SOUTH STREET BRIDGE.—NEW WEST APPROACH.

BY G. WHITEFIELD CHANCE.

The South Street Bridge, crossing the Schuylkill at Philadelphia, is one of the few bridges in this country erected on large cylindrical iron columns, filled with masonry, as piers. Two other bridges with such piers are well known, viz., that across the Harlem River, and the great Atchafalaya Bridge, on the Texas and Pacific Railway, built by Major Anderson.

It is very doubtful whether this method of obtaining supports for trusses possesses any material advantage over the ordinary caisson and masonry pier method; while for arch abutments, where the horizontal thrust comes into play so powerfully, this style of pier, as at present built, is of course not advisable.

The bridge, which it is our purpose to describe, was built between the years 1872 and 1876 under a commission authorized by an act of the State Legislature. It was erected in opposition to the wishes of City Councils, who filed a protest against the action of the Legislature.

Moses A. Dropsie and ex-Judge Findlay were the successive Presidents of the Bridge Commission. A contract to build the structure was made by the Commission with John W. Murphy, C. E., on March 30, 1870, for \$770,000. The total cost amounted to \$865,000.

Mr. Murphy died about a year before the completion of the bridge, and it was finished by his executors.*

The somewhat great length of time consumed in the erection of the structure was mainly due to legal delays.

GENERAL DESCRIPTION.

The bridge and approaches have a total length of 1,934 feet 7 inches. The bridge proper consists of two 195 feet 8 inch fixed spans, of the Murphy-Whipple form of truss, and a draw 198 feet 2 inches long, of the same type between.

The depth of all the trusses is twenty-seven feet.

* See biographical notice of John W. Murphy, C. E., by W. Barnet Le Van, read before the FRANKLIN INSTITUTE, Philadelphia, October 21, 1874.

The shore spans have a breadth of thirty-six feet between trusses, while the total width between railings on the outside of footways is fifty-five feet.

The columns of the trusses are of the Reeves patent.

The shore ends of the fixed spans each rest on stone abutments, while the river ends each rest on two eight feet in diameter iron columns. These columns are braced laterally, and the space between them filled in with loose stone and masonry.

The columns are of cast iron, and are in sections 10 feet in length, $13\frac{3}{4}$ inches thick, bolted together by inside flanges at each end, $23\frac{3}{4}$ inches wide and $13\frac{3}{4}$ inches thick. The flanges are pierced with holes five inches apart from centre to centre, which are filled with one and one-fourth inch bolts. The sections resting on rock are cut-off square and secured to the rock by means of iron brackets and fox wedges. Each ten feet section weighs 14,600 pounds. The inside of the columns is filled with rubble masonry.*

PIVOT PIER.

The pivot pier is formed of eight columns, four feet in diameter spaced equally around a circle of twenty-eight feet diameter, and tangent thereto. These columns carry the track on which the wheels of the turn-table run. The pivot rests on a six foot in diameter column, and has a Sellers' Patent Centre.

The six foot column weighs 10,800 pounds per section of ten feet, and the four foot column, which is one and one-fourth inches thick, 6,800 pounds per ten foot section.

The columns average about sixty feet in length. They are all braced vertically and horizontally by I-beams and tie rods, and below low water they are surrounded by a cribwork filled with rip rap. The load on the pivot pier from the draw span when open, is 400 tons.

The clear water way on each side of the pivot pier is seventy-seven feet.

Piers of masonry are placed up and down stream eighty-eight feet from the centre of pivot pier for supporting the draw when open, and also to serve as guard piers.

* For full description of method of sinking cylinders, see article by D. McN. Stauffer JOUR. FRANKLIN INSTITUTE, Vol, 64, p. 320.

EAST APPROACH.

Commencing at the river and going east is the abutment pier, 40 feet 10 inches in length, built on a hard gravelly soil; it is of granite with pilasters and Doric capitals.

Then come three conoidal brick arches of original design built on a line which curves to the left. The curve has a radius of 160 feet, and the central angle subtending the arc between the tangents at beginning and end of curve is $33^{\circ} 25'$, the length of curve being 114 feet 6 inches. The facing of these arches is of brown sandstone with granite trimmings, the piers being granite.*

After the arches, there is 363 feet 6 inches of broken range ashlar retaining wall of brown sandstone with granite trimmings, the approach descending at a steep grade to the level of the street. The total length of the approach is 518 feet 10 inches.

OLD WEST APPROACH.

Commencing at the river and going west was an abutment 40 feet 10 inches in length, similar to the eastern abutment, placed on 517 piles driven butt down, and connected by a timber grillage. Then came nine segmental brick arches, each of 43 feet 6 inches span, and 14 feet rise, 2 feet deep, placed on granite piers 5 feet 6 inches wide. These arches covered a distance of 391 feet 3 inches. After the line of arches was an abutment pier of granite 62 feet 4 inches long. Between this pier and the granite retaining wall 87 feet 4 inches long ending the approach, were three Pratt trusses, 244 feet 9 inches total length, resting on eight wrought iron columns. These trusses carried the approach across the Philadelphia, Wilmington and Baltimore and the tracks of the West Chester Railroad.

In the new west approach, the above enumerated features remain intact with the exception of the line of arches with their piers and the railroad abutment pier.

The total length of the west approach is 826 feet 6 inches.

PROFILE.

The general character of the soil along a profile section through the centre line of the bridge, is as follows: At the surface, tough

* For full description of conoidal arches, see "Proceedings of Engineers' Club of Philadelphia," Vol. 1, p. 95.

mud extending to considerable depth in some places, then coarse gravel underlying, then very coarse gravel, and finally an undulating micaceous gneiss. Lying directly on the rock in the river bed, are considerable quantities of drift wood, evincing great age and a long occupation by the river of its present position.

The rock which at the eastern river abutment is five feet below the bed of the river, or seven feet below low water, shelves off to eighteen feet at the draw pier, or thirty-four feet below low water, while at the western column pier it is thirty feet below the bottom or thirty-eight feet below low water.

The iron columns were all sunk to rock by means of the plenum pneumatic process.

CRACKS IN COLUMNS.

Some of the iron columns of the pivot pier have cracked badly.

Some of these cracks occurred shortly after the bridge was erected.

The columns were cast from Government cannon, originally made from cold blast charcoal pig.

The cracks commence at the joints and extend both ways in some instances, generally vertically, as far as six feet from the joints. They vary in width from zero to two and one-half inches.

It is most likely that the cracks were caused by water freezing inside of the columns. The force exerted by water in freezing, or in its effort to freeze when confined, is probably as great as 30,000 pounds per square inch. (Trautwine.)

From the fundamental formula in hydromechanics,

$$e = \frac{rp}{T}$$

in which,

e = the thickness of a pipe to resist longitudinal rupture,

p = the pressure on unit area,

T = ultimate tensile strength of material of pipe,

r = internal radius of pipe,

we may calculate how thick a pipe or column would be required to sustain a pressure of 30,000 pounds per square inch. Taking the ultimate tensile strength of the metal of Government cannon at 38,000 pounds per square inch, we find that the column should have a thickness of about eighteen inches, while it has only one

and one-fourth inches. This theoretical thickness is probably too great, owing to the fact that expansion could take place and so relieve the pressure.

Water could have entered the columns in several ways, either

PLATE I. Exhibiting Cracks in Iron Columns.

at the section joints, from the top, or through holes in the columns, four of which are shown under the I-beam in the column on the left of *Plate I*, which is an engraving taken from a photograph by Prof. L. M. Haupt. A somewhat significant fact is that out of nine

large cracks in the pivot pier columns, six are below the level of high stages of the river.

The verticality of the cracks shows a horizontal force of some kind acting radially from within.

The cracked sections have been bound around by wrought iron bands $\frac{3}{4}$ of an inch thick by $5\frac{7}{8}$ inches wide, clamped with bolts and nuts.

OLD ARCH PIERS.

The arch piers of the western approach were each built on eighty-four piles, not driven to rock, but to a hard gravel stratum. These piles, together with the piles used under the abutment piers, some 1,200 in all, were of Nova Scotia spruce, averaging ten inches on the head, and were driven butt ends down.

FAILURE OF.

On Sunday, February 10, 1878, a very unfortunate accident occurred to the west approach.

Pier No. 7, numbering from the river abutment westward and 385 feet from the river, sank at its northern end some sixteen feet, involving a falling in of its two arches; and since the arch piers were not sufficiently massive to withstand the horizontal thrust of each arch separately without the resisting thrust of the adjoining arch, the whole line of arches fell in ruins.

At pier No. 7, the piles were driven through fifteen feet of mud to a bed of gravel, by a 2,000-pound hammer, and received, as a final test, four blows from the hammer falling thirty feet, when one inch downward motion was the maximum allowance for each blow.

At the large abutment pier, 100 feet west of the failing pier, the gravel bed just mentioned is within a foot of the surface, and it seems to dip from this point uniformly towards the river, where it is forty-five feet below the surface.

D. McN. Stauffer, Assistant Engineer of the bridge, says: "The estimated load on the piles under the pier was 2,000 tons, or twenty-three tons on each pile. According to Rankine, for pile work under similar circumstances, each pile was good for eight tons frictional value, leaving fifteen tons on the toe of the pile. The tremor produced in the piles by travel on the bridge would gradually loosen them sufficiently to allow percolation of water down their sides, and finally throw the whole weight on the toe of

the pile. If the bed of gravel was merely a thin bed, or pocket, as the water softened it the additional weight, before sustained by friction, probably allowed a bunch of piles at the north end of the pier to settle down into the soft material beneath the gravel." He also says:

A small expenditure to put in tie rods between the two adjacent piers to No. 7 would have saved seven out of the nine arches. Borings made twenty feet from each end of the failing pier showed, at the south end gneiss 33 feet 8 inches below the surface, overlaid by from eighteen inches to twenty inches of gravel and then a considerable thickness of a hard, very compact, yellowish clay.

At the north end, rock was found thirty-seven feet below the surface, above which was 3 feet 8 inches of black mud and above this seven feet of gravel mixed with clay.

In excavating for the new foundations of pier No. 7, the largest pile found was fifteen feet in length. Some of the piles of the east row were found to have their ground ends higher than their heads, the piles pointing in a northeasterly direction (the pier runs nearly North and South), making an angle of about 30° with the horizon. The piles of the row next to the east row were found to have been broken off two feet below their heads, the remainder being held in place by the concrete surrounding.

The diagram of old arch with piers Nos. 6 and 7 (*Plate III. Fig. 2.*) will render it easy to make calculations for the total load on each pile.

The cut stone masonry of the face of the arch, including the arch rings, spandrel walls and coping, extended in on an average three feet. The arch was of brick while the haunching, as shown by the dotted lines, was of rubble. Above the haunching was gravel filling, on top of which was a granite pavement four inches deep. The piers were of granite, while the foundations were of rubble. A timber grillage, some two feet thick, covered the piles. The barrel of the arch was fifty-five feet long.

From Trautwine's formula for safe load for piles, we have :

$$L = \frac{F \times .023 \sqrt[3]{h} \times w}{s + 1}$$

in which,

L = safe load in tons ;

h = fall of ram in feet ;

w = weight of ram in pounds ;

s = last sinking of pile in inches ;

F = factor of safety.

Using the quantities before given, $h = 30$ feet : $w = 2,000$ pounds, and $s = 1$ inch, we find, taking one-third as the factor of safety, which is large considering the conditions there present, the safe load would equal 23.8 tons per pile.

NEW GIRDER APPROACH.

A temporary wooden structure was used for travel during the construction of the present handsome girder approach, completed December, 1885.

The new girder approach, which takes the place of the old arches, consists of 446 feet of wrought-iron plate girder bridge work, 57 feet in width, with a roadway 35 feet 8 inches, and two footways, each 9 feet 8 inches in width.

It is divided into nine spans, supported by wrought iron columns on masonry piers. Six of the piers are built on the old foundations, while the seventh or failing pier has an entirely new one. (*See Plate II.*)

The railroad abutment pier adjoining the arches was reduced in length to fifteen feet.

The foundations of pier No. 6 were strengthened at its south end and its plan was changed to make its transverse centre line oblique to the centre line of bridge, in order to accommodate certain railway tracks ; this involved in all a driving of forty-six piles.

Pier No. 7 was built over again, and its plan was also changed so as to make it parallel with pier No. 6.

Eighty-eight new piles were used in its foundations, from 22 to 30 feet long and about 12 inches in diameter on the head, some of which were driven to rock by a 2,200 pound hammer. These piles were of oak, straight growth and barked, and were originally about forty feet long when driven, but were cut off to -9 feet below datum.*

* City datum, $8\frac{52}{100}$ feet above mean low water, Delaware R.

The spaces between these piles were filled for three feet below their heads with concrete. They were capped transversely to the line of bridge with 12 x 12 inches hemlock timbers, fastened to the piles with locust tree nails $1\frac{1}{4}$ x 24 inches, and a platform 10 x 60 feet of 10 x 12 inches hemlock timbers at right angles to the caps, laid close, was then secured to the cap pieces at crossings by $1\frac{1}{4}$ x 18 inches locust tree nails.

Rubble masonry 9 x 59 feet was then laid on the platform and carried up with a batter of about one foot on two-thirds inch all around to within -33.5 feet of curb on roadway. Five courses of pitched ashlar, each about two feet deep, were then laid on and covered with a coping eighteen inches thick. Each pier is 5 feet 6 inches wide, and has sixteen bolts and eight plates built into it for anchoring the iron columns; there are two plates and four bolts to each column.

PLATE GIRDER SPANS.

The plate girder spans are each about forty-nine feet in length, and are formed of four lines of girders each about four and three-fourths feet deep, resting on four wrought iron columns at each pier. Each column is formed of two twelve-inch channel bars, weighing thirty pounds per lineal foot, connected on the flange side of their webs by a ten and one-half inch I-beam, thirty pounds per lineal foot. The columns are bolted to the piers by four one and one-fourth inch wrought iron bolts, extending through the coping and two additional courses of stone, and connected by two tie plates, each 4 x $\frac{1}{4}$ x 24 inches.

The inside lines of columns are placed sixteen feet transversely on the piers from the outside lines, while the inside lines are fifteen feet apart. Each column of the outside lines is braced with each column of the inside lines, on each of the piers, by a nine-inch I-beam, twenty-three and one-half pounds per lineal foot, placed at the top of columns, and the panel formed by the two columns, I-beam and pier, is tied with two one and one-fourth inch square wrought iron rods, with turnbuckles, placed diagonally.

The outside and inside lines of girders are connected over each pier and half way between spans by vertical panels of bracing, each consisting of two five-inch, ten-pound channel bars, placed at the bottom of the webs of the girders, and two three-fourths inch round wrought iron rods, placed diagonally, and running

from the top of one girder to the bottom of the other, with connections, as shown in *Plate III. Fig. I.* Each horizontal panel formed by the two girders and the two five-inch channels, just mentioned, dividing the span into two equal parts, together with the two five-inch channels over each pier, is tied by two diagonal round wrought iron rods, each one inch in diameter. All transverse rod bracing is tied at intersections by copper wire.

There is no bracing of any kind connecting the inside lines of girders.

At every second pier a distance of about one-half inch is allowed between the ends of girders for expansion, and slotted holes are made to give the bolts proper play.

FLOOR FORMATION.

On the girders in each span are placed, transversely, eighteen wrought iron nine-inch **I**-beams, flange four inches, twenty-eight pounds per lineal foot. The middle and two end beams in each span are riveted to the girders. Riveted to the **I**-beams mentioned, longitudinally, on each side of the bridge, to form the footways, are four twelve-inch channels, twenty pounds per lineal foot, placed 2 feet 9 inches apart; on the top of each outside line of channels, is riveted an eight inch, twelve and one-half pound channel to retain the footway surfacing and concrete. To this channel and the one below, the cornice, formed of channels and angles weighing about sixty pounds per lineal foot, is riveted. On the ends of the floor **I**-beams, ornamented castings are affixed.

Upon the channels and **I**-beams of the floor formation, are placed buckled plates, riveted thereto on two edges with one-half-inch rivets. These plates are of wrought iron $\frac{1}{4}$ inch thick and 3 feet square with $2\frac{1}{2}$ inch rise in the middle.

Upon the unsupported edges of the plates are placed tee bars, six and one-half pounds per lineal foot on roadway, and five and one-half pounds on footways. The flanges of these tees are riveted to the edges of adjoining plates.

At piers Nos. 1, 2, 4, 6 and 8, expansion joints are made in the floorway formation. Each is formed of two angles riveted to the upper flanges of two adjacent **I**-beams, and a plate, $\frac{3}{8}$ inch thick by 15 inches wide, to which 2 x 2-inch angles are riveted, placed upon the upturned edges thereof, with the angles turned down.

SURFACING.

Upon the buckled plates, up to one inch over their apices, is placed a layer of concrete, formed of two parts of gravel and one of German Portland cement, upon this is a layer one inch thick of Neuchatel asphalt composition, ironed to make water tight joint—arranged as shown in *Plate III. Fig. I.* A layer of concrete, four and one-half inches deep in the middle of roadway, covers the asphalt. The concrete is of the usual formula, viz., stone, four parts; sand, two parts; cement, one part.

On this concrete, is a layer of the first mentioned concrete two inches deep (not shown in *Plate III*), in which the granite blocks of the surface covering are laid. These blocks are about 6 x 9 inches in breadth and length and 3 inches deep. No joints over three-fourths inch wide were allowed by the specifications. As soon as the top layer of cement mortar had set, the joints of the pavements were grouted with Portland cement and sand half and half. No travel was allowed for two weeks after grouting. No stones over one and one-half inches in their largest dimension were allowed in the concrete of the superstructure.

The footways are formed of a layer of concrete about two inches deep over the apices of the buckled plates, on which is laid two inches deep, "Stuart's Granolithic Pavement," forming a most excellent surface.

Over piers Nos. 1, 3, 5 and 7 are projecting lookout bays in the footway formation. Each span of superstructure weighs 400 tons.

SPECIFICATIONS.

The specifications stipulated in regard to the work as follows :

* * * * *

(49.) Portland cement must weigh 112 pounds per struck U. S. bushel of 2150.42 cubic inches. It must be ground so fine that no residue remains after passing through a wire cloth sieve 3,600 meshes per square inch.

After being made into a briquette and remaining seven days in water it must show a tensile strength of not less than 200 pounds per square inch.

Other cement must not leave more than fifteen per cent. residue on wire sieve (3,600 meshes per square inch), and exhibit a

tensile strength of seventy-two pounds per square inch after remaining in water seven days.

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(51.) All mortar is to consist of cement and sand in the proportions of one part cement, two parts sand.

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(54.) All wrought iron shall be uniform in quality, tough, fibrous, free from cracks and flaws and with perfect edges.

All wrought iron in tension shall be capable of withstanding a tensile stress of 46,000 pounds per square inch of full section of specimen, with fifteen per cent. (web plates five per cent.) extension in eight inches, and of supporting fifty per cent. of that weight without permanent set.

All lateral and transverse tie rods shall have adjustable sleeve nuts and connections equal to the strength of the rods.

(55.) In all rivet work, the holes shall be accurately spaced and punched truly opposite. The rivets shall be of the best quality of rivet iron; shall completely fill the holes and have hemispherical heads.

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(58.) All new iron work shall be cleaned and receive one coat of red oxide of iron ground in pure boiled linseed oil before leaving the shops, and after erection shall receive two coats of the same tinted dark brown or black, as directed; the pigments also being ground in oil.

The contract price paid by the city for the work was \$81,920. The work included some repairs to the abutments and some other minor details necessary to place the approach in complete order for travel.

Work was commenced about the middle of June, 1884, and the approach was thrown open in the early part of December, 1885.

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