 108 feet below the surface of the river. All of the caissons went through about 50 feet of river bottom to a solid foundation on a hard stratum of clay; they were of timber construction filled with concrete, and on them the piers were built to a height of about 150 feet, making the total height of the pier and caisson about 200 feet. Four of the piers were faced with granite masonry and filled with concrete,while the fifth was of solid concrete construction.

In appearance the superstructure of the new bridge is very similar to the old, although the system of web members is different,being of the K type, while the old bridge is designed on the Warren truss system. The principal design of both bridges is the same, consisting of a central fixed span, from which a cantilever carries a suspended span on either side; an additional cantilever with an anchor arm 186 feet long carrying the other end of the suspended span on the Tennessee side, while a deck span meets the viaduct approach on the Arkansas side. It is a double track bridge, with a highway on either side outside of the trusses, the width


WOLF RIVER
LOOSAHATCHIE RIVER
OLD HEN ISLAND
MISSISSIPPI RIVER
TENNESSEE
CHICKENS ISL'D.
HOPEFIELD LAKE
Hopefield Revetment
Bridge Junction
Abandoned
Abandoned
TENNESSEE CHUTE
ARKANSAS CHUTE
PRESIDENTS ISLAND
ROCK ISLD
Bridge Siding
To Memphis
Brink
To Little Rock
To Kansas City and St Louis
To Rock Knob
Five Meridian
20'03'
20'04'
20'05'
20'06'
35'11'
35'10'
35'09'
35'08'
A.&M.R.B.&T.Co.
MEMPHIS BRIDGE
GENERAL MAP
Scale of Feet
Statute Mile
Contour lines reffered to mean Gulf level, old Biloxi datum. The shore line given is for water at stage 35 Memphis Weather Bureau Gage.

between trusses being 34 feet. This makes the total width of the structure 70 feet. The depth of the highest truss is 88 feet, making the total distance from the top of the highest steel to the bottom of the caisson 302 feet. The design was made on the basis of Cooper's E-70 loading, with a safe working stress of 60 per cent of the elastic limit; and most of the suspended span, and the truss members of the other spans, are of alloy steel. The total length of the main bridge is approximately 2300 feet. The main dimensions, the truss system, and the general design, giving the tension and compression members, are shown on the general elevation, Plate II.

The west approach viaduct, 2400 feet in length, is built on concrete pedestals, supported on concrete piles. Alternate spans of 40 and 80 feet were used, the steel girders being supported on braced steel towers, which carry the double track above, and highways on either side. The height of the viaduct varies from 55 to 70 feet, the grade being 1.125 per cent. This layout is clearly shown on the general plan of the West Approach, Plate III.

To meet this viaduct an earth fill is necessary, which varies in height from 20 to 70 feet, and is about a half mile in length, from the end of the viaduct to the junction of the Rock Island and the Frisco Railways. The entire Arkansas side of the river is low bottom land, subject to a yearly overflow, which even a complete system of government levees has failed to prevent; and the railways cross this bottom land successfully on filled roadbeds which have been raised from time to time to provide satisfactory operation during flood seasons.

On the Tennessee side, the approach is also about half a mile in length, for which very little fill was required, the maximum grade being about .82 per cent. All grade crossings are elim-

El Base of Rail = 298.54
El Top of Roadway = 299.69

2015'6½" (Level)

SEMI-SUBD. SPAN "B" 60'5½" — 14 Panels @ 29'0⅝" = 417'9½"

CANTILEVER ARM "C" (For Alley Design)
CANTILEVER ARM "C1" (For Urban Design) 60'5½" — 6 Panels @ 31'0⅝" = 186'3⅝"

FIXED SPAN "F" 62'10" — 13 Panels @ 31'0⅝" = 402'10"

CANTILEVER ARM "C" 60'5½" — 6 Panels @ 31'0⅝" = 186'3⅝"

SUSPENDED SPAN "S" 730'5½" — 14 Panels @ 29'0⅝" = 417'9½"

CANTILEVER ARM "C" 60'5½" — 6 Panels @ 31'0⅝" = 186'3⅝"

ANCHOR ARM "A" 34'6" — 6 Panels @ 31'0⅝" = 186'3⅝" (at ℄ Bott. Chord)

DECK SPAN "D" — 10 Panels @ 30'0 3/32" (at ℄ Top Chord)

℄ of Pier

3.6% Grade

Fixed — El. 288.0 — Expansion

Fixed — El. 288.0 — Fixed — El. 288.0 — Expansion

Fixed — El. 288.0 — Expansion

1.7% Grade

Roadway Rail Sta. El. 298.69

Bridge Seat El. 298.69

Sta. 26 + 02.31 — El. 111.02

Sta. 22 + 54.31 — El. 111.02

Sta. 16 + 30.19 — El. 38.26

Sta. 10 + 29.19 — El. 34.23

Sta. 2 + 34.31 — El. 123.02

Sta. 0 + 58.46

PIER V — PIER IV — PIER III — PIER II — PIER I

High Water Elevation = 285.85 (1937)

Low Iron Elevation = 290.55

℄ of Pier or Recharge

ELEVATION of MAIN BRIDGE

34'6" — 60'5½" — 62'10" — 730'5½" — 186'3⅝" (Vertical)

NOTE
Water barrel to be placed near ℄ of Trusses diagonally every 100 ft about

PLAN

Base of Rail (Level)

300' — 300'

Base of Rail (Vertical Curve) — 5" Tie — Top of Stringer — 36" Tie

VERTICAL CURVE for R.Y. TRACKS

3108' — 3108'

Base of Rail (Vertical Curve) — 36" Tie — Top of Stringer

VERTICAL CURVE for R.Y. TRACKS

Approved _____

Approved _____

A.&M.R.B.&T. Co.

MEMPHIS BRIDGE.

GENERAL ELEVATION & PLAN of MAIN BRIDGE

Scale 1/16" = 1'

Plate II

7

NOTE
Base of Rail on Vertical Curve 60 ft. long
Ties dopped to suit curve

Base of Rail El-296.43 (at ℄ Pier)
Top of Roadway El-289.20 (at ℄ Pier)

B. of Rail El-269.84

Provide Vertical Curve

Base of Rail Grade 1.126% ↓

Top of Pedestals El-228.0 ±
Fill El-213.0 ±

Top of R'Wall

El-238.71 ±

Top of R'Wall

3% Grade ↓

0.6% Grade

L.W. El-181.6 ±

Sta 26+02.31

60' 40' 60' 40' 60' 40'

inated by elevating the tracks and constructing two concrete subways at streets not closed.

3. History of construction.- The entire construction period occupied a little over three years, from July 1913 until September 1916. Borings had already been taken when the work was first contemplated in the early spring; and the contract for the substructure was let and work started early in July. The work on the substructure took approximately eighteen months, four months of which were consumed in preparation, building plant and equipment, and the remainder in sinking the caissons and building the piers. The first four caissons were sunk in five months time, and the fifth caisson was not finished until six months later, a period of high water intervening. The mat protection and revetment work was put in before the last caisson was started, and the masony construction progressed during the high water period, so that there was slight loss of time. The following table gives the important dates on the different operations and the comparative time required on the different piers.

Building & Sinking	Commenced	Finished	Days
Caisson I	Nov.23 1913.	Mar. 21 1914	120
Caisson II	June 25 1914	Oct. 2 1914	97
Caisson III	Sept 20 1913	Jan. 19 1914.	120
Caisson IVI	Oct. 16 1913	Feb. 15 1914	120
Caisson V	Feb. 9 1914	May 12 1914	63
Masonry Work			
Pier I	Mar. 1 1914	Jul.29 1914	150
Pier II	Sep.10 1914	Jan. 6 1915	116
Pier III	Nov.19 1913	Oct. 1 1914	310
Pier IV	Jan.9 1914	Jul.31 1914	200
Pier V	Apr. 6 1914	May 30 1914	54
Anchorage	Jun. 9 1914	Dec.11 1914	180
River mats	Jun.24 1914	Aug.26 1914	60
Shore mat	Sep. 8 1914	Oct.22 1914	44
Approach piles	Feb.22 1914	Sep.24 1914	210
Approach pedestals	Aug.15 1914	Oct.30 1914	75
West abutment	Aug.11 1914	Sep.30 1914	50

The entire construction program for the substructure was car-

ried out practically without accident, and set a record that could scarcely be surpassed.

There was a delay between the completion of the substructure and the commencement of the superstructure, due to financial disturbances attending the beginning of the war in Europe, which set the completion of the structure back about three months. It was then expected that the erection of the superstructure would take about nine months, and had no delays occurred it is probable that this would have been possible. As it happened, however, although the financial adjustments were made in time to start erection in April, 1915, the stage of the river was so abnormally high during the spring and summer of 1915 that the piles for falsework could not be started until September. The remainder of the period between high water stages was thus reduced to such an extent as to make the intented program impossible of achievement; and although the attempt was made under the stimulous of a bonus, a washout of the falsework occurred on the 24th of December, delaying the completion for several months. In order to accelerate the erection, an addition to the contract was made to enable the construction of the last span to be carried out by changing the method from falsework to cantilever erection, necessitating the driving of but six bents of falsework; and after a short delay this method was carried to a successful conclusion on Sept.15,1916. Trains had then been running, however, since July 15. The construction of the entire superstructure occupied seventeen months, therefore,instead of the nine months contemplated; and as three months were lost before starting pile driving, and four or five months more were lost on account of the wash-out of falsework, it is probable that the original schedule could have been carried out but for the abnormal

condition of the river.

The following schedule gives the dates on which the main operations were begun and concluded.

Falsework	Commenced	Finished	Days
Fixed Span	Sep. 7 1915	Nov. 4 1915	27
Span III-IV	Oct.13 1915	Dec.14 1915	31
Pier &V-6 bents	May 2 1916	Jun. 1 1916	29
Steel Erection			
Anchor Arm	Apr. 7 1915	Jul.22 1915	105
Pier I Cantilever	Jul.22 1915	Oct. 1 1915	69
Fixed Span	Oct.18 1915	Dec.22 1915	64
Pier II Cantilever	Feb.14 1916	Apr. 6 1916	52
Pier III Cantilever	Apr.27 1916	Jun. 7 1916	41
Pier IV Half Span	Jun.10 1916	Jun.28 1916	18
Deck Span	Aug.19 1915	Oct. 7 1915	38
Viaduct	Apr.27 1915	Jul.13 1915	76

II.Engineering Organization.

1. The main office-- While the main features of the design of a bridge are dependent usually on the genius of the engineer in charge the details of construction and the entire supervision are as a rule dependent on the organization at his command. On the New Memphis Bridge this organization consisted of an Assistant Engineer in charge of the business end of the main office; an inspection force for the inspection of material at the point of shipment; and a resident engineer in charge of the actual construction.

The design was of course made in the main office, the drafting room being more or less under the direct supervision of the consulting engineer himself. General drawings only were made of the substructure, which were modified and suplemented by engineer's and contractor's drawings in the field, all subject to the approval of the resident engineer. For the superstructure a complete set of design sheets was made up for the prospective bidders, and the detail drawings were made up from these by the contractor, subject to the approval of the engineer in charge.

The contracts were let from the main office, and in the case of the superstructure,vouchers for payment to the contractor were also prepared there. The Assistant Chief Engineer was kept informed of the progress of the work by regular reports, as explained later, and to him were referred any matters of great importance requiring a decision. He also kept in touch with the work by monthly visits, and had charge of all financial matters, including the payrole of all inspection and engineering employees.

2. Inspection bureau-- The main office was also kept in direct touch with the progress of material manufactured in the shop and

mills by an inspection bureau, organized distinct from the main engineering staff,but under the direct control of the Assistant Chief Engineer. At the shops of the Pennsylvania Steel Company, the main contractors for the superstructure, a chief inspector handled the entire work of supervising the inspection of material in the shop, reporting direct to the main office; his reports were also made to the resident engineer's office, thus keeping the entire work coordinated.

3.Supervision of construction-- The organization of the field forces fluctuated in size as the needs of the work required, consisting at one time of nine men; the resident engineer, assistant resident engineer,two instrument men,two rodmen, a draughtsman, a masonry inspector, and an inspector of granite at the quarry. This was during the substructure construction, while later during the erection of the superstructure there were but three assistants to the resident engineer, and during the last six months of erection there was but one. Although the personnel was recruited and the salaries paid by the main office,the resident engineer was responsible for the work of each of his assistants,and he himself was in personal touch with every phase of the work.

A field office was maintained during the entire construction period, housed in a former residence taken over for the purpose, this being less expensive than the construction of a new office building. The equipment of this office was simple and efficient, the furniture consisting of two desks,a drafting table, two rough tables,chairs, letter files, a typewriter, an electric fan- the last being a necessity in that climate- some small tools, and a camera and photographic outfit. The engineering equipment was also simple, though of the best quality, consisting of two transits-

a Berger and a Seely transit- two levels- a Gurley 20 inch and 22 inch- two Philadelphia level rods,four 100 foot steel tapes,graduated to hundredths of a foot, a 100 foot Chicago tape, a half dozen 50 foot tapes, with hundredth graduations, two thermometers, a spring balance for tension measurements in chaining, with plumb bobs, rules and miscellaneous smaller equipment, besides a series of screens and pans for testing sand and gravel. All of this equipment was in fairly constant use during the substructure construction, but only half of it was necessary during superstructure work.

Throughout the period of substructure construction, the duties of field supervision were varied and frequently arduous. In the first place, the surveys and location required careful and accurate engineering work,involving as it did the responsibility for so locating the foundations that the steel superstructure could be placed without difficulty. This required not only careful base line work and leveling, but also constant giving of lines and levels during the sinking of the caissons and the building of piers and pedestals. Secondly,it was necessary to inspect all material entering into the work, for quality, and also all workmanship in the placing of materials. Moreover, the contract being on a percentage basis, it was necessary to keep track of the quantities of all material, and to oversee the work with the intent of limiting the cost of work to a reasonable figure. Finally, the keeping of records and the making of reports was an important feature, where the plan of proceedure played so important a part in the progress of the work, requiring careful consideration of river gauge reports, and a constant lookout for satisfactory delivery of material, to forestall delays. The duties of checking contractor's drawings,designing retaining walls, abutments and other details of

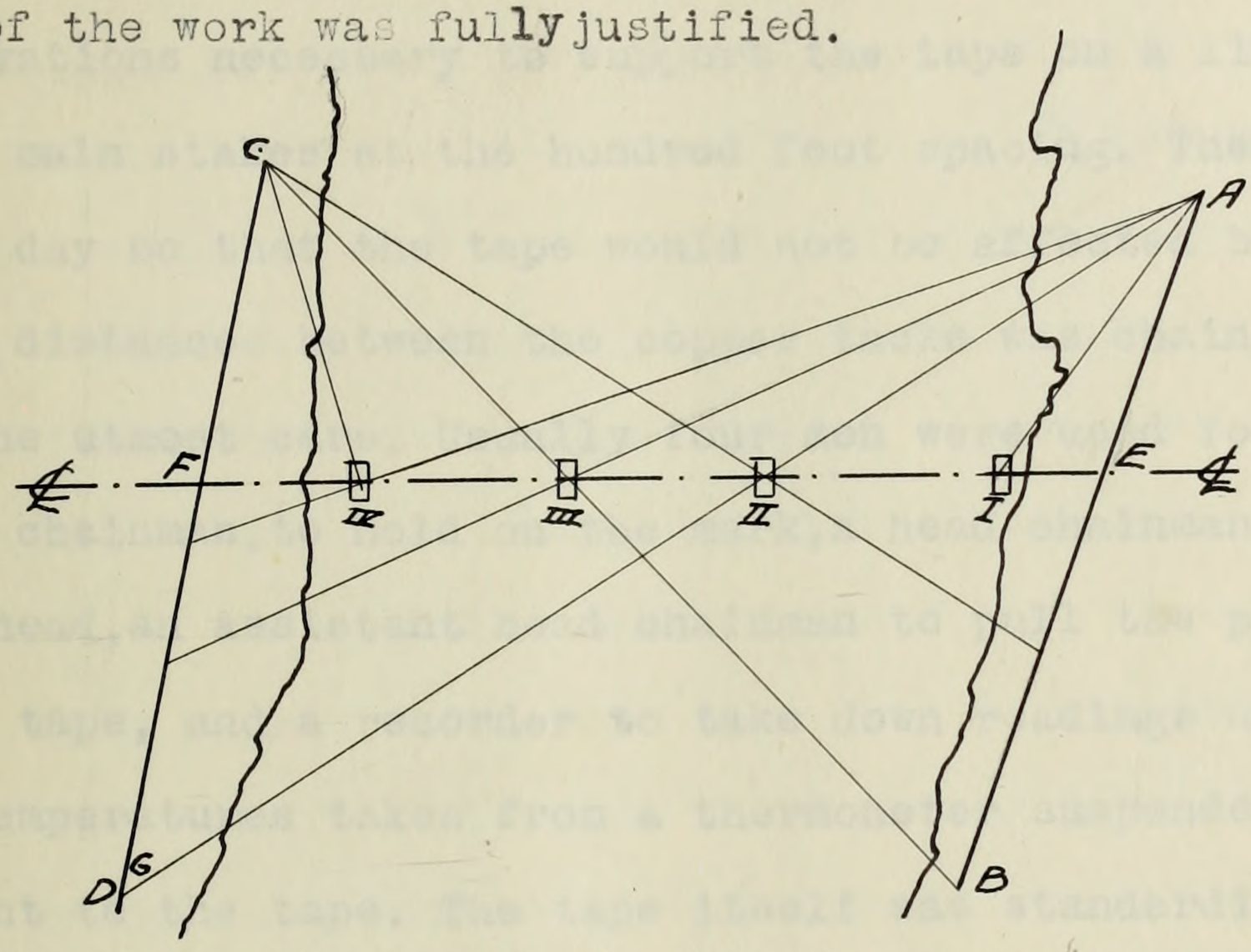
construction,as well as making record drawings of all work as actually performed,involved considerable care, and the approval of bills, payrolls,and all items of cost for voucher, was also no slight task.

On the other hand, the supervision of superstructure erection was much simplified by the form of the contract for the work, which threw all responsibility for locations on the contractor, and which, being a pound price contract, eliminated practically all necessity for cost keeping. The fact that all the material arrived on the work fabricated,needing only to be fitted in place, relieved all the duties of material inspection. Yet in order to insure smaoth progress and to guard against delays,all material was checked on arrival, and a record kept which would show at any time what material was on hand and any members that might be missing for continuous erection. Also a careful check was made of all pieces erected, not only for fit and position of the individual members, but also for the allignment of the entire structure; and one of the most important features of the inspection was the testing of riveted connections, insuring the strength of each individual rivet. In addition, complete records were kept of all progress, from which estimates were made for payment, and daily reports were made of each phase of the work, so that the main office was aware at all times of the progress made and the general state of operations.

PART ONE- SUBSTRUCTURE

III. Surveys and Location.

1.Base line work- Almost the first step to be taken by the engineering force in the field, after giving a line for the construction track to the approach of the bridge, was the establishment of base lines, from which to make the locations of the piers. On account of the great importance of securing absolute accuracy in pier locations, the base line work on which these locations depended was necessarily refined, and the extreme caution attending this phase of the work was fully justified.



The above figure illustrates the procedure of this work, which was as follows. On either side of the river,as close to the bank and as nearly parallel to it as possible, a transit line was run,about a thousand feet in length, designated the base line. At the extremities of these two base lines, A,B,C and D, concrete hubs were set, with scratched copper plugs to indicate the exact center, and over them were built transit houses to protect the instrument from sun and wind. The intersections of the center line of the bridge with these two lines were next obtained, and marked with

concrete hubs also, at E and F. The instrument then being set over these two latter hubs, the angles between the axis of the bridge and the two base lines, angles AEF and CFE were repeatedly read and averaged, until they were determined within an unquestioned accuracy of one second. The third step was the chaining of the base line, which was the most difficult task of all. Wood posts,four inches square,were driven on line slightly less than an even hundred feet apart,and a copper tack was driven in the top,with a cross scratch exactly on line, while at distances of twenty five feet between them additional stakes were driven, carrying spikes at elevations necessary to support the tape on a line with the top of the main stakes at the hundred foot spacing. Then choosing a cloudy day so that the tape would not be affected by the sun, each of the distances between the copper tacks was chained repeatedly, with the utmost care. Usually four men were used for this work, a rear chainman,to hold on the mark,a head chainman to read the mark ahead,an assistant head chainman to pull the proper tension on the tape, and a recorder to take down readings and also to record temperatures taken from a thermoneter suspended from a stake adjacent to the tape. The tape itself was standardized by the Bureau of Standards at Washington,D.C., so that the number of pounds pull required to eliminate error was known, as well as the tape correction for this individual tape; the readings themselves were estimated to the nearest thousandth of a foot. Careful levels were taken on the posts, and computations were then made with the use of logarithms to obtain the exact distance, making corrections for difference in level, for temperature, and for the tape correction. The coefficient of expansion was assumed as .0000065 this also being given by the Bureau of Standards, with the normal tem-

perature at 62 degrees Fahrenheit; and although comparison of readings taken on the coldest and warmest days seemed to indicate that this coefficient should have been somewhat greater, it was never sufficiently well proved to make any change in the basis of calculations. Care was always taken to maintain the tape and other equipment in the best of condition, and all computations thoroughly checked, and the average of many readings taken to ascertain the correct distance between the three hub points on each line.

The next step in the operations would have been to compute the angle between the base line, and the line through one end of the base line and the center of the proposed pier, after the distance between the first pier and the hub at E had been determined; the computation in each case depending on the solution of a triangle for which two sides and the included angle were known. Then setting the transit over one extremity of the base line as at A, this angle, as EAI would have been turned off repeatedly, and points set on the opposite bank of the river, as at G. The average of these points would have been made a permanent foresight, so that the center of the pier could at any time have been ascertained by the intersection of two transit lines, AG and EF. While this is sufficient to locate the pier, since in the process of sinking the caisson the actual center of the pier is frequently inaccessible, in practice it is found necessary to throw two intersections for each caisson, which will fall on the up and downstream edges of the caisson respectively.

The presence of the old bridge, however, access to which was granted the engineers by the owners, greatly facilitated the work of location, so that the original base lines, as a matter of fact, were never used. Instead, a line was chained on the deck of

the old bridge, using the same care in reading that attended the base line work of chaining, and from this line, points were thrown with a transit to the head of the old piers, set so that the distance between them as computed was equal to the distance between the proposed piers. To locate the new piers, it was then necessary only to set on the head of the old pier opposite, turn a right angle from a line parallel to the axis of the new bridge, and throw an intersection with the center line of the new bridge. The distance between the two center lines being just 200 feet, the work of locating the piers was thus much more readily performed than by using the long sight from the shore, although the actual chaining of the base line was nearly as difficult as in the first method, and the angle had to be turned off each time a location was made, instead of merely picking up a foresight. In addition, the chaining could not be carried out with nearly the regularity of the first method, since it was necessary not only to select days that were advantageous as far as weather conditions were concerned, but it was also necessary to work between the running of trains, which required rather rapid work. Moreover, for the purpose of giving final marks on the piers for setting the steel shoes, the point on the old bridge deck could not be transmitted to the coping of the pier with sufficient accuracy on account of the interference of the steel pedestal and post; and the method adopted to make this final location was to set the transit on the new pier coping, on a longitudinal offset from the center, and turn a series of right angles from the center line of the new bridge to the deck of the old bridge, where the distances had previously been determined, and thus computing the amount of the offset to measure back to the exact center. By repeating the right angles often enough, this method

located the piers within a probable error of a quarter of an inch. The widest variation from the average chained length of the entire two thousand feet was a tenth of a foot, and the variation from the average chained length between piers was correspondingly less.

After the exact centers of the piers had been located, brass plugs were set in the center of the coping and a point set on them with center punches to determine the point for future transit set-ups. Also, lines to facilitate the setting of the shoes were scratched on the granite masonry, at positions shown on the blue print diagram, Plate IV and V. These plates show the record that was kept of the final locations,and also the final levels, on all the piers and abutments for the main structure. It will be noted that Plate V shows the plug on Pier IV to have been set .018 feet from the exact center; this was due to the fact that check chainings, taken after the plug had been set, showed this correction, due evidently to a slight movement of the pier during a period of high water, which caused a settlement towards the river. This uneven settlement was also noted in the settlement levels that were taken at regular intervals of time, and the amount of the correction corresponded to the movement of the top of the pier that would have taken place with the settlement observed.

The laying out of the west approach viaduct was a comparatively simple matter, involving merely a considerable amount of chaining and instrument work. Concrete hubs were set on the center line about 400 feet apart, and the distances between them were carefully ascertained by base line measurements, similar in procedure to the base line work for the main bridge location. Stakes were then set on the center line at distances of alternately 40 and 80 feet apart, this being the spacing of the bents, and opposite each of these two

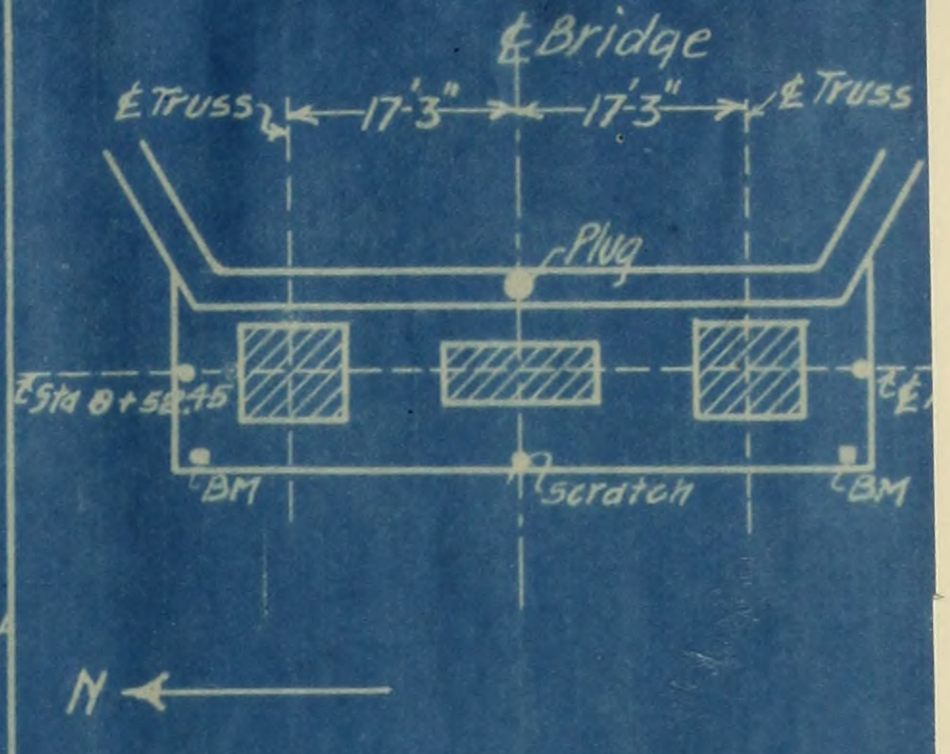
SURVEY POINTS & ELEVATIONS A&M PIERS SHEET 1 of 3

ANCHOR PIER

Plug on top parapet on Bridge ℄ at sta 0+47.037 which is 5.413 ft. east of ℄ of Pins (0+52.45)
Scratch-marks on coping on ℄ pins at N & S ends pier. & on W. edge of coping on bridge ℄.

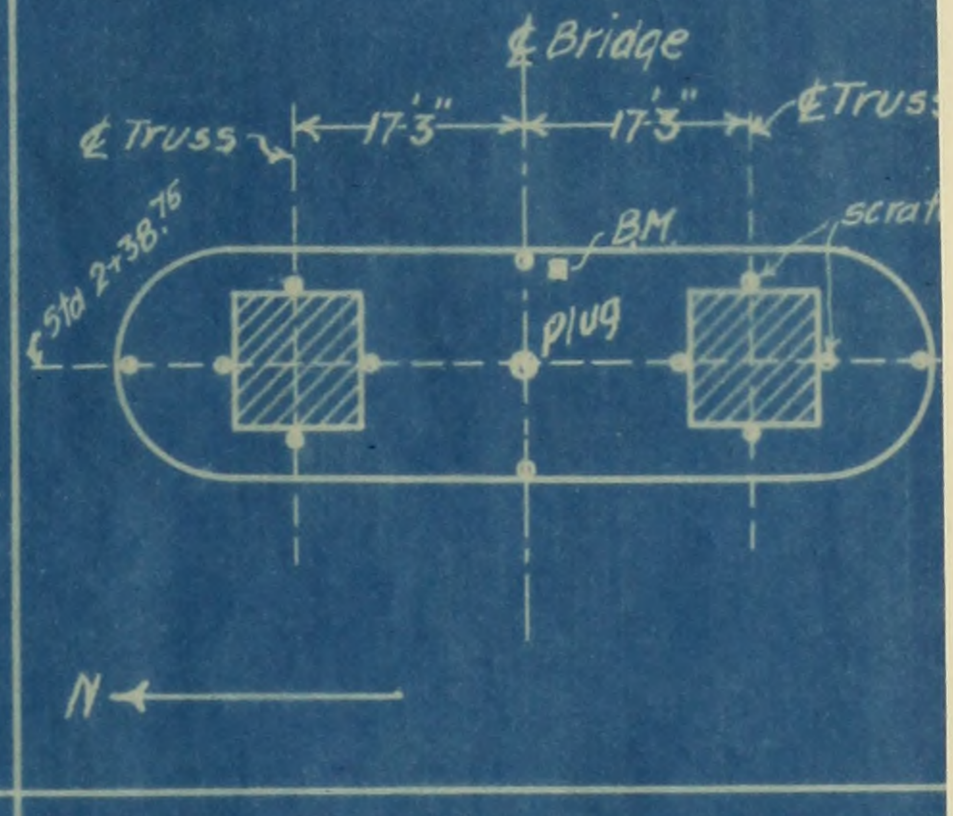
BM on SW corner coping Elev. = 283.228 1-12-15
BM " NW " " " " = 283.223 "

BM elevations referred to U.S.P.B.M. Del. Av. viaduct Elev = 295.680



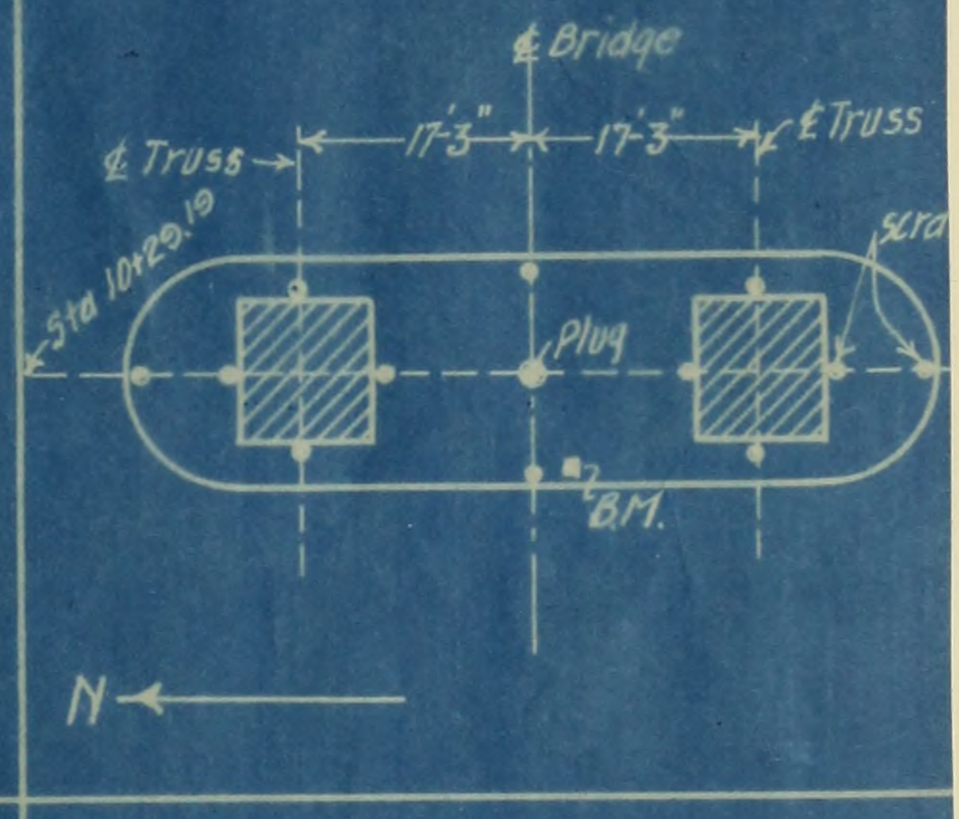
PIER I

Plug on coping at intersection of bridge ℄ & ℄ of pier at Sta 2+38.75
Scratch marks on ℄ pier at each end & at N & S edges of bridge seats.
Scratch marks on bridge ℄ at E & W edges coping.
" " " Truss ctrs " " " " br. seats.
BM on E. side coping near ℄ Elev = 281.980 1-12-15
Elev. of bushed bridge seats = 281.984 "
Elevations referred to U.S.P.B.M. Del. Av. viaduct Elev. = 295.680



PIER II

Plug on coping at intersection of bridge ℄ & ℄ of pier at sta 10+29.19
Scratch marks on ℄ pier at each end & at N. & S. edges of bridge seats.
Scratch marks on bridge ℄ at E & W edges of coping.
" " " Truss ctrs " " " " br. seats.
BM on W. side coping near ℄ Elev. = 281.996 1-13-15
" " S. bridge seat (low spot) Elev. = 282.009 1-14-15
Elevations referred to BM on top Frisco pier II Elev. = 283.070



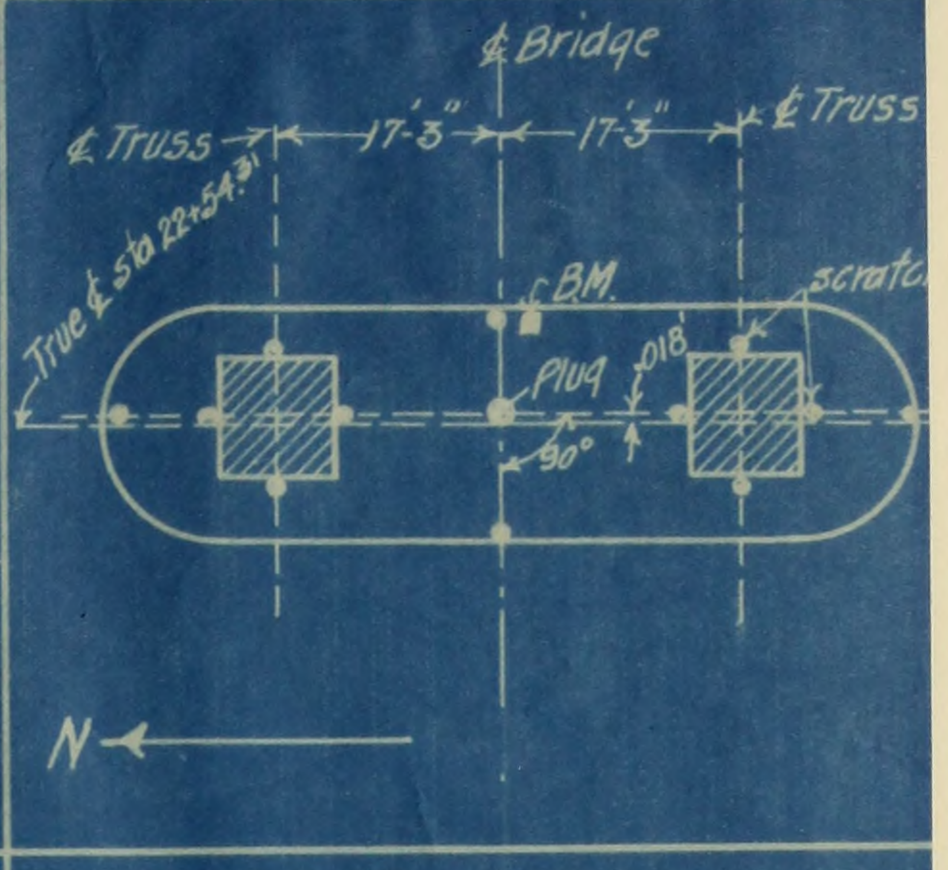
PIER III

Plug on coping at intersection of bridge ℄ & ℄ of pier at Sta 16+50.19
Scratch marks on ℄ pier at each end & at N & S edges of bridge seats.
Scratch marks on bridge ℄ at E & W edges of coping.
" " " Truss ctrs " " " " br. seats.
BM on W. side coping near ℄. Elev. = 281.977 1-13-15
Elev. of bushed bridge seats = 282.000 1-13-15
Elevations referred to BM on top Frisco pier III

SURVEY POINTS & ELEVATIONS A&M PIERS SHEET 2 of

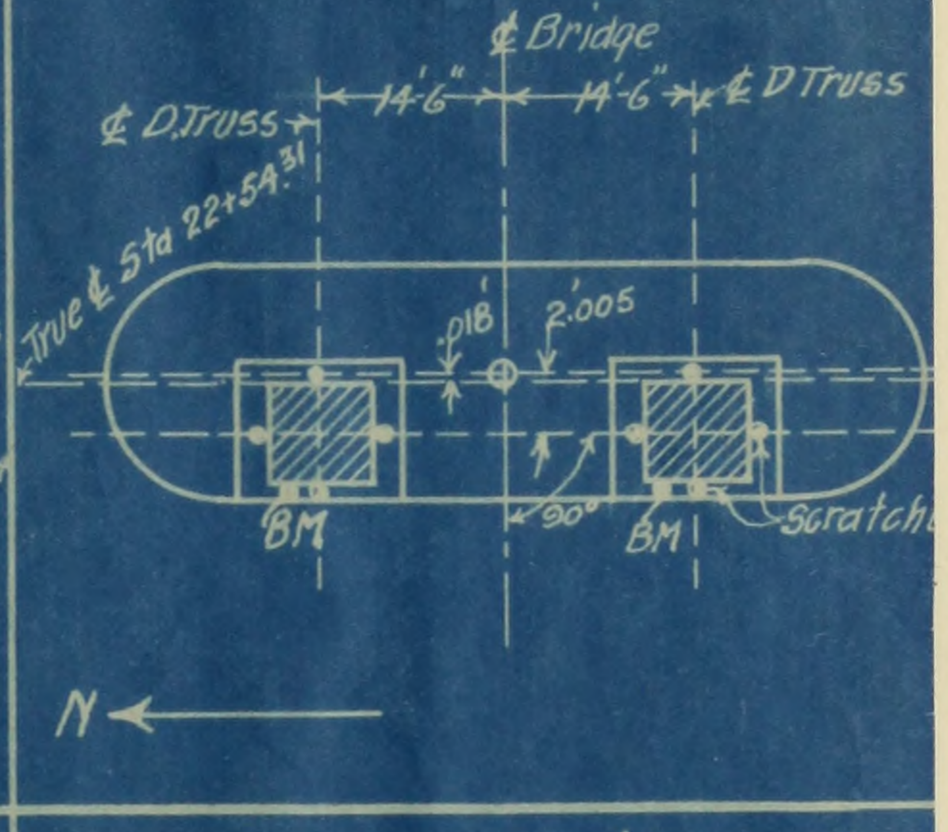
PIER III TOP

Plug on coping on bridge ℄ at sta 22+54.292 which is .018 east of plan ℄ of pier. (22+54.310)
Scratch marks on line thru plug at rt. angles to bridge ℄ at N.&S. ends of pier & at edges of bridge seats.
Scratch marks on bridge ℄ at E.&W edges of coping.
" " " " truss ctrs " " " " " br. seats.
BM on E. side of coping near ℄. Elev. = 284.997 1-13-15
Elev. of bushed bridge seats = 285.005 1-13-15
Elevations referred to B.M. on Frisco pier IV
Elev. = 283.018
Shoes set 5/16 west of scratches.



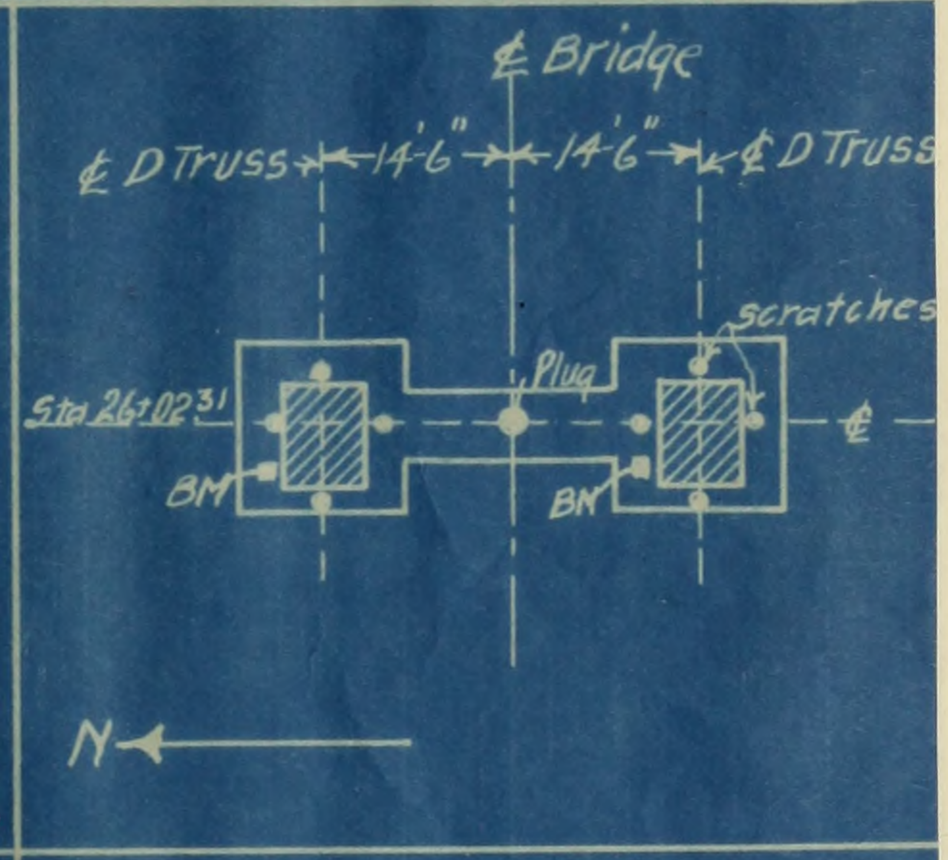
PIER IV NITCHES

Scratch marks at N.&S edges of bridge seats in nitches on line 2.005 west of plug on top, & therefore .018 east of plan ℄ bearing.
Scratch marks on ℄ deck trusses at E.&W edges of bridge seats in nitches.
B.M. on br. seat N. nitch. Elev = 254.911 = .089' low. 9-10-14
" " " " S. " " = 254.918 = .082 " "
Elevations referred to B.M. on Frisco pier IV
Elev = 283.018
Shoes set 3/8" west of scratches



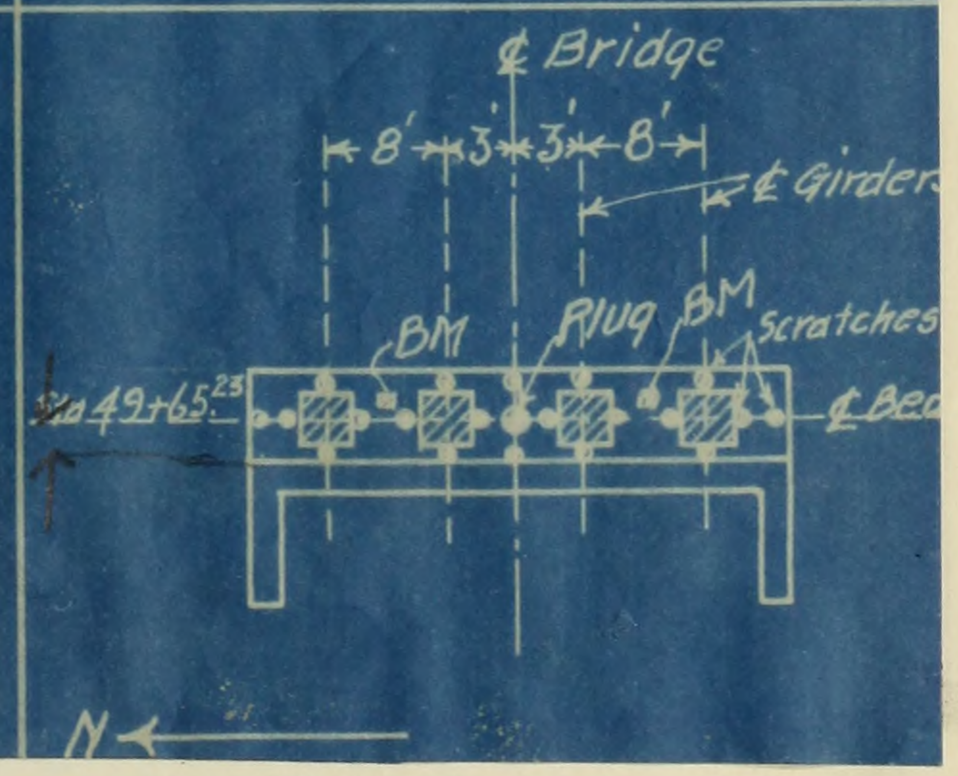
PIER V

Plug on top pier at intersection of bridge ℄ & ℄ pier Sta 26+02.31
Scratch marks on pier ℄ at N.&S edges of br. seats.
" " " Truss ctrs " E.&W " " " " .
B.M. on N. bridge seat. Elev. = 252.433 = .067' low. 9-10-14
" " S. " " " = 252.428 = .072 " "
Elevations referred to B.M. on Frisco pier IV
Elev. = 283.018



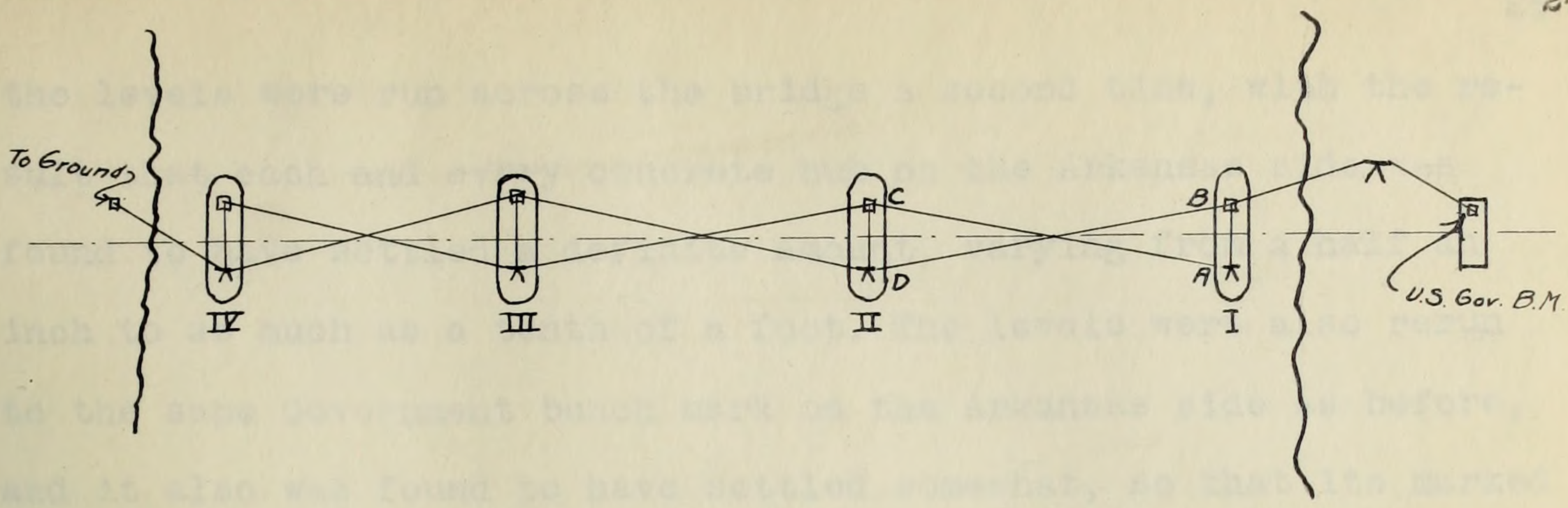
WEST ABUTMENT

Plug on coping at intersection of bridge ℄ & ℄ of bearing Sta. 49+65.23
Scratch marks on coping on ℄ bearing at N.&S. edges each bridge seat.
Scratch marks on ℄ of girders at E.&W. edges of each bridge seat.
B.M. on coping between N. br. sts. Elev. = 259.558
" " " " S. " " " = 259.589
Elevations referred to B.M. on Frisco pier IV



additional stakes were set, on one side of the center line and at right angles to it,at distances of about 100 and 200 feet out respectively. To locate the center of any pedestal at any time it was necessary therefore only to set over one of these side stakes, preferrably the further one, sight on the nearer one, and throw a line to intersect the longitudinal line of the pedestals, easily measured over from the center line. This proce¢dure was followed in giving the location for the pile driving, the base of the pedestals, and later to locate the anchor bolts set in the concrete pedestals, and the latter location was so accurate that not a single bolt had even to be bent to accomodate the superstructure, although they had been cast inside of a stove pipe covering to allow a movement of as much as an inch either way had it been necessary.

2. Leveling-- The problem of leveling was also much simplified by the existance of the old bridge. Had it been necessary to throw a level line entirely across the river with the instruments at hand, it is doubtful if extreme accuracy could have been obtained; but by reading between the old piers, and averaging several series of levels, a most accurate series of elevations was obtainable. This was accomplished not only by setting on an intermediate pier and reading a rod held on adjacent piers, but also by running a line by setting on each pier in turn, and reading a rod held on the same pier as the instrument, and then on the pier ahead, averaging up the readings on foresights and backsights to eliminate the error which would have been probable on account of the difference in the lengths of the sights.This is illustrated by the figure (page 24) which shows in detail how the levels were carried from the bluff on the east side of the river to the ground on the west side, and the way in which the cross reading was performed. Here the differ-



ence in elevation between B and C was taken as the average between the reading with the instrument at A and D, this average being a much more accurate determination than an elevation determined by simple leveling.

The bench marks thus determined were painted on the masonry coping and were used throughout the entire construction period to give levels on succeeding courses of masonry, and also for the final coping levels. All elevations were based on the elevation of a U.S. government B.M., established by the geological survey, cut on the coping of the east abutment of the old bridge; and after being transfered across the bridge, and down on the opposite shore by means of a steel tape, they were carried about a mile inland to another U.S. government bench mark, the record elevation for which was found to be about two hundredths high. Alomg the Arkansas center line elevations were taken on each of the concrete hubs previously set for center line work, these hubs being about a foot square and three or four feet deep.

A peculiar phenomenon was observed after the spring flood of 1914, which as usual overflowed the entire Arkansas bank, and kept it under water for about two months, covering it with a thin layer of river sediment. All elevations set from the concrete hubs after the flood seemed to be inaccurate when checked against elevations of the main piers, and after considerable trouble and vexation,

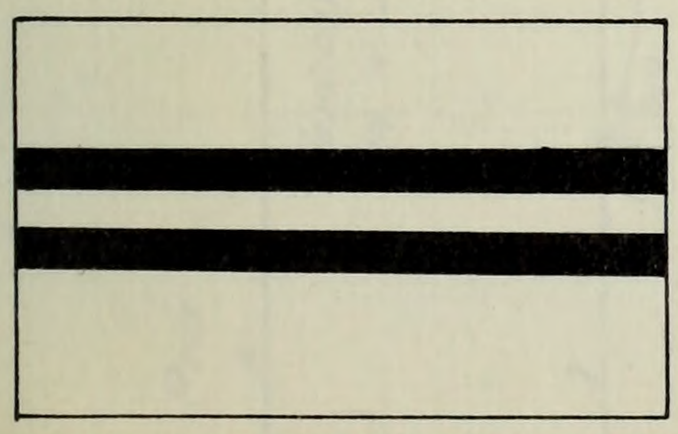
the levels were run across the bridge a second time, with the result that each and every concrete hub on the Arkansas side was found to have settled a definite amount, varying from a half an inch to as much as a tenth of a foot. The levels were also rerun to the same Government bench mark on the Arkansas side as before, and it also was found to have settled somewhat, so that its marked elevation was now .07 of a foot high instead of .02 as formerly. Communication with the U.S.Government Engineer's office disclosed the information that this occurance was far from unusual,and that a gradual settlement of entire portions of the river bank was a matter of frequent observation, caused no doubt by the compression of material under the additional load of the flood water.

Bench marks having once been established, the construction of the foundations involved merely routine leveling, on the caissons, piers, concrete piles, bases and pedestals,none of the work requireing more than the ordinary proceedure of leveling,except for finishing the coping, which was leveled to the sixty-fourth of an inch. The taking of settlement levels on the main piers, however, was a more interesting proceeding, and required a high degree of precision.

The pneumatic caissons, as has been described, were landed on a stratum of hard clay, at a depth of from forty to seventy feet below the river bottom. Part of the weight of the bridge was carried by the skin friction resistance of the soil against the sides of the caisson, and the remainder by the resistance of the the clay stratum against the bottom of the caisson.As the pier was built up, and the weight of the steel superstructure added, the pressure on this clay bottom obviously increased, and a corresponding compression occured, which caused a settlement of the pier.

These settlements were of course expected, and records of the amounts were kept chiefly to make certain that that they were not excessive, and to give data for future reference. The plate number VI on page 27 gives the complete record of these settlements, the greatest of which is seen to be .157 of a foot on Pier II, or about two inches. It is further seen that all the settlements were gradual and varied very nearly in proportion with the increase in load, and were very close to the settlements that were expected when the piers were designed.

To secure the measurements of these settlements, projecting knobs were cut in the masonry of both the new and old piers to be used as bench marks, and with the instrument setting on the nearest bank, a level line was thrown across from the old pier to each end of the new pier, it being assumed of course that all settlement on the old piers had ceased years previously. Two observers were used, one to watch the level vial, and keep the bubble centered, and the other other to take the reading; a tarpaulin was spread over the instrument to keep off the direct rays of the sun on all sunny days. The bubble reading was especially important, since an error of one tenth of a division in the bubble reading caused an error of a hundreth of a foot in the rod reading at the distance necessary to level, or 900 feet. Since the finest hair obtainable for the instrument covered a hundredth of a foot at this distance, the following expedient was used to eliminate this inaccuracy. A white card was ruled as shown in the figure, so that



the intermediate white line was a hundreth of a foot in width, just the space covered by the hair of the instrument. This card was slotted so as to fit over an ordinary rule,

SETTLEMENT OF PIERS - MEMPHIS BRIDGE

During Period of Construction

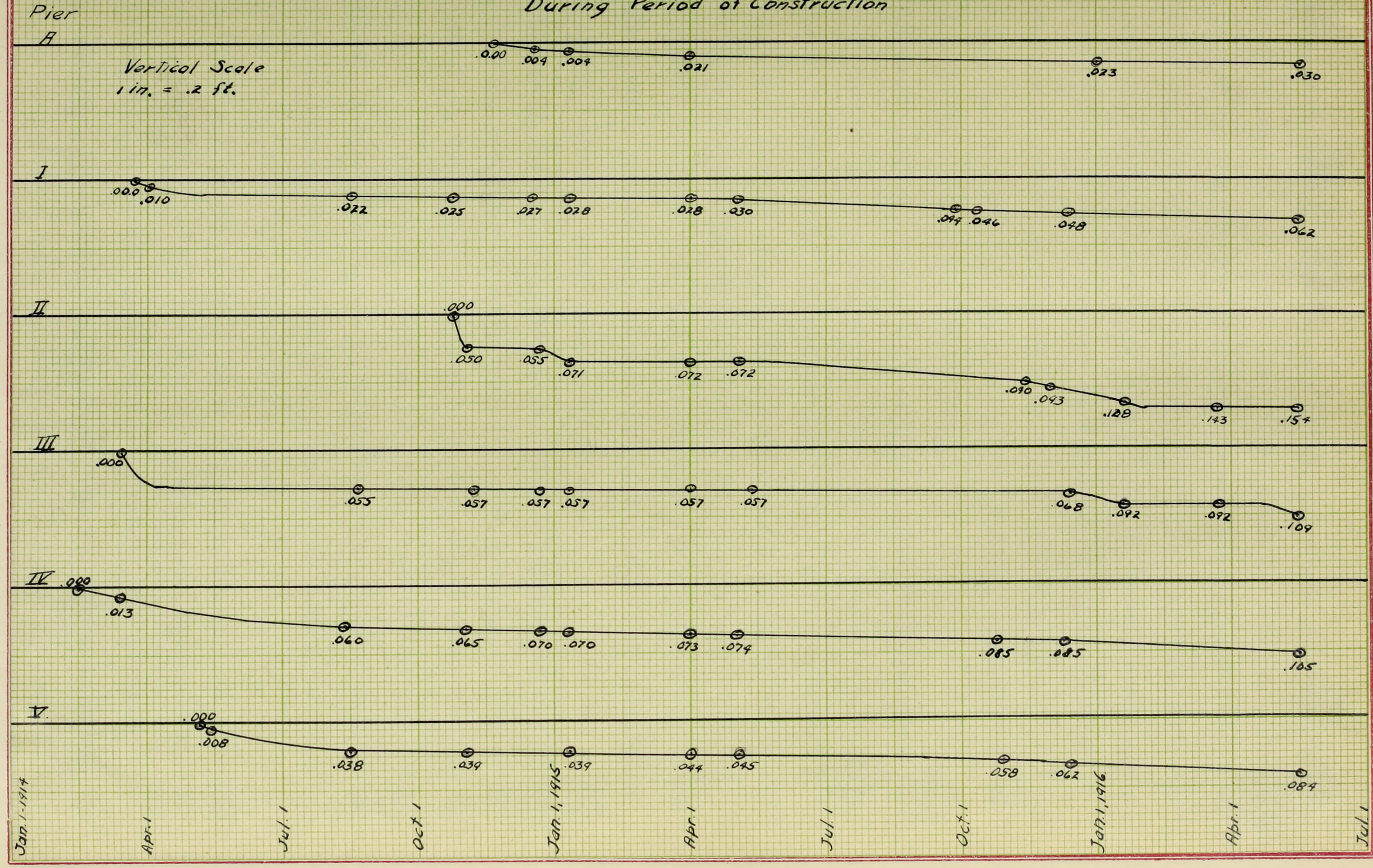


Plate VI

and the levelman then signaled the rodman to raise or lower this target until none of the white space was discernable, this position being tested by " springing the level"- or slightly pressing the barrel downwards until the least fringe of white showed above the hair, and then upwards until the same width of fringe showed below the hair. With a little practice an observer can tell whether or not the same pressure is required to make an equal width of fringe appear above and below the hair with far greater accuracy than he can set a target by simple observation.

These settlement levels were taken at regular intervals, as nearly as the stage of the river would permit, during the entire construction period, and as the diagram shows, the settlement practically ceased after the superstructure was entirely erected, and there was no further increment in load. None of the settlements were considered excessive, and as each was corrected as far as possible before the coping was set,the total effect on the level of the steel work was practically negligible.

3. Location of caissons.-- One of the most necessary of all of the engineer's duties was the supervision of the sinking of the caissons. From the time that the cutting edge touched the bottom of the river until the final position had been reached and the caisson sealed, daily locations were made, so that the position was known at all times, and directions given the sinking foreman for his guidance in carrying on the days work.

On the river caissons, the first step was the driving of a pile dock on three sides of the intended location,leaving about three feet of clearance on all sides for the caisson. The location of these piles was given by transit lines from the shore and from the bridge, no especial accuracy being required, since in fact the dock

was subject to considerable movement as the pressure on it varied with the rise and fall of the river. The caisson, after being built along the shore in a floating pontoon, was towed out opposite this dock, and launched by filling the supporting pontoon with water and causing it to sink, after which the two halves of the pontoon, built so as to split on a longitudinal section, were pulled out by lines fastened to a tug, leaving the caisson floating. It was next towed inside the dock and gradually sunk by filling the interior with concrete,care being exercised in making this filling to keep the concrete level, in order that the caisson would in turn settle in a level position and strike the bottom fairly. During this process it was necessary only to take frequent soundings, to ascertain when the caisson approached the bottom, and just before landing, it was kept as nearly level and as nearly in correct position as possible.

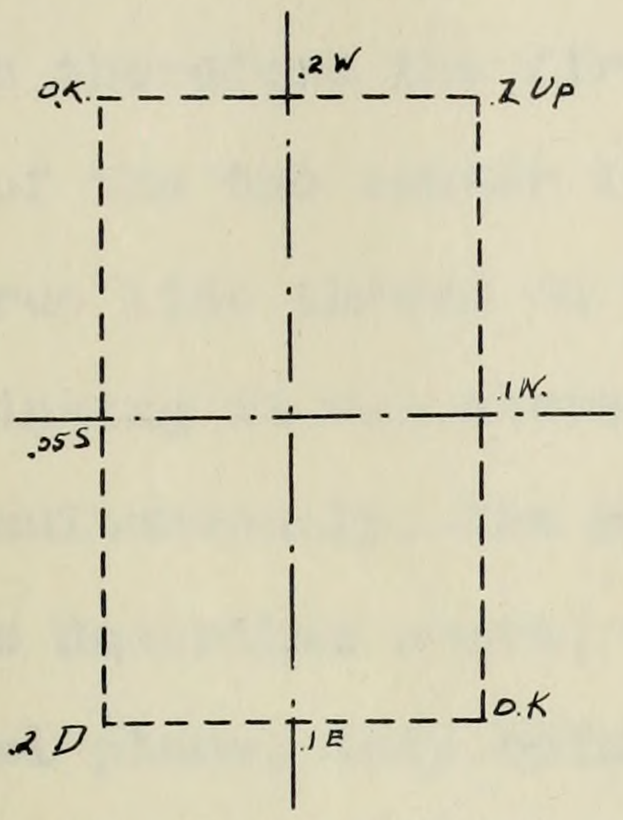
As soon as the caisson was landed on the bottom,and until it was sunk to final position, daily locations were taken to determine its exact position, in order to correct any deviation from the correct position, and insure landing the caisson in the exact final position. These locations were usually made just after a drop had been made in the sinking process, and the foreman was informed of the results immediately thereafter in order that the digging for the next drop could be planned, and any variation corrected. It was necessary to give the location of the cutting edge rather than the top of the caisson, and to do this required certain measurements of the caisson itself, as follows. The exact width of the caisson was a constant, which once determined remained the same; but as the caisson was built up, the exact height was measured,and marks kept on the inside of the outer wall from which to measure up as each succeeding course of timber was added. Then the center of each side

MEMPHIS BRIDGE

Position of caisson No. I

Date 3/21 9 A. M.

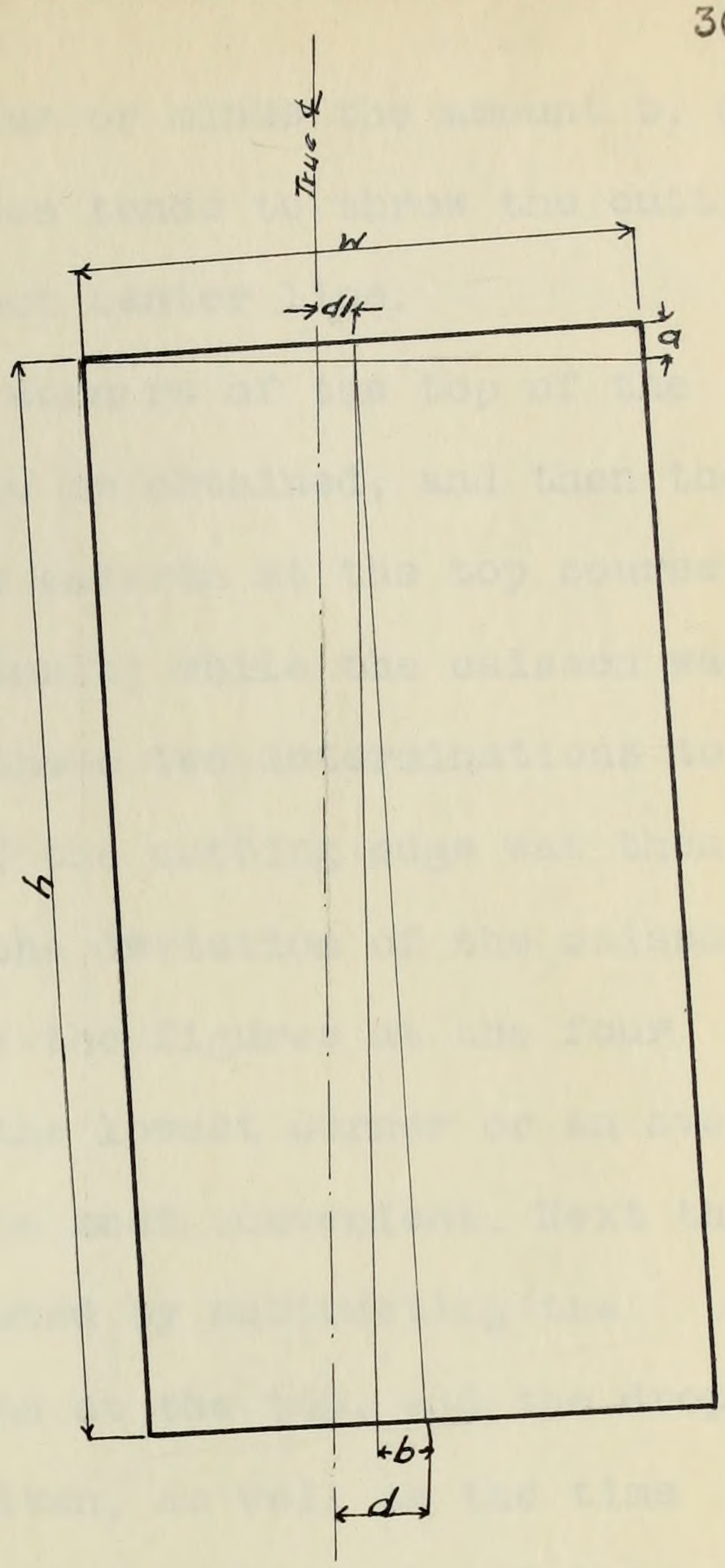
Upstream



Elev. Cutting Edge 150.7
Drop in 24 hrs. 3.2 Ft.

Distance to go 21.2 Ft.

Signed H.W.



was carried up also as the caisson was built, and the center line marked with copper tacks on the inside of the outer wall; this center line was obtained by squaring, since the caisson was never in a level position long enough to permit of plumbing.

The results of the location were transcribed on a card shown on the left above, and this card given to the foreman in charge of the sinking. The figures at the intersections of the center lines with the sides of the rectangle indicated the amount and direction of the diviation of the cutting edge from its correct location; these figures being obtained from the diviation at the top of the caisson by direct proportion, as shown by the figure at the right above. For by similar triangles, a:w = b:h, and the deviation at the bottom, d, equals

equals the diviation at the top, d1, plus or minus the amount b, depending on whether the tip of the caisson tends to throw the cutting edge further out or nearer to the correct center line.

The elevation of each of the four corners of the top of the caisson was therefore the first thing to be obtained, and then the deviation of the the center line of the caisson at the top course from the true line thrown on by the transit; while the caisson was actually sinking it was necessary for these two determinations to be made simultaneously. The position of the cutting edge was then computed as described above, and also the deviation of the caisson from a level plane, this being shown by the figures at the four corners of the rectangle on the card, the lowest corner or an average corner being marked O.K. as might be most convenient. Next the elevation of the cutting edge was computed by subtracting the height of the caisson from the elevation at the top, and the drop since the last previous location was given, as well as the time since this last location had been made. The approximate distance yet to go was indicated, computed from the probable final position of the caisson as indicated by the borings; this making a complete record for the sinking foreman. A typical location is shown filled in on the card on the previous page; from this card the foreman would give orders governing the digging in the caisson, deepening the excavation on the high corners when the caisson was only out of level, or deepening it along an entire side, and blocking up under the opposite side, when it was necessary to throw the caisson out of level in order to bring it back to line.

While sinking through sand, the caisson could be moved about quite easily by this method, a slight tipping of the caisson tending to move it bodily in the direction of the high edge. After the

clay was reached, however, any lateral movement became increasingly difficult, and if the caisson was in correct position when the clay was first struck, there was little need to use any precautions to keep the caisson level thereafter, as the pressure of the clay on the sides would keep the caisson in this same position. On caisson I, however, the pressure of the high bank on the shore side pushed the caisson out towards the river, and the caisson was sunk with the river side constantly low in order to bring it back towards the bank to correct location, an attempt which was only partially successful. The upper side frequently crushed through the heavy blocking that was placed under it to keep it up, and brought the caisson level again; although the position of the caisson when landed was not far from correct. In case it had been impossible to move the caisson by merely tipping it, it might have been found necessary to reduce the friction on the sides by water jets, and so forced the caisson in the desired direction.

On this pier, since it was seen that the caisson would probably be sealed somewhat out of line, the bottom course of masonry was offset slightly to compensate for the difference. On the other piers the masonry was set exactly in the center of the caisson, and locations taken during the remainder of the sinking in precisely the same way as had been done on the caissons, the center lines being carried up and marked by scratches in the granite, and elevations being carried up by bench marks on the four shoulders of the pier.The computations for filling out the card were also similar, but since the sinking by the time the masonry part of the pier was being constructed was mostly through clay, it was not necessary to make such frequent locations, especially since the sinking was correspondingly much slower; and in the harder material, when the

drop was sometimes less than a foot a day, locations were made but once orwtwice a week.

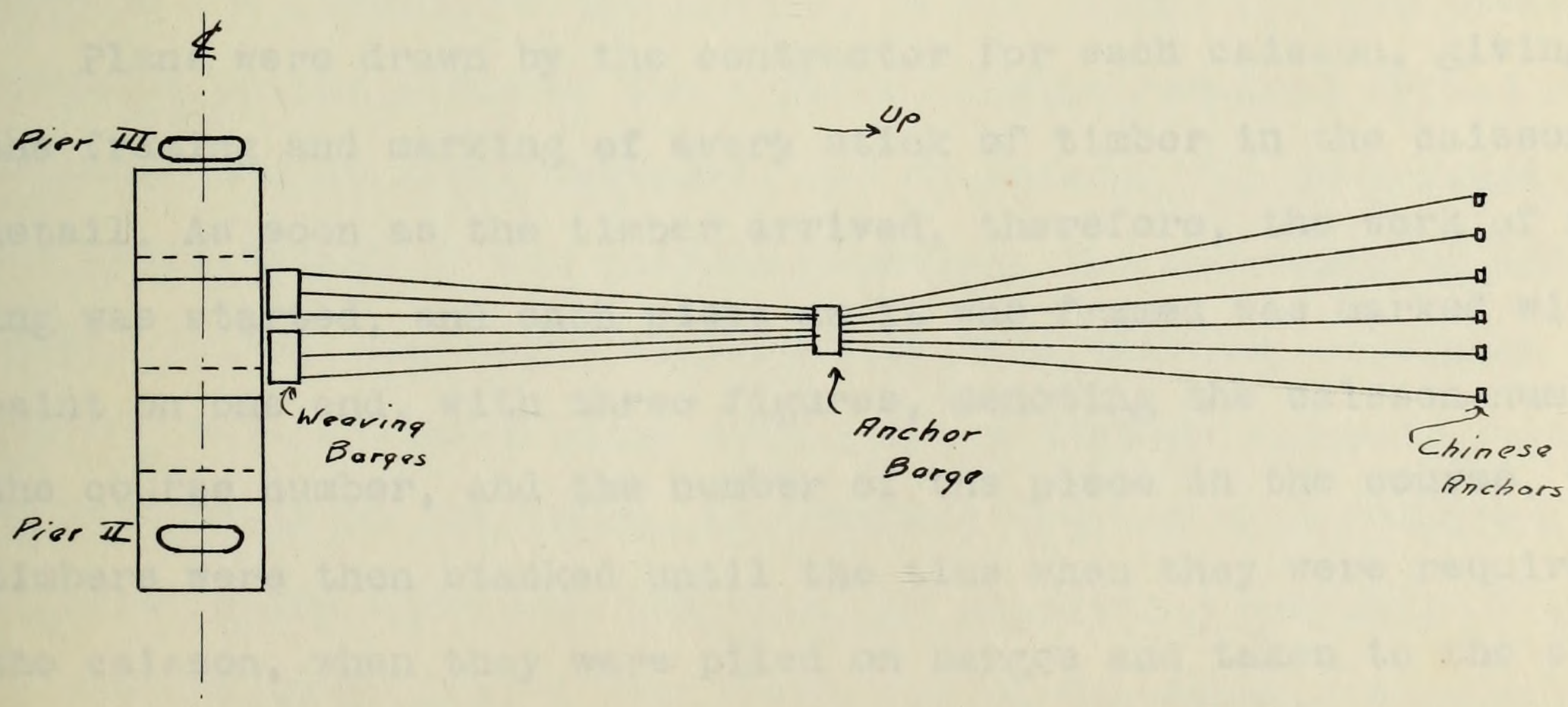
4.Location of channel mats,--One of the most interesting features of the substructure work was the construction and sinking of the channel mats. These were built approximately in the position that they were to take on the bottom of the river,held floating on the surface, and after completion were sunk by loading them with riprap. Four mats were placed in the channel, one about two hundred by three hundred feet, at the site of pier II, to prevent scour while sinking this the deepest of the caissons; and the other three about two hundred feet square each, spread out longitudinally under the fixed span, to prevent washing out the falsework later to be driven for the construction of this span.

The first step in the construction of these mats was the placing of Chinese anchors, large masses of reinforced concrete with protruding timber cross arms, which were to provide the anchorage for the cables which held the head of the mats. These anchors were cast on a barge, and when sufficiently set they were towed out in the river and dropped approximately two thousand feet above the bridge line and directly in line with the proposed mat location. Six of these anchors were used in all, and they were shifted once after sinking the first two mats to a position that would be satisfactory for the last two.

In order to construct the mats properly it was necessary to locate the position of the anchors as nearly correct as possible, and this was attempted at first by throwing two transits to an intersection at the location of the anchor. It was found impossible, however, to hold the tug in position as determined by signals from the two transit men long enough to get the anchors overboard; and

it was found that by starting upstream and floating down, keeping always in a line across stream as as given by one transit man, un coming opposite two range poles set on the bank the correct distance upstream, the anchors could be dropped to a very accurate position. Later this process was still further simplified by the use of field glasses sighting on two vertical posts on the old bridge previously determined as being on the correct line; one observer then watch the bridge to keep the tug on line, and the other gave the signal to drop the anchor as the range poles came in line.

The anchors having been placed, an anchor barge was fastened to it by cables approximately a thousand feet long, and from this barge additional cables of about the same length held the weaving barges from which the mats were woven, and also the cables to the head of the mat held the mat in position while it was being sunk. These cables could be adjusted to bring the mats to the required position just before sinking, which was in correct line and about ten to fifteen feet upstream from the desired position at the bottom, according to the strength of the current at the time. The figure below shows the relative positions of the equipment necessary for the construction of the mats.



IV. Inspection of Construction.

1. Timber and caisson construction--The first construction work on the substructure that required inspection was the timber work on the caissons. Previous to starting any of the permanent work there was of course a great deal of work required in the construction of barges and floating equipment, derricks, pontoon, pressure barge, and other plant; but practically no supervision was needed for this work with the exception of a general checking of plans and a check of the material to be turned in for payment. On the machinery of the plant, including the compressors, mixers and engines and derrick equipment, all of which was furnished by the contractor, no checking was required.

Timber being plentiful in that part of the country, no difficulty was experienced in obtaining a good grade of timber for the caisson construction, and no inspection was made at the point of shipment. The contractor assumed the responsibility for the quality of the material, and after delivery a surface inspection was made for wane and straightness; while the contractor took the necessary precautions to make sure that no delays would be caused by failures in shipment.

Plans were drawn by the contractor for each caisson, giving the framing and marking of every stick of timber in the caisson in detail. As soon as the timber arrived, therefore, the work of framing was started, and each piece as it was framed was marked with paint on one end, with three figures, denoting the caisson number, the course number, and the number of the piece in the course. These timbers were then stacked until the time when they were required for the caisson, when they were piled on barges and taken to the site,

and drift-bolted in place.

The pontoon for launching the two river caissons was built in a floating dry dock, and these caissons were built up partially in the pontoon, before taken to the site. On these caissons the cutting edge, of steel construction, was merely laid down in the bottom of the pontoon, which was of itself level, and the timber built up on it. The weight of all material going into the caisson was kept, and the computation of the weight and the displaced volume was made, to make certain that the caisson would be stable when floating after the pontoon had been sunk and withdrawn.

With the shore caissons, the site was first cleared off and the cutting edge laid out on blocking, giving it a level bearing, and the correct location for starting sinking, allowance being made for the crowding effect of the bank. The timber work was then built up on the cutting edge, and the principal points to be watched during the construction were the framing of joints, the proper drifting of the timber courses, the caulking and tarring of the caisson roof, the squaring up of the structure, and the adequate bracing of the whole.

Experience with the first caisson caused a few changes to be made in the framing of the others. It was found that the tremendous pressure on the sides of the working chamber required rather more bracing than at first designed, and on caisson II, on account of the great height of the caisson necessary for the depth of water found, it was considered advisible to bolt friction blocks on the outside walls,- these being simply heavy timbers securely fastened vertically on the walls, to develope greater skin friction. On caisson IV the expedient was tried of supporting one wall of the caisson on boxes filled with sand; and it was debated whether or

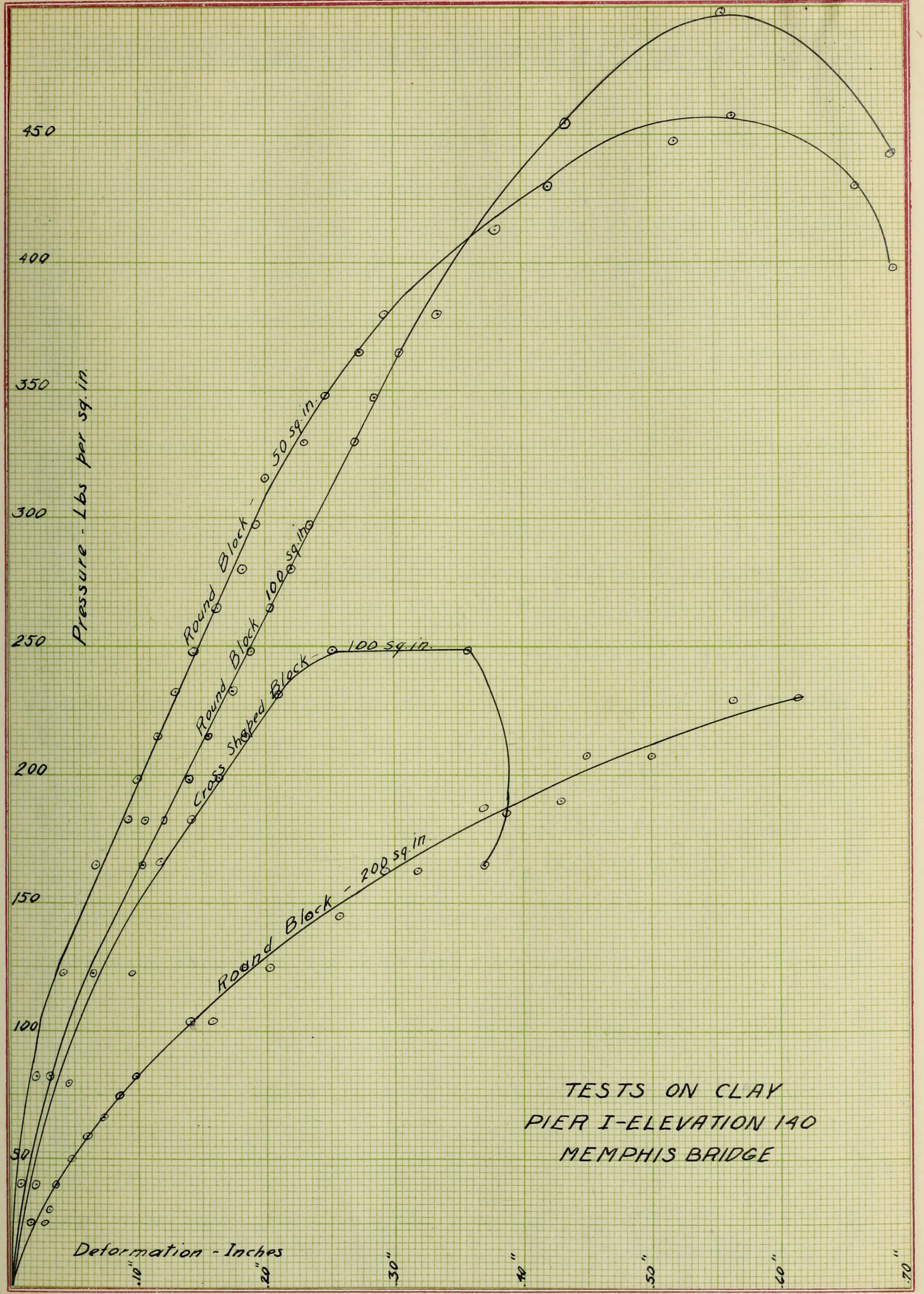
not the use of sand jacks might not be necessary to carry the weight until the caisson was sunk far enough for the skin friction to develope to the required amount. This method was never resorted to, however. On caisson II, the concreting could not be kept up as fast as the sinking, and in order to make sure that there would be no delay when the masonry started, a cofferdam was built around the top of the caisson, about fifteen feet high, securely bolted to the caisson and the joint caulked. This construction resulted in a great saving, since the cofferdam kept the water from the masonry while three courses were set, allowing the sinking to continue uninterruptedly. This top section or cofferdam was then removed, in order to leave no obstruction in the bottom of the river after the caisson was down. On those caissons that were required to be sunk further than at first contemplated, the difference in height was made up by adding a few courses to the top of the caisson, thus saving the cost of the masonry that would otherwise have been necessary.

Besides the inspection of the caisson itself, there was in fact very little inspection necessary on the actual sinking. When a location had been given to the sinking foreman, a trip to the working chamber was sometimes made to see that the proper steps were taken to correct the position; but as the location of the next day would check up on the results, this was seldom necessary. The foreman on this work was accustomed to take levels himself inside the working chamber with a hand level, and also to keep track of his progress by means of sighting across stakes driven in the bottom, and usually succeeded in keeping remarkably close touch on the position of the caisson. During the sinking it was usual for an inspector to go down in the air pressure but once in three days.

As the caisson neared its final position, however, more attention was paid to the excavation, in order to determine the character of the material at the bottom. It was thought necessary to continue the sinking for about six feet through the layer of stiff clay found below the sand and soft clay of the river bottom. The removal of this exceedingly stiff clay was so expensive that it required a great deal of judgement to say just when it was advisable to stop; the clay was too elastic for dynamiting, and too stiff to work with shovels, so that it was necessary to pick it out in small pieces. On one pier a layer of rock was found, part of which was removed as being too soft and loose for a bearing, while on pier II the clay was so difficult to excavate, and the wall of the caisson became so warped under pressure, that it was thought advisable to discontinue sinking three or four feet above the elevation planned. In all cases, before the sealing was begun, small pits were dug in the bottom to make sure that the material continued the same for the next six feet at least.

Bearing tests were also taken on the soil in all of the caissons, the facilities for these tests being very advantageous. It was only necessary to place a hydraulic jack below one of the roof timbers, and jack against a block of known size on the clay below, reading the pressure on a pressure guage, and calculate the pressure exerted by the jack per square inch of surface of the block; the distance that the block sank into the earth being determined by measuring down from a straightedge supported across the block and free from the affected area. Plate VII, page 39, gives the result of one series of such tests.

As can be seen from the plate, the clay was found to have very high supporting values. Experiments were made with differ-



TESTS ON CLAY
PIER I-ELEVATION 140
MEMPHIS BRIDGE

ent sizes and shapes of blocks, with the idea that the proportion of the area of the block to the perimeter might bear some relation to the supporting power; but the variation in the results were so great that no generalization could be made.

The tests were made on the surface of the ground in the caisson at a time when it was level, and it is thought that the pressure that the clay would sustain when there was a surcharge of material all around the pressure area would be even greater. An attempt was made to prove this by performing a test on an area much lower than the surrounding area, but the results were not satisfying, because of the practical difficulty of keeping the jack from kicking out when so far from the roof of the caisson.

In making these tests the surface was first prepared by setting the blocks in plaster of paris, leveling them to exact level before set up; and the deformations were read on a micrometer screw, so that the results were very accurate in so far as the readings were concerned. To allow for the time element, the pressure was increased uniformly, and readings taken at equal intervals. Readings were also continued after the load was removed, and as the micrometer bore directly on the block itself, the elasticity noted in the reading was actual. This elasticity is so marked as almost to resemble the that of an elastic material such as steel.

2.Concrete work--The inspection of concrete formed a large proportion of the inspection work of the substructure, and took up a great deal of the time of the inspection force; the work of inspecting the actual placing of the concrete naturally requiring the most attention. Inaddition, the inspection of the materials entering into the concrete were all inspected, including the cement,

sand, and gravel.

The inspection of cement was made at the cement mills by an organized inspection bureau, in accordance with a printed specification, this being the only material on the substructure for which a regular specification was gotten out. The method of taking samples and of performing the several required tests were outlined in detail, so that a perfectly definite procedure was followed. The cement was then shipped in sealed cars, and in addition each tenth sack was tagged with a number and the name of the inspection bureau, for purposes of identification. The field inspector removed and collected the tags, which were then checked against the regular reports of the inspection sent in weekly to the resident engineer, and in this way a record was kept which showed the particular quality of the cement going into any part of the work.

On the whole the cement showed little variation, all of it containing a rather large percentage of lime, which made it somewhat slow setting in action. The strength tests, however, all showed high values; in fact, they were so uniformly high that when later the strength of the concrete was found to be unsatisfactory, it was suspected that some of the fault might lie in the possibility of some of the cement passing by the inspector, and to make sure that this was not the case, samples were taken from sacks that were marked and from adjacent sacks that were unmarked, and sent for reinspection. Nothing was found to indicate that the cement was other than the best, however, and blame for the low strength of the concrete attached itself to the aggregate rather than the cement.

In that region practically the only source of sand and gravel was the river sand and gravel, which could be found almost anywhere along the river, where a change in the current had piled up

a bar. The proportion of sand and gravel in these bars was a very great variable, so that in order to secure anything like a uniform product, separation and washing was necessary. This was done at a commercial sand plant a short distancefrom the bridge, which washed the product delivered from suction dredges in the river and loaded it into barges which were towed to the site of the bridge.

The sand obtained by this process was clean and uniform, though rather fine, and when at all carefully washed, compared very favorably with the best concrete sands. The gravel, however, was far more scarce, and the very small sizes were more plentiful than the large; moreover, the tendency of the sand company was to deliver the gravel only partially washed, which further increased the degree of fineness of the product. By far the worst feature, however, was the presence of varying quantities of lignite mixed in with the gravel, which was washed down from beds of lignite far up the tributaries of the Mississippi, for the separation of which no simple process could be evolved.

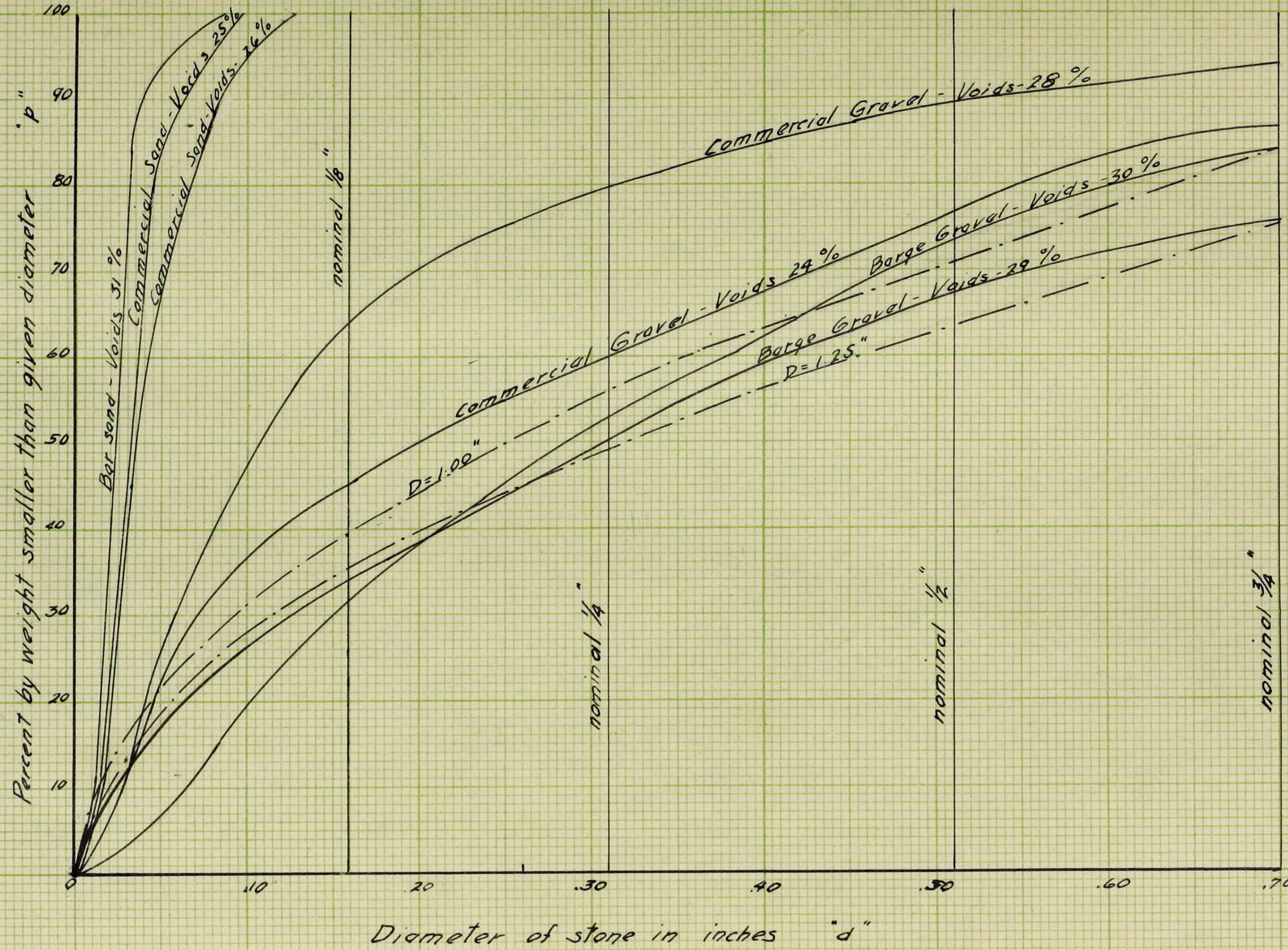
In order to secure the most dense concrete possible, the materials were used in proportion to the percentage of voids; that is, the proportions were such that the cement filled the voids in the sand, and the sand and cement filled the voids in the gravel. In order to accomplish this, screen and void tests were made of each barge of sand and gravel delivered, and the proportions to be used thus determined. As soon as a barge arrived, samples were taken which were representative of the entire load, and tests were made in a laboratory for that purpose, which was merely a small building equipped with scales, screens and pans.

The weight of a cubic foot of the dry material was first determined, and the cubic foot pan of material was then filled with

water, and weighed again; the increase in weight giving the weight of water which filled the voids, from which the volume of the voids was easily computed, and the percentage of voids determined. Next, to determine the degree of fineness of the material, it was passed successively through screens of varying sizes, and the residue left on the screen was weighed in each instance. From this the percentage of material passing a certain size of screen was easily computed, this giving an index of the gradation of the material.

The results of these oomputations were plotted in the form of a graph, so as to show at a glance the character of the particular test. Plates VIII and IX are representative graphs showing the characteristic curves obtained, both for the sand and the gravel. The curves obtained from the analysis of the sand were found to vary little, and in fact the sand was so uniform in quality that it was only occasionally analysed, other than the taking of the void test. But the gravel varied considerably, the two plates showing plainly the two characteristic forms of curves obtained, that in Plate IX being much the more frequent. This is seen to be an ogee curve, the average of which would show less than thirty per cent smaller than a quarter of an inch, and less than sixty per cent less than a half an inch. Greater percentages than these were not considered desireable, but only one of the samples of which the tests are shown was considered poor enough for rejection, this one having more than fifty per cent less than a quarter of an inch and nearly eighty per cent less than a half inch in diameter. No hard and fast rule was set for acceptance or rejection, but whenever the tests gave curves that tended to lie towards the top of the graph, the material dealer was notified that the material was not running satisfactorily, and attempts were made to secure a

ANALYSIS OF SAND AND GRAVEL
MEMPHIS BRIDGE



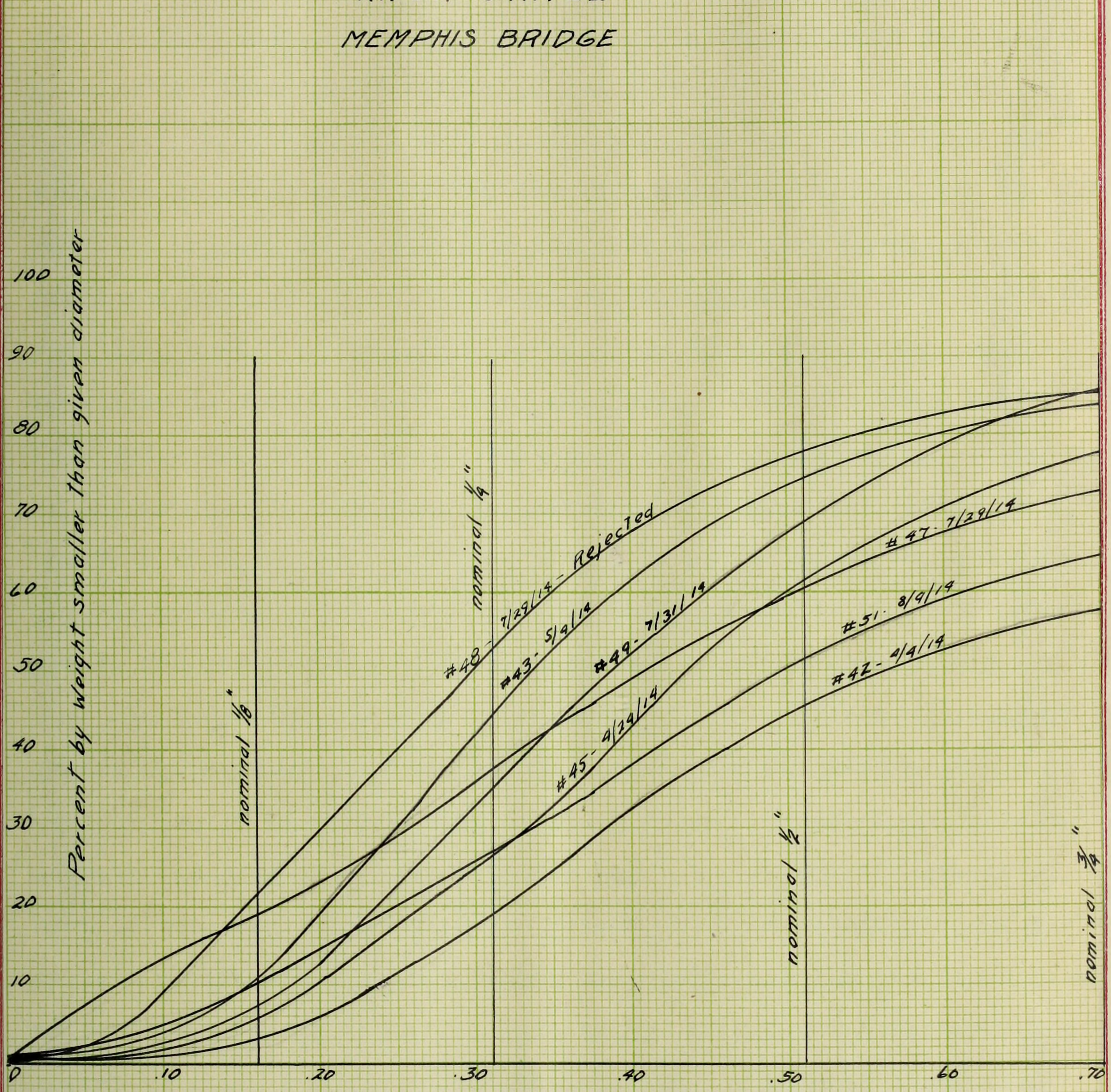
$$p^2 = \frac{10000\,d}{D}$$

D = nominal size of gravel

Plate VIII

ANALYSIS OF RIVER GRAVEL

MEMPHIS BRIDGE



larger size of gravel. It was only the difficulty in securing the kind of material wished in sufficient quantities to keep the work going without interruption that prompted the acceptance of some of the material used, the main objection being the presence of lignite rather than the gradation of the sizes, however.

It was determined at first that a one- two and a half-five mix would be the most satisfactory for the materials at hand, and the material hoppers leading to the concrete mixer were marked with a permanent line to which they could be filled and give this mix. Lines were also marked to indicate the point to which the hoppers were to be filled in order to give other mixtures, a one- two and a half-four and a half mix being the mix most frequently used, on account of the unusual fineness of the gravel previously noted. After an analysis of the gravel had been made, the inspector on the concreting was notified what mix to use for that particular barge of material, and the loading of the hoppers was governed accordingly.

An inspector was in general charge of the concreting whenever it was in progress, on both day and night shifts. After a gang had been broken in to the loading of the hoppers, the proper allowance of water to give to a mix- this was regulated during the greater part of the work by an automatic reservoir, that permitted just a certain definite quantity to enter the mixer- and the length of time to be allowed in the mixer for each batch, it was not considered necessary to watch the mixer continuously, and occasional inspection only was made of the process of mixing. As a rule the inspector was most concerned with the placing of the concrete, and the greatest of his difficulties was the attempt to eliminate the lignite.

This lignite was sometimes as much as fifteen percent of the total volume of the gravel. It was intended to reject anything over

five per cent, but this would have occasioned frequent delays; and as most of the work was mass work that did not show, excessive amounts of lignite were frequently passed. Naturally this affected the strength of the concrete, as was shown by test blocks that were made at intervals,and sent to the laboratory for strength tests. Samples were taken during the pouring of the concrete, placed in cylindrical moulds of sheet steel,hinged at the side and held with a pin, to permit easy removal,the moulds being also covered with parafin. After setting twenty-four hours in moist air, and seven days in water, the samples were crated and shipped to the laboratory, where they were subjected to the customary tests. While all the results obtained showed a very low strength, considering the large masses of the concrete and the relatively low stresses, it was not considered advisable to pay the difference in price to secure a different grade of material.

For the west approach pedestals, however, on which a large amount of surface was exposed, the appearance of the work was considered a sufficient excuse for obtaining a crushed rock for the concrete aggregate, this being brought in by cars from a distance of over fifty miles, the expense being over twice that of the river gravel used on the major part of the work. The cost of handling the crushed rock was also also considerably greater. However, wherever the river gravel was on work with exposed surfaces, it was impossible to keep all the lignite away from the face, and after a week or two of exposure, especially in warm weather, the lignite would expand and burst out, making an unsightly hole from which brown streaks would subsequently run down, as the rain gradually dissolved the lignite.

Two methods were used to minimize the effect of the lignite;

the first was to pour the concrete excessively dry, and endeavor to work it well along the forms, hoping thus to force the lignite to the interior; the second was to pour the concrete fairly wet and puddle it continually, this forcing the lignite to the surface, it being lighter than the mixture, and the greater part of it could then be raked together and shoveled out of the form. The second method was the most successful when carefully done, and really got rid of most of the lignite, but whenever vigilence was relaxed, there was danger of a batch of concrete covering a pile of lignite already gathered on the surface, and burying it in a pocket, which produced a more unsatisfactory result than by the first method. As a matter of fact, the only solution for the problem was a constant and careful inspection of the placing at all times.

As most of the concrete work was filling in the caisson and backing the courses of masonry, there was very little form work to be done. On the wing walls and abutments, however, as well as on Pier V, the concrete pier, wood forms were used, constructed in the usual manner. For these forms the center lines and elevations were given by the engineers, and a general supervision was given to insure adequate strength, and proper workmanship. The design of the parapet wall and the adjacent retaining walls was made in the office of the resident engineer, to fit the existing conditions, which were somewhat unusual in that the space back of the parapet wall was filled ground, and the wing walls had to be designed to act both as beams to span this filled area, supported by the anchor pier at one end and by solid earth at the other, and also as a wall to resist the pressure of the fill carrying the track on to the first span. To allow for some settlement of the wing walls under these conditions, they were designed with an expansion joint

at the juncture of the walls with the parapet; this joint being recessed and containing a lead connection plate to make the structure water tight and prevent soiling the masonry below. The wisdom of this provision was borne out by the subseqhent settlement of the walls and the opening of the joint for about an inch in width at the top, which would otherwise have caused a crack of considerable proportions. No provision was made for the expansion of the main parapet wall, some ninety feet in length, enough reinforcement being used along the face of the pier to take care of the expansion due to temperature. The decrease in thickness of the walls towards the top was made in steps rather than by inclining the rear wall, following the practice set by the main office. This was also observed in the design of the west abutment, where the wing walls were constructed long in advance of the fill, supported as cantilevers from the main abutment. These were much smaller than those on the east abutment, as the latter held the fill for the two highway approaches as well as that for the double railway track.

The forms for the pedestal bases for the thirty- eight piers of the west approach were constructed of wood, in the form of a truncated prism approximately fourteen feet square and six feet in height. They were solidly constructed, with two inch vertical siding and eight by eight waling pieces, bolted at the four corners. These forms were handled as a unit by a locomotive crane, about eight of them being provided for the entire work, which allowed four to be poured at one time. They were simply set on the bottom of the excavation around the tops of the piles, braced in position against the sides of the excavation, and filled with concrete to the proper height, which was marked by driving a projecting nail on the inside of the form for each location. As soon as the concrete had

set sufficiently, the form was lifted by means of a sling around the ends of the waling pieces, and carried to the next location. In a few instances the bolts had to be loosened to allow the form to lift off readily, but for the most part no difficulty was experienced, and the scheme worked out very economically.

On the pedestals themselves, which were cylindrical, or more strictly a truncated cone in form, steel forms were used, made of a light sheet steel with circular ribs of angles. These forms were centered by suspending a plumb bob from center marks on the top of the form, over actual center scratches previously made on the concrete base below, and bringing the two in coincidence by driving wooden wedges under the sides, the operation being very simple. As it was impossible to remove these forms as a unit after the concrete had set, on account of their height, they were cut in half on a vertical section, the halves being handled separately, and bolted together in position. This proceedure also worked out very economically, eight forms being used in all, which permitted the pouring of four forms while the remaining four were being removed and reset.

The anchor bolts were suspended from a template supported on the top of the pedestal form, which placed them exactly in position, this position then being checked with the transit and tape, as previously described in the treatment of the instrument work, with the satisfactory results noted.

After the inspection of the materials and the forms for the concrete, the inspection of the placing was a comparatively simple matter, requiring some diligence and judgement, and constant attention, but little actual work. When pouring in floating caissons, it was necessary to keep the concrete at nearly the same level at all

times, in order to keep the caisson balanced. The caisson always being below the mixer a considerable distance, the slope of the chutes was great enough to cause no difficulty from the tendency to run the concrete too wet, so that little was required of the inspector. It was important, however, when filling the pockets of the caisson, to make sure that pouring was discontinued when the level of the concrete was at the center of a cross timber, rather than a short distance below the timber, so that it would not leave a small space below the timber into which the concrete would not flow when concreting was resumed. This was necessary in order to avoid air pockets, and on account of the great number of cross timbers, and the frequent changing of spouts, it required considerable vigilence. In backing the masonry practically no inspection was required. In freezing weather, however, the water for mixing the concrete was heated, and care was taken to cover the concrete immediately after placing, to avoid the possibility of freezing.

The working chambers of the caissons on the main four piers were sealed with concrete, of which nearly half was placed dry. It was mixed dry in the mixer and locked into the caisson working chamber, where it was shoveled to the ends of the caisson and piled up to within four to six inches of the roof. In the moist compressed air this concrete set rapidly, and the space between it and the roof was then filled with dry concrete rammed in place. It was thus made certain that over half of the roof area was supported directly on the concrete filling. The remainder of the space was then filled with wet concrete, and the shafts were also filled with concrete to put a static head on the concrete below. The surge caused by the falling of the batch of concrete for the height of from eighty to over a hundred feet forced it tightly against the

ceiling; and afterward the filling of one shaft caused the concrete to rise in the other shaft for a height of forty or fifty feet, the shafts being about forty feet apart. Thus it was practically assured that the entire working chamber was tightly sealed. During the process of packing the dry concrete, a rigid inspection was given, since the work was difficult and was likely to be slighted by the laborers, especially since the compressed air workers, or "sand-hogs", are not over responsible. The air pressure was kept on the lines for several hours after the sealing was completed, and when it was released the settlement was very slight.

On the pouring of walls and pedestals the chief difficulty was in keeping the concrete the proper consistancy, and seeing that the lignite was removed in so far as possible. To avoid horizontal seams, the lifts were made as great as possible, and before the next pour was made, the top surface was picked to remove laitance and lignite, especially around the edges of the form, which were picked down a distance of five or six inches to secure good material for the next layer of concrete to join to. The lifts on the walls and piers were made about twenty feet in height, any greater height requiring excessive strength of forms, while the pedestals were poured in one lift in every case. The steel forms were oiled to permit easy removal, and should have given a very smooth appearance to the concrete surface, although it was impossible to pour the concrete dry enough to prevent entirely the water marks caused by water separating out of the mixture and running down the inside of the form. An inspector watched the pouring of every pedestal, and the water was kept to a minimum, so that the result was quite satisfactory. The difficulty from water marks was never experienced with the wood forms, which were wet thoroughly before

pouring so as to swell the lumber enough to make a smooth surface, which was nevertheless not so smooth as to allow the water to run freely down the form and leave marks on the surface.

The crushed rock used on the west approach concrete work was far more satisfactory than the gravel in the final appearance of the surface, and helped out the gravel supply to a considerable extent. It also made the inspection a much easier matter. For the majority of the work the mix approximated a one-two and a half-five mix, the only exception being the filling above the reinforced section of the anchor pier, where weight alone was needed, and where the shortage of washed gravel prompted the use of bar run material, which contained varying proportions of sand and gravel. Mixed in the proportion of one to six, however, it made a fair concrete, though not by any means a uniform material.

3. Concrete piles.--The concrete piles used on the west approach viaduct were a special feature in themselves, requiring entirely different treatment from the remainder of the concrete work. As a rule in that locality, such piles were cast in a regular manufacturing plant and shipped to the site of the work; but with the organization at hand the work could be done more economically by casting them at the site than by shipping them in.

In all 1306 piles were required, thirty-feet in length. The design of the piles was made by the resident engineer, after considerable study of practice both in this country and abroad. An octagonal shape was chosen, tapering from a diameter of sixteen inches at the top to twelve inches at the toe, the top being flat and the toe pointed;for longitudinal reinforcement eight square bars, three-quaters of an inch in diameter,the total area thus being 4.5 inches. Since the average area of a section of the pile was 200 square inch-

es, this gave a percentage of 2.25 for longitudinal reinforcement. These eight bars were tied together with a spiral reinforcement of quarter inch wire, the pitch of the spiral being approximately four to the foot, which gives a value of .5 percent for the hoop reinforcement. The total reinforcement was thus under three percent, the greater proportion being in the longitudinal direction, on account of the strain to which the pile would be subjected in handling. In fact the reinforcement is chiefly necessary to withstand these strains, since the concrete itself possesses sufficient strength when once in place for all the loads to which the piles would be subjected, no bending stresses being present. On account of the poor quality of the gravel, a rather rich mix was used, a one- two three mix, which compensated for the excessive amount of lignite which could not be avoided.

The device for preparing the reinforcement consisted of a 4 inch pipe the length of the pile, to which were attached supports to hold the eight longitudinal bars in a rigid position. The pipe itself was supported on bearings, and was provided with a handle for rotating it. The wire was then attached to one end and fed on to the rotating spool, the only care required being to keep the spacing correct, and to tie the wire to the bars at regular intervals. When the cage was completely wound and tied, the clamps which held the bars were loosened, and the interior pipe withdrawn, leaving the cage a tight unit which could be conveniently lifted about and placed in the forms. All of these operations were performed by inexperienced labor at a minimum cost, the output averaging about fourteen cages a day.

The forms for casting the piles were constructed of wood, in three longitudinal pieces,which when set up were held by wooden

clamps, wedged tight against spacers at the top. The ends of the form were closed with a hollowed out block at the foot to provide a point and with a flat piece with moulding to form a champfered edge on the flat top at the head. Fifty forms in all were used, with twice as many bottoms, so that the sides could be removed and set up on the reserve bottoms without disturbing the pile for several days. The piles were then rolled over and the bottoms also released. these fifty forms served for the entire job, being overhauled and repaired twice; which meant that each form was used on the average over twenty-five times.

As a rule fifty piles were poured at a time, and pourings came about every three or four days. It was necessary to have enough reinforcement cages wound and on hand so as not to cause delay in pouring the piles, and it was necessary to plan to have the piles cast in such an amount that they could set thirty days before required for driving. The progress diagram Plate X shows how this was carried out. There were always enough cages on hand for the work, and only near the very end of the work was there any danger of a shortage of thirty day piles for driving.

The forms were assembled for casting on the loading dock on the west bank, where they were accessible from the river mixer. They were handled usually by a locomotive crane, which also brought out and placed the wire cages. The pouring was done mostly at one point, the concrete being soft enough to flow the length of the pile, so that only the top few inches had to be filled by hand. Extreme care was taken to see that the concrete flowed evenly around the reinforcement, and that no pockets or large stones were left. Since the yardage was small, the actual time spent in pouring was very short, after all preparations had been made.

PROGRESS ON APPROACH FOUNDATIONS MEMPHIS BRIDGE

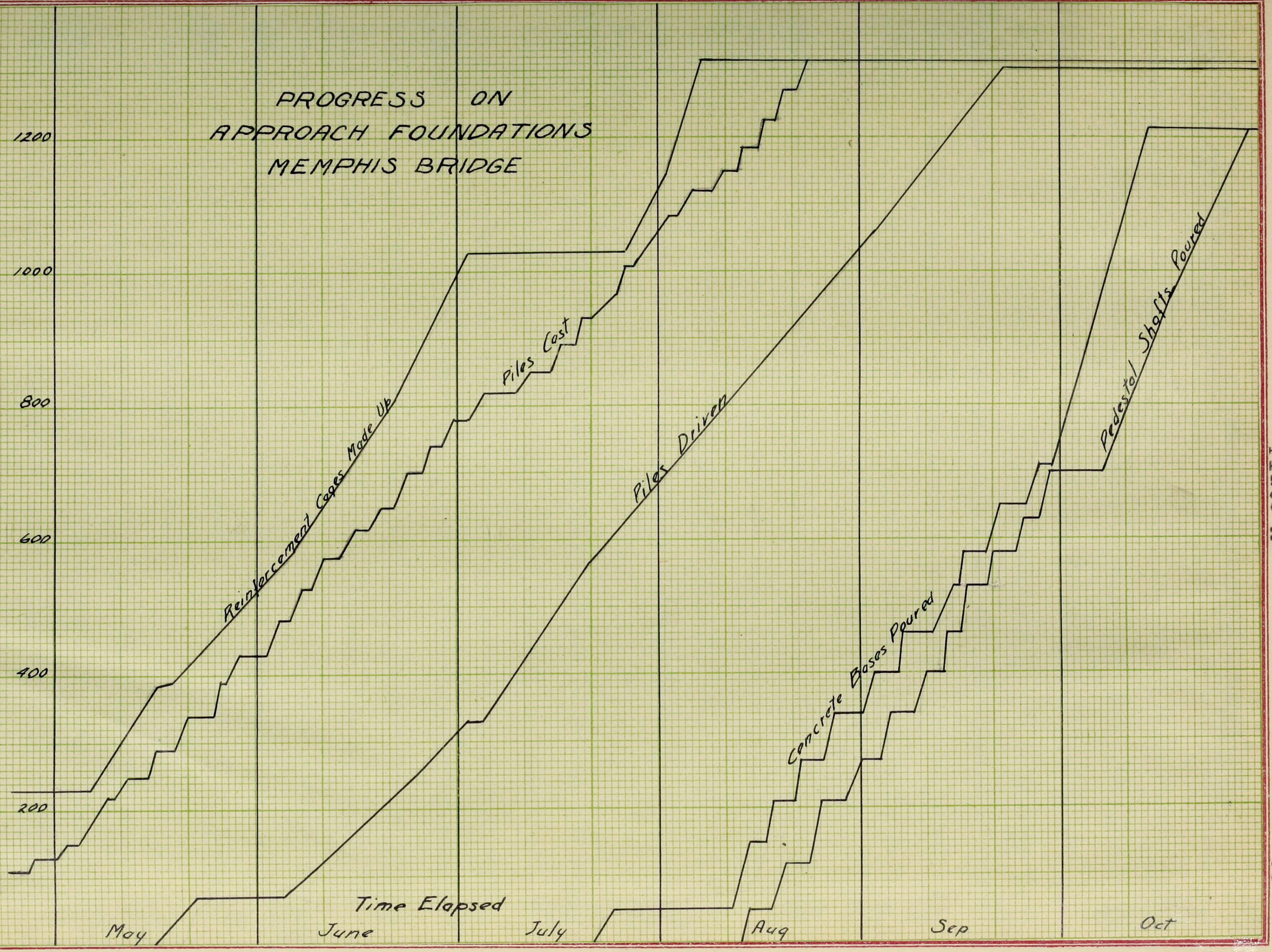


Plate X

A practice was made of keeping the piles on the bottom forms for two days after casting, though the side forms were removed as soon as the concrete had set sufficiently to stand up. The time elapsing before they could be handled to storage varied greatly with the weather and other conditions, and sometimes they were picked up with wire slings, supporting them at two points, in less than five days after pouring. They were then stacked in piles to set the required thirty days, and during the hot weather they were thoroughly wet down every day. Only one pile broke in handling, that one being dropped by accident, and cracked clear through the section. All of the piles showed hair cracks on the tension side when they were picked up, but none of them were of any consequence. Seven extra piles were cast, four of which were used to replace piles broken in driving, so that at the end only two remained.

The piles were driven with a steam hammer, a Vulcan #2. The driver was set on rollers of steel pipe,which were supported on long timbers laid along the edge of the excavation, which was made to the top of the final elevation before the driving was started. The driver was then easily moved back and forth across the excavated hole until all sixteen piles were driven. It was thus necessary to use a follower on all of the driving, and to drive the piles to the proper elævation it usual to mark the follower opposite a similar mark on the leads to which the follower should be driven to leave the top of the pile at the correct height.

A wire rope sling was used to pick up the piles, the same as is used with timber piles, and the piles showed an elasticity when being pulled up, at which time they were supported only at the two ends and subjected to considerable impact at the same time,that proved equal to all strains to which they were subjected. Once in

the leads,their weight carried them usually a third to a half of their length into the ground without any driving, but after that considerable difficulty was experienced. The ground was a mixture of river sand and silt, very unevenly distributed, so that when the silt was encountered the piles sank readily, and when sand was met with almost no progress could be made. After some experimenting it was found necessary to use a water jet to help drive the piles whenever sand was struck, and although there were some misgivings as to the strength of the piles thus driven, tests showed that this proceedure was entirely safe.

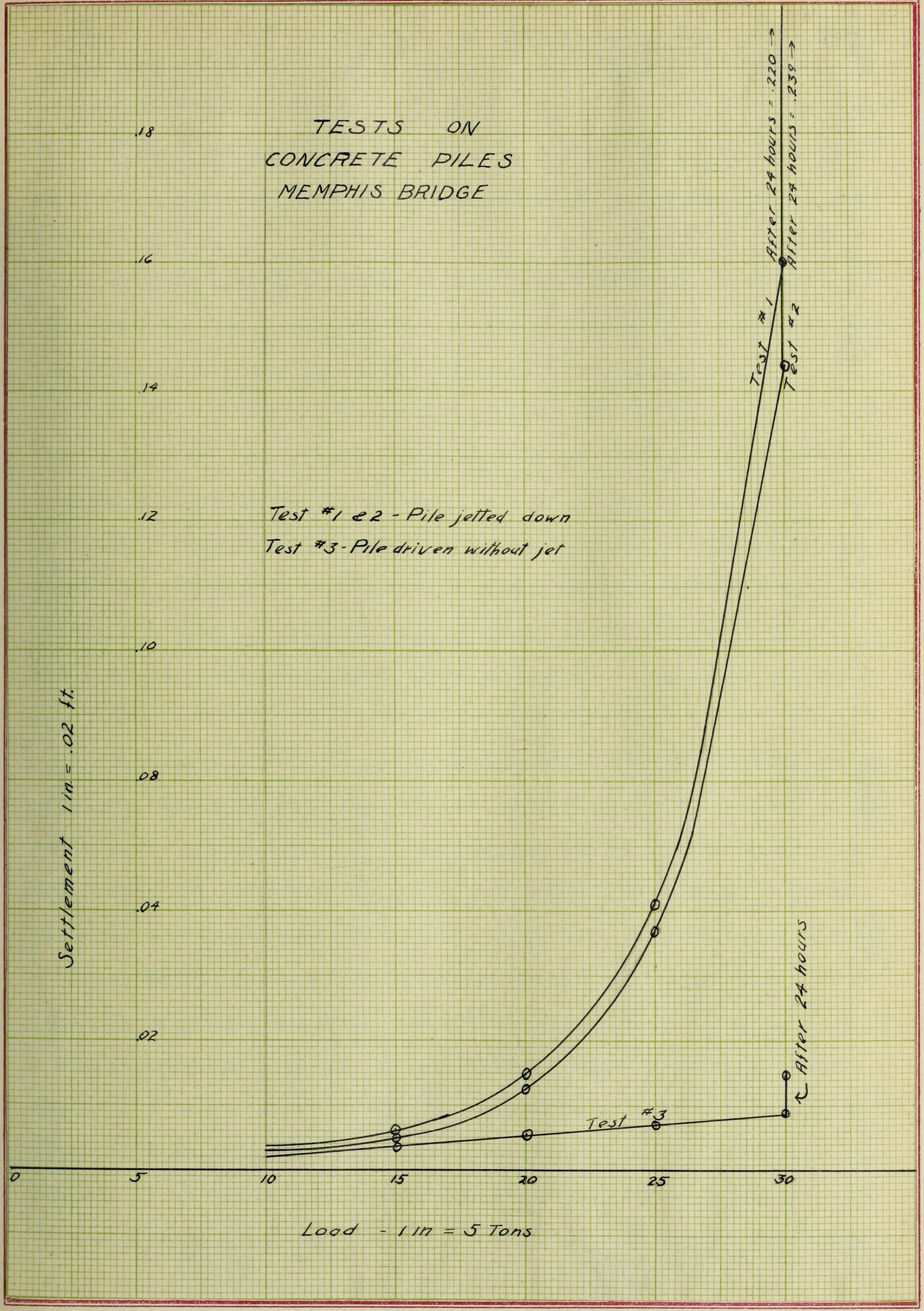
Three tests were made on concrete piles driven both with and without the jet, the results showing on the graph of loads and settlements, Plate XI. These tests were made by building a platform on top of the pile, constructed of timbers and planking,with a space left exactly at the center just large enough to allow a level rod to pass through and rest directly on the top of the pile itself. The platform was then loaded with sacks of cement, care being taken to preserve perfect balance during the loading, by observing the pressure on wedges which supported the sides of the platform until the load had been placed. The loads were made in increments of five tons each,and readings were taken with each increment, allowing several hours before the next increment was placed to let the effect of time on the settlement have its full influence. The readings were read with a level at a convenient distance, with all the customary precautions for accuracy.

As shown in the plate, the test marked #3, of an unjetted pile, gave a very good result, the settlement under thirty tons being hardly an eight of an inch at first, although resting over night brought a slight additional settlement.This pile required fifty-

TESTS ON CONCRETE PILES MEMPHIS BRIDGE

Test #1 & 2 - Pile jetted down

Test #3 - Pile driven without jet



four blows of the hammer for the last foot of driving, or less than a quarter of an inch per blow; the driving had been very slow during the last few feet preceeding, also, so that the time required to drive all the piles without the jet would have been almost prohibitive.

Tests #1 and #2 show the results obtained with piles jetted to position, tested immediately after being driven. Up to twenty tons, the settlement was very small, a little over an eighth of an inch, but from that point the settlement became increasingly rapid, and with a load of thirty tons, continued after the load was placed, without further increase in load. This of course practically constitutes a failure at thirty tons, caused by the loosening of the earth about the pile during the jetting. These piles were both jetted with little use of the hammer, about eighty blows being given for the last five feet, an average of a little less than an inch per blow.

Of course the Engineering News formula for the bearing value of piles, which is $P = \frac{2Wh}{s+.1}$ for a steam hammer, is scarcely applicable for use with piles that are jetted as were those in the last two tests; but to employ it for the hammer used would give a safe value of about ten tons. For the pile in test #3 it gives a value of about thirty tons, which may be assumed as not far from correct. In sandy material, however, the effects of jetting dissappear after a sufficient time has elapsed, as is well known from experience, and as was proved on this work by the endeavor to start moving again a jetted pile that had been left to set for some time; in many instances it was found impossible to budge it again without the use of the jet. Hence it may be assumed that as a matter of fact the jetted piles would also have carried thirty tons with safety by the

time that the concrete pedestal was placed on them. However, to be on the safe side, the policy was adopted of jetting the piles only to within the last two feet, and then driving them until they brought up with a final penetration of about a quarter of an inch.

This policy worked out very well from a practical standpoint, and although it was necessary to use the jet on the great majority of the piles, only a very few were driven below the proper elevation before bringing up with the proper penetration, the proper judgement having been used as to the correct time to withdraw the jet. Some of the piles were left above elevation, since it made little difference how much of the pile projected into the base, and since to have started the jet again would have loosened it too much, and to have continued driving would have taken an unwarranted amount of time, or damaged the pile.

It was found that the heads of the piles crushed rather easily under the concussion of the hammer, there being no provision in the pile itself to reinforce the head for this. The reinforcement of the pile ranto within two or three inches of the surface of the head, and when the concrete had crumbled to this point, the steel bent under the hammer and cracked the concrete further, until enough of the steel was exposed to form a mat of three or four inches in thickness after being crushed down. While this did not impair the strength of the pile to any extent, it caused some trouble in driving, and to prevent it many expedients were tried, with varying success. A rope cushion was found to be of some use, but it was finally found that a soft pine block,about six inches square placed on top of the concrete pile offered better protection than anything else. This block crushed easily under the hammer, but in doing so absorbed the shock, and saved the pile. About an average

of one block to the pile was found to be sufficient, some piles requiring more and some less; the blocks being inexpensive, and a stack of them being kept in readiness. It was found that as a rule the piles poured on the same day were similar as to the tendency to crush, being either all tough or all crumbling readily; this was evidently due to some variation either in the materials or the handling of the casting of the piles, or perhaps to the weather conditions, but although careful records were kept of all operations, no generalization could be made as to the exact cause.

Although no piles were broken above ground in the process of driving, four were broken below ground under the blows of the hammer at about the mid point, due to excessive resistance. Since it was difficult to withdraw the portion above the break on account of the resistance of the reinforcement, the pile was simply driven on down at whatever angle it took and the top concreted into the base, a new pile being driven to replace the old. The results of the entire process were considered very satisfactory, and the costs, given in detail in part X, were very reasonable.

4.Granite masonry-- Perhaps the most interesting of all the substructure inspection was that of the granite masonry, since it involved both careful planning and coordination of effort. Each block of granite required detailing for its particular position in the pier; each piece was carefully inspected by the inspector stationed at the quarry, and in addition a field inspection both on delivery and on placing was most rigid.

Plans for each course of masonry were prepared by the contractor from line drawings furnished by the engineers, supplemented by measurements of work in place taken during the sinking of the caissons. These plans were checked and approved by the resid-

ent engineer, and forwarded to the quarry sufficiently in advance of the cutting to enable the work to progress without interruption. The first dozen or more courses were detailed on a standard plan, with the dimensions of the base computed from the theoretical elevation of the bottom and the desired size at the top, with a uniform batter. The rise of these courses was uniform at three feet, while the rise of the courses near the top of the pier was as low as two feet, the intermediate course rises varying accordingly. The starling courses and the coping were also made on a standard plan, according to the size of the pier, but of course it was necessary to know the exact elevation of the bottom course before all the intermediate courses could be detailed. As soon as a pier reached its final elevation, therefore, the heights were worked out so as to grade the rises between the bottom and the starling course, and the dimensions of each stone varied accordingly so as to give uniform batter.

On the plan each stone was marked with the number of the pier, the course, and the position in the course. The inspector at the quarry, which was at Stone Mountain, Georgia, watched the quarrying of each stone, and after it was cut to dimension, checked the marking and loading of the blocks, sending reports of each shipment, showing the marks and measurements of each block and the computed volume of the same, to the resident engineer. This inspector was expected to reject any blocks not suitable for erection in the pier, and also to so plan the work as to ship in regular order the stones needed by courses in the piers under construction, to avoid as much as possible delays in sorting and placing the granite.

Shipment was made either in gondolas or flat cars, care be-

ing necessary to block the stones carefully, to prevent shifting about in the cars and consequent damage. As soon as a car was received at the site, a check measurement was taken on each stone, without reference to the report of the quarry inspector; the marking was freshened where necessary, and the blocks unloaded by an overhead travelling crane into the storage yard, being sorted into courses for each pier during the process. From the measurements taken before unloading the volume of the granite was computed for purposes of payment, being checked against the report of the quarry inspector. For purposes of computation it was best to measure the stones in feet and tenths of a foot, varying thus from the quarry method of measuring in feet and inches, and expressing the volume in cubic feet and twelths of a foot remaining. The total variation of the results obtained at the site and at the quarry was only a fraction of a per cent.

The actual face measurements taken on each stone were marked on the plan, to show the variation from the plan dimensions, and the whole was recomputed for each course, to find the actual thickness of joint required for the stones as finally furnished. This refinement was not necessary for all courses, but served to facilitate setting whenever a stone varied somewhat from the plan dimension.

With all these safeguards, the actual setting of the masonry occasioned very little difficulty. The stones being separated by courses, they could be easily run out and loaded on barges, a half a course to a barge, and were picked up from the barge by a floating derrick, and handled directly to their proper position in the pier. Very seldom was any cutting or chipping necessary, each course requiring but an hour or two to set, and then being

backed with concrete from the floating plant. The top courses were set with a derrick having a wooden boom 114 feet in length, a rather novel piece of equipment, which was most satisfatory in operation.

In backing the first three courses of masonry, steel bars one and one half inches in diameter were laid in the form of a mat in the concrete backing, in order to tie the course together firmly, and take any tension that might be caused by bending or twisting of the pier. The same proceedure was followed for each succeeding seventh course, and while this by no means gave a reinforced concrete structure, it would naturally add greatly to the strength of the pier. The top six courses were backed with granite blocks instead of with concrete, in order to give added strength under the bridge seats.

An inspector watched the setting of the masonry constantly, and the dimensions of the pier were checked up at frequent intervals. During the sinking of the caisson, the masonry was carried up by squaring from the top of the caisson, but as soon as the final elevation had been reached, the work was leveled as rapidly as possible and kept plumb thereafter. It was also brought to line from this point, while during the sinking it was necessary to keep it centered on the caisson rather than on the bridge line.

Each time that a course of masonry was trammed, a location card was given the foreman, showing the amount that each shoulder and nose was out of level and position, and the direction in which the succeeding stone should be moved in order to true the pier. While sinking the pier was trammed for each course, on account of the difficulty in keeping a course square while out of plumb; but after-sealing it was necessary to tram but every third course, the fore-

man usually keeping lines easily with a masons level.

A most secure bond was obtained by the alternate headers and stretchers, each header extending three feet into the interior of the pier. All of the stones were left with rock face, except the upstream side of the starling course, which was fine cut, and of course the coping. The noses of the piers were laid out as arcs of a circle, so that tramming the course was a most simple matter. This also simplified the making of plans from the work that would have been involved in the use of a parabolic curve for the nose, and in fact the only complicated stones in the entire pier were the starling nose stones.

After the coping course had been set and pointed, a space was laid out under each pedestal,which was bush hammered to a plane which was within a sixty-fourth of a inch of level, a very painstaking and expensive process. This was considered necessary in order to avoid any strains in the cast steel shoes, with the great concentration of bearing stress involved. It was not considered absolutely necessary to bring both bases on a pier to exactly the same level, but each base was brought to an exact plane separately, by laying off bench marks accurately over the entire surface, and bush hammering between these squares, checking the level with a steel straight-edge some eight feet long. Afterward the entire surface was checked with the engineers level to make sure that their was no variation greater than a thousandth of a foot.

On the whole the inspection and supervision of the granite masonry was most satisfactory, and the results obtained fully justified the attention that was given to this part of the work.

V. Records and Reports.

1.Diary and photographs- In connection with the supervision of the construction of the bridge, almost equal in importance to the field work of surveys and location, and the inspection of construction, is the office work of making records ad reports. Not the least of this office work is the maintaining of records of progress, which on this project was satisfactorily kept by means of a diary and by progress photographs.

The diary was kept in the form of a loose leaf book, for which a special form of page was printed, which could be filled out on a typewriter and filed in the book at the end of each days work. The form was such as could be easily filled in in a few moments time, and was faithfully kept up during the entire substructure construction, a page for each day, regardless of the amount of work.

On this record was kept the stage of the river, the amount that each caisson had been sunk during the last twenty-four hours and the elevation reached, the height to which each pier had been brought and the amount of masonry set, as well as the amount of timber framed and of concrete poured, and all other work under operation, with the force that was on each particular piece of work. Thus the diary proved very useful not only in preparing permanent records, and in segregating costs of different parts of the work, but also in making estimates of what could be done in a certain length of time, and the force necessary to use in this operation.

A far more interesting record of progress was kept by means of photographs. For this work a five by seven camera was used, with a high grade anastigmatic lens, so that good pictures could b

be obtained almost regardless of weather conditions. As a rule it was planned to take an average of at least one photograph a day, and during interesting parts of the construction a much larger number. Plates were found to give far better results than films for this work, and it was also found more satisfactory to letter the plates and make the prints on the work, although the developing of the plates was done by a commercial photographer. A title was given to each photograph, showing the stage of progress and the pier number or other work shown, the title being printed directly on the plate with india ink, or else, as was found somewhat more satisfactory, printed on a piece of transparant paper and pasted on the plate.

By keeping all progress photographs on file in consecutive order, a most complete record of progress was always at hand. Prints were also forwarded to the main office weekly, thus furnishing most complete information as the work progressed as to the exact work under way and the status on each day. The entire expense of this record was almost negligible compared to the satisfaction derived from the results.

2. Weekly reports and planning. In addition to the diary and the progress photographs, a weekly report of progress was made each week by the resident engineer and sent in to the main office. This report embodied the main features of the progress during the week, with special comment on points of interest, calling attention to any features on which action would be required. Plams for the coming week were then outlined, based on previous progress and the engineers judgement of the importance of succeeding steps. This report served the double purpose of informing the engineer in charge of any details on which his advice or

cooperation would be neceasary, and also of checking up the details with relation to the general plan for the date of completion.

In making such plans, there was always the very best coordination of effort and ideas between the contractors and the engineers, frequent conferences being held in order to assure the best interests of both parties. A great deal of the success of the work as regards both low costs and rapid progress was due to the harmony of this relation, for by discussing the ideas of both the engineer and contractor, all friction was avoided, and details were planned which frequently led to expedition of the work, and resulted also in saving of labor.

3. Progress charts and records. In keeping a record of the progress in sinking the caissons, perhaps the most simple and at the same time most accurate method is illustrated by the progress chart shown at the top of plate XII. This diagram was laid out in the form of a graph, with the horizontal distances representing the days elapsed in the construction, and the vertical distances representing the depths to which the caissons were sunk. The position of the caisson was then entered on the graph daily, thus showing at a glance the exact position of the cutting edge, the distance still to go, and the rate of progress. By plotting the stage of the river on the same graph daily, it was also possible to show the distance of the cutting edge below the river level, thus indicating the air pressure that it was necessary to carry. This diagram thus showed at all times the exact stage of progress on the sinking of all piers, and when complete it gave an accurate record of the rate of progress maintained, in a graphical form which made a comparison of the rates of progress on the different

caissons a very easy matter. It also indicated the difference in rate of sinking through different strata, by the slope of the progress line, and made possible a prediction as to future rates of sinking. As can be seen, four of the caissons were sunk within the first six months of work, while the last caisson, after an interval of nearly four months, required two months to sink.

On arriving in Memphis at the start of the work, the engineers found that the only record of the stage of the river during past years was in the form of printed reports of the U.S.Weather Bureau, which were in a cumbersome form which made study of river stages exceedingly difficult. In order to assemble this data in a form advantageous for use, the records for the past six years were plotted in graphical form, as shown in the diagram at the bottom of plate XII. In this form not only the stage of the river at any time of the year was shown, but also the rate at which the river rose and fell. This was particularly useful in predicting the rate of change to be expected during any rise, and also the probability of the stage at any time of the year. It can be seen that although the variations from the average are at some times great, yet the general curve of the stage throughout the year is fairly uniform.

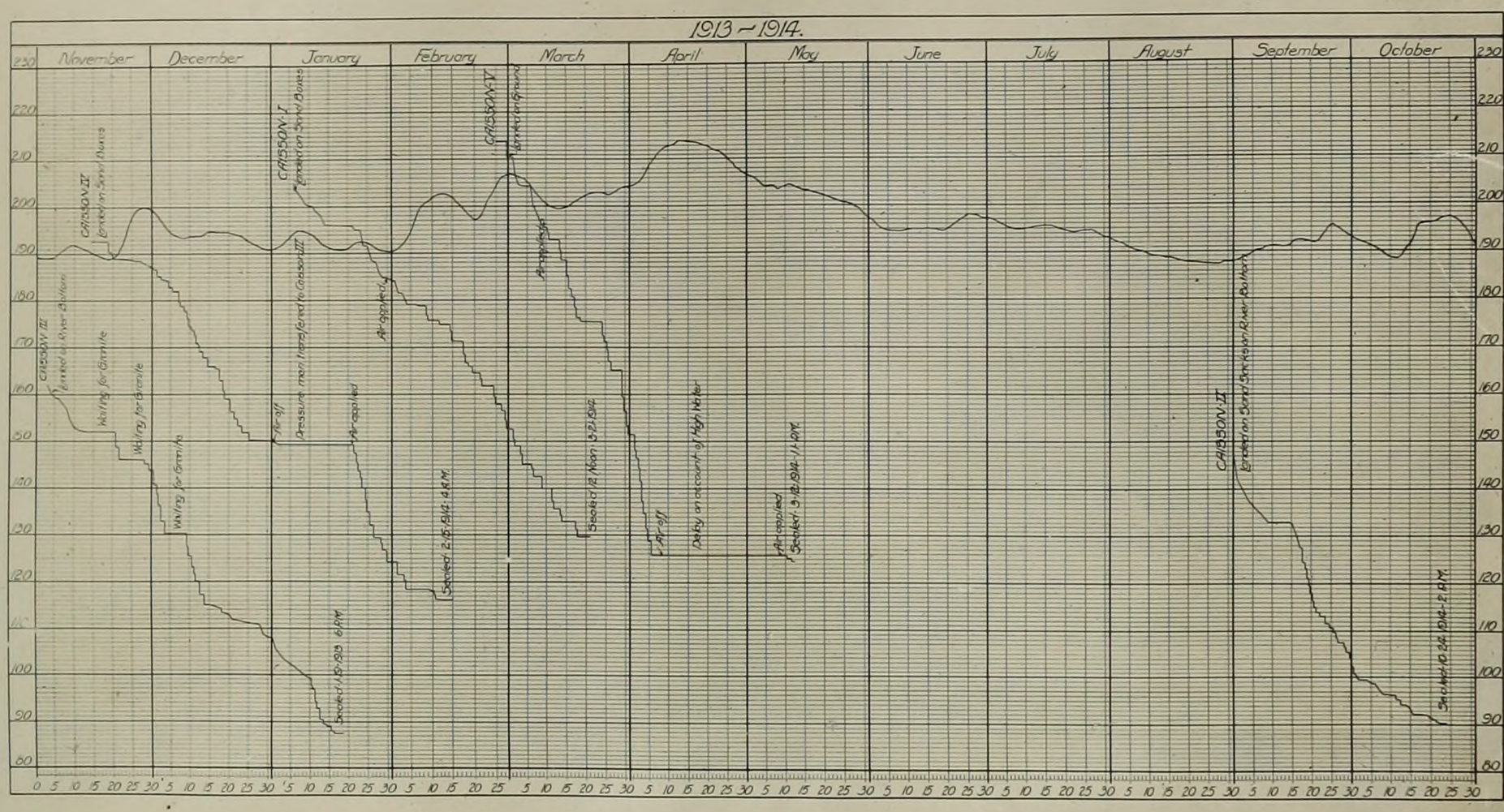
By plotting similar diagrams for points avove Memphis on the river, it might have been possible to have determined the rate of rise or fall to be expected there at any stage following a known rate of change at points above; but this study was never made, and the predictions of the weather bureau for the change in the river, based on the opinion of the government official, were relied on in planning work on which it was necessary to consider the variation of the river.

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MEMPHIS BRIDGE

DIAGRAM SHOWING RATE OF PROGRESS
IN SINKING OF CAISSONS.

Consulting Engineer in charge



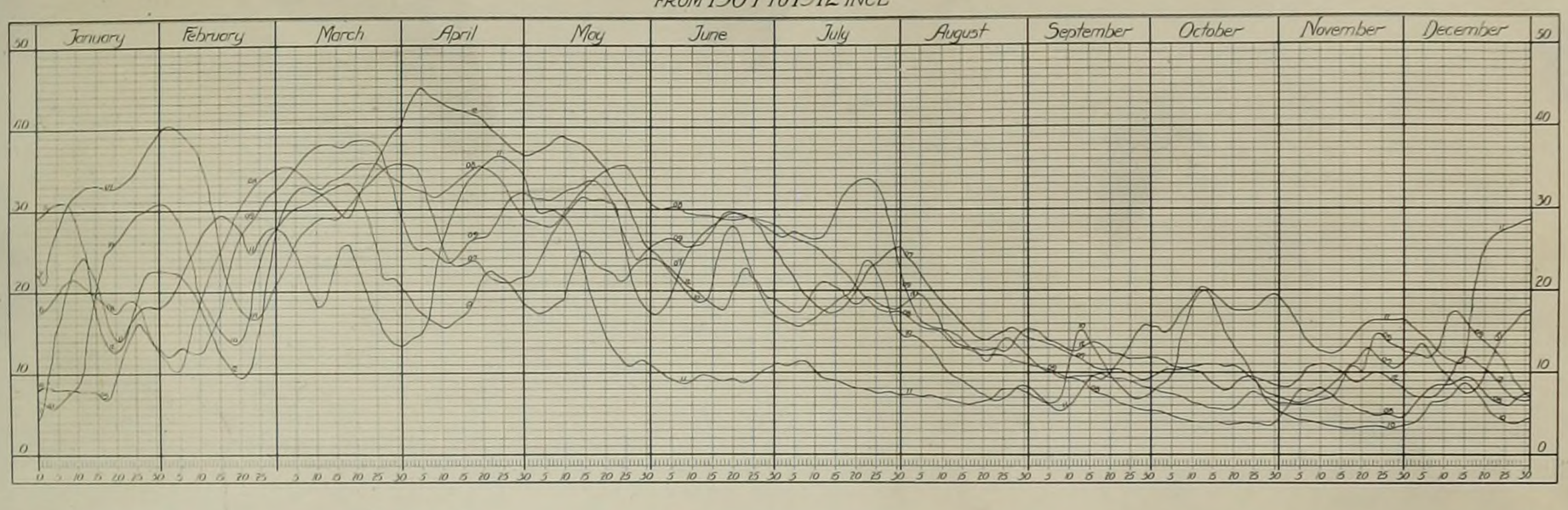
A.&M.R.B.&T.Co.

MEMPHIS BRIDGE

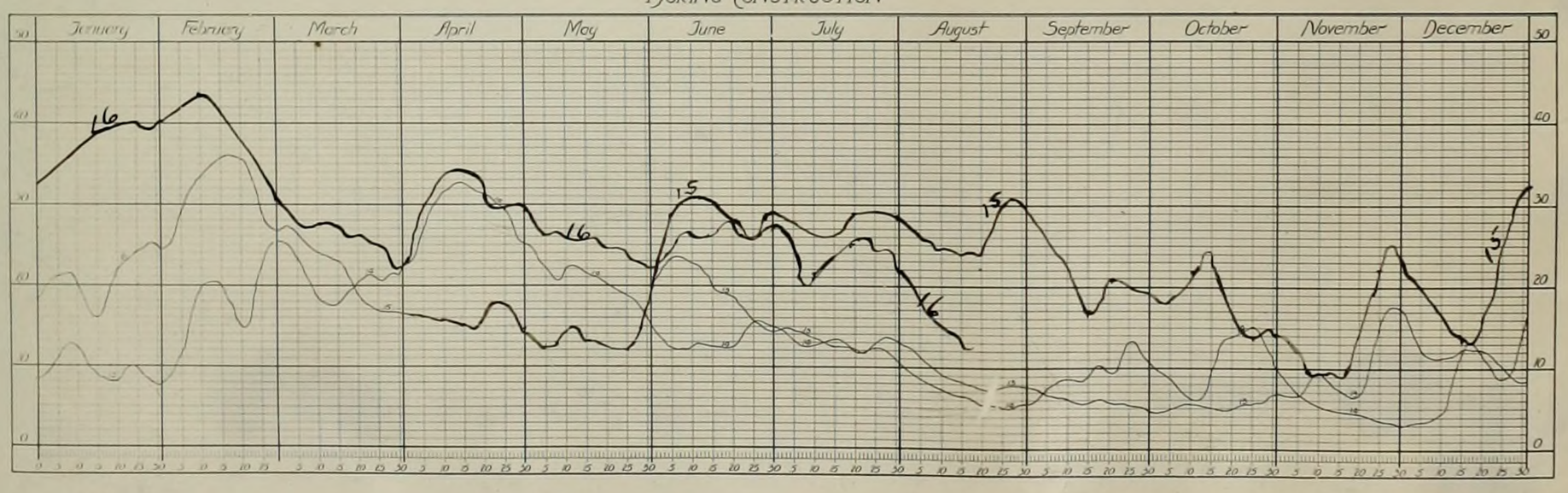
WATER GAUGE RECORD

Consulting Engineer in charge

FROM 1907 TO 1912 INC'L



DURING CONSTRUCTION



L.H. Bergsund - Del

4. Sinking sheet- In addition to the chart of sinking progress and the river guage chart discribed above, a most important form of record of sinking was kept in the shape of a sinking sheet, illustrated in plate XIII. This plate shows the form of sinking sheet kept for caisson II, and similar sheets were kept for each of the piers. As can be readily seen, this sheet gave practically all the engineering data necessary for a complete analysis of the the condition of the caisson at any time.

The elevations of the cutting edge, that of the sand about the caisson, and the stage of the river, were determined by daily observation, as previously explained, and entry made on the sinking sheet, which was posted for convenient reference. The difference between the average elevation of the cutting edge and the elevation of the river gave the depth of immersion, from which the calculated air pressure is obtained by multiplying by the constant .434 ,against which the indicated pressure, as shown by the pressure gauge, was checked. The weight of the caisson was calculated for each position, the calculation involving the determining of the weight of each bolt and piece of iron entering into the construction, as well as the weight of the concrete, timber, and grante masonry for each height of the pier.

The reaction due to the air pressure, obtained by multiplying the calculated air pressure by the area of the bottom of the caisson, amounts, of course, to the same thing as the bouyancy of the caisson, and this subtracted from the total weight of the caisson at that time gives the net weight supported by actual contact of the caisson with the earth. This net weight divided by the surface in contact, obtained by multiplying the perimeter by the average penetration, gives the figure shown on the last column of

RECORD OF SINKING CAISSON II

Date	Elevations of Cutting Edge					Sinkage		Elevations of Sand					Average Penetration of Caisson Ft.	Water Guage	Depth Immersed in Ft.	Weight on Caisson - Tons							Air Pressure		Reaction due to Air Pressure Tons	Net Weight Tons	Surface in Contact Sq. Ft.	Average Wt. per Sq. Ft. Exposed to Friction Pounds	Material	
	N.E.	N.W.	S.E.	S.W.	Average	In 24 hrs Ft.	Total Ft.	N.E.	N.W.	S.E.	S.W.	Average				Timber	Iron	Concrete	Locks & Shaft	Masonry	Sand	Water	Total	Indicated #/sq.in	Calculated #/sq.in					
Aug 22	168.6	168.6	168.6	168.6	1 168.6			139.0	140.8	142.5	141.8	141.03		187.9	19.3	1543	103		29			75	1675				1675			
23	158.5	158.1	159.5	159.1	158.8			139.0	140.8	142.5	141.8	141.03		187.8	29.0	1593	103	1061	29			10	2811				2811			
25	158.2	157.9	158.6	158.3	158.3			144.0	140.5	143.6	142.9	142.62		187.6	29.3	1638	112	1061	30			10	2851				2851			
28	156.8	156.5	157.1	156.8	156.8			143.5	141.5	142.5	142.5	142.75		187.5	30.7	1850	121	1061	34			10	3076				3076			
29	151.0	150.9	149.6	149.5	150.25			145.2	142.1	143.7	143.2	143.55		187.9	37.6	1850	121	1830	34			10	3845				3896			
31	148.0	148.0	148.3	148.3	148.17			143.2	142.1	143.7	143.2	143.55		188.0	39.8	1850	121	2090	34			10	4105				4105			
Sept. 1	142.9	142.6	141.6	141.3	142.10	.95	.95	143.7	143.4	143.1	142.0	143.05	.95	188.1	46.0	1850	121	3760	34			10	5775		19.99	5927	98	251	382	Jacked Sand	
2	140.8	140.9	140.9	141.0	140.90	1.20	2.15	142.9	141.3	142.6	141.4	142.05	1.15	188.4	47.5	1850	121	3990	34			10	6005	19.5	20.58	5308	697	304	4585	"	"
3	139.0	139.0	139.2	139.3	139.11	.79	3.94	142.6	142.3	142.2	141.2	142.08	2.97	188.9	49.7	1850	121	4600	34			10	6615	20.5	21.64	5580	1035	784	2640	"	"
4	137.2	137.7	137.2	137.8	137.50	1.61	5.55	143.0	144.3	142.3	141.1	142.68	5.18	189.5	52.0	1850	121	4950	34			10	6965	22.5	22.54	6135	830	1465	1170	"	"
5	136.9	136.7	136.7	136.6	136.73	.77	6.32	143.0	142.1	141.9	141.4	142.13	5.40	190.0	53.3	1850	121	5245	40			10	7466	24.0	23.11	6290	1176	1670	1410	Sand & Rip Rap	
6	135.7	135.8	135.9	135.5	135.60	1.13	7.45	143.1	142.2	142.2	141.9	142.32	6.72	190.2	54.6	1850	121	5866	40			10	7887	24.5	23.67	6443	1444	1774	1628	"	"
7	134.9	134.9	135.0	135.0	134.95	.45	8.10	142.7	142.3	141.8	141.8	142.15	7.20	190.5	55.5	1850	121	6427	40			10	8448	25.0	24.06	6549	1899	1801	1998	"	"
8	134.1	134.1	134.1	133.8	133.95	1.00	9.10	142.8	142.3	141.6	141.6	142.08	8.13	190.8	56.8	1850	121	7003	39			0	9008	25.5	24.62	6701	2307	2146	2150	"	"
9	133.1	133.2	133.1	133.2	133.15	.80	9.90	141.9	142.3	142.1	141.6	141.98	8.83	191.1	58.0	1850	121	7429	39			0	9429	24.5	25.19	6843	2586	2331	2219	"	"
10	133.1	133.2	133.1	133.2	133.15	.00	9.90	142.9	141.8	142.1	141.6	141.98	8.83	191.2	58.1	1850	121	7544	35			0	9550	25.0	25.18	6854	2696	2331	2313	"	"
11	133.1	133.2	133.1	133.2	133.15	.00	9.90	142.9	141.8	142.1	141.6	141.98	8.83	191.1	58.0	1850	128	7895	37	177		0	10087	25.0	25.14	6843	3244	2331	2789	"	"
12	133.1	133.2	133.1	133.2	133.15	.00	9.90	142.9	141.8	142.1	141.6	141.98	8.83	191.0	57.9	1751	126	7895	37	177		0	9986	25.0	25.10	6832	3154	2331	2706	"	"
13	133.1	133.2	133.1	133.2	133.15	.00	9.90	142.9	141.8	142.1	141.6	141.98	8.83	191.0	57.9	1751	132	8171	37	351		0	10442	25.0	25.10	6832	3612	2331	3099	"	"
14	133.1	133.2	133.1	133.2	133.15	.00	9.90	142.9	141.8	142.1	141.6	141.98	8.83	191.0	57.9	1751	138	8410	41	502		0	10842	25.0	25.10	6832	4010	2331	3440	"	"
15	132.9	132.9	133.0	133.0	133.60	.15	10.05	143.1	141.7	142.6	141.6	142.25	9.25	191.5	58.6	1751	144	8644	43	653		0	11235	27.0	25.36	6903	4332	2492	3548	"	"
16	131.0	131.0	130.6	130.6	130.82	2.18	12.23	142.5	142.5	142.6	142.3	142.72	11.90	192.3	61.5	1751	144	8644	43	802		0	11388	27.0	26.66	7257	4127	3192	2627	Sand	
17	127.84	127.75	127.93	127.39	127.59	3.23	15.46	143.1	142.1	141.8	142.1	142.28	14.69	192.5	64.9	1638	137	8644	43	951		882	12295	28.0	28.13	7657	4638	3878	2392	"	
18	124.60	124.99	124.03	124.37	124.48	3.11	18.57	143.3	141.5	141.9	196.9	143.40	18.92	192.4	67.9	1638	199	9325	49	1100		1018	13339	29.0	29.73	8011	5328	4985	2133	"	
19	120.98	121.08	121.10	121.20	121.09	3.39	21.96	143.5	142.9	143.7	145.7	143.95	22.86	192.2	71.1	1638	199	9544	51	1247	308	1192	14129	31.0	30.82	8388	5740	6035	1962	Sand & Gravel	
20	117.93	117.97	118.15	118.19	118.06	3.03	24.99	143.5	142.1	146.3	145.2	144.28	26.22	191.9	73.8	1638	199	9755	53	1396	308	1290	14589	32.5	31.99	8708	5881	6922	1700	"	"
21	115.27	115.32	114.83	114.88	115.07	2.99	27.98	143.4	142.3	146.3	145.2	144.30	24.23	191.7	76.6	1638	199	9970	55	1538	308	1390	15146	34.5	33.30	9037	6109	7717	1583	"	"
22	113.78	113.87	114.12	114.21	113.99	1.08	29.06	143.4	142.3	146.3	145.2	144.30	30.31	192.2	78.2	1638	199	10176	57	1650	308	1592	15500	35.0	33.90	9227	6373	8002	1593	Gravel & Stone	
23	113.32	113.37	112.77	112.82	113.07	.92	29.98	143.4	142.3	146.3	145.2	144.30	31.23	193.4	80.3	1638	199	10373	57	1680	308	1796	15309	38.5	34.81	9475	6329	8245	1535	"	"
24	111.88	111.88	111.92	111.92	111.65	1.42	31.40	143.4	142.3	146.3	145.2	144.30	32.65	194.6	83.0	1638	199	10573	59	1825	308	1887	16293	36.5	35.98	9799	6949	8620	1796	"	"
25	110.69	110.69	110.76	110.76	110.72	.93	32.33	143.4	142.3	146.3	145.2	144.30	33.58	195.3	84.6	1638	199	10766	63	1970	308	1991	16692	36.5	36.67	9982	6710	8865	1513	Sand & Clay	
26	110.10	110.05	109.37	109.32	109.71	1.01	33.34	143.4	142.3	146.3	145.2	144.30	34.59	195.3	85.6	1638	152	10952	65	2112	308	2096	17137	38.0	37.11	10101	7036	9132	1541	"	"
27	107.63	107.58	107.45	108.40	107.51	2.20	35.54	143.4	142.3	146.3	145.2	144.30	36.79	194.8	87.3	1638	152	10952	67	2256	308	2096	17969	38.0	38.84	10300	7168	9712	1476	"	"
28	107.63	107.58	107.45	107.90	107.51	.00	35.54	143.4	142.3	146.3	145.2	144.30	36.79	194.2	86.7	1638	152	10952	67	2256	308	2096	17968	38.0	38.58	10229	7290	9712	1991	"	"
29	105.38	105.33	105.46	105.91	105.39	2.12	37.66	143.1	141.6	146.4	145.0	144.78	39.39	193.5	88.1	1638	152	10952	67	2256	966	2157	17758	38.0	38.59	10295	7293	10399	1402	"	"
30	103.93	104.02	104.01	104.10	104.01	1.38	39.04	143.1	141.6	146.4	145.6	144.78	40.77	192.9	88.9	1638	152	10952	67	2256	966	2257	17758	40.0	38.59	10491	7267	10763	1350	Sand	
Oct. 1	100.89	100.98	100.74	100.83	100.86	3.15	42.19	142.6	143.1	144.5	144.5	144.68	42.82	192.5	91.6	1638	152	10952	67	2256	966	2405	17936	40.5	39.71	10809	7127	11304	1261	"	
2	99.28	99.33	99.41	99.46	99.37	1.49	43.60	142.6	143.1	144.5	144.5	144.68	44.31	192.1	92.7	1638	152	10952	67	2256	966	2512	18043	39.0	40.18	10937	7106	11698	1215	Tough Clay	
3	99.29	99.28	99.32	99.36	99.31	.06	43.54	142.0	143.2	146.4	147.8	144.85	45.54	191.7	92.9	1638	152	11137	69	2397	966	2512	18371	41.5	40.06	10904	7467	12022	1242	"	"
4	99.29	99.28	99.32	99.36	99.31	.00	43.54	142.0	143.2	146.4	147.8	144.85	45.54	191.3	92.0	1638	152	11137	71	2538	966	2512	18699	41.5	39.88	10855	7839	12022	1380	"	"
5	98.57	98.61	98.83	98.87	98.72	.54	44.33	142.0	143.2	146.4	147.8	144.85	46.31	191.0	92.3	1638	152	11137	71	2538	966	2512	18699	42.0	40.02	10893	7801	12178	1281	"	"
6	98.57	98.61	98.83	98.87	98.72	.00	44.33	143.8	144.8	146.0	148.5	144.78	47.06	190.5	91.8	1638	152	11137	71	2538	674	2331	18721	42.0	39.75	10820	7901	12423	1272	"	"
7	97.07	97.11	97.33	97.37	97.22	1.50	45.83	143.3	144.6	144.4	149.5	144.95	50.73	190.0	92.8	1638	152	11137	71	2538	679	2402	18792	42.0	40.18	10937	7855	13373	1180	"	"
8	96.23	96.35	96.61	96.73	96.48	.79	46.57	143.3	144.6	144.4	149.5	144.95	51.97	189.4	92.9	1638	152	11137	71	2538	679	2409	18799	42.0	40.22	10948	7851	13538	1155	"	"
9	96.33	96.35	96.61	96.73	96.48	.00	46.57	143.3	144.3	144.4	149.5	144.95	51.97	189.0	92.5	1638	152	11137	71	2538	679	2388	18778	42.0	40.05	10902	7876	13588	1159	"	"
10	96.12	96.24	96.50	96.62	96.37	.11	46.68	143.3	144.6	144.4	149.5	144.95	51.58	188.6	92.2	1638	152	11137	71	2538	679	2353	18743	42.0	39.92	10866	7875	13617	1157	"	"
11	96.12	96.24	96.50	96.62	96.37	.00	46.68	145.6	150.7	146.0	147.2	147.62	51.25	188.5	92.1	1638	154	11137	71	2538	679	2350	18740	42.0	39.88	10855	7885	13539	1165	"	"
12	95.19	95.23	95.44	95.53	95.33	1.09	47.72	145.6	150.7	148.1	145.6	147.50	52.17	188.4	93.1	1638	152	11137	71	2538	679	2416	18806	42.0	40.31	10972	7834	13713	1145	"	"
13	94.16	94.24	94.42	94.50	94.33	1.00	48.72	145.6	150.7	148.1	145.6	147.50	52.17	189.1	94.8	1638	152	11137	71	2538	679	2529	18919	43.0	41.05	11174	7740	14037	1103	"	"
14	94.16	94.24	94.42	94.50	94.33	.00	48.72	145.6	150.7	148.1	145.6	147.50	52.17	190.2	95.9	1638	152	11137	71	2538	679	2850	19240	43.5	41.52	11302	7938	14037	1131	"	"
15	93.26	93.36	93.53	93.63	93.49	.89	49.61	143.2	144.0	145.2	151.9	145.95	52.51	191.6	98.2	1638	152	11137	71	2538	679	2496	19386	44.0	42.56	11574	7812	13862	1127	"	"
16	92.08	92.08	92.10	92.10	92.09	1.35	50.96	144.4	147.2	143.9	149.2	146.18	54.09	193.1	101.0	1638	152	11137	73	2679	679	3069	19602	45.0	43.73	11903	7699	14256	1080	"	"
17	92.08	92.08	92.10	92.10	92.09	.00	50.96	144.4	147.2	143.9	149.2	146.18	54.09	195.3	103.2	1638	152	11137	75	2817	679	3158	19831	45.5	44.69	12165	7666	14256	1075	"	"
18	92.08	92.08	92.10	92.10	92.09	.00	50.96	144.4	147.2	143.9	149.2	146.18	54.09	195.5	103.4	1638	152	11137	75	2817	679	3173	19846	47.0	44.77	12186	7660	14256	1075	"	"
19	91.94	91.92	91.92	91.90	91.92	.17	51.13	144.4	147.2	143.9	149.2	146.18	52.46	195.7	103.8	1638	152	11137	75	2817	679	3202	19375	47.0	44.96	12256	7640	14256	1072	"	"
20	91.50	91.50	91.50	91.41	91.47	.44	51.57	142.5	147.1	148.4	152.7	147.22	55.74	195.8	104.3	1638	152	11137	75	2817	679	3240	19913	47.0	45.16	12293	7620	14256	1068	"	"
21	91.03	91.03	91.03	91.04	91.04	.49	52.01	142.5	147.1	148.6	152.7	147.22	56.18	196.1	105.1	1638	152	11137	75	2817	679	3300	19973	47.0	45.61	12388	7585	14256	1064	"	"
22	90.29	90.32	90.32	90.42	90.35	.69	52.70	142.5	147.1	148.6	152.7	147.22	56.67	196.3	106.0	1638	152	11137	77	2951	679	3367	20176	47.0	45.90	12494	7682	14256	1077	Cleaning	
23	90.20	90.23	90.25	90.29	90.24	.11	52.81	142.5	147.1	148.6	152.7	147.22	56.98	196.8	106.6	1638	152	11137	77	2951	679	3412	20221	48.0	46.16	12560	7656	14256	1074	Sealing	
24	90.20	90.23	90.25	90.29	90.24	.00	52.81	142.5	147.1	148.6	152.7	147.22	56.98	197.1	106.9	1638	152	11137	77	2951	679	3439	20243	48.0	46.29	12600	7643	14256	1072	Sealed 2 P.M.	

Plate XIII

the sinking sheet, designated " average weight exposed to friction, pounds per square foot". This figure is a very important index of the condition of the caisson, for by it could be determined the care necessary in handling the caisson. The skin friction could be depended upon to carry fron 500 to 1000 pounds per square foot; hence when the average weight exposed to friction was in the neighborhood of 1000 pounds, the caisson would settle slowly, and little pressure was carried by the cutting edge. Indeed, the friction was at times so great that the pressure had to be reduced considerably before the caisson would sink at all. When the weight exposed to friction became high, however, it meant that more of the weight must be carried on the cutting edge or cross timbers, and more care had to be taken in digging under them. Thus at times during the sinking when the weight exposed to friction was high, the caiswould cut through even heavy blocking placed under the timbers.

Naturally the keeping of the sinking sheet involves considerable time and effort, but if entries are made promptly each day it is much less trouble than would be thought, and the record is in so complete and convenient a form as to make it very worth while. On all five caissons the sheets were frequently consulted to find the condition of the caissons, and in their final form they constitute a valuable record.

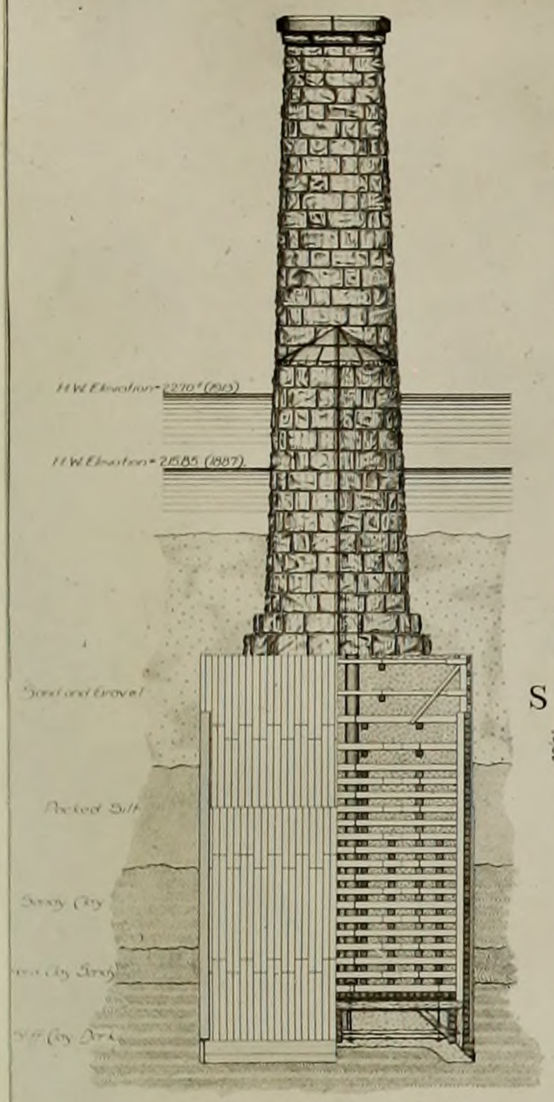
5. Record drawings- During the entire period of substructure construction, accurate records were kept of all deviations of the actual construction from the plans,both as regards changes in details, and as to actual dimensions which differed from the plan, in order to have sufficient data for the record drawings. These record drawings were prepared primarily for use in the engineers report,typical sheets of which are shown on plates XIV,XV, and XVI.

A.&M.R.B.&T.Co.

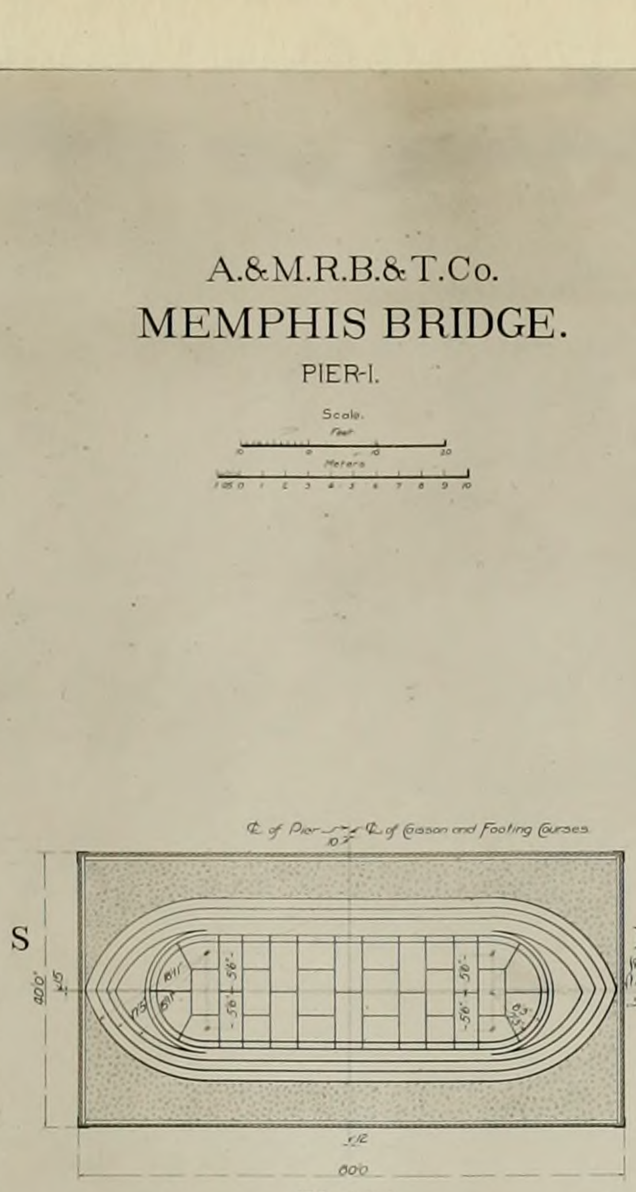
MEMPHIS BRIDGE.

PIER-I.

Scale.
Feet
0 0 10 20
Meters
1 0 1 2 3 4 5 6 7 8 9 10

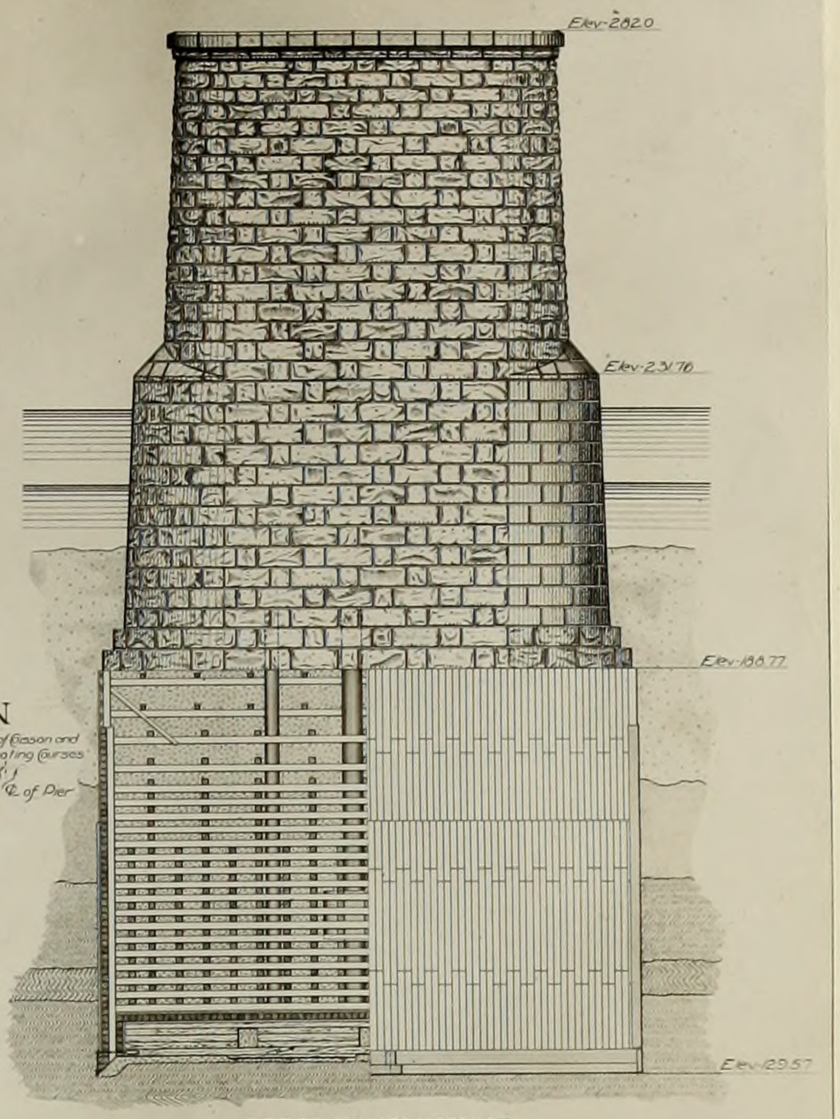


END ELEVATION



PLAN

Consulting Engineer in charge



SIDE ELEVATION

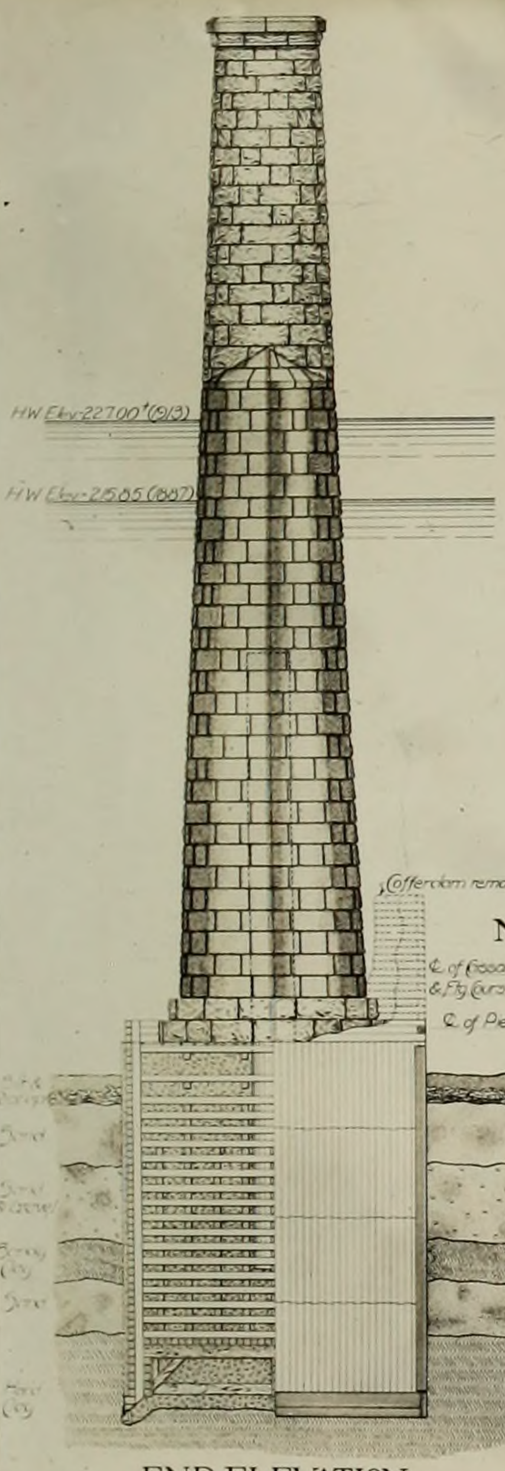
L.H. Bergstrom Del.

A.&M.R.B.&T.Co.

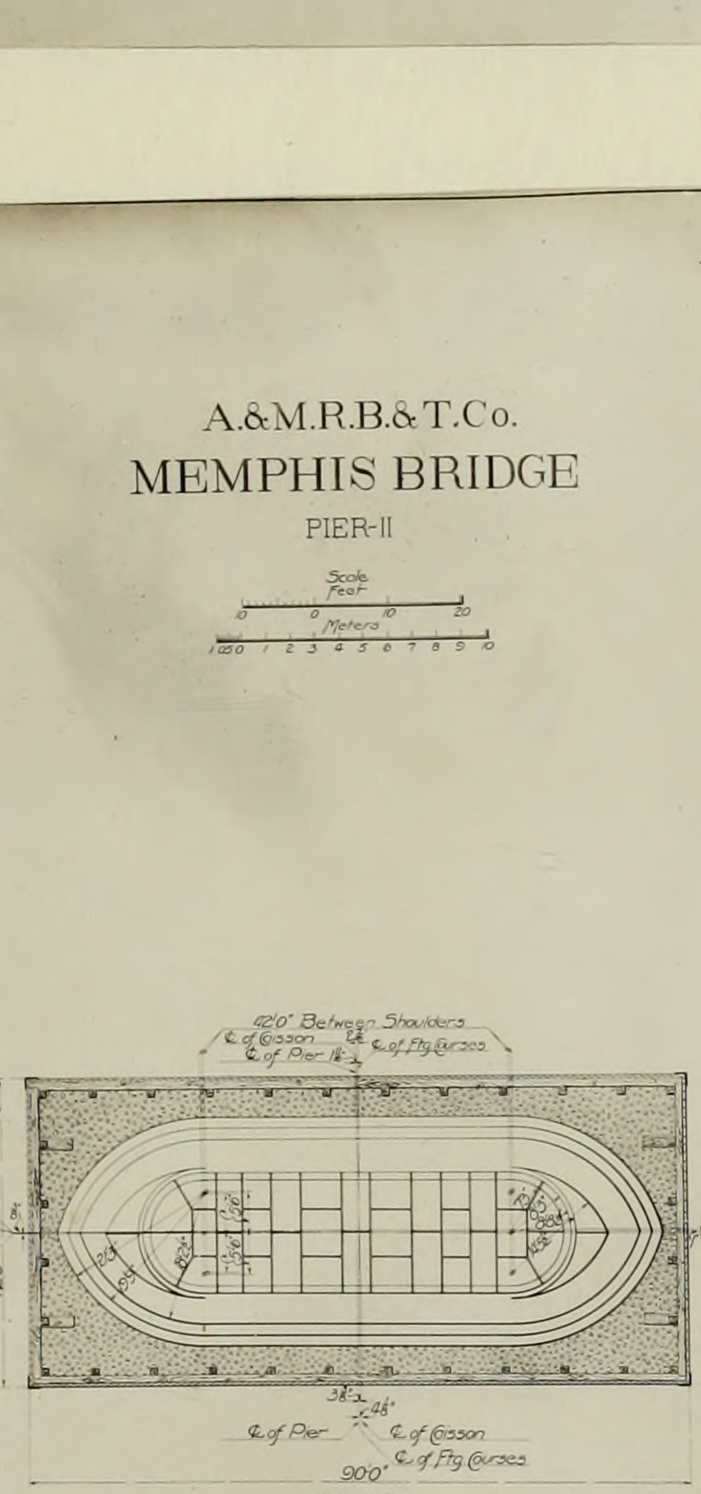
MEMPHIS BRIDGE

PIER-II

Scale
Feet
10 0 10 20
Meters
1 0 1 2 3 4 5 6 7 8 9 10

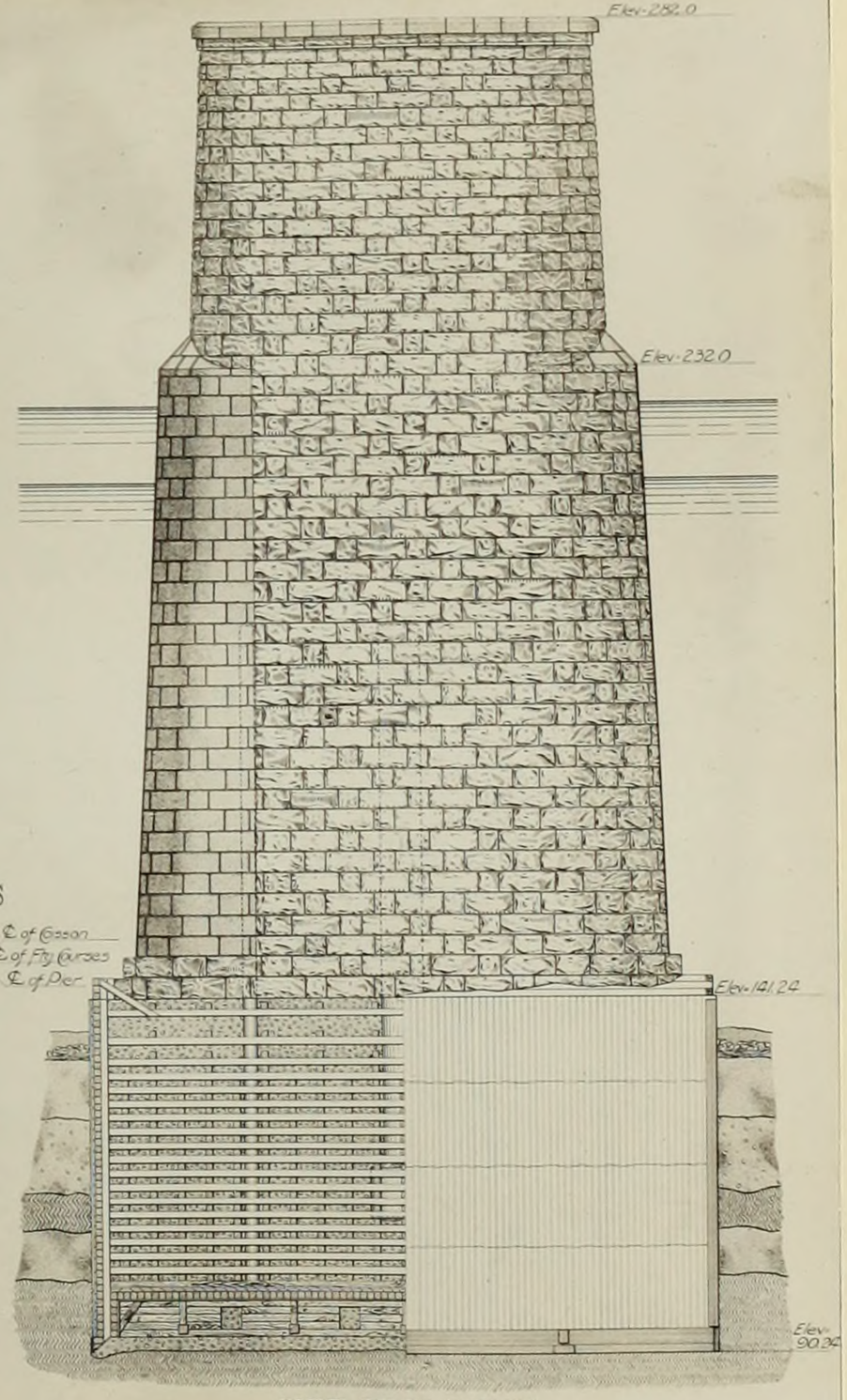


END ELEVATION



PLAN

Consulting Engineer in charge



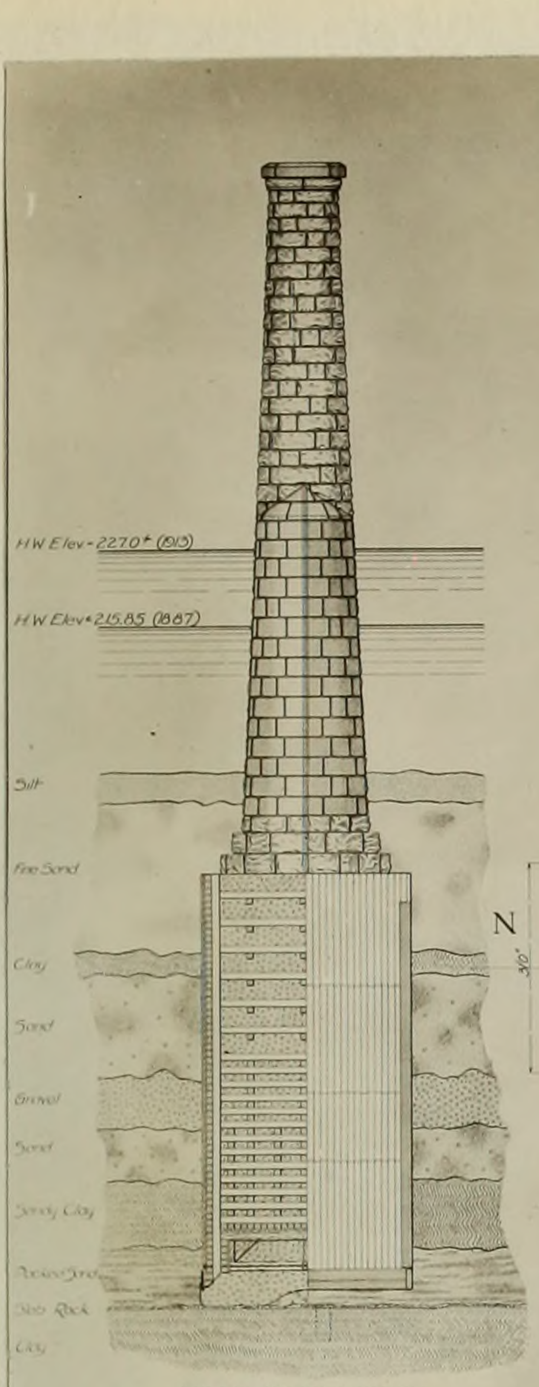
SIDE ELEVATION

L.H. Bergstrom Del.

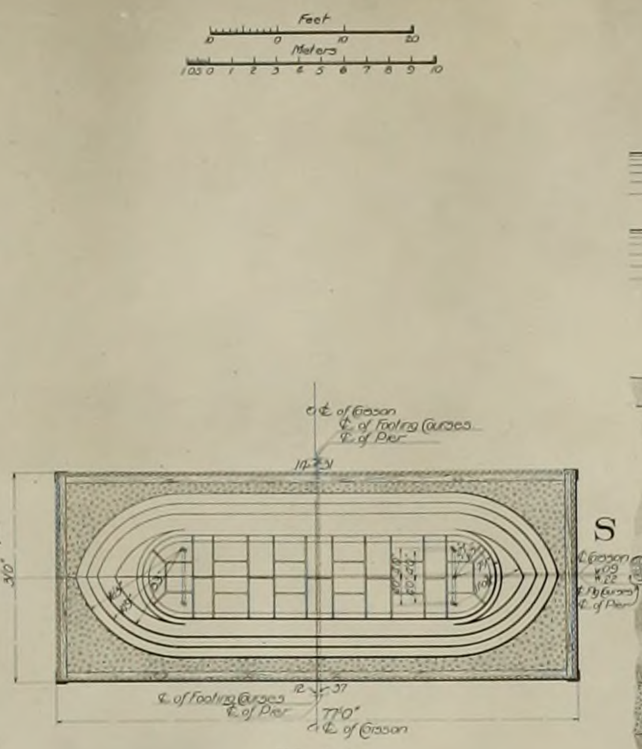
A.&M.R.B.&T.Co.

MEMPHIS BRIDGE

PIER-IV

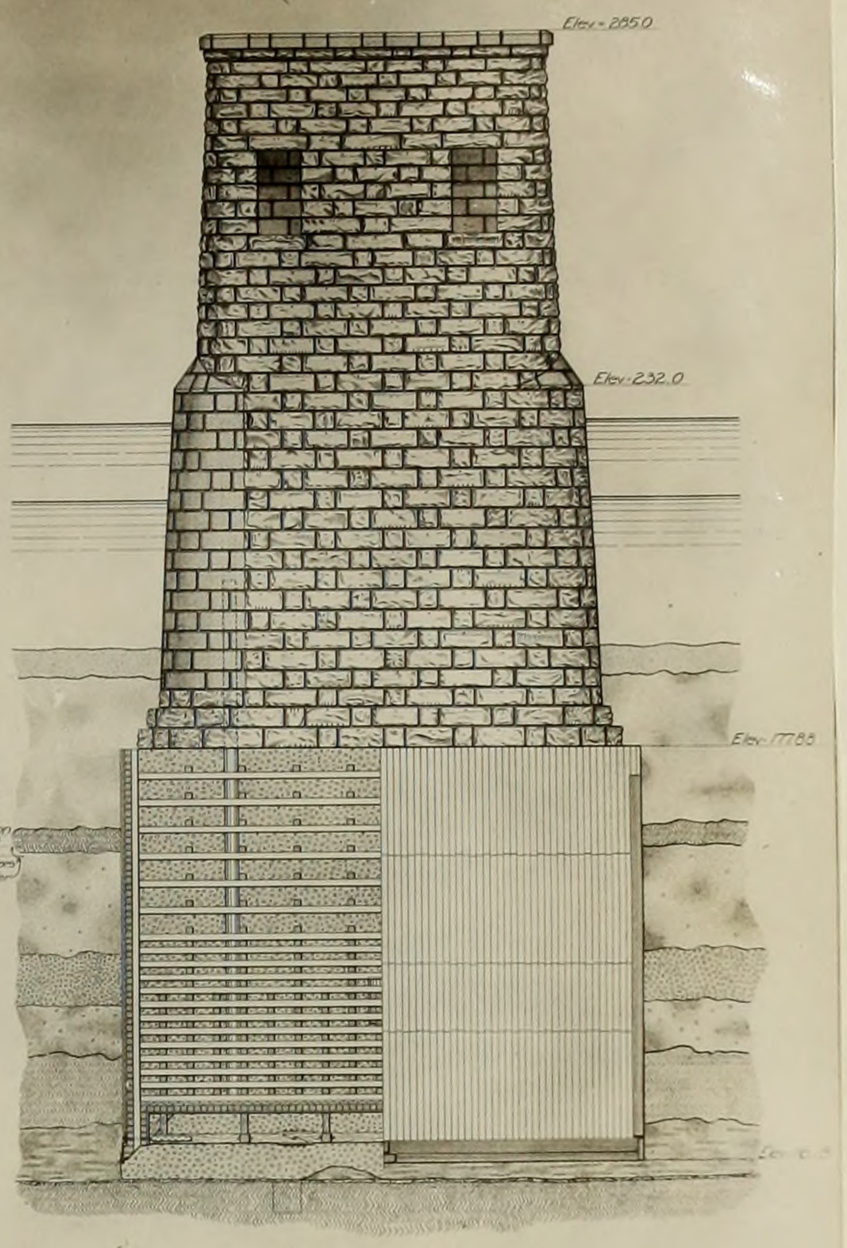


END ELEVATION



PLAN

Consulting Engineer in charge

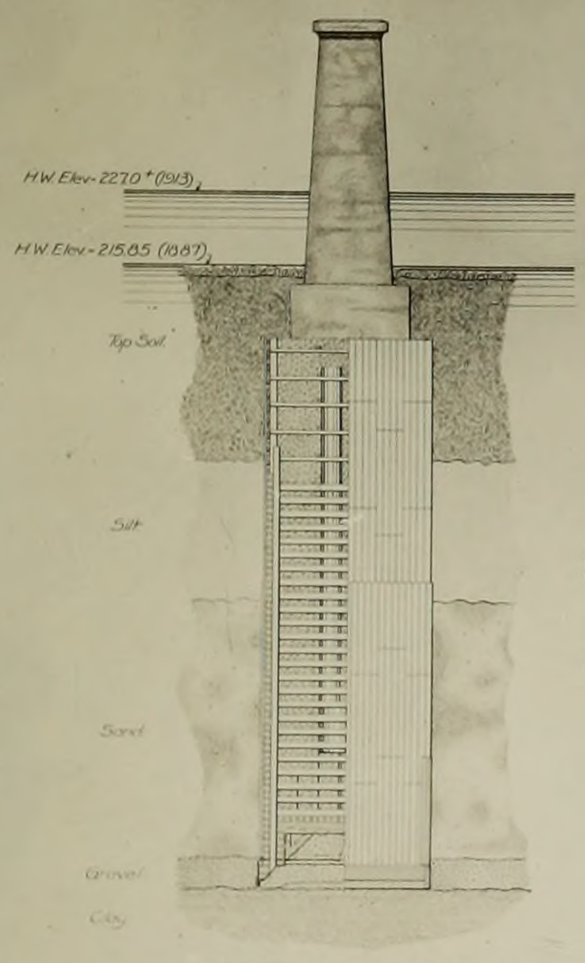


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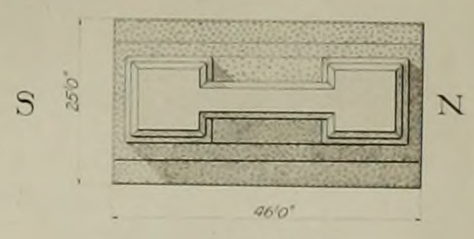
A.&M.R.B.&T.Co.

MEMPHIS BRIDGE

PIER-V

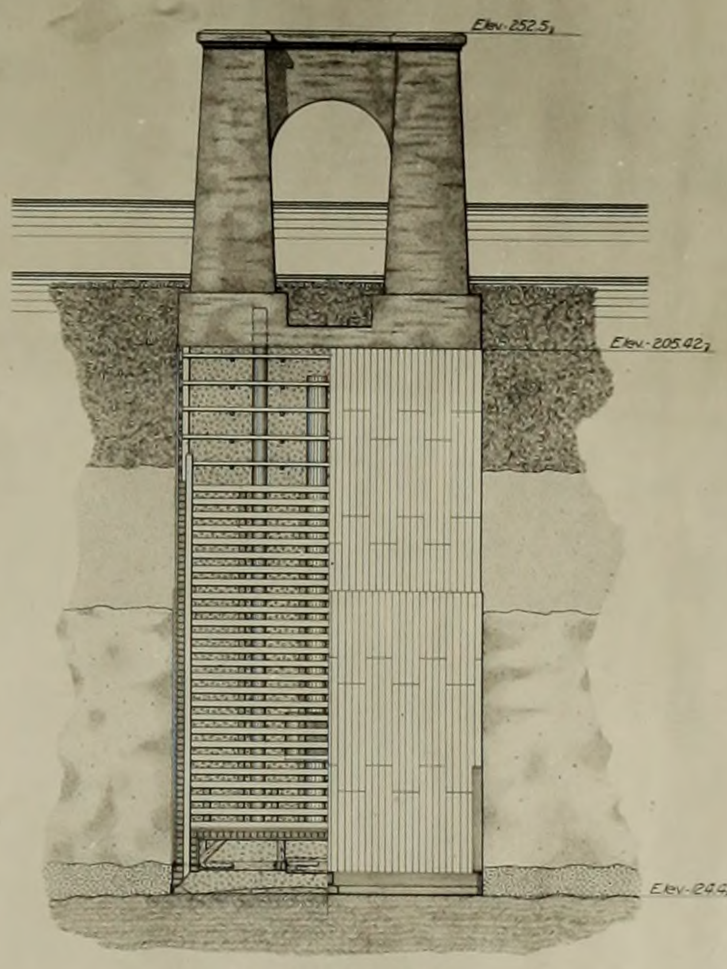


END ELEVATION



PLAN

Consulting Engineer in charge



SIDE ELEVATION

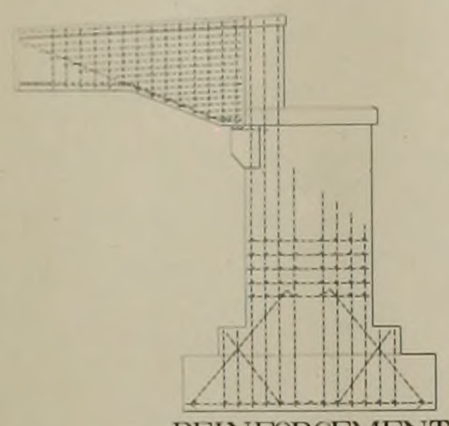
L.H. Bergsma - Del.

A.&M.R.B.&T Co.

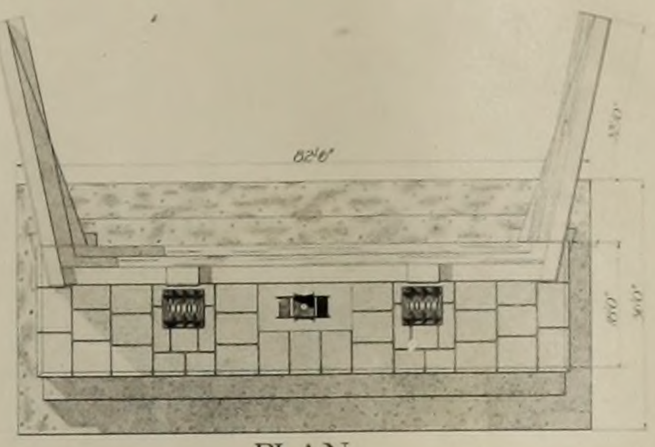
MEMPHIS BRIDGE

PIER-A

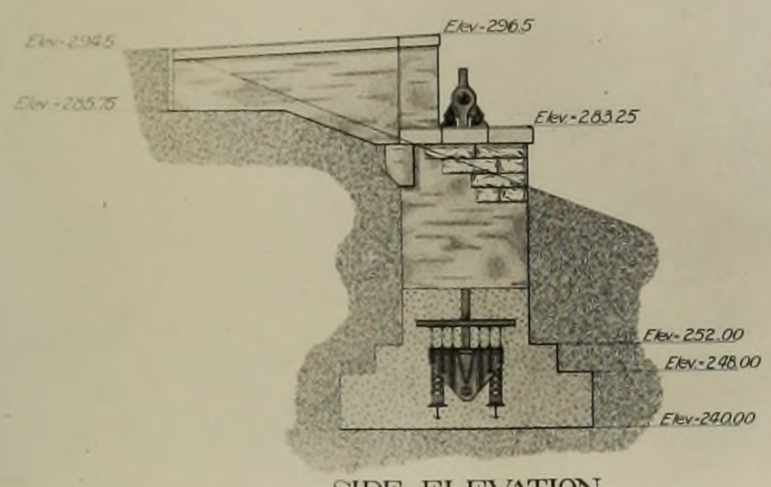
Scale
Feet
Meters



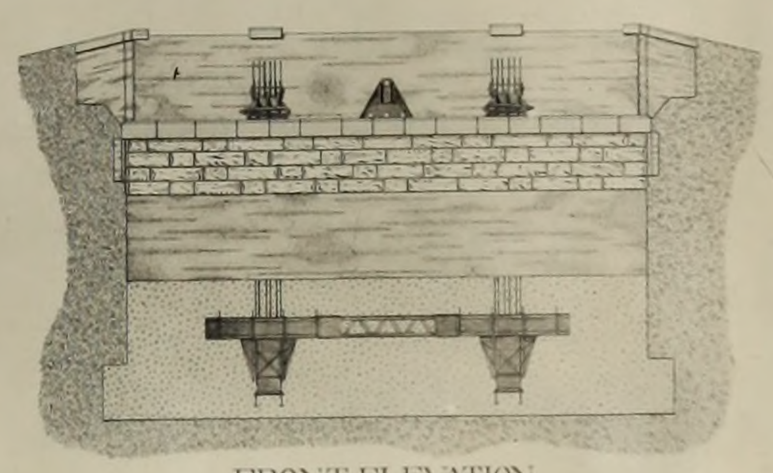
REINFORCEMENT



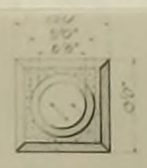
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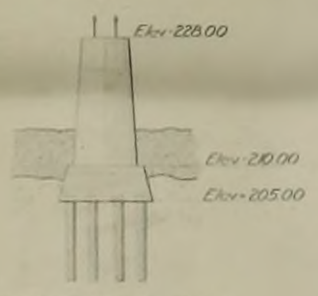


SIDE ELEVATION



FRONT ELEVATION





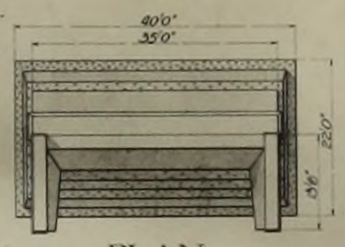
VIADUCT PEDESTAL

A.&M.R.B & T.Co.

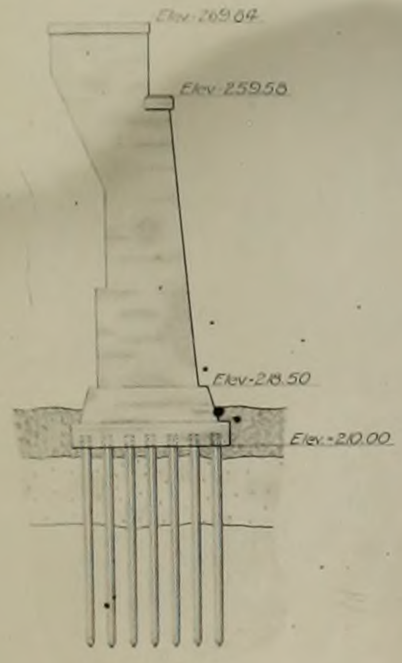
MEMPHIS BRIDGE

WEST ABUTMENT
AND
VIADUCT PEDESTALS

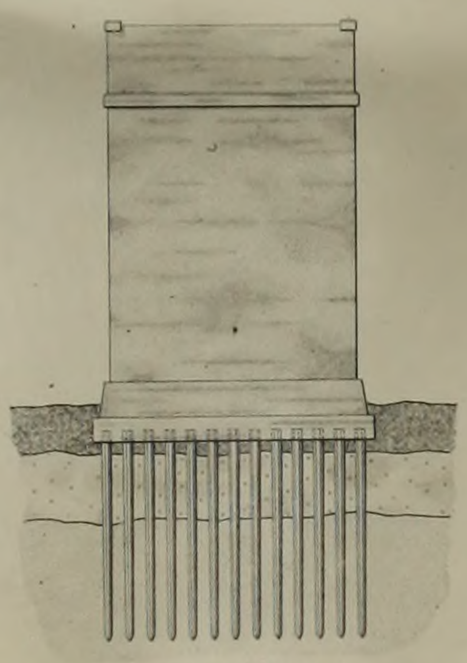
Scale
Feet
Meters



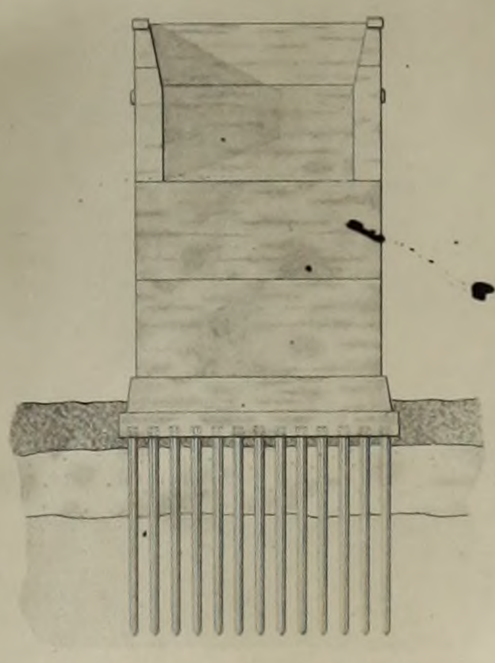
PLAN



SIDE ELEVATION



FRONT ELEVATION



REAR ELEVATION

For this work a draftsman was engaged during practically the entire construction period, drawing up plates of the piers and other parts of the comstruction from data given him by the engineers as the work progressed. In this way there was no chance for error in making the record drawing, and indeed so much care was taken to insure correct details, that the dimensions of each piece of granite was plotted in position to saale. The drawings of the piers also showed the exact framing of the caissons, and also indicated the character of the strata through which the caissons had been sunk. One of these plates was drawn for each pier, and also for the two abutments, plate XVI, the upper drawing showing the anchor pier, with the means for anchoring the arm of the cantilever, and the lower drawing showing the abutment against which the fill was later made on the Arkansas side. It can be seen that this form of record was comparatively expensive of time, but the results obtained repaid the effort, in the very effective presentation made possible in the engineers report .

6. Cost analysis and accounting- The substructure being a percentage contract, the keeping of costs was one of the important functions of the engineer; for in order to make up monthly estimates for payment it was necessary to check and approve all bills and payrolls. Each receipted bill was made out in duplicate, and after being checked by the resident enginner as to quantity and receipt of material, as well as to price of material, it was stampted with his approval and turned over to the auditor, to be included in the monthly voucher. Payrolls were likewise checked and approved by the resident engineer, before being passed for payment.

In addition to checking for payments, it was necessary to distribute each item of cost in accordance with the classification

of the interstate commerce commission. This entailed a division of all accounts between the piers and approaches, as well as a division between amounts expended on the Arkansas and Tennessee side of the river. The latter division was of little use, though fairly simple, but the division of costs between the various piers made possible an interesting analysis of costs, although it required a considerable amount of accounting. Since payroll sheets for each pier were kept separate, the division of labor costs was easy, and it was also fairly easy to keep account of the costs of material entering into different parts of the work. For some of the material , such as granite, the cost could be divided in proportion to the quantities used in each part with little difficulty. But the division of overhead charges was necessarily more difficult to make correctly, and required the exercise of considerable judgement; while the division of the costs of the mat work and channel and bank protection was most arbitrary.

After the completion of the work, when all the costs were known, statements were made up of unit costs on the work, based on actual quantities entering into the construction, and the costs as subdivided for the final accounting. The following pages show these unit and total costs on each pier and on the west approach, as worked out on this basis. The unit prices shown are the actual costs of the work without overhead or profit, the latter figure being added to the total cost of the pier, based on the distribution made by the auditor in consultation with the engineer. The cost of the mat work is also given without overhead charges, the total mat costs being divided between the two piers and the superstructure, as indicated. The summary of costs given on page 88 is in accordance with the auditors figures on January 1. 1917.

Cost of Anchorage Pier.

Excavation	5727 cu.yds @ 1.009		$ 5777.00	
Backfill			1058.30	
Cofferdam			7369.51	
Construction plant, derricks, etc			2114.09	
CONCRETE				
Material	2684 cu.yd. @	2.815	7556.08	
Labor	" " "	0.827	2218.75	
General	" " "	1.309	2513.36	13288.19
Concrete forms	10215 SQ.FT @	0.145		1483.73
Reinforcement	72420 # @	1.830		1325.13
GRANITE				
Plain	94.70 cu.yd. @	21.60	2045.55	
Dressed	89.62 " @	31.00	2778.22	
Mortar	12 " @	5.37	64.45	
Setting	184.32 " @	3.396	625.90	
General	" " @	2.878	530.47	6044.59
Derricks for masonry				741.90
Concreting eyebars			401.00	
Grading and riprapping bank			5260.00	
				$ 44863.44
Overhead and profit (4% of total overhead)				13241.25
			TOTAL	58104.69

Cost of Pier I.

CAISSON				
Timber	705678 B.M. @	25.007	17647.58	
Framing	"	15.415	10877.80	
Mscl material			9651.34	
Plant and equipment			2309.53	$ 40486.25
EXCAVATION				
Clearing site			520.50	
Dry excav.	2492.44 yd @	1.199	2989.65	
Sinking	6530.37 " "	3.319	21677.49	25187.64
CONCRETE -Working chamber				
Material	598 cu yd @	2.526	1510.85	
Labor	" "	2.479	1482.60	
General	" "	1.309	782.78	3776.23
CONCRETE- Avove deck				
Material	4361 cu yd @	2.732	11912.73	
Labor	" "	0.296	1289.35	
General		1.309	5708.55	18910.63
Reinforcement	15333.3 # @	1.64		251.47
GRANITE				
Plain	1712.60 cu yd @	21.60	36899.27	
Dressed	73.65 "	31.00	2283.15	
Setting	1786.25 "	4.432	7917.78	
Bushhammering coping			979.70	48079.90
Steel in shaft	10484 # @	2.85		298.84
Mortar and mscl	174 cu yd @	4.70		830.94
CONCRETE- In shaft				
Material	1991 cu yd @	2.489	4976.07	
Labor	"	0.416	830.05	
General	"	1.309	2606.22	8412.34
				$146234.24
Overhead and profit (7% of total overhead)				28799.84
			TOTAL	175034.08

Cost of Pier II.

CAISSON			
Timber 931068 B.M. @ 25.6	$ 23866.62		
Framing " 21.97	20455.40		
Mscl material	15978.37		
Plant and equipment	14117.86	$ 74418.25	
EXCAVATION			
Leveling site 29000 snd bgs @.117	3389.40		
Sinking 7247 CUYD @ 6.023	43644.20	47033.60	
Removing cofferdam		419.25	
CONCRETE- Working chamber			
Material 705 cu yd @ 3.038	2141.90		
Labor " " 4.208	2966.60		
General " " 1.309	922.85	6031.35	
CONCRETE- Avove deck			
Material 3850 cu yd @ 2.425	14185.90		
Labor " " 0.420	1616.60		
General " " 1.309	5039.65	20842.15	
Reinforcement 17660 # @ 1.64		315.63	
GRANITE			
Plain 2737.17 cu yd @ 21.61	58955.13		
Dressed 73.65 " " 31.00	2283.15		
Setting 2810.82 " " 4.299	11883,49		
Bushhammering coping	994.14	74115.91	
Steel in shaft 96400 # @ 1.846	1779.11		
Mscl material, mortar, etc	1440.00	3219.11	
CONCRETE- In shaft			
Material 3620 cu yd @ 2.036	7370.62		
Labor " " " 0.465	1682.75		
General " " " 1.309	4738.58	13791.95	
		$ 240187.20	
Proportion of cost of mat protection		14100.00	
Overhead and profit (27% fo total overhead)		91229.47	
	TOTAL	345516.67	

Cost of Pier III.

CAISSON			
Timber 821206 B.M. @ 25.691	$ 21098.30		
Framing " 20.44	16785.46		
Mscl material	15528.73		
Plant and equipment	11284.44	64696.43	
Dredging site	32.27		
Sinking 10432 cu yd @ 40.057	41790.82	41823.09	
CONCRETE-Working chamber			
Material 737 cu yd @ 2.991	2263.97		
Labor " " 3.265	2472.05		
General " " 1.309	990.91	5726.93	
CONCRETE -Avove deck			
Material 3836 cu yd @ 2.696	9998.65		
Labor " " 0.559	2142.40		
General " " 1.309	5021.32	17162.37	
Reinforcement 19051 # @ .0225		449.25	
GRANITE			
Plain 2840.79 cu yd @ 21.60	61230.16		
Dressed 73.65 " 31.00	2283.15		
Setting 2914.44 " 4.795	13386.01		
Bushhammering coping	933.05		
Mscl material	41.92	78374.29	
Mortar 261 cu yd @ 5.356		1398.08	
Steel in shaft 96400 # @ 1.846		1878.45	
CONCRETE -In shaft			
Material 3755 cu yd @ 2.687	10091.73		
Labor " .471	1568.00		
General " " 1.309	4915.30	16575.03	
			$228084.42
Overhead and profit (34% of total overhead)			99521.76
Proportion of cost of mat protection			37015.43
		TOTAL	364621.61

Cost of Pier IV.

CAISSON				
Timber	561127 B.M. @	25.059	$14062.50	
Framing	"	16.36	9184.60	
Mscl material			1267.67	
Plant and equipment			8849.62	33364.39
EXCAVATION				
Clearing site			561.34	
Dry excavation	348.3 cu yd @	1.715	597.40	
Sinking	6421.03 "	2.845	18271.14	19429.88
CONCRETE-Working chamber				
Material	819 cu yd @	2.677	2191.94	
Labor	" "	2.451	2007.65	
General	" "	1.309	1052.07	5251.66
CONCRETE- Avove deck				
Material	3373.0 cu yd @	2.604	8804.58	
Labor	" "	.279	942.15	
General	" "	1.309	4415.26	14241.99
GRANITE				
Plain	1720.29 cu yd @	21.60	37112.94	
Dressed	50.35 "	31.00	1560.85	
Setting	1770.64 "	4.694	8310.50	46984.29
Bushhammering coping				275.90
Mortar	205 cu yd @	4.655		954.31
Steel in shaft	39000# @	.0206		805.30
Mscl material				38.67
CONCRETE-In shaft				
Material	1425 cu yd @	2.501	3563.67	
Labor	" "	0.525	749.50	
General	" "	1.309	1865.33	6178.50
				$127519.89
Overhead and profit (11% of total overhead)				43554.33
		595@#		171074.22

Cost of Pier V.

CAISSON				
Timber	323169 B.M. @	24.899	8296.40	
Framing	"	20.441	6605.90	
Mscl material			5861.68	
Plant and equipment			324.45	21088.43
EXCAVATION				
Dry excavation	637.78 cu yd @	1.401	893.75	
Sinking	2995.11 "	2.565	7683.55	8577.30
CONCRETE- Working Chamber				
Material	196 cu yd @	2.969	554.55	
Labor	" "	2.830	358.75	
General	" "	1.830	256.55	1169.86
CONCRETE- Above deck				
Material	2275 cu yd @	2.482	5647.96	
Labor	" "	.548	1247.20	
General	" "	1.309	2977.98	9873.14
Wood forms	3951 sq ft @	0.398		1571.75
CONCRETE- In shaft				
Material	706 cu yd @	2.532	1787.36	
Labor	" "	.579	408.80	
General	" "	1.309	924.15	3120.51
Reinforcement	12818# @	.0199		376.15
General plant expence				137.50
				$45914.64
Overhead and profit (7% of total overhead)				29129.07
			TOTAL	75043.71

Cost of West Approach Substructure.

CONCRETE PILES

Wood forms	50 @	24.819		$1240.95	
Reinforcement cages	1315 @	4.992		6515.50	
Concrete 1.245 cu yd per pile					
Material	1315 piles @	3.793		4988.63	
Labor	" "	4.485		5897.85	
General	" "	1.595		2097.83	
Driving	1307 "	4.14		5508.00	
Pile driver				1777.24	28026.00

CONCRETE PEDESTALS

Steel forms	4 @	324.02	1296.08	
Wood forms	8	11.25	90.00	
Concrete plant			1213.08	
Concrete material	4695 yd @	4.051	19021.37	
" labor	"	1.551	7283.40	
Reinforcement	119455 # @	.02596	3100.74	
Excavation			5486.10	
Backfill and grading			1604.60	
Tests on piles			493.75	39589.12

WEST ABUTMENT

Forms	6063 sq ft @	0.143	866.28	
Reinforcement	5769 # @	.02107	121.52	
Concrete plant			590.40	
Concrete material	1010 yd @	4.151	4192.44	
" labor	"	.762	769.70	6540.34

$ 74153.46

Overhead and profit (10% of total overhead) 40686.01

TOTAL 114841.47

Cost of Mat Work.

MAT FOR PIER II.

Willow material	61200	sq ft	@.0555	3395.30	
" labor	"	" "	.0271	1659.40	
" general	"	"	.0393	2405.16	
Wire staples etc	"	"	.0233	1428.00	
Rip rap material	1048.7	tons	1.884	1975.75	
" " labor	"	"	.745	779.45	$11643.06

CHANNEL MATS

Willow material	119600	sq ft	@ .0555	6635.40	
" labor	"	"	.0300	3592.40	
" general	"	"	.0393	4700.28	
Wire staples etc	"	"	.0233	2790.67	
Rip rap material	1668.1	tons	1.884	3180.38	
" " labor	"	"	.653	1102.15	22001.28

BANK PROTECTION

Willow material	117000	sq ft	@ .0555	6899.62	
" labor	"	"	.0271	3696.90	
" general	"	"	.0393	4598.10	
Wire staples etc	"	"	.0233	2730.00	
Rip rap material	4116.75	tons	1.884	7754.00	
Labor sinking	52000	sq ft		1084.90	
" paving	65000	"	.018	1175.45	
Grading				2010.66	29939.71

$63584.05

Distribution of costs made by auditor

To Pier II	$ 14100.00	
To Pier III	37015.43	
To superstructure	12468.62	63584.05

Overhead Costs.

General overhead, material and freight	$ 135716.92	
General overhead, labor	70444.80	
Miscellaneous unclassified labor	22236.50	
Insurance other than liability	3943.57	
Liability insurance	20768.68	
10 % paid contractor	121746.86	
Deferred freight payments	7582.36	$ 382439.69
Credit for sale of plant		36277.94
NET OVERHEAD		346161.73

SUMMARY OF COST OF SUBSTRUCTURE

	Itemized Cost	Overhead Cost	TOTAL
Pier A	$ 44863.44	$ 13241.25	$ 58104.69
Pier I	146234.24	28799.84	175034.08
Pier II	254287.20	91229.47	345516.67
Pier III	265099.85	99521.76	364621.61
Pier IV	127519.89	43554.33	171074.22
Pier V	45914.64	29129.07	75043.71
Viaduct	74155.46	40686.01	114841.17
TOTAL	958074.72	346161.73	1304236.45

PART TWO- SUPERSTRUCTURE

VI. Inspection in Mill and Shop.

1. Tests of material- While practically all of the inspection of substructure work is performed in the field, a large part of the inspection of the superstructure of a bridge is necessary in the mill and the shop, a large percentage of the work being complete when the material is delivered on the site. Thus long before the substructure was complete, work had already started on the steel work,requiring the presense of inspectors to assure excellence of material and workmanship. The first work to be inspected is of course the work of getting out the material in the mill, and the most important part of mill inspection is the testing of material.

Since all material had to undergo specified tests, there was little to watch during the rolling of the members, except to oversee the taking of test pieces from specimen material; a surface inspection of all material rolled being easily possible at any time, as well as a check on the dimensions of the sections. The shipping weight is also a most sure check on the size of material turned out. Test requirements and regulations for mill inspection were set forth in all detail in the specifications, to assure proper facilities for inspection, making the contractor responsible for all the details for adequate testing and analysis.

The specifications covered also very explicitly the requirements for the various materials, carbon steel, alloy steel, cast steel and cast iron. This included the chemical composition of the material, the ultimate strength and elastic limit, the minimum elongation and reduction in area, process of manufacture,

appearance and uniformity, heat treatment, stamping of material, and tests; also shipping rules. Of these the two requirements calling for the most attention from the inspector were the chemical analysis and the physical tests.

As provided in the specifications, drillings for analysis were taken from an ingot in each heat, the analysis itself being made by the manufacturer's chemist at the mill, subject to check by the inspector. This analysis determines the percentage of carbon, manganese, sulphur and phosphorous in the steel, in the case of carbon steel, and in addition the amount of silican present in the case of the alloy steel. In addition, the alloy steel was required to contain not less than 1.2 percent of nickle, more than this amount being necessary to bring the steel up to the physical requirements specified.

Testing as specified was divided into two types; specimen tests and full sized tests. Full sized tests were required only for the alloy eye-bars, specimen tests being required for all other material. As a rule only tensile and cold bending tests were required, although for the alloy steel a drifting test was also specified, calling for an enlargement of rivet holes 50% without fracturing the metal. The size of the specimen, speed of the testing machine, and determination of the elastic limit on the drop of the beam were also covered by the specifications, and also the appearance of the fracture. It is duty of the inspector to see that the test specimens are properly taken, to witness the test and see that it is properly conducted, to take the necessary measurements and make the computations to determine if the test meets the requirements, and to pass on the acceptance of the material.

A form for making reports of such tests to the client or

MODJESKI & ANGIER
CIVIL ENGINEERS
220 S. MICHIGAN AVE., CHICAGO, ILL.
TELEPHONE, HARRISON 535

INSPECTION OF ALL MATERIAL AND WORK OF CONSTRUCTION, RAILS AND FITTINGS, RAILWAY EQUIPMENT, MACHINERY, ETC.

REPORT OF TESTS

FROM MILL _____ SHEET NO. _____

FOR SHOP _____ CONTRACT NO. _____

STRUCTURE _____

REPORTED TO _____ DATE _____

DESCRIPTION		LENGTH		PHYSICAL TENSILE TESTS								CHEMICAL ANALYSIS				SHIPMENTS	
SHAPE	SECTION	FEET	INCHES	HEAT NO.	ELAS LIMIT SQ. IN.	ULT STR. SQ. IN.	ELONG % 8 IN.	RED AREA %	FRAC-TURE	BEND	GRADE	CAR	MAN.	PHOS.	SUL.	DATE	WEIGHT

to the main office is shown on page 91, plate XVII. These standard tests are made with great facility in any of the laboratories of the large steel mills, and with the aids to computations in the form of tables or special slide rules, the entire test and computation becomes a very simple matter.

By far the most interesting part of the mill instection was the testing of full size eyebars of alloy steel. The alloy used, called Mayari steel, came from Cuba, and was here used for the first time in any important structure. It was classified as rivet steel, medium steel, eye-bar steel and pin steel. The eye-bar steel was specified to have an ultimate strength of from 95,000 to 110,000 pounds per square inch, a requirement that made necessary a very high grade and uniform product.

The eyebars were of such a large size that special equipment was necessary before they could be manufactured at all, and after a beginning had been made, great difficulty was experienced both in handling the bars, the material being unfamiliar to the mill men, and also in securing uniformity in the material itself. A great many attempts were made before any satisfactory results were obtained, and for a long time it appeared that it would be impossible to secure bars meeting the requirements of the full size test. Annealing also caused some trouble at first, and on the ten full size tests first made, complete failure resulted. Success in producing a satisfactory bar was finally obtained, however, and in all forty tests were made meeting the requirements in every particular.

Specimen tests were also made on the same heats from which the full size test pieces were taken, the results being compared with the latter test showing a good correspondence.

2. Supervision of fabrication- Next in importance to the inspection of eye-bar forging and manufacture, came the inspection of the work of fabrication of the steel in the shop. This included the inspection of all of the material for the main bridge in the shops of the Pennsylvania Steel Company at Steelton, Pennsylvania, and that for the Approach Viaduct in the shops of the Virginia Bridge and Iron Company at Memphis. The inspection in both places was of such a nature as to supervise in detail all of the work prior to erection, to assure excellence of workmanship and orderly progress in the shop, so as to eliminate the possibility of delay caused by ommisions, misfits, or rejection of material in the field, although the specifications specificly stated that acceptance in the shop did not relieve the contractor from the responsibility of any work that might be found defective at any later time.

Since the contractor for both pieces of work was responsible for the erection as well as the fabrication, there was every incentive for him to avoid errors as much as possible, and to take every step to assure a proper fit which would eliminate delays and expensive corrections in the field. Had the erection been let to another contractor, it would have been necessary to take a geat deal more care in the inspection of the material before final acceptance for shipment was given, for in that case it is exceedingly difficult to charge the costs of corrections back to the shopwith whom the responsibility rests. However, every attempt was made on the part of the inspectors to make sure that the material as shipped was perfect in every way.

As a matter of fact, with the force generally allotted to an inspection job, it is practically beyond the range of possibility

to accutually inspect each step in the process of fabrication with such a degree of thoroughness as to eliminate all errors, and the contractor's shop inspectors must be relied on to a certain extent to catch such mistakes as may get by the client's inspection in any event. Indeed, many inspectors neglect watching the progress of the work through the shop at all, in favor of attempting to see that each piece before acceptance is in exact conformity to the plans; but a much better result is obtained, and a much happier relationship maintained between the inspector and the contractor, when errors are caught early in the fabrication, before the expense of correction in the finished piece is so great. This idea was carried out all through the period of shop fabrication, with results highly satisfactory.

Working on this principle, the first duty of the inspector was to supervise in general the making of the patterns by which the different pieces were later to be cut and drilled. It was not attempted to check each pattern that was turned out, but in addition to seeing that the general workmanship was of the proper character, patterns selected at random were frequently checked to see that they closely adhered to the plans, the details of which had already been submitted to the chief engineer for approval. Attention was also given to the precedence of work in the pattern shop, to see that those patterns were prepared first which would lead to greatest speed and economy in the shop.

Another matter which concerned the contractor mainly, but which the inspector endeavored to oversee likewise, was the arrangement of material in the incoming yard, so as to call for as little sorting and rehandling as possible in getting out the pieces in the order needed for the shop work. Of course it was

also important to check each shipment with the mill reports, and examine the material to see that it bore the proper stamped numbers and had been passed by the inspector at the mill.

Next in order came the inspection of laying out the plates and angles and the sub-punching. In such cases as had templates by which the work was laid out, the inspection was a simple matter, requiring only the making sure that the proper material was used, as to size, straightness, and kind, and after the piece was stamped, the inspection of the punching. Only the carbon material was allowed to be sub-punched, and the size of the sub-punching with relation to the finished hole was specified. On such pieces as went through a multiple punch, a checking of the spacing on the machine is important, since here a slip is easily made. In all laying out, errors will sometimes occur, and it requires careful checking to secure work that will not require correction in reaming or in drilling, and that will leave no blank holes.

As soon as a piece of material has been cut,punched, or laid out, it is marked with an identification sign which it carries throughout its progress through the shop, until the pieces are finally made up for shipment and receive the shop coat of paint. The marks are painted with a white paint so as to easily distinguished, and bear a definite relation to the character of the piece,according to some system which the individual shop may adopt. A typical marking system is as follows;-

Prefix	a	- miscellaneous angles
"	b	- lace bars
"	c	- fitted stiffeners and connection angles
"	f	- fillers, not fitted
"	g	- fillers, requiring fitting.
"	p	- miscellaneous plates
"	s	- spliced plates
"	t	- batten plates
"	h	- miscellaneous bent pieces

Prefix m - miscellaneous pieces not listed above.

In this system, which was the one used by the Virginia Bridge and Iron Company, each assembly mark was composed of two letters and a numeral, the prefix letter designating the kind of piece, as noted in the table above, the suffix letter denoting the individual piece as detailed on the shop drawing, and the numeral denoting the number of the shop drawing on thich the piece first appeared, and on which it was detailed. Only the two letters appear on the drawings, the shop adding the proper numeral. For suffixes only the following letters are used; a,b,d,f,g,h,k,m,n, p,s,t,v,w,x,y.

The pieces thus marked and punched are ready for assembling and reaming. In inspecting this part of the work, some of the things to be watched are the proper painting of surfaces in contact, the use of a sufficient number of bolts in the fitting up to hold the pieces securly in position, adequate contact between surfaces in bearing, such as the ends of stiffeners on the flanges of girders in plate girder work, correct filler plates, and many other details to make certain that the work is in accordance with the drawings. Once under the reamer there is little to watch except to see that no errors are made by carelessness, and in reaming connections to be made in the field, to make sure of the accuracy of the work. In case the field connection is not fitted up before reaming, it is best to use a steel template or jig, which is applied to both of the connecting pieces, and through which the reaming is done, thus securing conformity..Although this is not always done, it is much more satisfactory, especially in heavy work or in important connections such as floorbeams or main bracing members.

Rivet inspection in the shop is not so important a matter as it is in the field, since most of it is done by power riveters, where the chance of loose rivets is reduced to a minimum. With the oil heaters commonly in use, also, the rivets are much more likely to be uniformly heated, although there is always a tendency to use rivets too cold, especially on piece work, where the attempt to drive the largest number of rivets keeps the heater busy. But if the men are given to understand that the inspector will insist on the rivets being hot and the dies well centered, no trouble will usually be experienced. In all shop work there will be a certain number of rivets which the power machines cannot reach, and which it is necessary to drive with a percussion hammer, and on these rivets a thorough inspection is necessary, to secure satisfactory results. This can always be best obtained by following up the riveters and inspecting immediately after driving, since this informs the men at once just what work will pass inspection, and makes for a higher standard of work.

There is also a great deal of finishing work which it is best to watch as it progresses, in order to secure the best results. Rough work in milling ends of columns and girders, chipping edges of plates and other finishing details can be caught in a final inspection and sent back for correction, but if the character of the work being done is watched and comment given from time to time, a much higher quality is obtained than would otherwise be possible.

For the main bridge, the specifications provided that the chords should be assembled at the shops in lengths of not less than six panels, in order to eliminate all possibility of error which would later interfere with field erection. This was done

in the yard outside of the shop, since considerable space was required, and the chord sections were laid up on blocking to the correct elevation, and centered with a transit. Distances were then checked, and centers marked on the steel, after which the end connection plates were reamed, thus assuring an accurate field fit. By thus lining up six panels at a time, or three chord members, it was certtain that the entire chord would be a straight line when fitted up, the connections having been reamed with the members in line. One section of portal bracing was likewise fitted up in the shop, and in the approach viaduct, several of the bents were assembled and checked before shipment, the latter as a general check only, selecting every fifth or sixth bent, to see that the general run of the work was satisfactory.

This shop assembly is expensive, and is frequently dispensed with, although on intricate work the entire structure is sometimes assembled in the shop. In the case of the main chords, shop assembly was practically necessary, and its worth well proved by the results. The eyebars, too, were assembled in stacks of a dozen or so and pins passed through both ends simultaneously, thus assuring the correct length, and avoiding difficulty in the field. All pin holes were bored only after the pieces were assembled and lined up, and the end bearing castings were also set up in the shop before they were allowed to be shipped.

One of the details most often slighted in shop inspection is the shop coat of paint, although its importance cannot be too much emphasised. Frequently there is considerable mill scale left on the steel, which if not scraped off will gradually peel off after the material is in place, leaving surfaces exposed which are sure to rust. During the progress of the steel through the

shop much of this will be knocked off, but it will always require a thorough inspection to make sure that the surface is ready for paint. Then too it frequently happens that dirt and grease accumulate on the surface, which is equally inimical to proper painting. Care must be taken to see that the proper kind of paint is used, that it is properly mixed, and that it is applied well, touching all parts of the piece. Connection plates on the main bridge were painted with red lead, in distinction from the main bridge steel, which was painted with "No-brac", of a black color. Machined surfaces were coated with white lead and oil, as were the pins; but so much difficulty was experienced with the latter, even when encased in wood slats, on account of rusting during shipment, that later a hard grease preparation was found to preserve the surface much better.

Either just before or just after painting, while the steel was laid out conveniently on racks, a final inspection was given, checking dimensions, rivet holes, angles and other details. Anything that might possibly help out the field work was especially watched, such as removing burrs from around rivet holes or on the edges of plates, and care was also taken to see that the piece was marked correctly and in an easily discernable place, to avoid any difficulty in identification later. When the piece had passed this final inspection, it was stamped with the inspection mark on the back of the inspectors hammer, signifying approval, and was then moved to the yard, ready for shipment.

Many other details besides those outlined above are required in adequate shop inspection, such as observing proper sizes of rivets and bolts, machining of castings, turning and boring of pins, and countless other shop practices. The specifications

covered this work very thoroughly, yet there are many things which come up in shop practice which require judgement on the part of the inspector. As yet there is no text book which adequately covers the subject of shop inspection in detail in all its branches, and the points outlined are meant only to call attention to the more important considerations which were taken into account on the inspection of this particualr project.

3.Estimating weights and shipments-Since all payments on the contract for superstructure were based on a pound price on shipping weights, it was quite important that these weights be accurate, and for this reason, as well as for the purpose of checking the actual amount of material in the different pieces, it was required that the inspectors estimate the weight of every piece of material in the structure.

In making up the bill of material for the contract, the manufacturer lists the steel required for each piece of a certain kind separately, with the number of pieces of its kind, with the estimated weight of the whole, in order to get out the material for the shop. This does not give an accurate weight for the finished piece, however, for it does not make allowance for the weight of the material sheared off in the shop. The inspector was required, therefore, to prepare new lists entirely, estimating the weight of each separate part of the finished piece, and adding so as to obtain the weight of the piece as shipped. Errors were frequently found in the contractors lists, also, which made the inspectors check the more important.

This estimating becomes a very arduous task at best, although it can be much simplified by system in listing parts. By using one page of a book for each piece,and listing each part by its

shop mark, giving the dimensions of the plate or angle, thickness of the metal, length, weight per foot for this size, and then the weight of the piece for each mark, easily obtained with a slide rule, the total for each page gives the weight of one piece. Parts with the same mark occuring on similar pieces can then be checked on succeeding pages and the weight inserted from the first calculation, and in this way all duplication is avoided, and weights of each piece obtained in an orderly manner.

When all weights have been calculated, they are best entered in some order in which an individual piece can readily be found, so that on making a shipment, the estimated weight can be quickly ascertained to check against the scale weight. This will catch any error immediately, saving sending a piece back for reweighing in case the inspector is not satisfied with its agreement with the estimated weight.

Each piece was supposed to be weighed separately, but oftem a great many pieces were weighed together when they were small, while the larger pieces, of two carload lengths, were weighed after loading, by taking the combined weight of both cars. In fact, at the Memphis shops no other scales than the railroad scales were available, so that all weighing had to be done in cars, practically all in carload lots to avoid shifting.

As soon as a car was weighed, therefore, the pieces were listed and the estimated weight obtained, and checked against the scale weight. Since but 2 1/2 per cent variation was allowed by the specification, it was impossible for the contractor to receive any advantage by recording a weight in excess of the estimated weight; but it was the practice for the inspector to watch each weighing, to verify the actual scale weight, thus prevent-

ing even the slight overpayment that the contractor might receive by recording an excess up to the 2 1/2 percent, and at the same time checking the general accordance of the material with the drawings.

It may be said that there is a great deal of sharp practice in weighing shipments on pound price contracts, since in the absence of the inspector it is easy to give an incorrect weight which it is not very probable will ever be noticed. Even with a vigilant inspection some errors are likely, due to hasty weighing on a not too delicate scale, and also to the fact that the scales frequently get out of adjustment. To correct this latter condition it is the policy of the railroads to send a test car to the shops in order to test out all scales at regular intervals, correcting the balance under different test loads so as to eliminate error as much as possible.

Invoices of each shipment are prepared by the contractor, and after being checked by the inspector, they are signed and approved, with the estimated weight and per cent of variation shown, to avoid any dispute with regard to payment at a later date. The contractors record for payment is then readily obtained from the summation of the invoices. Copies are therefore forwarded to the main office, and also to both the contrator's and the engineer's representative in the field.

4. Reports of progress- Not the most enjoyable of the inspector's duties is the making of weekly reports of progress on the work; but such reports are not only valuable in the information that they give to the main office, but also in requiring an orderly form of record to be kept, as well as requiring a summary of the work in hand, records which the inspector might otherwise

fail to keep.

Forms for the mill and foundry report, and for the shop inspection report, are shown on the two pages following. As can be seen, the former report is very simple, giving merely the actual weight accepted and shipped on each order, and the weight rejected. Summarized each week, this gave at once the total weight shipped to date, and the per cent of completion of the work.

The form for shop inspection was much more elaborate, giving the shop progress on each kind of piece being fabricated, as well as the number and weight of each shipment, identified further by date and car number. This record and report combined was much more difficult to prepare, but when filled out it gave not only a summary of the weights itemized for checking, but also the general shop progress, and the percentage of completion, as well as the summarized weight to date on which payment was due. Moreover, by listing the pieces by mark and number of pieces, an additional check was given on the order of the work, tending to catch any error in getting out the pieces in the order required for erection, or making a miscount of the number of pieces required.

These reports being forwarded to the main office and also to the Resident Engineer in the field each week, kept all parties concerned well informed as to the work in the shop and field, and simplified greatly the preparation of vouchers for monthly payments on work completed in the shop.

MODJESKI & ANGIER
CIVIL ENGINEERS
220 S. MICHIGAN AVE., CHICAGO, ILL.
NEW YORK CITY, 101 PARK AVE.
PITTSBURGH, PA., 1704 ARROTT BLDG.
ST. LOUIS, E-17 RAILWAY EXCHANGE
PORTLAND, ORE., 407-8 CORBETT BLDG.

INSPECTION OF ALL MATERIAL AND WORK OF CONSTRUCTION, RAILS AND FITTINGS, RAILWAY EQUIPMENT, MACHINERY, ETC.

WEEKLY MILL AND FOUNDRY REPORT

REPORT NO._____ FOR WEEK ENDING_____ 191____

ON _____

FOR _____

DESCRIPTION OF WORK	CONTRACTING SHOP	ROLLING MILL OR FOUNDRY	ORDER NUMBERS	INSPECTED, ACCEPTED AND SHIPPED DURING THE WEEK — WEIGHT IN POUNDS	TOTAL POUNDS TO DATE	APPROX PER CENT MATERIAL SHIPPED	REJECTED DURING THE WEEK — WEIGHT IN POUNDS	REJECTED DURING THE WEEK — CAUSE OF REJECTION

ESTIMATED WEIGHT { WROUGHT MATERIAL / CASTINGS

TOTAL WEIGHT

REJECTED PREVIOUSLY

TOTAL REJECTED TO DATE

MODJESKI & ANGIER
CIVIL ENGINEERS
220 S. MICHIGAN AVE., CHICAGO, ILL.
NEW YORK CITY, 101 PARK AVE.
PITTSBURGH, PA., 607 ARROTT BLDG.
PORTLAND, ORE., 407-8 CORBETT BLDG.

INSPECTION OF ALL MATERIAL AND WORK OF CONSTRUCTION, RAILS AND FITTINGS, RAILWAY EQUIPMENT, MACHINERY, ETC.

WEEKLY SHOP INSPECTION REPORT

REPORT NO._____ FOR WEEK ENDING_____

AT SHOP OF_____ CONTRACT NO._____

FOR_____

LOCATION_____

DESCRIPTION_____

REPORTED TO_____

MEMBER	MARK	SHOP PROGRESS					SHIPMENTS				
		No. Req'd	No. Fin. This W'k	Total Finished	Shipped This W'k	Total Shipped	No.	Date	Car Initials	Car Number	Weight

ESTIMATED WEIGHT

APPROXIMATE PER CENT. FINISHED

APPROXIMATE PER CENT. SHIPPED

APPROXIMATE DATE OF COMPLETION

REMARKS

TOTAL OF ABOVE

SHIPMENTS PREVIOUSLY MADE

TOTAL WEIGHT TO DATE

INSPECTOR

VII. Inspection of Field Erection.

1. Checking material received- The general subject of field erection divides itself nzturally into three parts; the checking of material as it arrives from the shop, the inspection of the actual work of erecting the steel, and the final inspection of the decking and painting.

Even before the first layout of the work was made, it was necessary to think of the superstructure, in order to plan sufficient storage space for the material as it arrived, since the space required for storage and classification on such a structure is an important item. On the Arkansas side the problem was simple, for the site was on bottom land, which could be utilized on either side of the right of way, and by using a locomotive crane on the construction track already in place, the material could easily be distributed along the viaduct at approximately the position in which it would later be erected. But since most of the material for the main spans could be handled during erection much more easily by taking it out from the Tennessee side, it was necessary to create a storage yard an this side.

The only ground available for this was property immediately adjacent to the right of way, which when the work was started was covered by small houses and shacks, all of which had first to be cleared away. During the last of the work on the substructure this site was cleared and a ladder track laid off from the approach track to the brodge, giving six siding tracks which could be used for running tracks for locomative cranes, and between which the material could be stored.

The first material to be delivered was the eyebar hanger and

connections to be embedded in the anchor pier. There was a considerable delay in shop progress immediately after the completion of the substructure, as explained previously, so that there was every opportunity to get the site into the most favorable condition to receive material and proceed with the erection; and before shipments began to arrive, a huge travelling crane was erected in the storage yard, on a broad gage track, running the greater part of the length of the yard. This crane had a swinging boom of about sixty foot radius, and had a lifting capacity of thirty tons, so that it could handle the heaviest pieces. The traveller ran on three rails under the post end, and two under the rear end, being propelled by cables leading to dead men at either end of a run; and on account of the difficulty in moving so heavy a structure, it was used mostly on the larger pieces, the majority of the work being handled by locomotive cranes, of which three were at times in use.

The material was stored without any prearranged plan, the sorting being done directly from the car, and a careful record being kept of the location of the various pieces. As material was used in erection, the space thus cleared was utilized again at once, in order to keep the bulk of the material as near the bridge as possible, and thus make the run with the piece for erection the least. At times the entire yard was filled up, for a distance of nearly three thousand feet, to where it was limited by the construction of the under ground street crossing; and some space on the other side had to be taken for storing the material for deaking.

Naturally it was to the interest of the contactor to keep the best kind of a record on the material on hand, in order to

avoid delays in erection, or rehandling of material, and consequent increased cost. But in order to check the contractors record, and thus reduce the liability for error, the engineers kept a separate record of all material, checking against the contractors record at frequent intervals.

As each shipment arrived, the mark of each piece was observed, either in the car or during the unloading, and recorded in a field book. These entries were later checked against the shipping invoice for each car, after which the piece was checked off in a permanent record book, which listed each piece of steel under its appropriate heading, such as top chord, bottom chord, diagonals, posts, bracing, etc. By refering to this record book at any time, therefore, the exact status of the material could be obtained at once, as to the number of pieces required of each kind, the number delivered and date of delivery, and later on as erection commenced, the number erected. Thus the pieces needed to continue erection and to complete the work could be ascertained at a glance.

All the material was examined on its arrival, and any portions on which the paint had been scraped off in transit were retouched with the original shop paint. Pins were unpacked as soon as received, and any rust spots removed, after which they were given a coating of graphite and grease, and stacked where they would not be injured until required, so that no difficulty would be experienced in driving. Care was also taken to see that all the material was properly blocked up from the ground, and between pieces, to avoid rust which might come from burying steel in the ground, or any injury or bending which might result from improper storage.

While there was a great deal involved in the proper handling of material in the storage yard, the actual amount of inspection

necessary was very little, and a few minuits a day sufficed to take care of this part of the work easily.

2. Supervision of erection- The most important work of the inspection force during the superstructure work was the supervision of erection, in which is included the riveting of the material. This consisted largely of general and detailed inspection of workmanship, and instrument work in connection with the laying of the steel.

The steel was loaded onto flat cars in the storage yard, and pulled out to the working point with a small locomotive or "dinky", when working on the Tennessee cantilever; and when working on the fixed span in the middle of the river it was taken out to an unloading trestle overhanging the river, from where it was lowered onto barges with a stiff leg derrick, and towed out to the falsework, where it was lifted with a derrick ready for erection with the traveller. A large part of successful erection consists in keeping the material moving forward in the correct order, and most of the plan reading is done in the yard, in order to get the exact peices necessary out to the point of erection when needed. In fact, after checking the pieces loaded to be taken out on the span, there was no need for watching the actual erection, since no mistake in getting an incorrect piece was then possible.

First to be erected on any span was naturally the bearing castings, which required extreme care in setting. Since the tops of the piers had been so carefully dressed, and the bottoms of the bolsters had been machined, no further work on the joint was necessary, the surface being merely covered with a thick coat of red lead, which served to fill any minor unevenesses, so that the steel shoe may be said to be in direct contact with the masonry.

The marking of the piers has been previously described, and the shoes being similarly marked on the centers with punch marks, the shoe could be set almost exactly in position with little or no trouble. The large pedestals came in three pieces, which were set up separately and bolted together; and having been already set up in the shop and match marked, the entire pedestal was quickly assembled. Then to make certain of the position, a transit was set up on the pier center, and right angles turned to the pin centers on the top of the pedestal, the distance between the two pin centers being checked with a tape at the same time, and the slighest diviation from true position was corrected by ramming with a heavy timber. On account of the weight of the pedestals there was no danger of subsequent movement, but work was started immediately on drilling holes in the masonry for the anchor bolts. These bolts were four feet long and two inches in diameter, and were split on the lower end, and driven in place on wedges which opened the split and made a secure anchorage. Most of the masonry drilling was done by hand with steel drills, and although expensive was performed without trouble. Later the inside of all shoes was filled with concrete, sloped off so as to drain all moisture out to the pier.

On the Tennessee side the erection started with the anchor arm, which was erected on false work consisting of a few bents of piles driven with a hammer in swinging leads suspended from a light derrick. This falsework was of a simple type, and requires little comment; the steel was erected with a heavy steel travelling derrick, which was later used for lifting steel out on the fixed span.

This span being so short, little attention was given to the

erection, with the exception of giving centers, since the river end was limited by the shoes, and the shore end by the anchor eye-bars. The anchorage itself was interesting, and required considerable care in adjustment. While the bottom of the bars were being concreted into the pier, they were suspended from the top pin, supported on strong timbers. A form was built around the bars to keep the concrete away , so as to prevent cracks fromta later disturbance and elongation of the bars as they gradually took up the stress during erection of the ccantilever.

The anchor pier settled as it was built up, the same as the rest of the piers, and as this settlement was not uniform in all directions, it resulted in leaving one pin slightly higher than the other, but not enough to influence the structure. The top pins connecting the bars in the pier to the bars forming the end post of the span, rested in a specially designed cast shoe, fitted with large wedges so placed as to be subject to tightening with four large through bolts. By bearing directly against the top of the pier, this device was able to stress the bars to any desired amount, by drawing in on the wedges; and after the span was in place, the shoes were adjusted so as to elongate the bars an amount sufficient to produce the maximum stress that would be required on them under full load. The stress on the two sets of bars was thus equalized, and the frequent increase and decrease of stress prevented.

When this result was attained, the wedges were locked, and the shoes concreted on the interior for protection. The spaces which had been left about the eyebars were then filled with concrete also, thus permanently sealing them from the air, and since future elongation was not required on account of the constant stress on the bars, future deteriorationoof the steel was prevented.

After the erection of the anchor arm was complete, the travelling derrick used for the erection was utilized to put up the top traveller or creeper with which the erection of the three cantilever arms was performed. This creeper was designed to be dragged forward on the top chord, being supported directly on stringers, which were later worked into the main bridge. On account of the slope of the chord, it was necessary for the rear of the traveller to be adjustable in height, and at each new position the entire platform was tilted up or down to bring it to level before any loads were lifted. The traveller was equipped with two booms, both of which were used together to lift the heavier pieces, while on the lighter work, by working on both sides of the work with the two booms at the same time, progress was far more rapid than with a single boom. The results obtained with this traveller were most satisfactory, the steel being picked up from the deck below or from the barges on the river with great facility.

During the erection of the cantilever arms, lines and levels on the span were taken with the addition of each panel. Little could be done to change the position if found incorrect, since each piece of steel fit directly into the adjacent piece with practically no room for play. At the end of the cantilever arm proper, however, occurred the adjusting wedges for lowering the suspended span into position, and here an adjustment was possible to take care of any variation in the position of the arm. The cantilevers varied very little as to line, as a matter of fact, excepting on the arm from pier III, and as soon as the transit line showed that the panels were close enough to line, riveting proceeded at once, without waiting for the span to be swung.

Levels were taken likewise with each additional panel, the readings being taken on the bottom chord, and figured out to give the line of the pin centers, for purposes of plotting. These readings were plotted each day in graphical form, to an exaggerated vertical scale, in order to show the amount of camber in the span. On the cantilever arm proper, the camber was nearly the same as the final amount to be left in the span, since in these heavy members little variation was to be expected with the additional weight; but after the wedges were inserted, the pin line took a sudden inclination upward, which was reduced as each succeeding panel was added, being pulled down by the weight and moment of the additional steel, until the center panel of the suspended span was left approximately two feet above its final elevation, pending the closing of the span by the operation of the wedges.

The fixed span, between piers II and III, being erected on falsework, required rather more instrument work during its erection. In itself the falsework was a considerable item and remarkable in several respects. As has already described, willow mat work had been sunk between these two piers, for a width of about two hundred feet, in order to protect the falsework, on account of the great depth of the water, and the piles were driven through this mat to a bearing in the soil below. The piles themselves were extremely long, few of them being under ninety feet in length, and some of them being as long as a hundred and fourteen feet. They were shipped to the site from Oregon, being of Oregon pine, and the freight charges amounted to more than the original cost of the piles; in length the piles required three flat cars, being loaded with the weight on the front and rear cars, with an idler in between.

After being unloaded in the material yard, the piles were dropped into the river, and rafted out to the fixed span, where they were driven with a floating pile driver, with double leads spaced the correct distance apart for the two rows of the bent. Double acting steam hammers were used for driving, of the type made by the Union Iron Works, which drove very rapidly, although causing several delays on account of breakdowns. On the whole the hammers could be considered quite satisfactory. By driving with two hammers, both rows at the same time, it was necessary to move the driver only once across the site for each bent, the sixty piles in the bent being driven usually in one day. No particular penetration was required, since the load to be carried per pile was very small, and driving was stopped when the desired elevation of the top was obtained, or when the driving became difficult. Of course the greatest stress in the piles was to be the bending stress, and it was necessary onlyto get a firm bearing in the earth in order to secure the foot of the pile.

As a rule, between one and two days were consumed in bracing and capping the piles to such an extent that the driver could move to the next bent, so that on an average three days were required for driving one bent. Steel cables were attached to the bottoms of the two outside piles in each row before driving, and after driving the other end of the cable was brought across and fastened to the top of the pile at the opposite side, and pulled taught, thus forming a diagonal bracing system of steel cable which was of great importance in adding to the strength of the structure. Timber bracing bolted in place was framed in just above the water level, with a systen of cross bracing from this level to the tops of the piles, some fifteen or twenty feet above, thus forming a

substantial framework to hold the tops of the piles, which was most necessary. The force of the current frequently whipped the piles about below this bracing for a distance of nearly a foot, causing a wearing motion which at times cut the bolts through the timber, entirely loosening the piles until additional bracing could be installed. Of course this was largely prevented as soon as the falsework had been erected and enough weight placed on it to stabalize the bents.

The spacong of the piles was a very simple matter, since accuracy was of little account. After the first row of piles had been driven at the correct distance from the pier, the succeeding bents were spaced by means of an outrigger on the pile driver, which kept it at the correct distance from the bent last driven. The elevations for cutting off the piles were given with an engineers level, from known elevations of masonry courses on the pier.

Following the pile driver, bents of falsework previously framed up in the yard and floated out to the span in barges, were erected on the pile caps by means of a light timber traveller with two booms, running on the top of the falsework itself. This traveller handled the bents rapidly, but little longitudinal bracing being required, so that the entire false work structure was complete soon after the pile driving was complete. A large travelling steel derrick, the same as had been previously used to erect the anchor arm, followed the timber traveller, and with its one boom lifted steel for the span from the downstream side, from barges on which it had been loaded from the material yard. This traveller placed the blocking on the top of the bents, the sand jacks on the blocking to support each panel point, the bottom chords and floor system, and hoisted all the balance of the steel

ready for erection with the travelling gantry, which followed it from pier to pier, completing the erection.

The gantry traveller was composed of three frames, of light timber construction, spanning the entire height of the completed span, and having two sets of lifting falls, operated from hoisting engines running on the tracks below. It was moved with great ease along the track, and lifted steel from cars on the center track below to its place in the span, using both sets of falls separately for all of the lighter work, and driving all the pins, making erection very rapid.

As soon as the erection of the falsework was started, centers were thrown on the top of the bents daily, to observe the movement of the structure. The steel floorbeams were then placed with their centers directly over the marked center on the falsework, given the same day. With the varying height of the river, the pressure on the falsework threw it out of line, and the variation from centerline became at times several inches. It so happened that during the erection of the center panels of floorbeams the river was extremely high, throwing the falsework considerably downstream, and the steel was thus set centered several inches on the upstream side of the falsework centers. Later the river went down, and the falsework moved back upstream with the lightened pressure, so that the steel was now upstream from the actual center line, an amount which came out five inches by the time the end shoe had been reached. This discrepency was taken care of by moving the roller bearings over on the bearing shoes, after removing the guides, and later jacking the last few panels back into line, so that the proper connection could be made.

The sand jacks were set at the start so as to give the cor-

rect camber in the span,to accomodate the erection. The riveting of the bottom chord progressed along with the erection, so that by the time that the last pin had been driven, the span was all ready for swinging. This was accomplished by removing the sand from the sand jacks, thus lowering the panel points until the weight was transfered from the blocking to the span itself, thus swinging the span free of all but the end supports. In lowering the jacks, it was necessary to use some precaution to keep the weight uniformly distributed, the jacks being lowered simultaneously, and the sand being removed from each jack at nearly the same rate, so asmnot to concentrate too much weight on any one jack. No hitch occurred in this proceedure, and the entire span was swung in a couple of hours.

It had been intended to construct the span between piers III and IV on falsework in a similar manner, and this entire span of falsework was placed, using the same pile driver and timber traveler, and the same method of construction as for the fixed span. The steel for this span was to have been raised with a stiff leg derrick which had been erected on pier III, and a small gantry crane, similar to the large gantry used on the fixed span, but of a less height on account of the smaller span, was set up and used to lay a part of the floor steel. At this stage of the erection, however, the river rose to a menancing height, and shortly after the swinging of the fixed span, the falsework gave way in part, destroying nearly all the work between these two piers, including both the gantry and the falsework travelers, and a considerable part of the floor steel. Practically none of this material was salvaged, although part of the steel still attached to the fixed span was saved by suspending it from the end posts by

steel cables, a proceeding which required a considerable risk to accomplish under the unstable condition of the small amount of falsework remaining.

The falsework under the fixed span did not go out until several days later, and since this span had already been swung, it made little difference, except for the loss of some of the falsework, most of it being rafted below the bridge and salvaged, while some was saved by attaching it to the span above, and thus suspending it when the piles below washed away. The tenacity of these piles was remarkable, for soundings taken along the bents during the highest stage showed a depth of nearly a hundred feet, indicating that the piles were supported by only three of four feet of penetration at the foot, and yet held against an enormous pressure. Nothing but the willow mat could have accomplished this result, showing how secure a bearing was afforded the foot of the piles by this method. How great the pressure was can be shown somewhat by the fact that even the small amount of falsework attached to the fixed span above was sufficient to pull the center of the span thirteen inches out of line downstream. Of course this deformation was the result of the flexibility of the unriveted span, and was reduced immediately when the pull of the falsework was removed.

As soon as the river had gone down enough to permit of resuming operations, the same traveler that had been used to erect the cantilever from pier I was put up on the fixed span, and the work of erecting the cantilever from pier II was started. With the exception of lifting the steel for this arm from barges on the river instead of from cars on the span, the erection of this arm was in every way similar to the first, and involved no more difficulty. The two arms met in the middle with both ends elevat-

ed about two feet, this tipping action of the wedges having the effect of shortening the upper chord and lengthening the lower chord, so that before lowering the gap between the upper chord ends was about eight inches, while the lower chord eye-bars, which were fitted into slotted holes instead of the standard circular hole, hung down in the center on account of the same amount of lengthening in this member.

The wedges which accomplished the tipping of the arms and with which the span was lowered were so arranged in the chords that the large section of the wedge pushed out the bottom chord and similarly in the top device, the large section of the wedge pulled in on the top chord. When it was desired to lower the span, therefore, it was necessary only to let the wedges slip out from their seat, so that the chords were no longer held from assuming the position to which the weight of the span forced it. As a matter of fact, the weight of the span was not in itself sufficient to force out the wedges, the slope to the wedge surface being very slight, and the removal was therefore secured by the operation of screws with which the device was equipped. The screws on all eight of the wedges were opperated at the same speed, so as to lower the span uniformly, and the lowering was accomplished successfully inside of about two hours from the time that the screws were first turned. The turning itself was done with ropes attached to timber lever arms, the power for pulling the ropes being secured with stationary engines on the deck.

This span thus erected, the top traveler was removed to the other end of the fixed span for the erection of the cantilever from pier III. In order to erect this span by the cantilever method instead of the falsework method first planned, it was necessary

to alter somewhat the method of support of the suspended span, and to equip the chords with the devices for holding the wedges to lower the span. Some difficulty was encountered in the erection of this span on account of the twist which had occurred in the fixed span, the bow in the downstream direction in this span having the tendency to turn the adjacent cantilever arm upstream. At the end of six panels, the center of the arm was nearly six inches upstream, and it was brought back by the use of steel cables attached to diagonal points in each panel in the plane of the bottom chord, with steam boat ratchets fastened to each of the diagonal braces thus formed. By tightening these ratchets in turn, each panel was gradually brought to the square in successive moves, until the entire span was brought back to center, when the regular bottom laterals were placed and riveted, thus holding the span in place.

Since the suspended span between piers III and IV was supported by a cantilever on the end nearest pier III only, the other end resting directly on pierIV, it was impossible to use the cantilever method of erection for this entire span, and the half nearest pier IV had to be erected on falsework. By this time, however, the river had fallen to such an extent as to make this process entirely safe, and this half was erected on six bents of falsework in much the same manner as the fixed span, with no difficulty whatever. In making the connection to swing the span, therefore, a combination of the methods of lowering was necessary, the wedges being removed at the same time that the sand jacks on the falsework were lowered, and at such a rate that this half of the suspended span would come in position at the same time that the pierIV half was lowered to its final position, the connection

between them then being made with no difficulty.

What threatened to be muchmmuch more serious was the connection of the suspended span to pier IV, this being on account of the method of erection of this half of the span. Since the cantilever arm was finished before the falsework was ready, it was decided in order to save the expense of placing a traveler on this span, to erect with a locomotive crane run out from the main bridge and the cantilever. Accordingly the floor system was laid from the end of the cantilever on to the falsework, and the crane run across, erection of the floor system being then continued to the pier. On account of the bottom chord of the cantibeing thrust forward, however, the floorsystem was found to overlap the center of the pier, the end pin coming several inches beyond the pin hole in the end bearing. This bearing was therefore loosened from the pedestal below, and the pin driven, after which the erection with the locomotive crane proceeded , the shoe being still several inches from center on the base. As the span was lowered with the sand jacks, screw jacks bracing against the adjacent deck span were placed against these shoes, forcing them gradually to correct position as the span was lowered. The erection of the three main spans was thus successfully completed.

Both the approach viaduct and the deck span had been erected for some time previous. The viaduct was erected with a steel traveler, with two booms, which handeled the eighty foot boxed girder spans with ease, and erected the transferse bents, consisting of cross girder and columns with diagonal bracing, as a unit, these bents having been assembled ahead of the traveler with a locomotive crane. This erection was extremely rapid and satisfactory, the bents all lineing up with no difficulty, and

all anchor bolts being found tobe correct. The bents were plumbed with a transit during erection, and after making allowance for temperature expansion, the last bent was found to be exactly plumb, with no observable variation. On some of the expansion points in the girders, it was found necessary to enlarge the slot, this being caused by an overrun in the length of the girders rather than an incorrect distance between piers, as was found by checking the dimensions of the girders.

The same traveler that erected the viaduct continued forward and erected the deck span also, on falsework set up on blocking on the ground below, this span being over ground which was above the level of the river during a large part of the year. This was the most simple of all of the spans, the swing with the lowering of the sand jacks being a simple operation. The only features of note in this span were the shoes set in nitches in pier IV, requiring some careful manipulating and some chipping of masonry, since the end pins had to be driven before the shoes could be placed, andthe two pieces of chord with the shoe being somewhat cumbersome to handle; also the bearings on pier V, which were unique in being a combination roller bearing, to take care of the expansion of the deck span, and swivel pin bearing, to take care of the expansion in the viaduct .

On both the viaduct and the deck span, the shoes were wedged up from the masonry and a rust joint made, this making a most satisfactory bearing, the refinement of dressing the masonry for a neat fit, as was done for the main spans, not being required for the light loads involved. The rust joint was composed of a mixture of ninety percent iron filings and ten percent sal amoniac, worked up to a consistency that could be rammed under the shoe,

previously wedged up at least a half inch from the masonry. After several hours this material set up very hard, and the wedges could be removed, leaving a permanent joint which gave an even bearing of the shoe on the pier, and which became harder and more durable with the elapse of time.

Before placing the rust joint, levels were taken on all the piers, and squares painted on each one,on which the elevation was computed, so that later by measuring up from these squares, all of the shoes could be set at the same level, by wedging up the proper distance. The maximum variation in the elevation of all of the tops of the piers was three quaters of an inch, so that allowing a half inch for the minimum joint, the heaviest joint which it was necessary to use was an inch and a quarter. After all the joints had been placed, the bases of the columns and the buttom pedestals were filled with concrete, as described for the main bearings.

In addition to the general supervision of the erection processes outlined above, a great deal of detail inspection was necessary during the erection. Although nearly all the connections lined up fairly well, there are always some in which the holes do not match at first, and it is the duty of the inspector to see that the work is pulled up until the holes are good enough to permit of riveting, sometimes an arduous proceedure. Usually this is attempted by the use of drift pins, which is likely to damage the metal about the holes, and in such cases the inspector must insist on the use of some better device, either jacks or ratchets, to pull up the work. Also it is necessary to see that a proper number of bolts and pins are used in each connection before attempting to swing the spans, it being generally required

that at least half of the holes be filled, and that at least one third of these be pinned, the rest bolted.

Besides inspecting the fit of riveted connections, it is necessary to inspect the fit of all pin connections, seeing that the proper spacers have been inserted between eyebars, since the moments on the pins are figured from certain positions of the bar on the pin, which must therefore be maintained. Spacers are made of rings of light steel, which are likely to be mixed up before placing, and also which frequently fall out during driving of the pin unless watched. After the pin is driven, it should be seen that the excess length is evenly divided, and then that the pin rods are placed with the pin caps to cover the ends, and the nuts checked to prevent them from working loose.

All expansion points require careful inspection. In the case of a sliding expansion, common in girders, it should be seen that the sliding surface is smooth, that the slotted hole is well centered at normal temperature, and of sufficient size, and that the bolts fit well and are pulled up snug and checked. In the case of roller expansions, of which there were two on this bridge, one for the deck span on pier V and one on the main span on pier II, it should be seen that the rollers are free and even on the bearing, and that the bearing is free and smooth; also that the rollers themselves are upright at normal temperature. Where this is not the case, as happened on pier V, the rollers must be moved so as to assume an upright position, a result easily accomplished by moving the individual rollers one at a time, after removing the lock bars from the outside. For swivel and rocker expansions, on the viaduct on pier V and the abutment respectively, nothing was necessary except to see that the pin was well centered. In the

case of the especially designed expansion floorbeams and stringers at the expansion points at the juncture of the cantilever arms and the suspended spans, it was necessary to see that there were no interferences, that the mechanism worked freely at the limits in either direction, and that all bearing surfaces were fitted with grease cups to properly lubricate the bearings. This applied also to the sliding surfaces in both the top and bottom chords.

In addition to the attention necessary to see that expansion is properly provided for, there are always innumerable minor interferences that cannot be forseen, but which require correction in the field. A slight overrun in the thickness of a plate, the neglect to cope an angle sufficiently, clearances that are too close to make conveniently, rivets and plates that interfere with erection, all call for judgement in correcting, both on the part of the contractor to avoid excessive additional costs, and on the part of the inspector to see that the strength of the structure is not impaired. Much judgement is also needed in straightening members which have been bent during erection, which can never be entirely avoided.

But of all the duties of supervision, the inspecting of the riveting is by far the most rigorous. Seemingly a simple matter, it requires more than a little judgement, and an amount of time and work that would hardly be suspected. Here more than anywhere else is there a likehood of friction between the contractor and the inspection force, and more need for perseverance and skill on the part of the inspector to secure good work, as well as judgement to secure speed and cooperation..

This is not so necessary in the case of power driven rivets, which were required in all the tension splices in the bottom chord.

Two bull riveters were used on this work, operated by air, and working on chain falls from a support above the splice. With these a very rapid riveting of the splices was obtained, and as the power drew up the work well and always drove the rivets home, there were few loose rivets to be cut out. In fact, so uniform were the results that it was scarcely nexessary to inspect the bull driven rivets except for some slip in workmanship.

These machines could not reach to all points, however, and in addition they were so cumbersome that they were used only where specified, all other rivets being driven with percussion hammers. With the points so scattered, there was a great deal of moving of scaffolds necessary, especially on the viaduct. With four men working in a gang, fitting up the steel, bolting and riveting, the ordinary days drive averaged from 250 to 300 rivets for each gang, although occasional records of six and seven hundred were made.

During the riveting an inspector was present on the work constantly, one inspector taking care of from five to eight gangs. As soon as a point had been driven, before moving the scaffold, the inspector was called over to pass on the work. This involved tapping each rivet with a light hammer, about twelve ounces in weight, to determine if all rivets were tight, and any found loose were marked with a crayon for removal. When such rivets had been cut out and redriven, the point was again examined by the inspector, and if found satisfactory, was marked approved, after which the gang moved to the next point. It being the natural tendency for the riveters to slight the work, leaving loose rivets, or even artificially caulking loose rivets to make them appear tight, it devolves on the inspector to insist on a certain standard of work,

and to allow no diviation from this standard. This is the more difficult because loose rivets are not invariably the result of poor workmanship, since too much paint between plates will frequently produce the same result, and sometimes in light metal where there is a great deal of spring, it is almost impossible to drive rivets that will not slide a little with a good blow. As a rule, however, if the metal is pulled up well- a most essential point- and the rivets are heated properly and bucked up firmly during the driving, there will be no difficulty, and to get the four men in the gang working together harmoniously so as to take care of these details, is the secret of good rivet inspection. No amount of cutting out will produce as good a job as can be obtained by using care in driving, and by helping to organize the gang and get them to working together, the inspector can get better results than by rigid inspection afterwards.

This requires that the inspector have a good knowledge of the requirement of proper riveting, and also that he be present at all times, so as not to cause a delay when it is desired to move a scaffold. It also requires a great deal of judgement to determine just when the men have done their best to get a tight job, and when it will be better to leave a slightly defective rivet than to try to cut it out and run the risk of making matters worse. There will always be points so difficult of access that perfect rivets are impossible, and some points will task the ingenuity of both inspectors and men. Another difficulty is the practice of contractors of offering a bonus to the men for driving rivets in excess of a certain number each day, a practice which has a tendency to lead the men to slight the work in order to get a large number of rivets; but if the inspector is conscientious in his

work, and the limiting number is not too high, this is often found to be an advantage rather than a difficulty. In fact, it was a common experience that the worst results were obtained near the close of the work, when the fear of discharge led the men to inferior work purposly, in the hope of thus prolonging the life of their job.

Many other factors are important in obtaining a greater output from the men, among them being the furnishing of the best of tools and dollies for bucking up, providing adequate scaffolds, keeping the air supply constant, fitting up difficult work with an extra gang, and other details, in which the inspector can assist with his advice while generally supervising the work.

After finishing the riveting there are always some holes in which rivets cannot possivly be driven, and for which turned bolts must be substituted. Such bolts must be tight, and checked to prevent loosening. There will also be numerous repair jobs, such as providing walkways for the attendant to reach points requiring lubrication, providing handrails around pedestals, supports for lighting the span in accordance with the U.S.Engineer's Corps requirements, and many other things, all of which the engineer is responsible for.

3.- Inspection of decking and painting- All of the decking on both the railway and the highway was composed of creosoted timber, shipped in on cars, already frammed and dapped, from the creasoting works in Louisianna. This required the services of an inspector at the plant, both to see that the framing was correctly done, and in order to seethat the specification with regard to the creosoting was carried out.

Plans were drawn by the steel contractors for the framing of

the timber to fit the steel, and since the steel contracts called for laying all decking, the contractor was responsible for the correctness of the framing. The decking itself was purchased directly by the Bridge Company and furnished to the contractors, hence the engineer was responsibe for the quality of the timber and the quantity furnished, as well as the creosoting process.

The inspector at the plant inspected the timber for straightness and compliance with the timber specifications, and checked the framing in accordance with the contractor's plans. For each charge the volume of the timber entering the cylinder was computed, and the quantity of oil put in the cylinder obtained, to see that the number of pounds of oil per cubic foot specified, fifteen, was obtained for each charge. The conditions for each charge were also noted, the inches of vacuum and time in the vacuum, the pressure under which the charge of oil was made and the length of time for the charge, and the whole embodied in weekly reports sent in to the resident engineer.

When the work first started, an English oil was in use, of a light density and containing very little insoluable tar products. The supply of this oil was interfered with by the war, however, and on more than half of the work it was necessary to waive the specifications enough to permit of the use of the heavier American oil, which may have been equally efficacious as a preservative, but which left a thick coating on the outside of the timber which made handling for more difficult and objectionable.

After coming from the charge, each piece of timber was marked with a stamp on the end in accordance with a marking diagram furnished by the steel contractors, and loaded on cars for shipment. The inspector made out invoices for each shipment, showing the

number of pieces of each mark shipped, and the feet board measure in the shipment, the latter being required for making up the statement for payment.

On arriving at the site, the material was unloaded and stacked ready for laying, the various kinds of pieces being sorted out in so far as possible. This work was done by the steel company, although they did not assume responsibility for the material until they started to lay it on the structure, even the fire insurance being carried by the Bridge Company in the meantime. Since the creosoting process weakens the timber considerably and makes it particularly subject to abrasion, the contractors were not allowed to use this material during the construction, but were obliged to deck the bridge is so far as it need to be decked for construction use with temporary decking of their own. As soon as the work began to near completion, the permanent decking was brought out and laid one track at a time, so as not to interfere with the use of the track during comstruction. For a large part of the work the guardrails were already dapped, and with the use of air drills for boring the holes for the bolts to secure the ties to the girders, the whole decking process was very rapidly performed.

The engineers kept careful records of all shipment of the decking, checking each car on arrival, and generally supervising the storage. Some difficulty was experienced in reading the marks on the timber, on account of the thickness of the oil used for creosoting, but a small amount of framing on the bridge sufficed to correct all errors. All fresh cuts made in the field were coated with oil before placing the timber, although the penetration of the original charge was so good as to make this scarcely necessary. The guard rail was laid in sections with separations sufficient

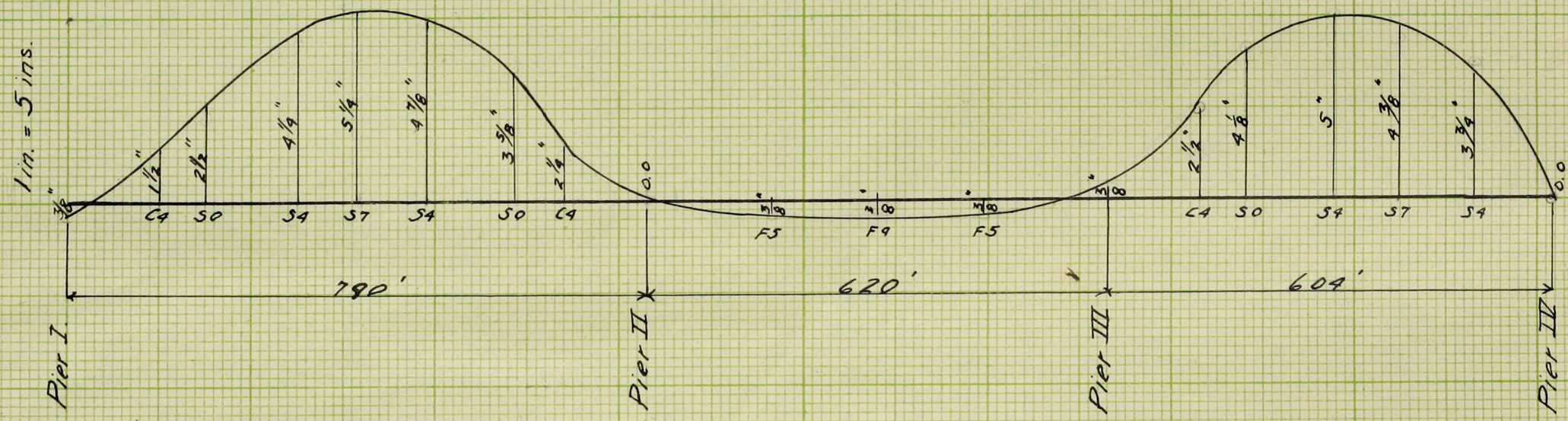
to provide for the expansion in the steel. For the roadway, all planking was laid with spaces of three eights of an inch between planks; the planks being spiked to the joists with square wrought iron spikes, driven with a percussion hammer.

The permanent rail was laid immediately after the decking, screw spikes being used for fastening the tie plates to the deck. The rail expansion joints, of which there were three, for each of the main expansion points, were bolted to the deck, and allowed for an expansion of six inches in the rail at each point. Centers for this track were run through the bridge with a transit, marked on the center of the cross girders and floorbeams with a cold chisel mark, which left a permant center mark for future use in making repairs to the track.

After the span was thus given the full dead load, levels were run to determine the amount of permanent camber finally left in the bridge. The results are shown in the diagram, plate XX, page 132. As can be seen, the fixed span was left nearly level under full dead load, though a load on either adjacent span tended to make it camber upward. Both the suspended spans were left with a camber of approximately five inches.

One of the most important elements in the life of a steel bridge is the protective coating, and the choice of the paint to be used on the structure is an important part of the engineering supervision. The specifications called for one shop coat and two field coats, the choice of the paint to be used to be subject to the approval of the engineer. In accordance with the best opinion on protective covering, the shop coat is expected to afford a waterproof covering which will adhere closely to the steel and prevent corrosion from the presence of moisture or on account of

FINAL CAMBER IN MAIN SPANS
MEMPHIS BRIDGE



1 inch = 250 feet

Plate XX

electrolytic action, while not at all adequate to resist the action of the elements or of chemicals in the atmosphere, this latter protection being afforded by the field coats. The best shop coat in accordance with this theory would seem to be red lead in oil, which forms an impervious covering which is elastic and durable, and preserves the metal from corrosion admirably. Red lead itself, however, is not very resistent to atmospheric action, and also is difficult to apply evenly, and on account of the red lead settling to the bottom of the mixture, is difficult to keep in a uniform consistency, in addition to being very expensive. For these reasons it seemed best to specify for shop coats a paint which while containing sufficient red lead to give the preservative qualities required, had enough of other ingredients to give the proper resistence to the atmosphere, and at the same time give uniformity of flow. For the main superstructure the shop coat used was "Mamolith Carbon" and for the viaduct "Detroit Graphite", both patent paints with which very good results were obtained.

At the very beginning of the work, samples of different kinds of paint were secured from many different manufacturers, for the purpose of making a service test before selecting the paint for the field coat, and each manufacturer was invited to submit as many samples as desired, together with his specifications for applying the same, which were rigidly adhered to in making the test. In all about thirty specimens were tested.

For this test steel plates about six by ten inches were used, held rigidly by wires in a wood frame, the entire outfit being placed in an exposed position where the plates would be subject to all the action of rain, wind and sun. The plates were numbered in the panel, and a careful record of the kind of paint and con-

ditions under which the painting had been done was kept, care being taken to have the paint spread uniformly and mixed the the right consistency, so as to give a fair test. Once a month the entire number of test pieces was examined and notes made in the record book of any deterioration, so as to ascertain the time elapsed between the first evidence of failure and the ultimate breakdown.

It was found that rust specks began to appear on some of the panels after the first six months of exposure, and inside the first year all but a very few of the panels showed some signs of breaking down, either flecks of rust coming through, or else a cracking or peeling. Some few had entirely broken down in this time, the entire panel being a mass of rust spots. The test was continued for about two and a half years, and after the first year the deterioration became more general, being more or less rapid with various paints, and with different numbers of coats. In general, the panels painted with two or three coats of a product which was advertised to contain carbon or graphite seemed to stand up the longest, but when the final examination was made, the results showed a practical failure of ninety percent of the samples, over half being completely broken down, the balance showing from five to ten large rust spots scattered over the surface, and only three of all the samples being what may be called intact, with only a slight rusting where the wires were attached, entirely to be expected on account of the thinness of the metal and the slight wearing on the wire. Of these three paints two were used on the field coating of the bridge, " No-brack " being used on the main bridge and Detroit Graphite on the viaduct. This test was most startling in showing the exaggerated claims

made for so many of the forms of commercial paint.

After selecting the kind of paint to be used, it is of the utmost importance to see that the application of the paint is properly performed, nearly as much depending on the manner of application as on the intrinsic value of the paint itself. The importance of securing a good shop coat has already been noted, and cannot be too much emphasized, since it is impossible to secure good work in the field on top of a poor shop coat, especially where the metal has not been properly cleaned, or where there is mill scale under the shop coat.

On the shipments from Pennsylvania, it was found that the shop paint was considerable damaged when the steel arrived, and it was always insisted on that this material be touched up at once, so as to prevent any further rusting during the time that the steel was in storage or being erected. This period was necessarily from a year to eighteen months, although the first field coat was applied as soon after erection as possible. The field rivets were spotted with a coat of the shop paint as soon as the points were approved by the inspector, and the first field coat followed directly after the riveting. Most of the steel had been so handled in the yard as to be fairly clean, and little cleaning was required except for the deck span, which had been unloaded ready for erection on the ground beneath the span when the river had overflown its banks, depositing a layer of river sediment on the steel which required a great deal of washing and scrubbing to remove. No amount of effort would fully remove the stain on the paint, so that a careful examination was necessary to determine when all of the dirt was removed that was possible. After the field coat had been applied, no difference between this and the

other steel could be observed.

A very great deal depends on the willingness and ability of the painters in cleaning and painting carefully, since no amount of inspection will absolutely assure good workmanship throughout. On the viaduct it was found necessary to rule the painting subcontractor from the work, on account of repeatedly failing to follow out the inspector's instructions, but on most of the work very good results were obtained. The two field coats were of a different color, the first being green and the second black, in order to easily detect misses or "holidays" in the second coat, and the contractor was required to swab all places which a brush would not reach, such as the eyebar heads where closely packed and the ends of built up members on pins. The tops of stringers were painted before the ties were laid, and all points inaccessible after erection were given an extra coat in the shop. Many places seemingly inaccessible were reached by means of long handled brushes, and before final acceptance a thorough inspection was made of the entire structure, to assure the very best condition of protective coating that could be obtained.

VIII. Records and Reports.

1. Diary and photographs- On the superstructure there was no need to keep so thorough a system of progress reports as on the substructure, first because the nature of the work did not demand so thorough a knowledge of each detail, much of the work having already been completed in the shop, and second because the unit price form of contract threw most of the responsibility for progress and all responsibility for cost on the contractor rather than on the engineer. Nevertheless a very complete form of record was maintained, the engineer being at all times in touch with the planning of the work, and assuming partial responsibility for progress.

A most satisfactory and comprehensive form of record was contained in the daily report or diary, the form for which is shown in plate XXI, page 138. On the left side of the sheet was entered each day the material unloaded, with the contract for which it was intended, the spans being divided into different contracts, thus keeping the steel report separate for the different spans. The car number for each entry was given, thus identifying the shipment, and the weight of carban and alloy material in the shipment. By adding the previous days report, this record became accumulative, so that the percent delivered to date could be ascertained at a glance. Similarly on the right of the sheet each separate member was entered as it was erected,with the contract number to identify the span to which it belonged, and the weight of the piece, listed in the carbon or alloy column as required; and this record also was totaled each day, so as to give the percent erected at all times.

DAILY PROGRESS REPORT

ARKANSAS AND MEMPHIS RAILWAY BRIDGE AND TERMINAL COMPANY

OFFICE OF RESIDENT ENGINEER

837 DELAWARE AVENUE

MEMPHIS, TENN.

MATERIAL UNLOADED				MATERIAL ERECTED			
CONTRACT No.	CAR No.	WEIGHT		CONTRACT No.	MEMBER	WEIGHT	
		ALLOY	CARBON			ALLOY	CARBON
Total today				Total today			
Total previous				Total previous			
Total to date				Total to date			
Per cent. unloaded				Per cent. erected			

REPORT OF RIVETING

	CONTRACT	CONTRACT	CONTRACT	CONTRACT
No. of Rivet Gangs				
Driven today				
Driven previously				
Driven to date				
Rivets required				
Per cent. riveted				

DIARY. River Stage Weather

Approximate Force, Erection men, Falsework men, Yard men. Total number of men working today

Plate XXI

In addition this diary sheet showed the progress of the riveting on each span, with the number of rivets driven each day and the total driven to date, with the percent of completion. Also a notation was made of the stage of the river, which was kept throughout the entire job, and a record of the number of men working on each part of the structure, and following that remarks were made as to general progress on each phase of the work, and any notes of interest or record which might have a bearing on the work and useful for reference. A copy of this report was sent to the main office daily, thus keeping the chief engineer in complete touch with all parts of the erection process.

All during the superstructure erection, moreover, the same progress photographs were made as was described for the substructure. These were taken on the average of one each day, and aimed to record all movements of interest, both as a matter of record, and also to give the main office an idea of the manner in which the work was being carried out. The entire series not only formed a valuable record but also an interesting story of the process of erecting the bridge.

With the diary sheet and the photographs, the engineers at the main office were well supplied with information as to progress, but two other methods of report were used in addition. The one was a weekly letter telling of the general progress of work, and calling attention to any points or any details needing the action of the main office, as well as outlining the expected progress during the following week. The other was a monthly report in the shape of a line diagram of the entire bridge, showing in colored ink the members previously erected and the members erected during the month. At the resident engineer's office a similar line

diagram was kept up to date, showing in different colors the members erected during successive months, and also the falsework installed monthly. This diagram was useful in showing the percent of completion of the entire structure with respect to length, much better than could any statement of percent of completion according to weight; and also in showing the relative rate of progress monthly, thus indicating what could be expected for the remainder of the erection.

2. Records for payment- Since the final settlement of the contract for superstructure was made on the report of the shop inspector of the total weight shipped, as summarized on the shipping invoices, all records for payment made in the field were for partial payments only, and did not require a very high degree of accuracy. In fact, the diary sheet was in itself a most satisfactory record of completion for monthly payments, since the sheet for the last day of the month gave both the total weight for which delivery price should be paid, and the weight for which the erection price should be paid.

The entry for material delivered, being taken from the contractors certified invoices for each shipment, became in effect a summary of the invoices on the entire work, and the entry made on the day the last shipment was received was the total weight for which the contractor received final payment. The entry for material erected, on the other hand, was made from the from the weight of each individual piece of steel as entered from the invoices opposite the mark of the member concerned in the engineer's record book, as already described. In thus entering and transposing, some few errors were natural, especially on account of many pieces having the same mark, so that the total showing when all material had been

erected was somewhat different from the inspector's final report; the error, however, being a small fraction of a percent, and in no way affecting the payments on the work.

This method of checking the steel was in fact most satisfactory, and while involving considerable care in maintaining the record, on account of being handled as it came in each day, the actual work involved was small. Familiarity with the arrangement of the record book made entry from invoice to book a simple matter, and the corresponding entry from book to diary sheet was similarly an easy matter. Not only did the record book thus give a permanent record of the progress and condition on all the spans, but it also saved hunting through invoices to obtain weights of members when making up estimates, and avoided the errors inevitable in making up a monthly estimate from a large number of invoices, in which there is considerable duplication of marking.

This record book proved of great value also in keeping track of the material to replace that lost during the washout. Part of this was replaced without additional cost by the steel company, but compensation was made in part by paying an additional price of two cents a pound for both the railway and roadway stringers that were lost, this being the greater part of the weight, and the allowance being necessary to secure the completing of the work.

The record of all pieces of decking as delivered and erected was also kept in the record book, with an outline of the material required to complete the work, so that reference to the book gave the percentage of decking delivered at any time, and also the number of pieces required to complete. This record of material on hand was checked against the inspector's report of material shipped

from the creosoting works, and near the end of the shipments, a schedule was made up of pieces required to complete, taken from the record of delivered material, which was included in the last shipment, together with the allowance of extra pieces, in order to complete the decking and have several pieces of each kind on hand to replace damaged work and make repairs in the future. The payment for the creosoted material was made directly by the bridge company, on invoices of the contractor, certified by the inspector, at different rates per thousand for different classes of material.

A summary of the cost of the superstructure is as follows.

Steel for Main Bridge.

Carbon steel	14,889,839 #	@ .0486	$	723,646.18
Alloy steel	17,802,254	.0578		1,028,970.28
Wedges	412,564	.095		39,193.58
Additional replace	663,586	.02		13,271.72
		TOTAL		1,805,081.76

Steel for Viaduct.

Main contract	11,420,740 #	@ .0275		314,070.35
Add'l Roadway	724,320	.035		25,351.20
		TOTAL		339,421.55

Total cost of steel superstructure	$	2,144,503.31
Total cost of creosoted decking		108,631.73
Mat protection charged to superstructure		12,468.62
TOTAL FOR SUPERSTRUCTURE		2,265,603.66

CONCLUSION

IX. General Summary.

1, Preparation of engineer's report. No better summary of the engineering supervision or of the entire construction of the Memphis Bridge can be made than that contained in the final report of the consulting engineer to the president of the Bridge Company upon the completion of the work. This report was printed and bound in a folio volume with numerous plates illustrating the work, the whole forming a most concise and readable description of the more important features of the construction, giving all the essential points of interest to the engineering profession, yet at the same time so written as to be easily understood by the layman.

From the very inception of the work, the engineer's records were so kept as to mimimize the task of assembling the data for the final report, which would otherwise have been extremely arduous. But with the diaries and schedules that had been prepared throughout the entire job, and the drawings and diagrams that were ready for photographic reproduction, the preparation of the report became more a matter of editing, to make a proper choice of the material to be contained, and to group the whole in the most presentable manner.

The body of the report is very brief, giving only a general narrative of the project, and a description of both the substructure and superstructure. The general narrative covers the time from the first instructions to the consulting engineer to proceed with the work, to the turning over of the bridge to the client, giving in succession the steps taken by the engineer and the resulting progress on the project. These steps have already

been described in detail in the previous chapters, and may be summarized herewith as follows; the preliminary design, selection of the site, obtaining the approval of the War Department, establishing the field office and laying out the work, letting the contract for the substructure and supervision of this construction, preparing plans, securing bids and letting contracts for the superstructure, adjusting superstructure contracts on account of financial complications and again on account of the washing out of the falsework, and the supervision and completion of the superstructure.

Next in order comes the description of the bridge itself, giving the general physical conditions of the location governing the design, the division of the bridge into spans,giving the main dimensions and clearances, the type of superstructure and a comparison with the old bridge, and a statement of the grades on the approaches. Following this is a more detailed description of both substructure and superstructure, giving the points of greatest interest in the design and construction.

The main considerations in designing the piers is first taken up, based on the original borings, the records from the old bridge, and the modifications based on tests on the clay. In this design, the skin friction was assumed at 400 pounds per square foot, a quite conservative figure, and the size of the different piers was such as to give final pressures on the foundations varying from 3.1 to 5.1 tons per square foot for the four main piers. A table gives the main dimensions of these piers, and the weights sustained, and a description of the construction of the piers and the sinking of the caissons is given in brief form. Next the piers are taken up in order individually, with a history of the con-

struction, describing the difficulties encountered, the variations made in the design, the mat protection work, and the accident in the sinking of pier V, due to gas in the working chamber. A table of the volumes of the piers and the unit costs is given, with a comparison of these costs with those obtaining on the construction of the old bridge more than twenty years previous; and a list of the floating equipment and barges used in the substructure construction and becoming the property of the bridge company on the completion of the work concludes the description of this part of the work.

The description of the superstnucture takes up first the reasons for selecting the cantilever type of design, and the advantages of oonstructing the superstructure in the manner chosen. The question of the advantage obtained through the use of an alloy steel is also considered, showing the resulting economy from the use of " Mayari " steel. Expansion devices and the method of anchoring the Tennessee arm are described, and the assumed loadings in making the design are given, which in general are based on Cooper's E 55 loading on both tracks. The total weight of both carbon and alloy steel in the various parts of the structure are then given summarized in tabular form, and following that a brief history of the erection of the superstructure, A description of the west approach viaduct completes the main body of the report.

Reproductions from the progress photographs illustrate the work and add much to the attractiveness, since such views give the best possible description of the bridge and the processes of construction. Several appendices supplement the main report, giving lists of the personnel of the bridge company, of the engineers and contractors employees, a copy of the acts of congress author-

izing the construction of the bridge, copies of the specifications for cement and for the superstrucure of the main bridge and viaduct, and also copies of the results of tests on eyebars, already commented on.

The preparation of plates showing the substructure construction has been previously described. In addition to the record drawings of piers and abutments giving the final dimensions of the work as actually constructed, and of the caisson details and general map, reproductions were made of the charts showing the records of the river guage and also of the progress in sinking, and in addition the record sheets of the sinking of the two most important caissons were given. The whole gave a most comprehensive resume of the entire substructure construction.

For the superstructure, record drawings were required of the contractors as part of their contract, since the latter were in a better position to produce them in connection with the detailing of the steel than were the engineers. These record drawing included stress sheets for all the spans, and detailed elevations of a part of each span, with typical sections, and were not by any means working drawings, but rather typical details to show the actual type of construction of all parts of the structure, to indicate the general dimensions, size of material, and make up of members and connections, without the confusion of detailed dimensions and rivet spacing. In this form they afford an accurate yet easily readable record of the entire superstructure.

The compilation of this report naturally involved considerable time and study, but it was produced in complete form a few months after the completion of the bridge, and forms a most creditable record of the efficiency of the engineering supervision.

2. Summary of quantities and costs- The engineer's report having summarized the main features of the bridge so thoroughly, there remains little that can be given without duplication; however, the following tables, taken from computations made by the engineers in the field, give information not therein contained, which may nevertheless be of some interest.

SUMMARY OF TIMBER - SUBSTRUCTURE

Timber in Anchor Pier	160,842	ft, B.M.
" " Caisson I	705,678	" "
" " " II	931,068	" "
" " " III	821,206	" "
" " " IV	561,127	" "
" " " V	323,169	" "
TOTAL	3,342,169	" "

SUMMARY OF CONCRETE- SUBSTRUCTURE

	Caisson	Shaft	Total	
Anchor Pier, wing walls			86	cu.yd.
Anchor Pier, body			2670	"
Pier I	4959	1900	6859	"
Pier II	4555	3670	8225	"
Pier III	4593	3860	8453	"
Pier IV	4192	1390	5482	"
Pier V	2471	642	3113	"
Piles			1623	"
Pedestals	base 2300	2330	4630	"
West Abutment			900	"
		TOTAL	42,041	"

SUMMARY OF GRANITE- SUBSTRUCTURE

	Volume of granite	Vol. of pier	Per cent granite
Anchor Pier	4,470 . cu.ft.	76,567 cu.ft.	5.8 %
Pier I	48,228 "	97,613 "	49.5 %
Pier II	75,890 "	174,877 "	43.5 %
Pier III	78,690 "	180,031 "	43.5 %
Pier IV	47,807 "	83,906 "	57.0 %
TOTAL	255,085 "	612,994 "	41.7 %

SUMMARY OF STEEL- SUPERSTRUCTURE

	Carbon	Alloy	Total
Deck Span	2439463 #	327522 #	2766985 #
Anchor Arm	2246358	1247260	3493618
Cantilever Arms	2256740	4467490	6724230
Suspended Spans	3353546	4933106	8286652
Fixed Span	3654794	6826876	10481670
Roadways	938938		938938
TOTAL IN MAIN SPANS	14889839	17802254	32692093
Adjusting Wedges	412564		412564
Strengthening,(addition)	278889		278889
Replace Railway "	384697		384697
Repairs(not paid for)	2720		2720
Replace Roadway "	558609		558609
TOTAL FROM PA. STEEL CO.	16527318	17802254	34329572
Approach Viaduct	12145060		12145060
TOTAL STEEL FURNISHED			46474632
			= 23237 TONS

SUMMARY OF COSTS

Substructure

Item	Quantity		Unit Price	Total
1. Dry Excavation	9204	cu.yd.	$ 3.22	$ 29,750
2. Pneumatic Excavation	33,625	" "	5.50	185,000
3. Timber in caissons	3,342	M.B.M.	95.00	318,650
4. Concrete, working chamber	3,055	cu.yd.	9.80	29,850
5. Concrete, mass work	31,170	" "	6.05	188,650
6. Concrete, form work	6,497	" "	10.45	67,986
7. Granite Masonry	9,448	" "	37.30	352,775
8. Reinforcement	204	Tons	71.40	14,575
9. Concrete Piles	39,210	lin ft.	.97	38,125
10. Mats and Bank Protection				78,875
			SUBSTRUCTURE TOTAL	1,304,236

Superstructure

1. Steel, main bridge	16,346	Tons	110.00	1,805,082
2. Steel, viaduct	6,072	"	55.80	339,422
3. Creosoted Decking	2,090	M.B.M.	51.80	108,632
4. Mat work, falsework protection				12,468
			SUPERSTRUCTURE TOTAL	2,265,604

TOTAL COST OF BRIDGE $ 3,569,840

STATEMENT OF EXPENDITURES FOR CONSTRUCTION OF MEMPHIS BRIDGE

JANUARY 1, 1907.

Interstate Commerce Commission Classification.

1. Engineering		$ 168,775.69
2. Land for Trans.Purpose		198,150.12
3. Grading		194,934.44
6. Bridges,Trestles & Culverts		
6a.Anchor Pier	$ 58,104.69	
6a.Pier I	175,034.08	
6a.Pier II	345,516.67	
6a.Pier III	364,621.61	
6a.Pier IV	171,074.22	
6a.Pier V	75,943.71	
6a.Via.Substructure	114,841.17	1,304,236.45
6b.Main Superst.	1,805,081.76	
6b.Via. "	339,421.55	
6b.Decking	108,631.73	
6b.Mat Protection	12,468.62	2,265,603.66
6c.Approach Subways		26,169.76
8. Ties		54,390.03
9. Rails		21,396.41
10.Other track material		21,057.77
11.Ballast		3,356.61
12.Track laying and surfacing		11,457.20
15. Crossings and signs		31,235.99
16.Buildings		638.26
17.Roadway buildings		187.35
25.Telegraph and telephone lines		1,137.78
27.Signals and interlocks		2,056.31
35.Miscl structures		93.42
37.Roadway machines		84.00
38.Roadway small tools		373.02
40.Revenue during construction		3,666,07Cr.
43.Other expenses		908.97
TOTAL ROAD EXP.		4,302,575.37

GENERAL EXPENDITURES

71.Organization expenditures		2,071.85
72.General office and clerks		20,168.44
73.Law		24,638.14
74.Stationery and printing		1,162.02
75.Taxes		40,482.74
76.Interest during construction period		667,231.48
76a " " " received		21,888.23Cr.
77.Other expenses		2,304.24
TOTAL GENERAL EX.		736,170.68
GRAND TOTAL		$ 5,038,747.05

X. Results of Engineering Supervision.

In the preceeding pages a study has been made of the construction of the New Memphis Bridge, with special reference to the engineering supervision of the project during construction, and the methods used in this supervision have been described in detail. In this last chapter an attempt will be made to show the need of such supervision on construction work of this character, and the results that are obtained by it.

Indeed, on a project of the scope and magnitude of the one under consideration, it would be impossible to think of undertaking the construction without the most competent engineering advice, both in the planning and the execution of the work; and the services of the highest engineering talent would have been required in a consulting capacity, even if the details of inspection had been entrusted to inferior assistance. On work of less importance, especially, such as all ordinary sized bridges, it is usual for the railroads to use the regular engineering force for such duties, instead of calling in a specialist, with results that no doubt entirely justify this practice. To such an extent has the designing and detailing of steel bridges been standardized, moreover, that it is becoming the tendency to accept the standard design of some steel company for all bridge work, without securing any outside engineering advice. This latter practice cannot be approved, since it leads to inferior workmanship and uneconomical design, without the assurance of permanence and strength; and the absence of adequate supervision frequently results in disputes with the contractor, delays in completion, and excessive costs.

It is usually considered that the greatest value of engineering supervision lies in the securing of excellence of workmanship; and indeed the underlying idea of the greater part of such supervision is that of inspection, in order to force the contractor to perform his work correctly, and comply with the specifications. While this view of the duties of the engineer is very limited, yet a great deal can be accomplished by conscientious inspecting of all construction work, and the results of such inspection should not be depreciated.

This cannot be better illustrated than by the condition of the Eads Bridge in St.Louis, which it was the privilege of the writer recently to investigate. After close on to fifty years of service, being much of the time far more heavily loaded than originally contemplated, the physical condition of the bridge today is almost as perfect as the day it was finished. Care has been taken to preserve the steel by adequate painting, and with the exception of some minor repairs of pin points, and a strengthening of the floor system, practically no defects have required any attention in all the years of use; and the granite piers shows no signs of deterioration whatever. The secret for this perfection can be found by studying the very comprehensive report prepared by Professor Woodward on the construction of the bridge, which describes minutely the extreme pains taken to secure the very best materials and workmanship throughout the entire construction. This bridge being a departure from ordinary bridge construction, many experiments were performed to ascertain the best grade of materials and the best shop practice, and no pains were spared to obtain the very best that was possible. As a result the structure stands today as a monument to the painstaking supervision as well as the genius

of the designer and builder, Capt.Eads.

In contrast to this, another bridge in the same locality, the Merchants Bridge, although erected over twenty years later, already shows several defects, due to careless shop work, which have necessitated expensive repairs, a condition which could easily have been prevented by careful inspection during fabrication and construction. Many other examples of deterioration of more recent structures exist, enough to give adequate proof of the very great value of thorough inspection; and considering the large amount of the investment, and the comparatively small cost of competent inspection service, it would seem entirely unnecessary to point out the wisdom of securing the very best of inspection, in order to lessen the possibility of rapid depreciation, and the exorbitant cost of repairs.

But the highest type of engineering supervision means much more than close inspection, and a constructive inspection, in cooperation with the contractor, will secure results far superior than will ever be possible by a watch-dog policy. By taking active charge of construction, and using initiative and judgement in handling the work, the engineer will secure for his client not only the very best in the way of workmanship, but will also actually secure more reasonable costs, a more rapid prosecution of the work, and eliminate disputes which are otherwise almost unavoidable.

Particularly in creating harmony between the different contractors and between the contractors and the client is the function of the engineer an important one. By assuming the entire responsibility for the correctness of the location of all substructure, all cause for argument between the two main contractors is eliminated, and by passing on each phase of the work as it pro-

gresses, there can be no dispute as to the performance of all contract obligations. As an arbritrator on all questions which may arise, the engineer by rendering wise and just decisions can secure the good will of all parties, and by assuring the contractor of fair treatment and equitable estimates and remuneration for his work, a harmonious relationship can be established which is in the interest of all parties concerned.

Next, by coordinating efforts of the different contractors, and giving careful consideration to methods of procedure, very much can be done to prosecute the entire project more rapidly than in any other way. Even the offering of a bonus for early completion will seldom accomplish results as satisfactory as can be obtained by adequate supervision of the work; and by constructive criticism and helpful suggestions, as well as constant pushing and careful planning, the engineer can do more than would be thought possible to secure rapid work. Without such supervision, work will inevitably tend to lag, and frequently by a delay in some detail overlooked until the last minute, the completion of the entire structure will be postponed. This function of the engineer, frequently ignored by socalled inspectors, is one of the most important of all.

Lastly, one of the most important results of competent supervision is the obtaining of results with reasonable costs. This is of course especially true on contracts taken on a cost plus percentage basis, but even on lump sum contracts there will usually be extra work on which costs can be reduced by careful supervision, and on unit price contracts there is opportunity for a considerable saving by careful work on the part of the engineer. By an examination of the costs on the different units of the substructure,

given on preceding pages, it is readily seen that the cost of the work, even on a percentage basis, is far less than would ordinarily be obtained on competitive bids, and is really most reasonable, a result due not only to the efficiency of the contractor, but also in large measure to the supervision of the engineer. The summary of all costs of the bridge project shows that the engineering costs amount to three and a third percent of the total cost of the work, an amount which might easily have been saved in the reduction of costs through careful supervision alone, without considering the other results of having competent engineering service.

The beneficial results of the constructive type of supervision have already been demonstrated in the case of the Memphis Bridge, in securing an adequate structure, to the entire satisfaction of the client, maintaining the good will of the contractors, within a remarkably short time, and within a very reasonable cost. This type of supervision is highly desirable on all engineering work, and should be encouraged as much as possible. The results of the care taken to secure good material and workmanship will, it is hoped, prove equally beneficial, and will be shown in time by the durability of the structure and the service rendered.
