

to move the length of the screws, when the work had to be suspended to re-arrange the screws and blocking. The first day the house was moved 3 feet, the second day 5 feet, the third day 3 feet 10 inches and the fourth day 2 feet, the whole distance (13 feet 10 inches) being completed on the morning of August 25, while the actual time of moving was 13 hours and forty minutes. After the building was in its destined place the braces and ties were cleared away, the traverses not supporting the walls taken up, and such of the rollers as were loose taken out, while such as were left were firmly cemented as part of the new foundation. The entire cost was \$30,000 in currency. Larger buildings have been raised in this country, but never so large a one removed, and thousands of people watched the curious operation."—*Engineering*.

SUPERSTRUCTURE OF THE CHESTNUT STREET BRIDGE.

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[AT page 413, Volume XLIX. of this *Journal* will be found the abstract of a paper read before the Franklin Institute, by Mr. Strickland Kneass, C. E., on the Chestnut Street Bridge, then in course of erection. Since that time, the bridge has been finished and thoroughly tested by a constant and heavy traffic, and we now give from Mr. Kneass' Report to the City, a full account of the superstructure, which was only alluded to in the former paper.—ED.]

Before entering upon a detailed description of the superstructure, it may not be amiss to allude to some of the cast iron bridges which have been previously erected, for the purpose of showing that in adopting this general plan of bridge, we have not attempted anything new in the principles of construction, or used any material that has not for many years withstood the test of the changes of temperature and the effect of heavy traffic. The first cast-iron bridge erected in England was over the Severn at Colebrook Dale, in the year 1777; it has five arch ribs, with a clear span of 100 feet 6 inches, and a rise of 45 feet, a width of 26 feet, and a sectional area in each rib of $56\frac{1}{4}$ square inches.

At *Buildwas*, a bridge with three arch ribs, 130 feet span, with 17 feet rise and width of 18 feet, having a sectional area of 37.5 square inches to each rib, was finished in 1796.

In the same year the *Sunderland Bridge* over the Wear was completed, having six arch ribs, with a span of 236 feet, and rise of 34 feet, and a width of 32 feet, the sectional area of rib being 46·5 square inches.

Bristol, 100 feet span, 15 feet rise, having six arch ribs, and 32 square inches in each, of date 1806.

Bonar, 150 feet span, 20 feet rise, four ribs, and 45 square inches section, of date 1812.

Cauxhall, 78 feet span, 14 feet rise, ten ribs, 1816.

Southwark, 240 feet span, 24 feet rise, having eight ribs, with 214 square inches of section, date of 1818.

Twickenbury, 170 feet span, 17 feet rise, four ribs, with 36 square inches of section, of date of 1826.

Plymouth, 100 feet span, 14·5 rise, five ribs and 64 square inches section, 1821; and the latest the renewal of the Westminster, with an arch partly of cast and wrought-iron, having 120 feet span, 20 feet rise; are all it is believed in constant use. The widths of these bridges vary from 16 feet to 42 feet, except the Westminster, which is 85 feet.

In France they commenced the use of cast-iron with the "Pont des Arts," with span of 60 feet 8 inches, and versed sine 12 feet, the depth of the arches being but six inches; afterwards the "Pont du Jardin du Roi" was begun in 1800, and finished in 1806, with span of 105 feet and 10 feet rise, having seven ribs, but owing to the high price of iron in France, and therefore a desire to reduce proportions to their minimum with their exceeding high standard of strength of material the French Engineers assumed in making their proportions, none of these bridges were successful, and have either been removed or greatly modified in plan and arrangement. The "Pont de Carrousel" at Paris, 187 feet span, and 15·5 feet rise, a very handsome structure, was built in 1836—has five ribs, with a sectional area to each of 165 square inches, and is therefore proportioned more in accordance with those built by the English Engineers; it is now in full use. In other parts of France there are cast-iron arched bridges of later date which have proved all that their constructions proposed.

In Russia we find the extensive cast-iron bridge built by our townsman, Joseph Harrison, Jr., across the Neva at St. Petersburg, which, though subjected to the most severe tests of changes

in temperature, stands a monument to American professional skill. This bridge has seven spans, with 157 feet as the largest.

The only example in our own country is the remarkable bridge over Rock Creek, at Washington City, built by a distinguished Philadelphian, Major-General Meigs, U. S. A. This bridge has a clear span of 200 feet, and rise of 20 feet, with a width 26·33 feet, and two supporting arches. The remarkable feature of this bridge is that the arches are cast-iron pipes four feet diameter, through which is brought the entire water supply for the City of Washington. The detail of this structure, in the originality of its double and peculiar adaptation as a viaduct and aqueduct, is most interesting. In designing a bridge to be constructed, I may say, entirely of cast-iron—*i. e.*, where the stability of the structure is dependent entirely upon that material, it is of course essential that it should not be subjected to other than compressive strains, therefore the arch is the proper form, and with a superincumbent roadway so arranged in weight, so as to give, so far as judicious, that inertia to the structure which can only be had to perfection in stone arch bridges. In the structure now to be described, as regards this point, we have obtained very favorable results, as with the constant traffic upon it, and with a large body of men passing over it with a band of music, at cadence step, a tremulous motion sufficient to but slightly disturb the surface of a vessel of water standing upon it was discovered—that this bridge has been constructed with but one pier, may subject it to criticism architecturally, but this arrangement was determined upon for the purpose of causing as little destruction to the river navigation as possible, and placing the pier in such position in the river as to correspond in line with the western pier of the Market street bridge, 500 feet up stream. The width from out to out is 42 feet, with two footways, exclusive of the plinth of the railing of 7 feet 3 inches, and 26 feet of carriage way. Each span is composed of six arches, placed at distances of 8 feet 8 $\frac{3}{4}$ inches, and 7 feet 10 $\frac{3}{4}$ inches from centre to centre. They are four feet in depth, and 2 $\frac{1}{2}$ inches thick, with upper and lower webs of same thickness, and 8 inches wide; thus giving a compressive area of 147·5 square inches to each arch rib. These arches were cast in lengths of 12 feet 10 inches, with end flanches 12 inches wide, having three side-stays from body of segment, and were secured to each other by four screw-bolts 1 $\frac{3}{4}$ inches in diameter.

The outside arches or ribs are slightly reduced in section, and are cast with ornamental face.

Each rib is footed upon the abutment, and keyed into heavy skewback plates, which are set into granite blocks, 4 feet wide, 4 feet high and 5 feet deep; the iron plate is 4 inches thick, and placed with heavy sheet lead, intervening between the stone and the iron, to correct any irregularities in the stone face. At each junction of arch, rib segment, which are, of necessity, opposite each other, throughout the bridge; the several ribs are tied together with wrought-iron ties of channel iron, 6 inches wide and $\frac{3}{4}$ inches thick, with two inch depth of side rail, and are trussed by a system of intervening cast-iron braces and wrought-iron tie rods; with this arrangement, the vertical position of the ribs are secured.

For the purpose of preserving a true line on the ribs, cruciform cast-iron lateral bracing is introduced, with lengths of 15 feet and $15\frac{1}{2}$ feet, reducing in size from 10 inches at the middle to 6 inches at the segment where they abut, with 1 inch thickness of metal. The system is carried from the abutment to the crown, with two series, and has been found to operate precisely as designed; for in the progress of construction it was requisite that the false works should be so planned as to allow the free and uninterrupted use of the river by the constantly passing tugs with their long line of canal boats in tow. They were therefore subjected to frequent disarrangement of line, from the boats striking the framing; but by the use of the lateral bracing, and wedging at the heel, we could, without the least difficulty, bring our work to the proper line. This was continually occurring, until the key was fixed and our false works were removed.

The upper web of the arch rib, at distances of 4.25 feet horizontal measurement, is increased in width to 12 inches, so as to form a footing for the spandrill castings, which are formed of three cast-iron columns with $\frac{3}{4}$ inch of metal. These castings are each 12 feet 9 inches long, comprising three columns. Those under the roadway extended in elevation only to the under side of the floor beam, to be hereafter described, while the two at the curb line have an increased height, so as to form the curb, dividing the carriage and footway. The outside castings are ornamental in design, and carried up to form a base, to which the side railing is secured. The height of these castings vary from 19 feet $4\frac{1}{8}$ inches (interior), to 1 foot $5\frac{1}{4}$ inches at crown; those at the pier being higher than at

abutment by 2 feet 9 inches, so as to give a curved line to the general profile of bridge, which, it is thought, adds much to the general appearance of the structure, as the inclination upon the bridge from each abutment, is tangential to the gradient on the approaches, rising to the pier with an arc of a circle of 4,900 feet radius.

Through these spandrill castings, at about half the distance between the arch and the line of the outer entablature, is carried a strut, adding its mite of strength to the arch, but intended particularly to tie together, and prevent flexure in the columns. This strut, starting at half the height of column at abutment, with a regular curve, disappears in the arch rib at crown. The sizes of the columns gradually decrease with their height, from 8 inches at abutment, to 4 inches at crown. At the foot of each column is a square face, planed to the inclination of the arch; and to facilitate construction, the footings on each casting are in parallel planes, the two outer being in the same plane, and the middle foot differing by versed sine of segment. Each foot is secured with 4 by $1\frac{1}{2}$ inch screw-bolts, with a key notched half into foot and top of rib, so as to relieve any possible lateral strain upon the bolts.

The bracing in the spandrills is arranged with pipe and cruciform diagonals. As before stated, each spandrill casting comprised three of the principal standards or columns, and at the centre column of each of these castings, extending to 4 feet 9 inches from the abutment or pier, is a diagonal brace, with a double series, one above and below the strut before alluded to, as far as the height of the castings permit, beyond which they become single braces. They are tied at the foot of post or top of arch with swivel tie-rods, $1\frac{1}{4}$ inches in diameter, the double lines having an intermediate tie-rod of same diameter at the elevation of the strut rib. All the other columns have the pipe brace, with a rod passing through them, and also the columns, the entire width of the bridge. The pipe braces vary in size from 10 inches diameter at middle and 6 inches at face, bearing against the columns, to 6 and 3 inches near the crown.

The diagonals are cruciform, 6 inches wide, and $\frac{3}{4}$ inch metal, bolted and keyed at top and bottom.

We thus, it is believed, have the main frame of bridge, strutted and tied, so as to prevent any lateral motion or vertical flexure in the main supports of the roadway; and in all cases where a tensile strain is to be resisted, have used wrought-iron, while the cast-iron throughout is subject only to compressive force.

For the carriage-way, there are wrought-iron Phoenix beams laid over each head of column, in length extending from curb to curb. These beams are 9 inches deep, and placed at distances of 4 feet 3 inches from centre to centre. They rest on top of the spandrill posts, in cast-iron chairs, bolted to the spandrill cap as well as the beam. At the curb rib, they are similarly secured on the top of the column, openings in the castings having been made to receive them. They thus perform the double duty of a support to the road-way, and a tie for the upper set of diagonal bracing. The foot-ways are supported in the same manner with beams of wrought-iron 6 inches deep.

For the carriage-way, a ribbed cast-iron arched plate sets upon the floor beams, having an arch of $3\frac{1}{4}$ inches in its width of 425 feet. Four of these fill the space between the curbs, and are bolted together both transversely and longitudinally. Upon these was placed carefully prepared hydraulic concrete, so as to give an even surface, and prevent water settling in the depressions at the floor beams, or getting at the iron by percolation through the road-way. Upon this was placed a layer of clear screened gravel, 4 inches deep, in and upon which was laid the road-way pavement of cubical granite blocks, 3 inches wide, 8 inches long, and $4\frac{1}{2}$ inches deep, the surface of which was grouted with hydraulic lime water.

A double track city passenger railroad passes over the bridge, track of which is laid with the tram rail, 7 inches wide, on longitudinal stringer and cross-tie, the tie being bedded in bottom layer of concrete. Timber was preferred for this, as it is surrounded with preservatives, and gives a double elasticity to the road-way, the line of rails being not only used by the cars, but by the entire traffic upon the bridge.

The foot-ways are similarly constructed, with flat iron plates, filled with sand, and covered with flag-stone 2 inches thick.

The railing is very heavy, having a top width of $10\frac{3}{4}$ inches at cap, and a height above foot-way of 3 feet 8 inches, including plinth. The entire work of the interior is painted with a composition of turpentine, lime and coal tar, in proportions of 1 pint of turpentine, 1 lb. quick lime, and 1 gallon of coal tar, which forms a varnish impenetrable to moisture, and durable. The outridge is painted with a tint of Pictou stone, so managed as to throw out the Gothic ornamentation of the outside ribs, spandrills and entablature.

The only provision that has been made for expansion and con-

traction, is on the railing, which sets in a casing fitted into the lamp pedestal on the abutments and pier, thus allowing free action without showing an open joint, and on the curbs where they connect with the stone at the abutments and pier. All other portions of the structure dependent upon and secured to the arch itself, will accommodate itself to the change of elevation at the crown, without any derangement.

In general design this bridge is of the Ornate Gothic. The outer ribs and spandrills are highly ornamented, the arch having a succession of foliated circles, finishing to a corresponding panel at crown, which is filled with a United States shield. The columns are clustered with appropriate cap and base, and bound together with an ornamental lancet, arches above and below the street. The frieze is a range of rich Gothic arches, with ornamental drops, and surmounted by a richly membered cornice. The railing corresponds in design, having heavy cruciform ballusters, joined by lancet arches, and set upon a full base, and covered with a heavy, moulded cap.

As regards strength of this structure, and treating the arches as built with a succession of vouissors, and performing functions the same as if built of stone, we find that the horizontal pressure at the crown of each road-way rib is, with 100 lbs. per square foot of transient load, 512,585 lbs., equal to 3,475 lbs. per square inch of section, and at skewback, 529,542 lbs., or 3,590 lbs. per square inch of section. Taking the crushing power of best iron at 107,000 lbs. per square inch, the maximum load that would probably be placed upon it, would give a pressure at crown of but $\frac{1}{31}$, its ultimate strength.

The Southwark Bridge, at London, has a horizontal thrust of $\frac{1}{23}$, its ultimate strength, taking the same maximum of the value of cast-iron to resist the compression. As to the expansion and contraction of the main arches, and the consequent rise and fall, on account of the variations of temperature: We have examinations taken at 99 degrees and 12 degrees Fahrenheit, and find the difference of elevation to be $2\frac{5}{8}$ inches, showing a contraction of 0.1107 feet in the length of arch rib, which, for the length of arch, 194.27 feet, taken by measurement, at the first temperature, gives 0.001272 feet contraction per degree, or, still further, 0.00000654 feet per degree per foot of length; thus approximating very closely to the recorded result.

The only material change of plan which has been made in this

structure, differing from cast-iron bridges heretofore erected, is the use of wrought-iron for transverse ties for the main arches, instead of cast-iron. I believe, invariably in the foreign bridges, they have placed a heavy, cast-iron plate at each joint of segment of arch rib, extending entirely across the structure, and, as invariably, the tension strain brought upon this plate by the irregular expansion and contraction of the several arches, has broken it, but to no disadvantage as regards the permanency of the structure, as by strapping the severed parts with wrought-iron, the same point is gained which we have to arrive at in original construction.

In the erection of this bridge, it was necessary that there should be no obstruction placed in the river, whereby its free use by the steam tugs would be interfered with, and therefore, a frame work was erected, so as to leave a clear space in middle of each span of 70 feet, which was bridged by Howe trusses 8 feet deep.

The frame work, at abutments, was erected upon piles, giving a firm base; but on each side of pier, a crib was sunk for the bearing of frame, and bridged to pier.

As regards the piles, we had no trouble; but the compressing together of the cribs, although sunk upon rock, being made of round timber, was a most serious annoyance, as requiring constant wedging to keep the rib segments in proper position, both as regards alignment and elevation. Yet, when the key was inserted, and the arches took their bearing, the elevation of crown was within $\frac{3}{8}$ inch of the height intended, and the alignment was correct.

The work upon this bridge was commenced, at the eastern abutment, on the 19th September, 1861, but owing to the increase in cost of material and labor, consequent upon the rebellion, with the delay of litigation, it was not thrown open to public travel until July 4, 1866.

The cost of this structure, as reported to Councils, June 11, 1861, deduced from the detail of proposals and the estimate of quantities prepared at this Department, was \$431,424, but the allotment was made conditioned that its cost should not exceed \$415,000, as follows:—

Masonry and Approaches,	\$280,433	
Iron Super. and Erecting,	134,577	
	<hr/>	\$415,000

The final estimate of masonry, of date September 14, 1866, made up with schedule of prices upon original bid, and quantities of the

several kinds of work done, exclusive of a comparatively small sum for extra work—for full completion, amounted to \$279,383.

	\$279,383 89
The final Estimate of the Superstructure is now ready, and amounts to.....	134,587 49
Total cost under original contract,.....	\$413,971 38

For the purpose of exhibiting the total amounts actually paid, and also what may be estimated as the entire cost, when all the affairs connected with the bridge erection shall have been settled up, the following statement is given:—

Total cost as before noted,.....	\$413,971 38
Extra work of Masonry, not specified in con- tract,	\$3,865 85
Advance of prices on Masonry made by Coun- cils, December 10, 1863,	77,116 32
	<hr/> \$80,982 17
Cost of Bridge as completed,.....	\$494,953 55
Of this amount there has been paid by the Chestnut & Walnut Street Passenger Railroad Company,	\$100,000 00
Leaving as a cost to the City,	<hr/> \$394,953 55

It will thus be seen, that had not the condition of the country so changed the basis upon which the contractors made up their bids, as to warrant an increase of the contract prices by the Select and Common Councils of the City, the entire work would have been completed for \$417,657.23, or only \$2,657.23 over the contract; while if we deduct the amount paid for *extra work*, or work that could not be foreseen in designing a construction of such magnitude, the final estimate would be \$1,208.62 less than the contract limit.

BRIDGE CONSTRUCTION, 1869.

BRIDGE construction has been advancing rapidly during the past year, and principally in the United States. Nature has been kind to American Engineers in giving them great obstacles to overcome, while necessity has rigidly limited outlay; and hence arises a special fertility of invention and a special class of work.

But Holland has been building large Bridges too, and Russia is just commencing on a greater scale than any other European country.