Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 3456.*)

"The Breydon Viaduct at Great Yarmouth."

By William Marriott, and Theodore Graham Gribble, MM. Inst. C.E.

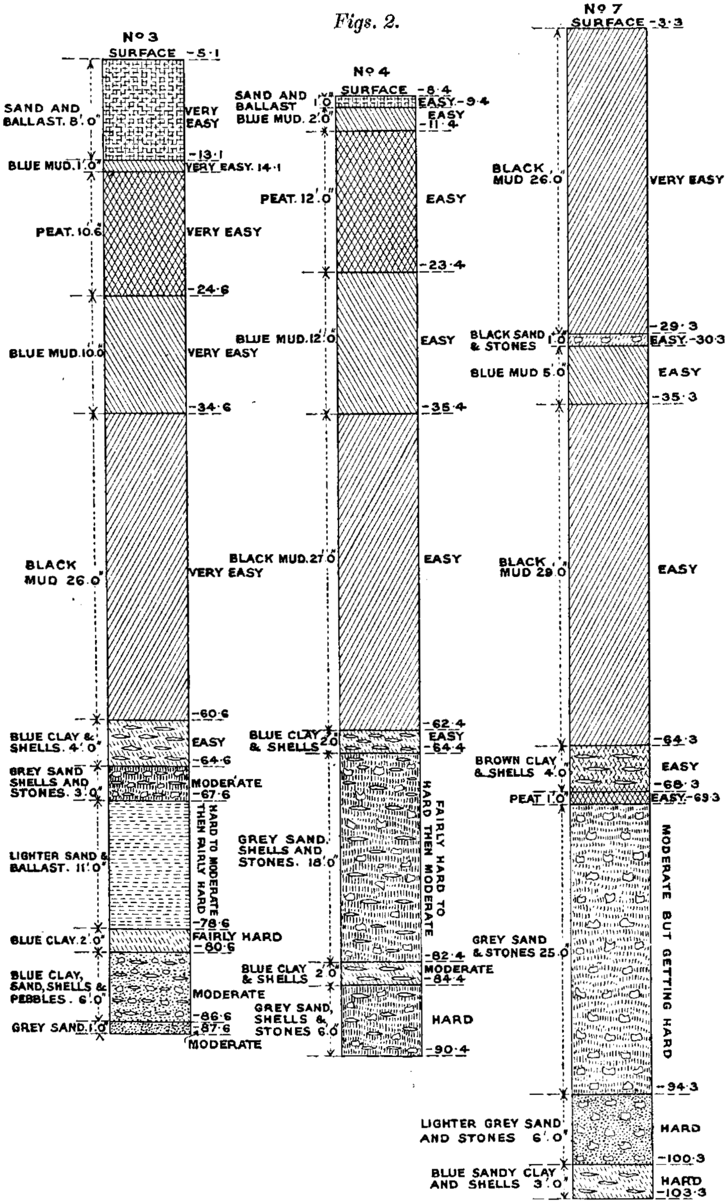
By an Act of Parliament dated 6 August 1897, the Midland and Great Northern Railway Companies were authorized to construct a railway connecting their existing joint-line at Great Yarmouth with the new railway which they, in conjunction with the Great Eastern Railway Company, were then constructing between Yarmouth and Lowestoft.

The principal engineering feature of the line is a steel viaduct of five spans over the estuary of the River Yare, commonly called Breydon Water. The viaduct consists of three fixed spans of girders of the Whipple-Murphy type, each 169 feet 10 inches in length over the end-plates, one swing-span, affording two equal openings of 60 feet clear waterway, and one fixed span of 110 feet 6 inches over the end-plates, Figs. 1, Plate 8. A space of 3 inches was allowed between the end-plates of adjacent girders, to provide for expansion and for possible discrepancies between the triangulation measurement and the shop measurement of the girders. The determination of the exact location and skew of the swing-span involved a considerable amount of work. A survey of the whole river-bed was made for about ½ mile on each side of the site, and was plotted to a large scale. The river takes a right-angle bend on the Norwich side of the bridge, almost immediately above the swing-span. A line representing the track of a vessel necessary to negotiate this bend was laid down on the plan and from it the exact angle of the skew was determined. On viewing the site of the channel at low water, from the turret of the bridge, it is immediately apparent that the site and skew are correct and could not be improved upon.

Foundations.—In order to obtain data for designing the foundations, trial borings were taken close to the sites for piers Nos, 3, 4 and 7. These were carried to depths of 83 feet, 82 feet, and

100 feet respectively, below the surface, *Figs.* 2. The beds passed

Figs. 2.



through are the alluvial or estuarine deposits, and it has been estimated that these, with perhaps some Pliocene deposits, extend down to about 150 feet below ordnance datum, and at this depth the London clay would probably be struck. The diameter of the borings in each case was 4 inches, and the driving was done with a 400-lb. monkey, the drop being 1 foot to 2 feet 6 inches.

It will be seen that the river mud gradually stiffens down to a depth of 60 feet below low-water level, where it may be termed a weak blue clay, after which beds of clay and sand alternate, so that caissons or cylinders would have been impracticable. If caissons had been adopted, they would have required a depth of about 100 feet below rail-level, and the weight of the concrete filling inside them would of itself have been too great for the foundation without any external load. It was therefore decided to use a pile foundation, in which all timber-work would be submerged and therefore practically imperishable, Figs. 3, Plate 8. By this means the height of the masonry was limited to about 45 feet, and the weight was brought well within the supporting-power of the piling as ascertained by the driving of a trial pile.

The weight which each pile has to support, neglecting any assistance from the clay between the piles, is as follows:—

Pier.	Tons.
No. 1	6·81
„ 2	9·18
„ 3	12·21
„ 4	9·43
„ 5	10·51
„ 6	9·83
„ 7	9·53

The piles were of American pitch-pine, driven inside a coffer-dam of close pile-work without puddle, strutted and braced from side to side. The coffer-dam piles were specified to be tongued and grooved, but the contractor preferred to take the responsibility of driving them ungrooved and afterwards employing a diver to caulk them. Some difficulty was experienced in making the dams water-tight, but no serious mishap occurred. The piles were specified to be driven by a 30-cwt. power-hammer, until the aggregate set from six blows at a fall of 5 feet did not exceed 1½ inch. Although a trial pile was driven, it was apprehended from the result of the borings that there would be considerable variation in the supporting-power of the piles, and where required provision was made for increasing the number. In some of the piers extra piles were driven, thus compacting the piled area as well as supplying additional support; in the case of the pivot-pier and its two adjacent piers a complete internal coffer-dam was driven, and all these extra piles were utilized as additional support for the masonry. The variation in the load per pile is approximately that of the calculated average supporting-power. The weight of the hammer was 23 cwts. and the average fall was 7½ feet. The aggregate set from the last six blows varied between 1·8 inch and 4·4 inches. When the calculated supporting-power of the number of piles shown on the drawing fell below that required by the specification, more piles were driven, in preference to scarfing and driving deeper.

The heads of the supporting-piles were sawn off at the bottom of the dam; those of the coffer-dam were bored from the inside, plugged, and broken off. The heads of the piles were secured with a nest of concrete about 3 feet in thickness and capped with a grid of whole timbers, forming a platform upon which the masonry was carried up. The hearting of the piers is formed of good cement-concrete, gauged 5 to 1. The specified tensile test of the cement was 350 lbs. per square inch, but the average resistance was about 440 lbs. per square inch. The facing of the piers is of Staffordshire brindle-bricks, the cutwaters and coping being of Bramley Fall stone. The girder bed-stones and the roller-path of the swing-bridge are of Cornish granite. The timber protection of the swing-span piers is of more substantial character than would have been requisite for the existing river-traffic, but was considered necessary by the Haven Commissioners in view of the possible development of the waterway by dredging. The heads of all the fender-piles have cast-iron galvanized caps.

General Design of Superstructure.—The three longer fixed spans are precisely similar, are 24 feet 2 inches in depth at the centre, and have a camber of 6 inches. The ratio of length to depth, 7 to 1, was determined as the most economical after considerable calculation, the question of greatest economy being affected by the practical consideration of least waste in using standard sections. A ratio of 8 to 1 was found to involve about 10 per cent. more material. The swing-span is of the same depth as the three longer fixed spans. A shallower girder would have been somewhat more economical but would not have been so convenient for the arrangement of the turret, and would have been less sightly in general outline. The shorter fixed span at the Lowestoft end is necessarily shallower, but was made, as far as possible, of similar general appearance. A plate-girder would have been quite practicable for this span, but would have involved more material. A comparative calculation was made of the cost of the whole structure with short or with long spans, taking as an alternative six plate-girder spans in place of the three longer fixed spans; the saving in the cost of the superstructure with short spans was found to be greatly overbalanced by the extra cost of the foundations. The position of the swing-span being fixed by the Haven Commissioners, it is believed that the dimensions selected are the most economical that could be chosen.

In making the calculations for the girders, the rolling-load assumed was that of a train of the heaviest engines of the parent companies, three of which can come upon one of the longer spans. From this was deduced what may be termed the "blanket" load, that is, the uniform rolling-load which will cover the maximum bending-moment in any position of the wheels. The maximum static effect close to one abutment being ascertained by placing a pair of the heaviest driving-wheels, say, 6 inches from it, the "blanket" load is given by the equation $W = \frac{2\,M}{C - 0 \cdot 25}$, in which W denotes the equivalent uniform load in tons per foot run, M denotes the maximum possible bending-moment in foot-tons at 6 inches from the end, and C denotes the half-span in feet. Allowance for impact was made by the Wöhler-Weyrauch formula.

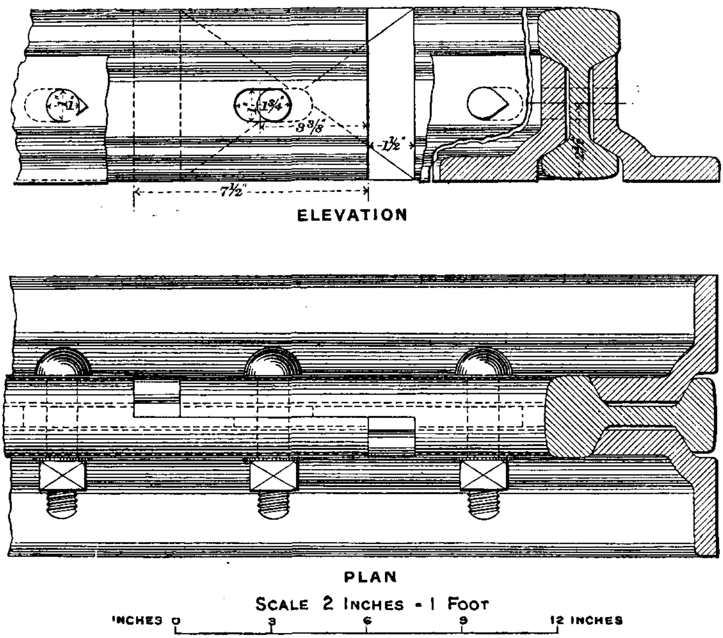
Main Girders.—The main girders are of single triangulation, having the central panel in the fixed spans counterbraced, and in the swing-span of solid plate, Figs. 5, Plate 8. The panels have the diagonals arranged as tie-struts, with extra allowance of material for alternating stress where such stress is possible. The web-members were arranged with the principal plates in the same plane as the vertical flange-plates, to secure as far as possible axial stresses, the attachment being in all cases by means of double cover-plates, and the spaces being packed solid.

The wind-pressure allowed for was 300 lbs. per lineal foot on the lower flange, and 150 lbs. per lineal foot on the upper flange. In the case of the swing-span, however, the lateral bracing was made considerably stronger to provide for shock when latching.

The flooring is composed of cross-girders and rail-bearing girders with longitudinal timbers of Karri-wood. The cross-girders have triangular ends, forming one piece with the gusset, and constituting, together with the upper wind-bracing, a closed frame of great lateral stiffness. The rail-bearing girders are of the same depth as the cross-girders, and, in addition to their web-attachment, have flange-covers traversing the cross-girders, producing complete continuity of stress and a distribution of the live-load over several cross-girders.

The following provision has been made for the expansion of the girders. A steel bed-plate casting is bolted to the stonework. A gun-metal strip is recessed into this $\frac{3}{8}$ inch and fixed with twenty-four $\frac{3}{4}$-inch gun-metal screws. This strip has a flat surface for a distance of $2\frac{1}{2}$ inches on each side of the centre, and then tapers 1 in 152 downwards. On this rests the rocker, of cast steel, fixed to the underside of the girder. This has a level surface, bearing on the gun-metal strip, for a width of 1 inch on each side of the centre, and then tapers 1 in 176 upwards. To retain the lubricant of tallow and oil, the bed-plate has a raised rim all round and a

Figs. 7.



$\frac{1}{8}$-inch copper cap prevents dust, etc., getting in, Figs. 6, Plate 8. Up to the present time very little expansion has been noticed. Provision has also been made for the expansion of the permanent-way at the same piers as for the girders of the three long spans. The rails are spliced vertically along the centre for $7\frac{1}{2}$ inches, and are allowed $1\frac{1}{2}$ inch clearance, *Figs. 7*. They have five slotted holes on each side and one through the splice. The spliced ends are held in position by lengths of angle fish-plates fixed to sole timbers, clearance being allowed between the adjacent angle fish-plates, *Figs. 8* and *9*. The girders are fixed at piers Nos. 2, 4 and 6, and the expansion arrangements are provided at Nos. 1, 3 and 7, Figs. 1, Plate 8.

Scarcely any hand-riveting was done, either at the works or at the site. The bulk of the riveting was done with the De Bergue pneumatic tool. In places where this was not practicable, the Boyer percussion-machine and pneumatic holder-up were used. The compressor was a Tangye machine working up to a pressure of 100 lbs. per square inch. In designing the riveted joints no assistance from the "bite" of the machine or the contraction of the rivet-shank in cooling was relied upon, but numerous experiments were made at the Department of Tests of the Midland Railway, by the courtesy of Mr. S. W. Johnson, M. Inst. C.E.,

Figs. 8.

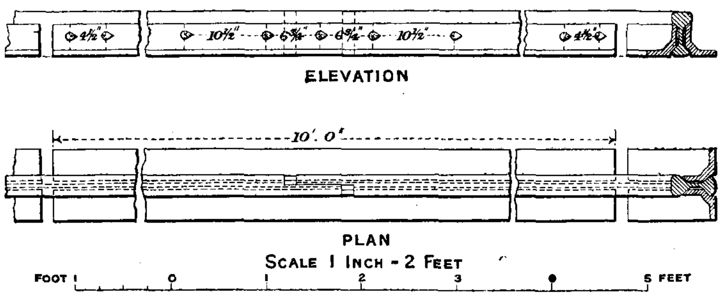
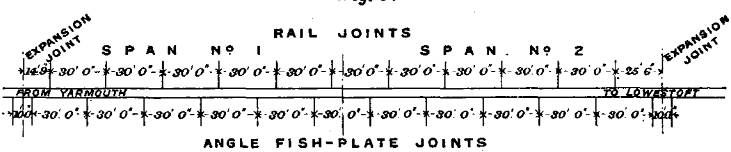


Fig. 9.



to determine the relative frictional resistance of hand-riveting, Boyer percussion-riveting, De Bergue pneumatic riveting, and hydraulic riveting. Applying the result to a tension-joint of the 108-foot fixed span, the different methods of riveting gave the following relations between the ultimate strength of the group of rivets and that of the bars themselves :—

Hand-riveting	19 per cent.
Boyer riveting	15¼ „ „
De Bergue riveting	16¾ „ „
Hydraulic riveting	33 „ „

The hand-riveting of the experiments was done by a first-class gang, which is difficult to obtain on erection-work. Hydraulic riveting was of course impracticable.

Turntable and Rack of Swing-Span.—The centre-pivot is of cast iron, and weighs about 7 tons. The cap from which the whole span is suspended is of cast steel and weighs about 3 tons. Between the cap and the pivot-head is a pair of steel bearing-plates having two concentric V-shaped grooves, in which sixty-nine hardened steel balls, 2 inches in diameter, supply the bearing. The V grooves are arranged to give four points of contact to each ball, being the extremities of the diameters of two circles forming the ends of a frustum of an imaginary cone having its apex in the centre of the pivot and its axis horizontal, thus giving true rotary motion and avoiding slip. The cap carries the bridge by means of eight suspension-bolts of crucible steel, 4 inches in diameter, the girders resting on a pair of very heavy fish-bellied girders similar to those of an engine turntable, Figs. 10, Plate 9. Except when closed, the swing-span is supported almost entirely on the ball-bearing, the live ring and spider-frame merely acting as guides and checks. The live ring, on the other hand, is capable of taking the whole weight of the bridge, and can be made to do so should it be necessary to carry out repairs to the centre pivot while the bridge is in operation. In ordinary working the weight is so divided between the live ring and the ball-bearing, by adjusting the suspension-bolts, that the least resistance is offered to the swinging of the bridge, and this is found to be when practically the whole weight is carried on the centre-pivot. The weight is distributed over the live ring by a circular steel box-girder. The roller-path of the live ring is composed of a pair of circular cast-iron girders, each in six segments, having cast-steel plates as roller-tracks, made to the inclination of the rollers, the plates being adjusted to the true level by means of folding-wedges, Figs. 11, Plate 9. The lower path casting carries a rack of twelve cast-steel segments having 144 cycloidal teeth, 10 inches in breadth, the pitch-circle being 18 feet 4½ inches in diameter. The live ring is composed of twenty-four cast-steel rollers, being frustums of cones 1 foot 3 inches in length and 1 foot 6 inches in mean diameter, turned and bushed with gun-metal. The spindles at the outer ends are carried in cast-iron clip-blocks between two angle-steel stay-rings. The inner ends are carried by a cast-steel spider-frame bushed with gun-metal to receive the pivot. A detachable snow-screen of thin plate is fastened in the winter months to the stay-rings of the spider-frame to protect the rollers from becoming clogged.

Turning Machinery.—The two pinions operating on the rack carried by the lower path casting are of cast steel machined all over, the teeth being machine-cut from the solid. The main vertical shafts are of steel, 5 inches in diameter, turned all over and tapered at their lower ends to take the pinions. The fish-bellied carrying-girders project on either side of the circular box-girder, each end carrying a cast-steel bracket which supports the main vertical shaft, and also a cast-steel sleeve through which the end of the shaft passes, thus giving good support to the pinion. In addition to the lower bracket which carries the weight of the main shaft, there are two supporting-brackets of cast iron, with caps and bushed with gun-metal, one at the top and the other intermediate. Directly under the top bearing on each main shaft there is fitted a friction-brake for checking the motion of the bridge at the moment it is being locked, or, in case of heavy winds, which are very frequent, to steady the bridge, and also to keep it locked when open for river traffic. The brakes are worked from the turret by means of a hand-wheel and a worm gearing with a worm-wheel on a horizontal shaft under the turret-floor, which operates the brake-straps of each shaft by means of right- and left-hand screws, Figs. 12, Plate 9. The power for turning the bridge is furnished by an Otto gas-engine of 11 brake-HP. working at 200 revolutions per minute, the speed being reduced by spur-, worm- and bevel-gearing to 1·55 revolution per minute at the main vertical shafts. Reversal of the direction of turning is effected by means of a set of mitre-wheels. The worm-wheel is provided, on each side of its boss, with claws into which gears a corresponding claw-clutch (of the crown-wheel type) sliding on a key on the shaft, and either clutch is brought into gear according to the direction of turning. In the event of the wind catching the bridge and causing it to overrun the engine, the clutch simply slips out of gear. The first-motion shaft is connected to the engine crank-shaft by a friction-clutch, which allows of the load being put on gradually, thus avoiding shock. By means of a friction-clutch at its extremity the counter-shaft is also coupled to the three-throw hydraulic pumps for supplying hydraulic pressure to the lifting and slide-block cylinders, Figs. 12, Plate 9.

Lifting and Slide-block Gearing.—The end lifts and slide bearing-blocks are operated by hydraulic rams, controlled from the turret. The lift- and return-cylinders are in one casting of special cast iron, and are 18 inches in diameter by 9 inches stroke and 7 inches in diameter by 9 inches stroke respectively. The rams are cased with gun-metal and are coupled together by two steel rods

6 inches by 1 inch in cross-section. The thrust-block is faced with a hardened steel plate, one edge of which is bevelled and coincides with a bevelled strip on the bed-block, which ensures correct alignment when lifting. The stroke of each ram is governed by the other, each in its turn acting as a stop for the other. The length of the thrust-blocks is so arranged as to just lift the ends of the bridge clear of the bearing-blocks when the ram is at the end of its stroke. This gear is carried in the box-girders attached to the ends of the main girders. Another pair of hydraulic cylinders, $5\frac{1}{2}$ inches in diameter by $12\frac{1}{2}$ inches stroke, is provided for withdrawing and returning the bearing-blocks, which are carried in angle-slides. The hydraulic pressure-mains are of iron, lap-welded, 2 inches in internal diameter between the working-valves and rail-level, thence $1\frac{1}{2}$ inch in diameter to the lifting-cylinders, 1 inch in diameter to the return-cylinders, and 1 inch in diameter to the cylinders for operating the slide bearing-blocks. The glycerine mixture, containing 10 per cent. to 50 per cent. of glycerine, according to the temperature, is pumped directly into the pipes at a working-pressure of 600 lbs. per square inch, and escape-valves are provided so that when the working-valve is closed, with the pumps still working, the mixture returns to the cast-iron tanks provided directly under, and forming a base for, the pumps, Figs. 13, Plate 9. As the situation of the bridge is very exposed, gas jets are provided at all important points for warming purposes. The bridge is locked, when in position for a train to pass over it, by a spring lock-bolt 4 inches by 3 inches in cross-section, made of steel, with the working-faces hardened. When the bridge is swinging into the closed position the lock-bolt strikes on an inclined plane provided on the curb-castings, which depresses it, the recoil of the spring effecting the locking when the bridge is in position. The lock-bolt is withdrawn from the turret by means of a lever and connecting-wire. The curb-castings are heavy castings placed at the ends of the fixed spans, next to the swing-span, to support the ends of the rails.

The operations for opening the bridge were specified to occupy not more than $3\frac{3}{4}$ minutes from the time the lock-bolts were withdrawn to the time the bridge was brought to a stand at right-angles to the railway. The operation was found to be capable of being performed in about 4 minutes, the time taken depending upon the skill of the operator in the turret and upon the weather conditions.

Emergency-gear.—In case of a breakdown in the machinery a complete emergency-gear is provided for operating the bridge; a crab is placed at one end of the centre-pier fendering, and a wire rope is carried from it round a bollard to a shackle at the end of the main girder, for swinging the bridge. The end lifts are performed by four 100-ton hydraulic jacks. In the case, however, of only the turret-machinery being disabled, the hydraulic rams in the end box-girders can still be operated, for lifting and lowering the ends of the bridge, by hand-pumps provided near the ends of the bridge, at rail-level. The working of the slide-blocks is also provided for by a hand gear, consisting of a worm and worm-wheel worked from rail-level by a removable crank-handle and a pair of bevel-wheels.

Gas- and Water-supply.—The gas-pipe for supplying the engines in the turret is laid across the bed of the channel, and consists of a copper pipe, 2 inches in internal diameter, cased in a cast-iron pipe 9 inches in diameter, to prevent the small pipe being caught by an anchor. It discharges into the bottom chamber of a cast-iron well 3 feet in diameter, which extends above high-water level. A pump is provided in the well for removing any water which may accumulate in the bottom chamber. Should the pipe across the channel fail, recourse may be had to another pipe which runs along the swing-span at rail-level and discharges into a gas-holder of 500 cubic feet capacity, fixed on the centre-pier fendering, which is always kept filled in case of emergency. The water-pipe for supplying the circulating-tanks for the gas-engines, which are fitted in the roof of the turret, also runs along the swing-span at rail-level. Flexible hose-connections for these pipes are provided at the junction of the swing-span and the fixed spans.

Signalling and Lighting.—The viaduct being for a single line of rails, whilst the rest of the line is double, single-line junction-boxes are provided at either end of the bridge. This section is worked on the electric train tablet block-system.

In addition to the tablet block-system, the following provision is made for control of the single line from the bridge-turret, by which no train can be accepted by the adjacent signalman without the permission of the operator in the turret. In the turret there is a bridge-controlling lever which must be in position before any of the lifting or turning operations can be performed. The movement of this lever unlocks the bridge, the position of the lever being electrically indicated in the signal-boxes at either end of the bridge. When the bridge-controlling levers in the signal-boxes at either end of the bridge are in their normal positions the bridge is unlocked, and the single-line train tablet-circuit, the down-block on the south side, and the up-block on the north side are disconnected simultaneously. When the bridge is in position for a train and the bridge-controlling levers are over, the train tablet-circuit and the up and down block-circuits are connected up; on the withdrawal of a tablet, a bridge-controlling lever is electrically locked in position by the tablet. When once the turret-man has withdrawn the bearing-blocks, the bridge-controlling lever is electrically locked until the blocks are again home. In the case of a failure of the electrical or mechanical locking an Annett key is provided in both the north and the south boxes, the withdrawal of which from the lever-frame locks the home-signals. By placing this key in a special locking-box near the end of the swing-span, the two plungers—one worked from the box and the other from the turret—can be withdrawn, thus releasing the bridge and leaving it free to open. The levers in the turret are grouped, and the movements are electrically repeated, viz., bridge locked, bridge unlocked, bridge lifted, bridge lowered, blocks on, blocks off.

An efficient arrangement for day and night signalling for the river-traffic, by means of balls and lamps, has been provided to meet the requirements of the Yarmouth Harbour Commissioners, and has been approved by the Board of Trade. For the purpose of steering vessels through the bridge, green lights have been fixed on the centre dolphin and white lights on the two adjacent dolphins.

Testing of the Bridge.—The testing of the bridge took place on 8 July, 1903. A train of the heaviest engines was placed upon each span in succession. The deflection of the longer fixed spans was 0·68 inch, the calculated deflection being 0·62 inch. The deflection of the shorter fixed span was 0·375 inch, the calculated deflection being 0·39 inch. The deflection of the swing-span under live load was not taken; the calculated deflection was 0·02 inch. The swing-span was tested for dead-load deflections when swinging, after the completion of the erection, and at the same time the pressure required to remove this deflection was recorded by gauges. The deflection was ½ inch, and the four pressures were about 30 tons each. The corresponding figures as calculated were 0·375 inch and 30·3 tons.

The whole work has been carried out in three contracts under Mr. Alexander Ross, M. Inst. C.E., as Engineer-in-Chief, and Mr. William Marriott, M. Inst. C.E., District Engineer and Locomotive Superintendent to the Midland and Great Northern Railways Joint Committee, as executive Engineer, to whom Mr. Graham Gribble, M. Inst. C.E., acted as Chief Assistant, and Mr. A. E. Glennie as Resident Engineer, Mr. W. E. Newman superintending the mechanical portion of the work. The contractor for the substructure was Mr. Henry Lovatt, of Wolverhampton, and the contractors for the superstructure were Messrs. E. Finch and Company, of Chepstow. The hydraulic equipment was supplied and fixed by Messrs. Sir William G. Armstrong, Whitworth and Company, of Newcastle.

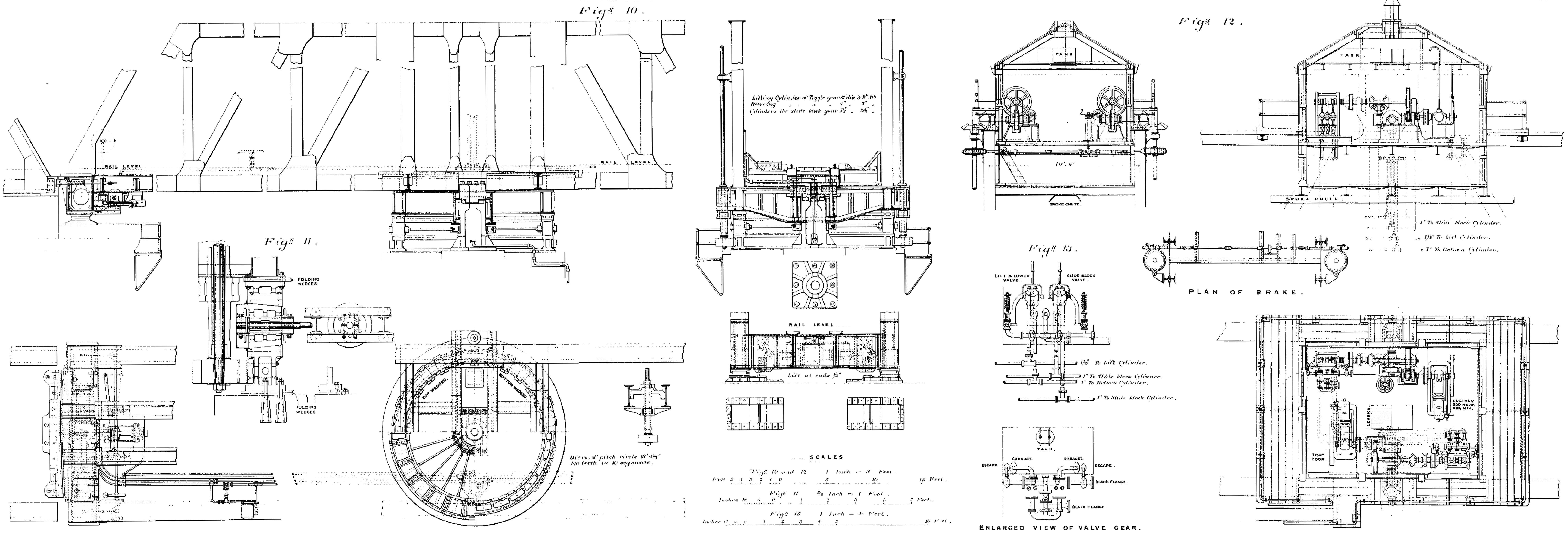
The Paper is accompanied by nine drawings, from which Plates 8 and 9 and the Figures in the text have been prepared; and by nine photographs, which may be seen in the Library of the Institution.

BREYDON VIADUCT: GREAT YARMOUTH.

PLATE 8.

W. MARRIOTT and T.G. GRIBBLE.

BREYDON VIADUCT: GREAT YARMOUTH.



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