Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 2858.*)

"The Reconstruction and Widening of Barnes Bridge, L. & S. W. Ry."

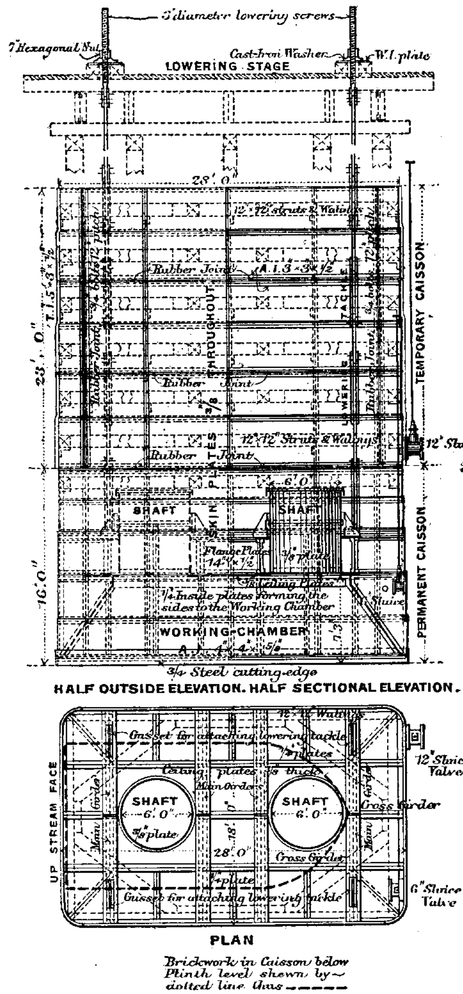
By Alfred Weeks Szlumper, M. Inst. C.E.

Barnes Bridge was one of the largest of the cast-iron bridges on the London and South Western Railway, all of which have for some years past been undergoing reconstruction and strengthening. It carried the loop-line between Barnes and Feltham over the River Thames, and consisted of three openings, with an arch in brickwork on the Surrey side over Barnes Terrace, its total length being 450 feet. The openings over the river were of cast-iron ribs, each 120 feet span, with a versed sine of 12 feet. They were of 2-inch metal, 3 feet deep, with 12-inch flanges, the horizontal member being supported by ornamental spandrel standards over the haunches. The ribs were fixed into iron skewbacks, or shoes, at each bearing, and were constructed in six sections. Each opening consisted of four such ribs, two carrying a line of way and parapet. The superstructure was of timber joists, about 3 feet apart, and longitudinals with 3-inch decking. The parapet was of cast-iron, and was bolted to the outside ribs. The bridge was built about forty years ago, by Messrs. Brassey, from the designs of the late Mr. Joseph Locke, Past-President Inst. C.E. An extensive system of wrought-iron bracing to all the ribs was subsequently inserted, and an apron of sheeting-piles and bags of concrete was built around each pier to arrest the scour produced by the strong current in the river at this spot.

In 1891 it was decided to proceed with the reconstruction of the bridge, simultaneously with the widening rendered necessary in connection with the railway between Barnes and Chiswick. The piers and abutments of the old bridge, of brickwork faced with Bramley Fall stone, have been lengthened 27 feet above the cutwaters, and 34 feet respectively. The bridge has been widened sufficiently to accommodate three lines of way; and a public footway, approached by staircases on each bank of the river, has been added. Borings disclosed London clay at a depth of about 16 inches below the bed of the river, overlain, on the site of the abutments, by a bed of alluvial gravel and sand.

Abutments.—The foundations for the abutments were inserted by ordinary cofferdams, and to connect the new brickwork with the old, a vertical chase was cut in the latter. The cofferdams consisted of a single row of 14-inch pitch-pine piles, sawn square, and driven to a depth of 12 inches below the level of the bottom of the excavations, at a distance of 8 feet in front of the concrete, in the Middlesex abutment, and about half that amount in the Surrey abutment. The pile-shoes were of the ordinary sheeting-shoe pattern, weighing 82 lbs. each, with a solid cast-iron point, and were secured to the pile by wrought-iron straps and spikes. The piles were driven by a Lacour steam pile-driver having a 25-cwt. monkey, at an average rate of three piles per hour when in full working order. The flank of the cofferdams was made good to the abutments by a 16-inch timber cut to the curved batter of the face and bolted to the brickwork, a tapered closing pile being then driven in the flank and the joint between the shaped pile and the brickwork being grouted with neat cement. A trench was excavated to the bottom of the old concrete and against the last pile, 3 feet wide, and extending 12 inches in front of the concrete; this was filled with clay puddle to make a watertight joint. A sluice, 15 inches square, constructed of 2-inch elm, was inserted in the face of the dam at the level of the bed of the river, and a sump 5 feet square was excavated to a level of 2 feet below the bottom of the foundations. Where necessary the joints between the piles were caulked with tarred oakum. To permit of future dredging operations and to protect them from scour, the abutments were founded in the London clay at a depth of 24 feet below the surface. To secure the old abutments the whole of the trench was lined with 2-inch runners. The main struts were of fir, 12 inches square, placed 8 feet apart, the walings being 12 inches by 6 inches and the props 8 inches square. Although little water percolated through the cofferdams, a considerable volume of land-water from the gravel was encountered; this was conveyed to the sump and pumped out by a 4-inch steam bucket-pump. The concrete used for all the foundations was composed of Thames ballast and Portland cement in the ratio of 5 to 1. The old abutments were underpinned at the junction with the new work where necessary. The whole of the Middlesex abutment cofferdam was removed when the brickwork was completed; but in the Surrey cofferdam, the piles forming the face of the dam were left in, sawn off at the level of the bed of the river, excepting a pile every 8 feet which subsequently formed the supports for the towing path. The piles to the Middlesex abutment cofferdam and staging were drawn by hand-power, a powerful hand-winch, manned by from four to six men, and heavy chain tackle being used. Those forming the Surrey abutment and pier staging were removed by a 50-ton hydraulic jack.

Figs. 1.



Scale, 16 feet to 1 inch.

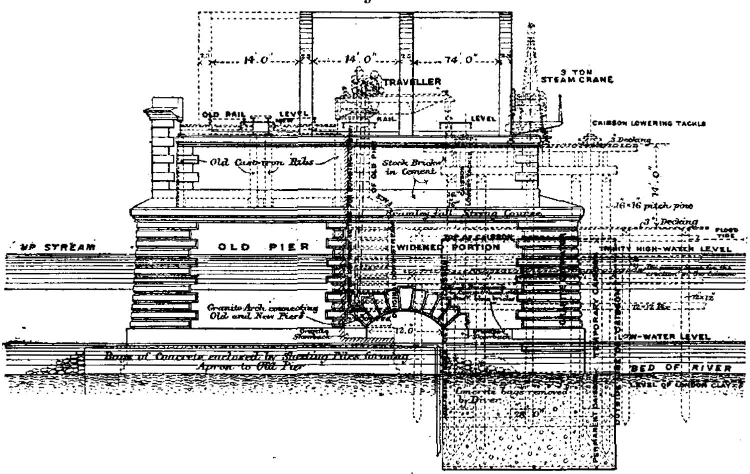
Piers. — The pier-foundations were built by the aid of wrought-iron caissons; as it was thought that the vibration caused by driving piles 15 feet or 20 feet into the London clay, if cofferdams had been used in the vicinity of the old piers, might have been dangerous to the old ribs. There might also have been some difficulty in making good the cofferdam to the old piers. A considerable amount of pumping would probably have been necessary, and this would have had a tendency to cause settlement in the old bridge, the foundations of which were of uncertain depth. If a blow occurred the old structure would have been endangered. Caissons presented none of these disadvantages, and they were so designed that, if necessary, compressed air could be used. The necessity for this, however, did not arise. The caissons, *Figs. 1*, consisted of two parts, the lower portion permanent, 28 feet by 18 feet by 16 feet deep, and the upper portion temporary, 28 feet by 18 feet by 23 feet deep, the junction between the two being arranged at the level of the bed of the river. The top of the temporary caisson reached to spring-tide level, about 3 feet above ordinary H.W.M., when the permanent caisson was completely sunk. A floor was fixed on the stiffening girders in the permanent caisson 7 feet 3 inches from the cutting-edge, the space below forming the working-chamber, access to which was obtained by means of two shafts, each 6 feet in diameter, piercing the floor and extending to within 1 foot 6 inches of the top of the permanent caisson. Immediately above this floor a series of cells were built, and as the caisson was lowered concrete was placed in them for kentledge. In the skin of the permanent and temporary caissons, a 6-inch and a 12-inch sluice respectively were fixed. Watertight joints were secured by the insertion of a continuous washer of indiarubber 4 inches by $\frac{3}{4}$ inch between the different sections. The caissons were erected upon a temporary staging immediately over their permanent position and were lowered by the aid of four sets of lowering-links, terminating in 3-inch screws and 6-inch nuts, turned by large spanners. The bed of the river was prepared by divers to receive the caisson, and the average rate of descent after the caissons were sealed was 15 inches per day. A 6-inch donkey-pump was found sufficient to deal with the water until the sluices were permanently closed and the water pumped out, after which the excavations were entirely free from water. A few beds of septaria, varying in depth between 6 inches and 12 inches, were met with, and it became necessary to remove the nodules beneath the cutting-edge. The total weight of concrete placed in the cells in the Middlesex pier caisson to overcome skin-friction was 80 tons, and in the Surrey pier caisson 148 tons, the former giving friction of 2·03 cwt. per square foot and the latter 2·95 cwt. A depth of 16 feet below the bed of the river having been reached, the remainder of the permanent concrete was placed in the caisson. The timber strutting was inserted as the lowering proceeded, seven frames of timber being used, about 3 feet 9 inches apart vertically; the whole of the timber was 12 inches square fir. As the brickwork and masonry proceeded the timber struts were struck at low water, a new series of short struts with walings against the new work, when sufficiently set with "soldiers" against the main walings, being put in.

The up-stream ends of the new piers were built about 8 feet from the cutwater to the old piers; this enabled the new work to be erected without in any way interfering with or endangering the foundations of the old piers. A granite arch, of 12 feet span and 4 feet thick, was built connecting the old and new piers, *Figs. 2* and *3;* the springing level being 2 feet 3 inches above low-water level. The skewback, also of granite, consisted in each case of two stones only, and those in the caisson being in position, the brickwork and granite cutwater was finished to T.H.W. level; and, a toothing having been left in the up-stream face of the brickwork in line with the back of the skewback, the up-stream end of the temporary caisson was removed. Meanwhile, the down-stream end of the old pier was cut away to a point close to the outside cast-iron rib down to the level of the bed of the new skewback; this was now set in position and the centering, consisting of four strong timber ribs and 2½-inch lagging, was erected. The granite connecting arch was then built, two strips of 7 lb. lead, 2½ inches wide, being laid between the bed joints of each voussoir, the face joints being pointed in a quick-setting Portland cement and then run in with Portland-cement grout, 2 of washed sand to 1 of cement. The skewbacks and arches were built by an overhead traveller erected between the high-level stage and the outside cast-iron rib. The connecting arch and the brickwork above it to T.H.W.M. were built as tide work.

The brickwork of the abutments and piers was of best London stocks in Portland-cement mortar, in the ratio of 2 of Thames sand to 1 of cement, faced with Staffordshire blue bricks up to the first string course. This string was of Bramley Fall stone 2 feet deep, and above it the work consists of stock brickwork, also in cement mortar, with a top string course similar to the lower one. The cutwaters of the piers are built of Cornish granite in 18-inch courses capped by an apron in Bramley Fall stone. The bed-stones are also of Cornish granite, 5 feet by 4 feet by 2 feet 6 inches, set back 9 inches from the face of the brickwork. The steam-crane placed on the high-level stage delivered all the material for building the piers, excepting the granite connecting arches and skewbacks. The total weight, including the superstructure placed upon the foundations of the piers, is approximately 3⅕ tons per square foot.

During the cutting down of the old piers, the setting of the skewbacks, and the building of the connection between the new and old piers to the first string course, a period of seven weeks, single-line working was established over the bridge, under the electric train-tablet system. A permanent signal-box exists on the Surrey side of the bridge, and a temporary one was erected on the Middlesex side, switches being placed in the down line near each box. The work could be carried on at one pier at a time only; this of course nearly doubled the time occupied, but the advantage was gained that the same temporary caisson was available for both piers. The staging in the river was kept within the smallest limits, viz., about 470 square yards to each pier, and of this, cement and material sheds occupied an area of 64 yards. It was built with fir piles, 12 inches square, driven, at distances of 9 feet apart, to a depth of between 6 feet and 10 feet into the bed of the river.

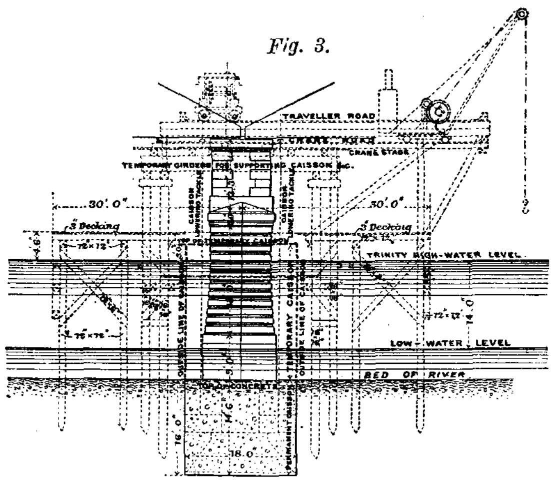
Fig. 2



FRONT ELEVATION
Scale, 32 feet to 1 inch.

In the case of the Middlesex pier staging, the piles were drawn by a wreck raiser or "samson," belonging to the Thames Conservancy. This craft is 70 feet in length, and 24 feet beam, its tonnage being 150. It is fitted with powerful steam-winches actuated by a 12-HP. winding-engine. Three strong davits project over the bows, accommodating a 6-inch steel hawser connected to the winding-drum by heavy chain luff-tackle. A 2-inch iron sling-chain was placed loosely around the pile to be withdrawn at the level of the water, and the steel hawser was then made fast to it and slackened out, to allow the sling to drop to the bed of the river. The winding engine was then set in motion and the pile was quickly drawn. In some cases, however, the winding continued until the bulwarks of the craft touched the water-level, the tension which was then exerted amounting to about 50 tons. The average power required, however, was between 25 tons and 30 tons. The piles were removed at the average rate of three per hour by this craft, but it could not be economically employed where there was, at low tide, a smaller depth of water than her draught, as she could only be worked when afloat. In accordance with the requirements of the Thames Conservancy, twelve of the cluster piles close to the skin of the caisson were cut off 6 feet below low-water level, which varied between 12 inches and 24 inches below the bed of the river. This necessitated dredging a small trench in front of the pile for

Fig. 3.



END ELEVATION.

Scale, 32 feet to 1 inch.

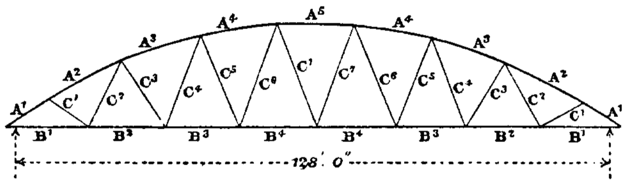
the diver to work in; five holes were bored through the pile with a 2-inch auger at the level required, a rope being then made fast to the top of the pile which was pulled over by a hand-winch.

The total cost of the cofferdams, caissons, staging, pumping and other temporary works was £8,742; the average cost per foot run of the cofferdams, including the temporary staging in the river, and removal of the same, also pumping, was £17; omitting the temporary staging and pumping, the cost was £11 10*s.* per foot run.

Girders.—The main girders are of the single-braced bowstring type, 129 feet 4 inches in length, the bracing being arranged in eight bays. The booms are 2 feet 3 inches wide, the top one being built to a radius of 112 feet 5 inches, with a versed sine of

20 feet. The girders are placed 16 feet 3 inches from centre to centre, and the superstructure consists of a corrugated wrought-iron flooring, 9 inches deep and ½ inch in thickness. The public footway, 8 feet wide, on the down-stream face of the bridge, is carried on cantilevers fixed to the bottom booms of the main girders. The principal resulting stresses in the main girders, *Fig. 4*, were calculated for an effective span of 128 feet, with a depth of girder in the centre of 20 feet, the distributed rolling

Fig. 4.



and dead loads being respectively 211·8 tons and 104·2 tons. The total stresses in tons are as shown in the following Table:—

Upper boom.	A^1	A^2	A^3	A^4	A^5
+	260·8	278·0	264·1	259·1	257·7

Lower boom.	B^1	B^2	B^3	B^4
−	219·9	237·7	246·1	249·0

Bracing.	C^1	C^2	C^3	C^4	C^5	C^6	C^7
−	36·1	35·5	38·8	37·6	42·5	40·7	42·8
+	..	3·5	2·3	14·0	9·5	16·6	14·6

The moment of inertia of the corrugated flooring is given by

$$I = 2\int_{\frac{D}{2}-2t}^{\frac{D}{2}} B\,x^2\,d\,x + 2\int_{o}^{\frac{D}{2}-t} t\sec\theta\,x^2\,d\,x,$$

where D = depth over all = 9 inches.
t = thickness = ½ inch for each plate.
B = breadth deducting rivet holes.
θ = angle of slope of side of trough = 30°.

Therefore

$$I = 2 \times \left(\frac{6\cdot75 - 1\cdot75}{3}\right) \times (4\cdot5^3 - 3\cdot5^3) + \frac{2\sec 30^\circ}{3} \times 4^3$$

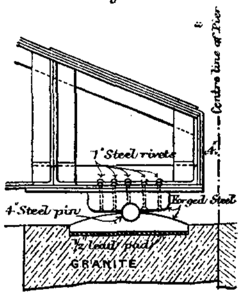
$$= \frac{482\cdot5}{3} + \frac{2\cdot31 \times 64}{3} = 210.$$

The moment of resistance $= \frac{210 \times 5}{4\cdot5} = 233$ inch-tons.

Now the greatest concentrated load to be sustained by the flooring is 18 tons on a pair of driving-wheels. Assuming this load to be distributed over only three bays of flooring, the bending moment at the centre of one bay would be $3 \times 54 = 162$ tons. The moment of resistance of 233 inch-tons, therefore, leaves a safe margin. The actual deflection measured under a passing engine with 18 tons on the driving-wheels was $\frac{5}{32}$ inch; the load required to produce this is found to be 1·8 ton, showing the weight to be distributed over five bays of the flooring.

Bearings.—The bearings on the Middlesex abutment and Surrey pier, *Fig. 5*, are fixed, those on the Surrey abutment and Middlesex pier, *Figs. 6*, being movable. The efficiency of the ordinary roller-bearing is open to considerable doubt; in some railway bridges where such bearings are in use, there is little or no evidence of any movement of the rollers—probably the result of their becoming clogged by the accumulation of rust, dirt, &c.; moreover, the bearing-blocks, which are usually made of cast-iron, are not unfrequently found to be cracked. The method adopted at Barnes is one designed to obviate these defects. All bearings are "hinged" or pivoted on steel pins, and instead of cast-iron, the bearing-blocks are of forged steel. The distance between the centres of the steel pins of each girder is 126 feet 4 inches. An upper block, 1 foot 8 inches by 3 feet by $4\frac{3}{4}$ inches, is riveted to the ends of all the girders, and in the case of the fixed bearings, *Fig. 5*, a corresponding lower block, but 2 feet 6 inches by 3 feet by $4\frac{3}{4}$ inches in the centre, tapering off to 2 inches at the ends, is placed upon a $\frac{1}{2}$-inch lead pad in a recess on the granite bed-stone. Between this upper and the lower bearing-blocks is fixed a 4-inch steel pin or pivot, the hole to accommodate this pin being bored half in each block.

Fig. 5.

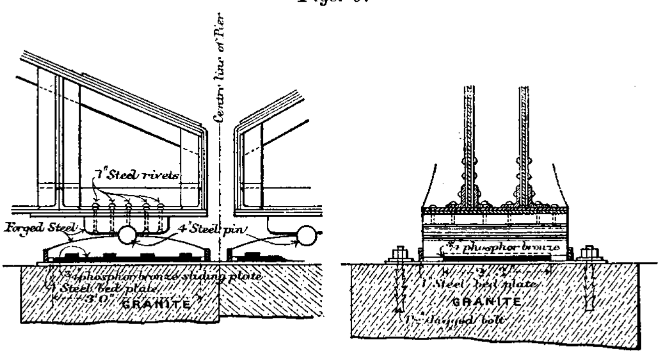


Scale, ¼ inch to 1 foot.

In the case of the movable or expansion bearings, *Figs. 6*, the lower block is 3 feet 3 inches by 3 feet by 6 inches in the centre, tapering off to 2 inches at the ends; four grooves are formed in the lower surface at right angles to the centre line of the main girder, and a phosphor-bronze sliding-plate, 3 feet by 2 feet 3 inches by $\frac{3}{4}$ inch, is placed under this block, being held in position by four projections or ribs formed on the upper surface of the plate fitting into the grooves under the bearing-block. This phosphor-bronze plate slides upon a steel plate, 4 feet 6 inches by 3 feet 8 inches by 1 inch, fixed to the top of the granite bed-stones by lewis bolts. In order to prevent dust and dirt from getting under the phosphor-bronze sliding-plate, a strip of gun-metal, 3 inches by 1 inch, is bolted to the edges and sides of the lower bearing-block projecting down to the steel plate. The steel bearing-blocks and the phosphor-bronze plate are machined on all surfaces, and before being placed in position the sliding surfaces were well oiled. These expansion bearings are very sensitive.

Erection of Ironwork.—The whole of the ironwork was delivered by barges alongside the abutments and was unloaded on to the widened portion of the embankment on both sides of the river, the main girders in sections of maximum weight of 5 tons. The girders spanning the side openings of the widened portion of the bridge were put together and riveted on this embankment and then

Figs. 6.

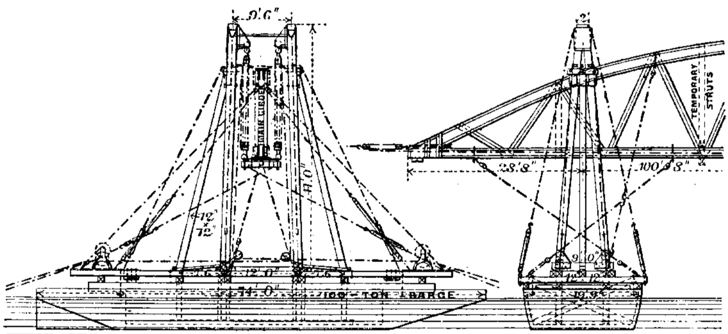


Scale, ¼ inch to 1 foot.

floated out into position; those for the central opening were erected and riveted on these side openings after the corrugated flooring was in place, being afterwards floated out into position similarly to the side openings. The girders on the old portion of the bridge were erected in position.

Floating the Girders into Position.—The riveting being completed, the timber-blocks were removed and the girder lowered on to two pairs of 8-inch by 6-inch rolled-iron joists, one pair at the land end and the other 42 feet from the opposite end, bearing upon a temporary line of railway metals consisting of three rows of rails. Two pairs of raking struts of timber were then inserted near the centre of the girder, and steel-wire guys were made fast to the top boom to steady it. A $2\frac{1}{4}$-inch steel hawser was made fast to the front of the main girder and returned to a steam-winch, the bight passing through a snatch-block held in position by a $3\frac{1}{4}$-inch steel hawser anchored on the opposite side of the river; a check-rope secured to the back end of the girder was controlled by a steam-crane, and 5 tons of kentledge were placed on this end of the girder. All being ready for launching the girder, the steam-winch was set in motion moving it about 40 feet forward over the abutment. A timber derrick erected upon a 100-ton barge, *Figs. 7*, was now floated into position under the girder to a point 29 feet from the projecting end, and was secured to the girder by a rolled-iron joist saddle suspended from the derrick by strong tackle, being placed at such a level that at the next tide the weight of the girder would be taken by this derrick. To control the movement of the barge, heavy ship anchors were placed above and below the bridge; and 7-inch cables were made fast to them,

Figs. 7.



Scale, 32 feet to 1 inch.

terminating in luff-tackle and worked by hand-winches on the barge. Between the two tides guy-ropes were disposed about the girder at various points and made fast to the barge so as to control its position; the last operation being to remove the kentledge and the front pair of rolled-iron joists and to secure the girder to the saddle and derrick. As soon as the barge took up the weight of the girder by the rising tide, a start was made for the pier by setting the steam-winch in motion at a very slow rate, and striking the land end of the girders with heavy sledge hammers, hauling in the front anchor cables and slacking out those in the rear on the barge. A heavy plumb-bob was suspended from the top of the derrick to the deck of the barge, and any tendency to list was immediately counteracted by hauling on or slackening out on the guy-ropes. About one hour before high tide was the moment selected for the start, so as to insure ample time to reach the pier prior to ebb tide setting in, and the average time taken in the actual floating out was twenty-five minutes. Having reached the pier, the girder was lowered on to the steel pins and adjusted in position, the tackle suspending the saddle terminating on hand-winches provided for this purpose. The falling tide, too, assisted this operation. At the following high tide the derrick was floated away, the necessity of lowering the inside pair of legs, so as to clear the girder, delaying the floating away until that time. Temporary struts were placed between the new girder and the outside cast-iron rib, so as to steady the former until the next girder was floated out and the corrugated flooring and wind-ties placed in position. All the main girders on the widened portion of the bridge were placed in position in this manner, and costly temporary staging in the river was entirely avoided. The requests made by the Thames Conservancy in regard to the number and size of the openings, if such staging was used, led the ironwork contractors to adopt this method, which proved a complete success and was carried out without the least mishap.

The ironwork on the widened portion of the bridge having been completed, the up line was diverted on to this new portion, and the erection of the next adjoining bay commenced. The main girders were built on the decking of the old bridge immediately over but 3 feet above the level of their permanent positions. Temporary balks of timber were placed between these new girders and the inside girders on the widened portion of the bridge, and the old cast-iron ribs on the down-stream face of the old bridge were secured to them. The work of removing the timber cross-girders, unbolting the joints, and cutting away the ties and struts, was now commenced. One span only at a time was dealt with, each section of the rib being lowered into a barge below, and subsequently taken to Nine Elms scrap heap. As soon as the old ribs were interfered with, it was considered desirable to close the old bridge to railway traffic, and single-line working was established over the widened portion of the bridge. Meanwhile, the work of cutting away and rebuilding the old abutments and piers above springing level, to take the new girders, proceeded; the girders were then lowered on to their bearings and the corrugated flooring was fixed in position. This second bay of ironwork being finished, double-line working was re-established, the new bay accommodating the down line.

Permanent Way.—The permanent way, consisting of 87-lb. bull-headed rails and chairs, is carried upon 16-inch by 8-inch pitch-pine longitudinals, secured to the summits of the corrugated flooring by angle-iron lugs and coach screws; transomes 8 inches by 6 inches and $\frac{7}{8}$-inch tie-bolts being fixed every 8 feet. A timber wheel-guard, 14 inches square, also of pitch pine, is placed against each longitudinal, and is held in position by holding-down bolts through the flooring.

Quality of Iron and Steel.—The wrought-iron plates were specified to stand a tensile stress of 21 tons per square inch of original section with the fibre, with a contraction of fractured area of not less than 10 per cent., and 18 tons against the fibre, with a contraction of not less than 3 per cent. Angle-bars and T-irons were required to stand a tensile stress of 22 tons per square inch before fracture, with a contraction of fractured area of not less than 12 per cent., and iron for rivets, bolts, &c., 24 tons before fracture, with a contraction of not less than 20 per cent. Steel was specified to stand, either with or against the fibre, a tensile stress of not less than 27 tons, or more than 31 tons per square inch of original sectional area, with an elongation of 20 per cent. in a length of 10 inches.

Tests.—The structure was tested with stationary loads placed upon the centres of the spans, as well as with loads moving over them at speed. The results are given in the appended Table:—

Girders.	Test No. 1.		Test No. 2.		Test No. 3.		Permanent Set.
	Load (Stationary).	Deflection.	Load (Stationary).	Deflection.	Load (Moving).	Deflection.	
Down-stream—	Tons.	Inch.	Tons.	Inch.	Tons.	Inch.	Inch.
Surrey span . .	110[1]	$\frac{1}{4}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[5]	0
Centre " . .	110[1]	$\frac{1}{4}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[5]	0
Middlesex span .	110[1]	$\frac{1}{4}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[5]	0
Up-stream—							
Surrey span . .	110[1]	$\frac{3}{16}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[6]	0
Centre " . .	110[1]	$\frac{3}{16}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[6]	$\frac{1}{32}$
Middlesex span .	110[1]	$\frac{3}{16}$	220[3]	$\frac{5}{16}$	220[3]	$\frac{5}{16}$[6]	$\frac{1}{32}$
Centre—							
Surrey span . .	220[2]	$\frac{3}{8}$	440[4]	$\frac{7}{16}$	440[4]	$\frac{7}{16}$[7]	0
Centre " . .	220[2]	$\frac{3}{8}$	440[4]	$\frac{1}{2}$	440[4]	$\frac{1}{2}$[7]	$\frac{1}{32}$
Middlesex span .	220[2]	$\frac{3}{8}$	440[4]	$\frac{7}{16}$	440[4]	$\frac{7}{16}$[7]	$\frac{1}{32}$
Corrugated flooring (clear span 14 feet) . . .	..	..	..	..	18	$\frac{5}{32}$	0

[1] Two bogie tank-engines; wheel-base 61 feet 10 inches; weight on pair of driving-wheels, 18 tons.

[2] Four bogie tank-engines; two on each line of way.

[3] Four bogie tank-engines; wheel-base 132 feet 3 inches; weight on pair of driving-wheels, 18 tons.

[4] Eight bogie tank-engines; four on each line of way.

[5] Lateral movement on bottom boom, about $\frac{3}{32}$ inch.

[6] Vibration in struts but slight.

[7] Movement on expansion-bearings between $\frac{1}{16}$ inch and $\frac{1}{8}$ inch.

The consulting engineer of the railway company was Mr. W. R. Galbraith, M. Inst. C.E. The chief engineer was Mr. Edmund Andrews, M. Inst. C.E., by whom the works were designed, the Author acting as resident engineer in charge.

The Paper is accompanied by five sheets of tracings and six photographs, from which the *Figs.* in the text have been prepared.

APPENDIX.

SCHEDULE OF COSTS OF PRINCIPAL ITEMS.

		£	s.	d.
Fir in piles	per cubic foot	0	1	3
Pitch-pine piles	,, ,,	0	2	0
Preparing and driving piles	per foot driven	0	1	9
Pile-shoes, bolts, dogs, &c.	per pound	0	0	3
Drawing piles	each	0	12	0
Cutting off piles below low water	,,	0	15	0
Wrought-iron in caissons, put together	per ton	18	0	0
Lowering caissons into position	,,	10	0	0
Excavation in river-bed within cofferdams or caissons, and remove to a shoot provided by railway company (close to work)	per cubic yard	0	9	6
Pumping by steam pump	per hour	0	6	0
Concrete in foundations in Portland cement 5 to 1	per cubic yard	0	15	0
Stock brickwork in cement, including all labour below T.H.W.M.	per cubic yard	1	13	6
Stock brickwork in cement, including all labour above T.H.W.M.	per cubic yard	1	10	6
Cornish granite (not including labour)	per cubic foot	0	6	6
Diver, with dress and all apparatus and one attendant	per hour	0	12	0
Wrought-iron in bowstring girders, fixed complete	per ton	14	0	0
Wrought-iron in corrugated flooring	,,	13	10	0
Forged steel	,,	24	0	0
$\frac{3}{8}$-inch curved plates	,,	12	0	0