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"The Iron Bridges on the Hull, Barnsley, and West Riding Junction Railway."

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In the following Paper the leading types of the bridges on the Hull and Barnsley Railway will be dealt with. The total length of the railway under construction and now nearly completed is 67 miles.

There are in all one hundred and six bridges and culverts with iron superstructures varying in span from 10 to 248 feet. Those over the rivers Ouse and Hull are swing or opening bridges. Eleven are lattice-girder bridges; eighty-eight are plate-girder bridges; and seven are covered with built-up trough flooring. The total weight of ironwork used in their construction amounts roughly to about 6,000 tons.

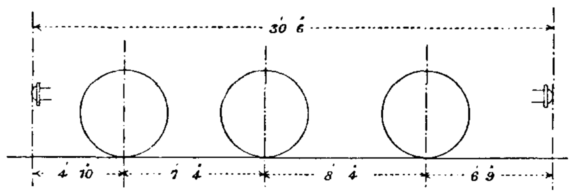
Of the lattice-girder bridges six are constructed of parallel booms or flanges and of the simple "N" truss similar to Plate 9, Fig. 9, one being a continuous-girder bridge over three spans. There are five bowstring bridges, three of which are shown in Plates 9 and 10, Figs. 14 to 41.

Of the plate-girder bridges seventy-five are of the three-girder type with trough flooring, Plate 9, Figs. 6 and 7, and five of the two-girder type with cross-girders and rail-bearers. The former class has been adopted because of the small space required for construction, the cross-sleepers being placed in the floor troughs, thus enabling the abutments, and embankments, which are very extensive, to be kept as low as possible. In no case are the rails carried by main-girders running directly under them. Durability has been carefully considered rather than cheapness in first cost, and additional weight has been put into various portions of the structures, which are more exposed to the action of the weather, in order to reduce the cost of maintenance.

The loads taken when computing the various sections required for main-girders are as follows, and are calculated from a heavy six-wheeled coupled tank engine, 30 feet 6 inches long, and weighing 46·8 tons, as shown in the annexed figure:—

TABLE of ROLLING LOADS.

Span of Bridge.	Rolling Load for Single Line per Lineal Foot.
Feet.	Tons.
10 to 15	3·00
16 „ 25	2·50
26 „ 40	2·00
41 „ 70	1·66
71 „ 100	1·54



Total weight 46·8 tons = 1·534 ton per lineal foot.

HEAVIEST GREAT WESTERN RAILWAY TANK ENGINE.

NOTE.—The Table is prepared for this engine.

For cross-girders 16 tons on an axle (8 tons per wheel) has been taken as the maximum local load, but further allowance has been made in providing flange-areas for the lurching of an engine, such as would bring a weight of 12 tons on one wheel, reducing that on the other to 4 tons. The same maximum weight also has been taken in calculating rail-bearer sections, assuming that the rails, which weigh 80 lbs. per yard, and the longitudinal timbers, 18 inches by 6 inches, distribute the load to a certain extent.

The strains in the girders, &c., have in nearly all cases been computed graphically.

With these general remarks the Author will now proceed to a description of a few examples.

The character of bridge-flooring adopted for the smaller bridges is shown in Plate 9, Figs. 1 to 7. It is difficult to make this form of built-up trough decking quite watertight, unless it is covered with some kind of asphalt; but in cases where it has been used for crossing streets in Hull it has been made absolutely so, by the use of Lockwood's covering, consisting of alternate layers of brattice cloth and asphalt. Before adopting this flooring, it was thought advisable to test its strength and continuity. Accordingly five troughs were riveted together and supported on timber bearers 12 feet apart from centre to centre; everything was arranged to reproduce as much as possible the strains in actual practice, and a load of $66\frac{1}{4}$ tons was applied gradually in the troughs between A and B, and D and E. The following deflections were taken at the centre of the top of each trough:—

DEFLECTIONS at the CENTRES of the TROUGHS.

Load.	A.	B.	C.	D.	E.
Tons.	Inch.	Inch.	Inch.	Inch.	Inch.
$41\frac{1}{2}$	$\frac{1}{16}$	$\frac{1}{16}$ full	..	$\frac{1}{16}$ full	$\frac{1}{16}$
51	$\frac{5}{32}$	$\frac{3}{16}$	$\frac{1}{16}$	$\frac{3}{16}$	$\frac{5}{32}$
60	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{1}{8}$	$\frac{5}{16}$ full	$\frac{7}{32}$
$66\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{8}$ bare	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{1}{4}$

This, though by no means a severe test, showed very fair continuity, and that the trough "C" considerably helped its neighbours to carry the load.

Plate 9, Figs. 5 to 8, represent the girders and flooring for a bridge of 50 feet clear span over the Beverley Road in Hull. The bridge is of the three-girder type. This arrangement of girders is economical, both in ironwork and abutments, and is permissible so long as the girders do not stand more than 3 feet above rail-level, which is the maximum height usually allowed by the Board of Trade. The construction gauge is shown in dotted lines in the cross-section of the bridge, from which the economy in width is apparent. The side girders are spaced 25 feet apart over all, and the centre girder is set 1 inch low, so that the flooring may be drained through $\frac{3}{4}$-inch holes into two wrought-iron half-round gutters. The rivets throughout the girders are 4 inches pitch except in the web covers and in the main angle-irons; where those which pass through the web are reduced in the centre girder by stages from 4 inches near the centre to $2\frac{1}{2}$ inches over the abutments.

The practice of reducing the pitch is not in general use; but on reflection, its propriety is obvious, as in the case of an ordinary plate-girder, carrying a uniformly-distributed load, the maximum strain in the flanges occurs at the centre, being reduced to nil over the abutments, following the ordinates of a parabola if graphically represented, Fig. 4, Plate 9. For example, suppose a strain of 100 tons at the centre in each flange, compression in the top, and tension in the bottom, and neither tension nor compression at the abutment ends, it follows that each 100 tons must have passed out from its flange, and neutralized the other; the only way possible being through the web. It will be observed that the rate of diminution of strain in the flanges increases more rapidly as the abutment is reached, and it is to meet this increasing strain on the connection between flanges and web, that the rivets through the web and angle-irons are reduced in pitch. As, however, there are two rivets through the flange to every one rivet through the web, it is not necessary to alter the pitch of the flange-rivets until it becomes more than double that of the web-rivets.

The necessary web-rivet pitch can be determined by observing the strain passed out of the flange in any given length of girder, as indicated in Fig. 4. It will be observed that the shallower the proportion of girder, the greater will be the strain to provide for. On this bridge ornamental cast-iron facia girders, which conceal those carrying the railway, are provided. A general idea of their appearance can be gathered from Fig. 8.

Before proceeding to describe the lattice-girder bridge, Plate 9, Figs. 9, 10, 11, the Author would draw attention to the considerations which should govern the general form of lattice to be adopted for main-girders, with cross-girder construction. The duty of the main-girders is to carry the load borne by the flooring of the bridge. Upon reflection it will be seen that there exists an economical distance at which cross-girders should be placed, so that the maximum weight transmitted by the rail-bearer to the cross-girder will be nearly that of a pair of drivers directly over the cross-girder. This distance is generally about 8 or 10 feet. In a close multiple system of bracing a very irregular amount of load finds its way into each system, there not being a cross-girder at each apex to transmit load. Further, the areas necessarily provided, near the centre, in the diagonals are greatly in excess of those theoretically required.

Another objection to the multiple system is, that from want of great nicety in manufacture some members cannot take the strains allotted to them in theory by the designer, and consequently a great strain is brought to bear on some, while others carry absolutely nothing.

The Author is convinced, from personal observation, that when lattice-girders are loaded they become appreciably shallower, owing to the compression of metal in the struts; the elongation in the ties yielding the deflection of the girder. This is not in accordance with the usual calculations for girders of the Charing Cross bridge type, as the verticals are thus brought into compression.

Since it is more difficult to arrange small sections in wrought iron as suitably for resisting compression as tension, those members which have to resist compression should be designed so as to receive a minimum amount of pressure and at the same time be as short as possible.

The above process of reasoning leads to the simple "N" truss, as satisfying all the above requirements, and this truss has been adopted by the Engineer of the Hull and Barnsley Railway.

Plate 9, Figs. 9 to 13, show a single system lattice-girder bridge, carrying a double line of railway over the Knottingley and Goole canal. The main-girders are 122 feet 8 inches between the centres of the bearings, 25 feet 3 inches apart in the clear, and 12 feet deep between the centres of the booms. The top boom is 2 feet 9 inches wide, and 1 foot 3 inches deep. The section is made up of four vertical plates in pairs, and eight angle-irons, arranged as in Fig. 12. A plate 2 feet 9 inches wide connects the two flitches together. The top boom is carried down at each end over the supports forming the ends of the girder. The bottom boom is similar to the top, except that there is no horizontal plate. This form of boom is designed especially with the object of placing the metal symmetrically about the lines of force, so as to bring a uniform strain over the whole of the section, and thus avoid any cross- or bending-strains. The main-girders are built to a camber of 2 inches. The cross-girders are attached to the bottom of the verticals by means of a tongue-plate, which passes up between the two flitches of the bottom boom, being riveted to them and the verticals. This arrangement applies the load carried by the cross-girders evenly and centrally to the main-girders, which is very desirable, and prevents the inner flitch carrying an under proportion of load. The rivets are also all in double shear in the connection, which is preferable to the method sometimes adopted, of simply hanging the cross-girders by the rivet-heads on to the main-girder. The cross-girders and verticals are spaced 8 feet apart. The verticals are composed of four angle-irons and distance plates. The diagonals are flat bars riveted to gusset-plates, projecting from between each pair of flitch-plates of the booms.

Special attention has been directed to the placing of the rivets connecting the various bars and plates together, so as to minimize the loss of section due to rivet-holes, as indicated in Plate 9, Fig. 11. The rivets in the boom-joints are all spaced so as to balance around the lines of force which act upon them, thus giving the theoretical advantages of pin-connections.

The main-girders are carried at the fixed end by a cast-iron rocker frame, having a 5-inch turned rocker pin 2 feet 9 inches long. The expansion end of the girders rests on five turned rollers 4 inches in diameter and 2 feet 9 inches long. The cross-girders are 2 feet deep at the centre, and 1 foot 3 inches at the ends. The flanges are 12 inches wide. The rail-bearers and flooring are sunk 5 inches below the top of the cross-girders, so as to minimize the space required for construction. By this means the tops of the sleepers are brought level with those of the cross-girders.

Plate 9, Figs. 14 to 19, illustrate a bowstring girder bridge over the North-Eastern Railway at Hull, carrying a double line of rails. The span of the girders is 140 feet; these are parabolic, 18 feet at their greatest depth between the centres of the booms. The verticals are 8 feet 8 inches apart. The diagonal bracing, except the centre bay which is of flat bars, is formed of channel-irons. The booms consist of four channel-irons and four plates; and are stiffened between the verticals by diaphragms (Fig. 16).

The cross-girders are attached underneath the bottom boom by two plates connecting the web of the cross-girder with the diaphragm plate at the bottom of each vertical. The top angle-irons of the cross-girders (Fig. 17) are stopped at this plate to allow them to clip the web, and a cover angle-iron is riveted across the gap, the angle-irons and the plates being each $\frac{1}{2}$ inch thick, thus preserving the effective continuity of the cross-girder angle-irons. The ends of six cross-girders on each side of the bridge are prolonged, and carry raking struts, formed of tee-irons braced with small tee-irons. The main-girders are further stiffened by overhead bracing, which, owing to the skew of the abutments, is rather difficult to arrange.

The main girders have a camber of $2\frac{1}{4}$ inches. It is, however, in the Author's opinion, open to question whether it be correct to give a camber to bowstring-girders beyond a very small amount, as, the bottom boom being generally in uniform tension throughout its entire length, the upward curvature produces a slightly additional strain in the verticals and top boom in its effort to attain a straight line.

This bridge was built without having been previously erected at the manufacturer's works, and came together very satisfactorily and without any difficulty, the only awkward portion of the operation being putting in the rivets in the booms which connect the sides of the channel-irons together. A similar bridge made by a different firm, however, gave some little trouble, owing to the different system adopted in its manufacture. These were the only two bridges built without having been previously completely put together at the works, and in the Author's opinion, although perhaps cheaper for the manufacturer, it is somewhat risky from the engineer's point of view.

Hull Bridge.

Hull bridge, Plate 9, Figs. 22 to 30, is a swing bridge, which carries the railway across the river Hull, having two spans of 50-feet clear waterway. When open for railway traffic, the main-girders are supported on the two shore abutments only, but when swinging they are lowered bodily about 4 inches, so as to rest upon a central pier, composed of twelve wrought-iron piles 8 inches in diameter, fitted with cast-iron screws 3 feet 9 inches in diameter, pitched in a circle 33 feet in diameter round a central cylinder. The bridge is worked by hydraulic power, and can be swung open in either direction, but will not turn entirely round.

The main-girders, which are of the bowstring type (Fig. 20), are 148 feet 6 inches span, 25 feet apart in the clear, and 20 feet deep at the centre, the verticals being 8 feet 3 inches apart. The diagonals, which are flat bars, are riveted to gusset-plates, which project from between the main angle-irons, the flitch-plates being stopped so as to admit them. The two adjacent flitch-plates and gussets are connected by an inside and outside cover-plate. The verticals are formed of four angle-irons, riveted at the centre to web-plates, and towards the ends to plate distance pieces. The girders are stiffened by raking struts, and are further connected by head-stays and overhead bracing at the five verticals near the centre. The normal cross-girders are 3 feet deep at the centre, for the sake of great stiffness, curving up under the main-girders to 1 foot 3 inches deep. They are attached to the bottom booms by tongue-plates passing up into the bottom of the verticals.

When swinging, the main-girders rest upon four wrought-iron bogie-frames (Figs. 22, 23, and 24), each provided with two cast-steel coned wheels, 2 feet 9 inches in diameter, and 8 inches broad. The wheels of the bogie-frames are 8 feet 3 inches apart, so that the maximum weight passing down each pile will only be half that carried by one bogie, which would be close upon 45 tons in case of failure of the centre press, and 20 tons in the ordinary working of the bridge. There are also two smaller castors which serve to steady the bridge, but take no weight. The rollers and castors travel on a bevelled cast-iron roller-path, bolted to an annular girder 3 feet deep, which rests on the pile caps.

Twelve radial girders connect the pile-caps with the centre cylinder, and form a flooring, on which is laid decking carrying the hydraulic turning gear. The wrought-iron piles are braced by 2-inch bar cross-bracing in two tiers, having horizontal rings, and also radial arms to the centre cylinder. The screw-piles, which are 3 feet 9 inches in diameter, are sunk into the hard boulder clay which underlies the bed of the river at a depth of about 12 feet. Each pile, after being screwed down, was tested with a load of 60 tons, applied for seven days, and the average settlement, which was very uniform, slightly exceeded 1 inch.

The centre cylinder is sunk into the boulder clay, and is filled with cement concrete. It is lined with tarred felt to allow of the concrete swelling during the process of setting. The cylinder was tested with 281 tons applied for fourteen days, when the total settlement was $1\frac{5}{8}$ inch.

The levers for operating the bridge are situated in the signal cabin at the top of the accumulator house, which forms part of the eastern abutment, and which also contains the signal levers and usual appliances for controlling the railway traffic. In an adjoining arch is placed an 8 HP. Otto gas-engine, which works the hydraulic pumps to charge the accumulator. The accumulator is 14 inches in diameter, and has a lift of 14 feet. It is weighted to produce a pressure of 860 lbs. per square inch.

Four hydraulic presses for lifting the bridge are arranged on the abutments, having plungers 1 foot 4 inches in diameter, 6 inches length of stroke; and there is one press on the centre cylinder $26\frac{3}{8}$ inches in diameter, the top of the plunger being securely bolted to the under side of the centre box-girder, serving as a pivot, round which the bridge turns. These five presses are sufficiently powerful to raise the whole of the swinging span, which weighs about 357 tons, off the abutments.

The ends of the girders rest on cast-iron horseshoe-shaped blocks, embracing the end press-plungers on three sides. These blocks are capable of being moved inwards towards the centre of the bridge by a system of rods and wire ropes, worked by two small hydraulic cylinders on the east abutment; and they are arranged to act against either end of a lever pivoted at the centre, on the bridge, to which the rope gear is connected. There is a spring-catch lock-bolt on the east abutment.

The turning-power is placed in the centre pier, and consists of two horizontal single-acting cylinders of the usual Armstrong type, such as are seen on cranes, &c., having plungers 15 inches in diameter, and 6 feet length of stroke, fitted with sheaves and chains, with four-fold multiplying gear. The chains pass round, and are fixed to, a wrought-iron drum 14 feet in diameter. Hand force-pumps are also provided on each abutment, and the pipes are arranged so that the bridge may be worked in case the hydraulic communication across the river should be interrupted, or the main pumps break down.

All the water passes back into a receiving tank. A mixture of 1 part of glycerine to 4 parts of water is used to prevent the pipes, &c., bursting during frost. This solution will not freeze at a temperature above 15° Fahrenheit.

The working of the bridge shortly is as follows :—

1. Pressure is admitted to the centre and end presses, and the bridge rises off the bearing blocks.

2. Pressure is let into one abutment cylinder, and the resting blocks are withdrawn by the rope gear.

3. The end presses are opened to the exhaust, and the bridge sinks on to the centre pier bogies.

4. The spring-catch is withdrawn, and the bridge is then free to swing.

5. Pressure is admitted for turning the cylinder, and the bridge swings open as desired.

The bridge is closed by reversing the above operations. The difference in camber in the main-girders when the bridge is hanging free, and when resting on the abutments, is 2 inches.

The railway signals are interlocked with the hydraulic levers, which are also interlocked, so that it is not possible to work the bridge improperly. A system of detector bolts is also provided, which renders it impossible to lower the bridge unless all the resting blocks are in their correct positions; and further, electric contact is automatically broken by the first movement for opening the bridge, to give notice to the adjoining cabins that the bridge is about to be swung.

The erection of the ironwork was carried on upon a temporary staging formed of piles driven into the bed of the river. The girders were erected with a reverse camber of $\frac{3}{4}$ inch. When the blocks were slacked, and the bearing came on to the centre pier, the average deflection at each end was $\frac{3}{4}$ inch. The bridge is protected from damage when open by a permanent timber staging.

The piles were screwed down by a worm-wheel gear secured to staging. The pile shaft passing through the centre of the wheel, provided with a long key, fitted a continuous key-way cut in the pile. The centre cylinder was bolted together in lengths and calked on the staging, and then lowered to the bed of the river, when fresh rings were added as the cylinder sank. The core was removed by navvies, the cylinder being kept dry.

The peculiar construction of this bridge, which is similar to a fixed bridge when in position for the passage of trains, with only a light braced central pier to carry it when swinging, is due to the onerous requirements of those interested in the navigation and drainage of the river.

Ouse Bridge.

This bridge (Plate 10, Figs. 31 to 42), in point of size, is the most important work of the line. It is composed of two shore spans of 77 feet 6 inches each, reaching from the abutments to the intermediate piers, of four cylinders 6 feet in diameter, with 10-feet bottom lengths, and a swinging span of 248 feet, supported on a centre pier of eight 6-feet cylinders, with 10-feet bottom lengths, giving two spans of 100-feet clear waterway on each side.

The centre span, which is turned by hydraulic power, is protected from injury, when open to the river, by a timber staging, which also carries the hydraulic engines for pumping the water used for turning the bridge. The girders rest always on a "live ring" over the centre pier, the ends being supported when open for traffic on resting-blocks on the intermediate piers.

The main-girders of the side spans are 11 feet 6 inches deep, and are somewhat of the bowstring form, the ends being filled in with a plate-screen to meet the views of the Board of Trade. The girders are 25 feet apart in the clear. The verticals are 8 feet apart, and composed of four angle-irons and distance-plates. There is a double system of bar diagonal bracing. The cross-girders are 8 feet apart, and are riveted through the inner flitch-plate to the bottom of the verticals. They are 2 feet 6 inches deep at the centre, and 1 foot 9 inches at the ends. The flooring is $\frac{3}{8}$ inch thick, curved at the end to the radius of the swinging span, and riveted to the rail-bearers and cross-girders. The main-girders bear on rockers and cast-iron frames, on the abutment, and on the box-girders of the intermediate pier.

The intermediate pier is formed of four cast-iron cylinders, 14 feet apart from centre to centre, sunk 3 feet into the clay, which is about 14 feet below the bed of the river. The number of cylinders was determined by the area necessary to give a safe pressure on the clay, which was considered to be 4 tons per square foot.

The cylinder-tops are finished with an ornamental casting. The cylinders are filled with cement concrete, and are lined with felt. Brick rings are introduced at the joints, so arranged that in case of settlement or expansion of the concrete the weight of the superstructure cannot be brought to bear upon the castings, which are intended merely to act as a skin.

A double tier of wrought-iron diagonal bracing, 9 feet deep (Fig. 41), is placed between the cylinders, and securely connected to them by a horizontal channel-iron frame, bolted to the castings. This bracing is intended to take the shocks produced by the closing of the bridge, and to prevent oscillation from passing trains. A box-girder rests on the top of each pair of cylinders. The box-girders carry the ends of the shore and swinging spans, and are connected together by a saddle-girder, on which the end rail-bearers of the shore span rest.

Swinging Span.—The main-girders of the swinging span are also of the bowstring form, screened at the ends similarly to the shore spans.

The booms are 19 feet 3 inches deep at the centre, and 25 feet apart in the clear. The top boom is 3 feet 4 inches wide, and is composed of six angle-irons and four plates 1 foot 9 inches deep at the centre, reduced gradually to 1 foot 6 inches at the ends, placed in pairs $1\frac{1}{2}$ inch apart (Figs. 34 and 39). A weather-plate runs along the top of the boom. The bottom boom is of similar section, being 1 foot 9 inches deep throughout. Diaphragms are riveted between each vertical in the top and bottom booms. The greatest strains in the booms occur towards the centre, when the bridge is swinging.

The verticals are 8 feet 8 inches apart, except the three centre bays, which are 10 feet 8 inches, and the adjoining bay, which is 9 feet 8 inches. They are composed of four angle-irons, framed round between the boom-plates, and stiffened by distance-plates. The four centre verticals are built up double, with raking struts from the underside of the top boom to projecting brackets riveted to the lower boom. There are also headstays and diagonal bracing, the two centre headstays also carrying the platform on which is erected the valve-house. A double system of the diagonal bracing is formed of flat bars. These are attached to the booms by gusset-plates riveted between each pair of vertical plates, the rivets in the joints and covers being arranged symmetrically, and placed so as to occasion the least destruction of area from rivet-holes. A sample joint is shown (Fig. 38), from which the general arrangement can readily be seen.

The normal cross-girders are similar to those for the side spans, being riveted to the lower boom-plates, and further attached to the verticals by triangular brackets (Fig. 39). The second cross-girder from the centre, on each side, is of box-girder form. These girders distribute part of the weight of the main-girders and superstructure on to the circular roller-path below. The end cross-girders are also box-girders, and contain hydraulic gear for springing the extremities of the bridge, so that the resting-blocks may be moved (Fig. 41).

Great care has been taken that the centre portion of the bridge should possess great rigidity, by distributing the weight equally over the whole surface of the upper roller-path, so that each roller may receive its due share of the weight. A circular wrought-iron distributing girder, Fig. 33, acts as an equalizer or distributor of the pressure produced by the main and cross-girders on to the cast-iron upper roller-path. On the outer face of the roller-path is bolted a toothed rack, into which gear the pinions of the driving machinery. The upper roller-path is bolted together in segments, and has twelve radial arms connecting them to a boss at the centre, which turns round the top of the centre cylinder. To the underside of the cast-iron roller-path is bolted a cast-steel bevelled face, 1 foot 4 inches wide and 2 inches thick, turned to accurately agree with the coning of the rollers.

The rollers forming the live ring are twenty-four in number; they are 2 feet 9 inches in diameter at the centre, and 1 foot 2 inches wide, being formed of cast-iron centres, hooped with coned steel tires, 2 inches thick. The centres are fitted with phosphor-bronze bushes, bored to receive the ends of the radial spokes, which maintain the rollers in their correct positions on the roller-paths. These spokes are fitted with adjustment couplings, having right- and left-handed screws and lock-nuts. The rollers are maintained in their proper relative positions by an outer and inner ring formed of angle-irons. The inner ends of the radial spokes are attached to a boss, which also turns round the top casting of the centre cylinder (Fig. 33). The lower roller-path is of cast iron, fitted with a similar cast-steel face. It is bolted to the top flange of an annular-girder, to which is fixed a wrought-iron casing, so arranged as to protect the live ring and gear from the weather. The bottom flange of the annular-girder supports twenty-four cast-iron girders, on which is bolted oak decking, carrying the hydraulic engines and gear for turning the bridge. The annular-girder rests on a rectangular box-girder, having corner brackets to connect the whole rigidly together. The box-girder is supported by eight cast-iron cylinders filled with concrete, 6 feet in diameter, with 10-feet bottom lengths, sunk at each corner, and at the centre of each side of the box-girder. These cylinders are similar to those forming the intermediate piers.

As the clay proved too elastic to be relied on for the support of the movable part of the bridge, the engineer determined to sink through it to the sand overlying the New Red Sandstone, which forms a rigid foundation, at a depth of about 20 feet.

The centre cylinder forms, so to speak, a peg, round which the bridge and live ring turn; it does not support the bridge, but contains the hydraulic accumulator (Fig. 40). A cast-iron top piece is bolted to the upper length, provided with phosphor-bronze bushes, for the reception of the centre bosses, of the radial arms and radial spokes of the rollers. Ladders are provided, with trap-doors for entering the engine-room through the bridge flooring, for reaching the valve-house, and also for descending on to the staging.

Hydraulic Machinery.—The ends of the swinging span, when open for railway traffic, bear upon four cast-iron resting-blocks, supported on the box-girders of the intermediate piers. When it is intended to open the bridge, the ends are raised by means of "knuckle gear" contained in the end cross-girders (Fig. 41), the girders springing up slightly, so that the blocks can be withdrawn by small direct-acting hydraulic cylinders, placed one under each end of the bridge. Each knuckle gear is calculated to lift 65 tons.

Spring-catches, which shoot into the ends of the side-span girders, are fitted at diagonal corners for stopping the bridge in position after swinging. They are made to fit the striking-plates with very little play, so that if the bridge is closed too quickly the bolts will not enter, but allow the girders to swing past, and thus prevent serious jar to the structure.

The turning engines and fittings are in duplicate in the engine-room, within the centre pier; they are of the oscillating, three-cylinder, single-acting type, and have plungers $3\frac{7}{8}$ inches in diameter, with 14 inches length of stroke. The crank-shaft carries a toothed wheel, connected through gearing with the pinion which works into the rack, fixed to the upper roller-path. Each engine is amply powerful to turn the bridge singly, and makes one hundred and twenty-seven revolutions to every complete turn of the bridge.

In the valve-house erected on the top of the main-girders are placed the levers, &c., for working the bridge, and also the levers for working the railway-signals, interlocked in such a manner that it is impossible for the bridge-man to operate the bridge until he has put all the signals to danger. The usual telegraphic instruments are also provided.

The first movement for opening the bridge breaks electric contact with the shore, thus automatically giving warning (if the bridge-man has neglected to do so) to the adjacent section that the line is blocked. An ingenious arrangement is adopted by which, when the bridge is turned end for end, the name plates for signal levers and instruments automatically change and correct themselves.

The hydraulic accumulator contained in the centre cylinder is weighted to produce a pressure of 700 lbs. on the square inch. The steam-engines and boilers to charge the accumulator are all in duplicate, and are situated in an engine-house erected at the north end of the staging. Each engine is designed to give 20 actual HP. The bedplates serve as receiving-tanks for the exhaust water returned from the hydraulic gear. A mixture of glycerine and water is used as in the Hull bridge. The boilers are internally fired and of the multitubular type. There are two settling-tanks 28 feet long by 8 feet by 3 feet. These are necessary owing to the river water being heavily charged with warp, which, however, settles after three or four days.

The operations of opening and closing the bridge are as follow :—

1st. All the signal-levers being "at danger," the bridge-man pulls over lever A working the knuckles, and the ends of the bridge rise about $\frac{3}{8}$ inch.

2nd. He then pulls over the lever B, causing the resting blocks to slide clear of their bearings.

3rd. He next puts back lever A, when the knuckles relax, leaving the bridge supported only by the centre pier.

4th. The catch-bolts are then withdrawn by pressing the lever C, and the bridge is free to open.

5th. The bridge is opened by turning the handle D in the direction in which it is intended that the bridge shall revolve.

The bridge is closed in a similar manner, the ends being gently brought up, by the spring-catches, and further proved in position, by projections on the cast-iron bearings, which engage with the knuckle shoes when raising the bridge; this arrangement is most useful. The resting-blocks being inserted and the knuckle gear released, the bridge is fit for railway traffic.

The signal levers are interlocked with a controlling lever which inserts bolts into the resting-blocks and shore spans, so that unless all are in true position the signals cannot be lowered. This movement also makes electric contact between the bridge and the shore.

The bridge can be opened in one minute and a-half.

Lighting.—The bridge is provided with oil lamps showing red lights at the centre of each span and over the piers; a head light at the top of the valve-house having red and green dioptric lenses, indicating by night whether the bridge is open or closed to the river.

Erection.—The swinging span was erected on the permanent staging, which was covered with temporary timbers at the required level. No special difficulties were entailed during this process, the three centre bays being erected and riveted first, and then lowered on to the distributing girder; the roller-paths, live ring, &c., having been already placed in position and carefully adjusted. The remaining bays were then added by degrees and riveted. When the blocks on which the girders were erected with a reverse camber of $1\frac{1}{2}$ inch were removed, the average droop at the ends was $1\frac{5}{8}$ inch, the bottom of the span being nearly straight. This droop is very slight bearing in mind the shallow proportions of the girders. The set of diagonals pointing towards the ends of the bridge were not riveted till after the erecting-blocks had been removed, as, owing to the droop at the ends, and the compression of the verticals when the bridge is swinging, these bars require to be appreciably shorter, in order to be tight and ready to take tension, when the bridge is closed.

Variations in temperature have a marked influence on the girders, careful observations of which have been taken; the greatest vertical movement was $\frac{7}{8}$ inch between 52° and 98° Fahrenheit. The cylinders were sunk from temporary staging. The lower lengths, having been bolted together and calked, were lowered on to the bed of the river, and fresh lengths were added from time to time. The clay was excavated from the interior by a Priestman's grab, which removed the core, divers having to be employed to break down the material from the sides ready for the grab. The cylinders were kept continually filled with water, as the bottom of the river is treacherous, the top-clay being puffy and soft. Cast-iron weights caused the cylinders to follow the excavation. The required depth having been reached, the cylinders were filled with cement concrete lowered in a box having a trap-door bottom.

The cylinders of the centre pier were tested with a dead load of 186 tons, equivalent to 4·78 tons per square foot of base, including concrete, &c., applied for seven days, the average settlement being $1\frac{1}{4}$ inch. Those of the intermediate piers were tested with 214 tons, equal to 4·5 tons per square foot of base for twenty-one days, and the average settlement was $4\frac{3}{8}$ inches, the amount per day gradually diminishing to nothing.

The permanent staging for the protection of the bridge is 293 feet long, having rounded ends. It is formed of 13-inch piles securely braced together and decked over on the top. The top is 9 feet above high water. The headway under the opening spans is 15 feet at ordinary high-water spring tides.

The setting out and construction of the bridge were very satisfactory. The ends of the swing portion have the required 2 inches clearance between the shore spans almost to a nicety. Mr. J. P. Cooper, Assoc. M. Inst. C.E., was Resident Engineer in charge of the bridge.

The swing bridges and the greater part of the ironwork were manufactured by Messrs. Handyside and Co. of Derby. The Horsley Company, the Butterley Company, Mr. John Butler of Leeds, and Messrs. Eastwood, Swingler and Co., also constructed bridges for the line. Sir W. G. Armstrong, Mitchell and Co., supplied the hydraulic machinery for the swing bridges, and Messrs. Lucas and Aird were contractors for the line.

In conclusion, the Author would offer his best thanks to Mr. W. Shelford, M. Inst. C.E., who has willingly and unreservedly allowed the details and experience of the foregoing works to be described, and for the privilege of bringing under notice details with which he has personally been connected.

The Paper is accompanied with numerous diagrams and small scale drawings, from which Plates 9 and 10 and the cut in the text have been prepared.

[APPENDIX.

APPENDIX.

THE general terms of the specification in a compressed form under which the ironwork was constructed are as follow:—

All holes in main girders to be drilled or punched $\frac{1}{8}$ inch less in diameter than the finished size, and after the girders are put together rimered out to full size.

The rivet holes in the various members must coincide, so that when the plates, &c., are put together, a rivet $\frac{1}{32}$ inch less in diameter than the holes can enter without the use of the drift.

All plates to be machined at the edges.

All forgings to be made from the best hammered scrap iron.

The iron used must be of such quality as to meet the following requirements as shown by test samples:

Description.	Breaking weight per Square Inch not less than	Contraction per Square Inch original Area not less than
Plate Girders.	Tons.	Per cent.
Plates with grain	20	15
Bars up to 10 inches wide . . .	20	20
Tee-irons, angle-irons	20	20
Lattice Girders.		
Bars	24	20
Angle-irons, tee-irons, channel-irons	22	15
Plates (with grain)	21	10
„ (cross „)	18	5

Rivets must be capable of being bent double cold.

Castings.—Castings to be run from such a mixture of metals as shall produce a tough strong grey iron.

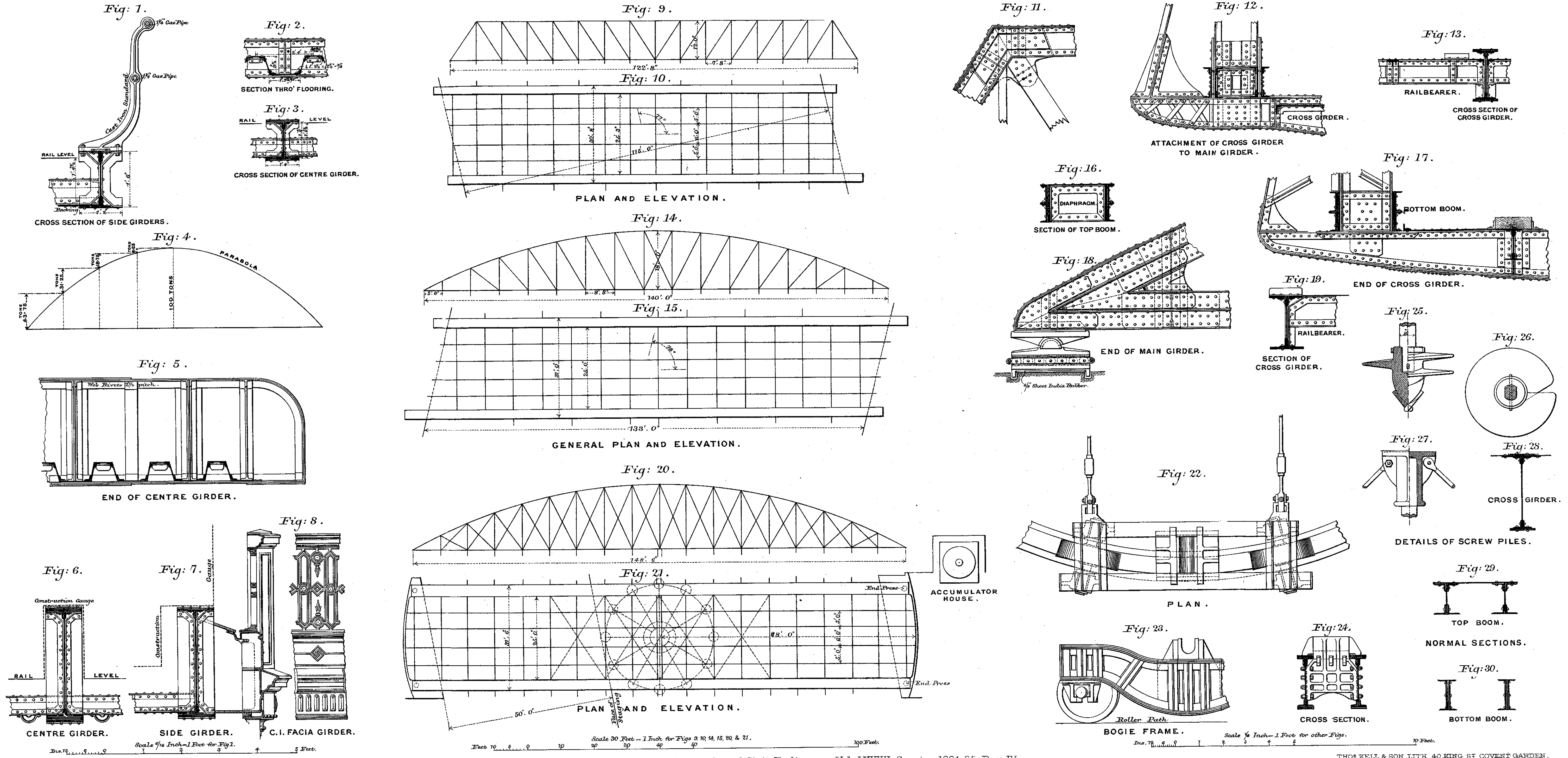
Three test-bars 3 feet 6 inches long, 2 inches deep, and 1 inch thick, to be run from each melting from which castings are made.

Test-bars to be placed bottom face downwards between bearings 3 feet apart in the clear, and must support, without breaking, a weight of 28 cwt. applied at the centre with a deflection of not less than $\frac{5}{16}$ inch, otherwise the castings represented by the test-bars will be rejected.

Some little difficulty was experienced with reference to the protection of the ironwork from rust, and a variety of mixtures of tar, pitch, tallow, resin, &c., were tried; also "tar varnishes" by different makers with varying success. In the Author's opinion good tar, thinned if necessary with naphtha or petroleum is next best to good paint.

Some paints will not dry for years on ironwork if applied over fresh tar, and if paint is put on first the tar will dry, but will permanently soften the paint underneath, and they both will be rubbed off together.

IRON BRIDGES
ON THE HULL AND BARNSLEY RAILWAY.

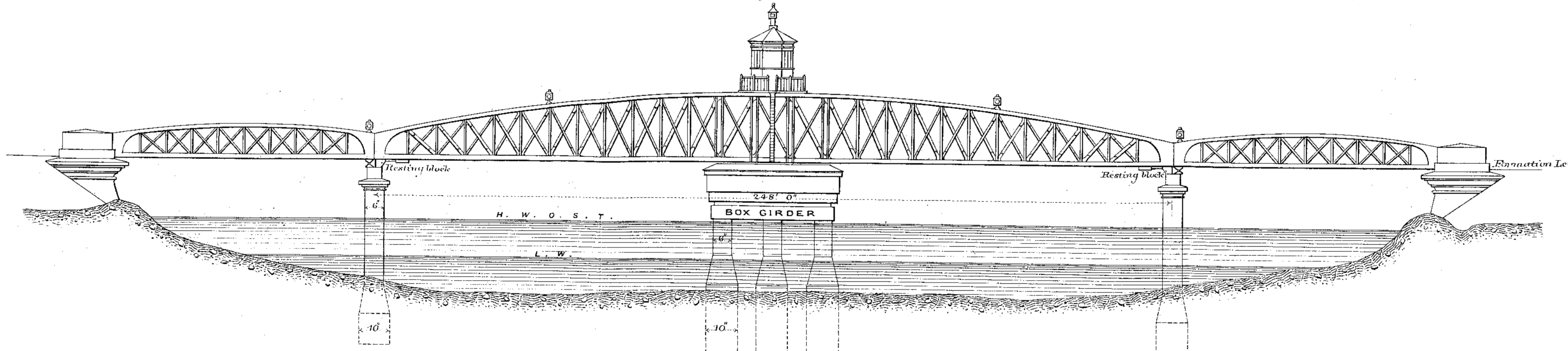


WILFRID STOKES, DELT.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

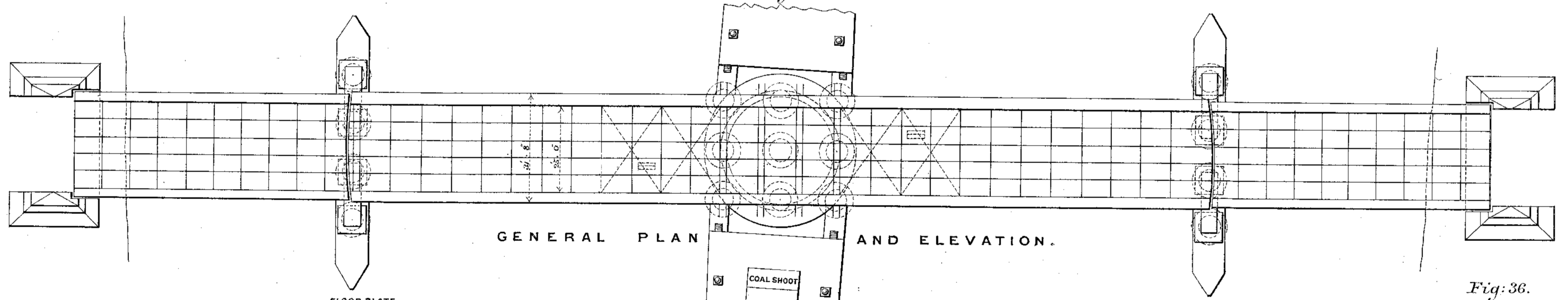
IRON BRIDGES
ON THE HULL AND BARNSLEY RAILWAY.

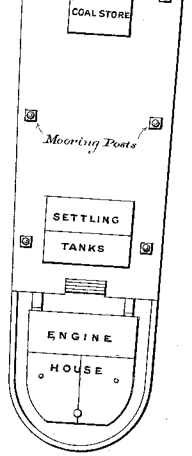
Fig: 31.



GENERAL ELEVATION.

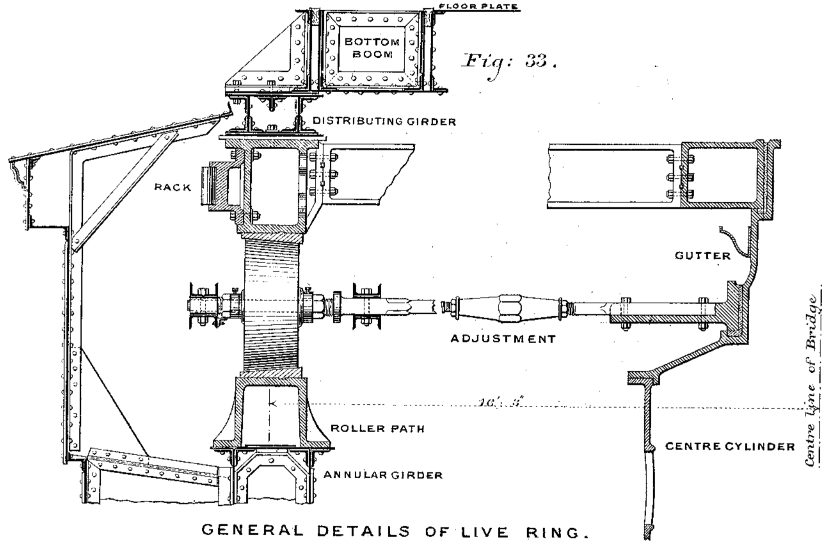
Fig: 32.





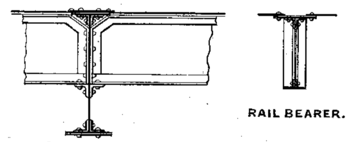
GENERAL PLAN AND ELEVATION.

Fig: 33.



GENERAL DETAILS OF LIVE RING.

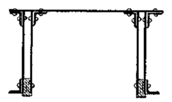
Fig: 35.



CROSS GIRDER.

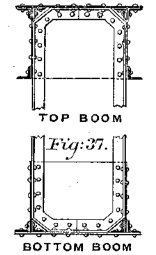
RAIL BEARER.

Fig: 34.



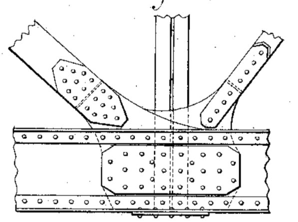
TOP BOOM.

Fig: 36.



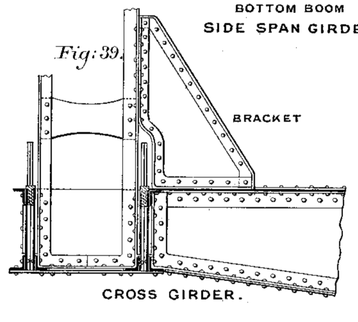
BOTTOM BOOM
SIDE SPAN GIRDER.

Fig: 38.



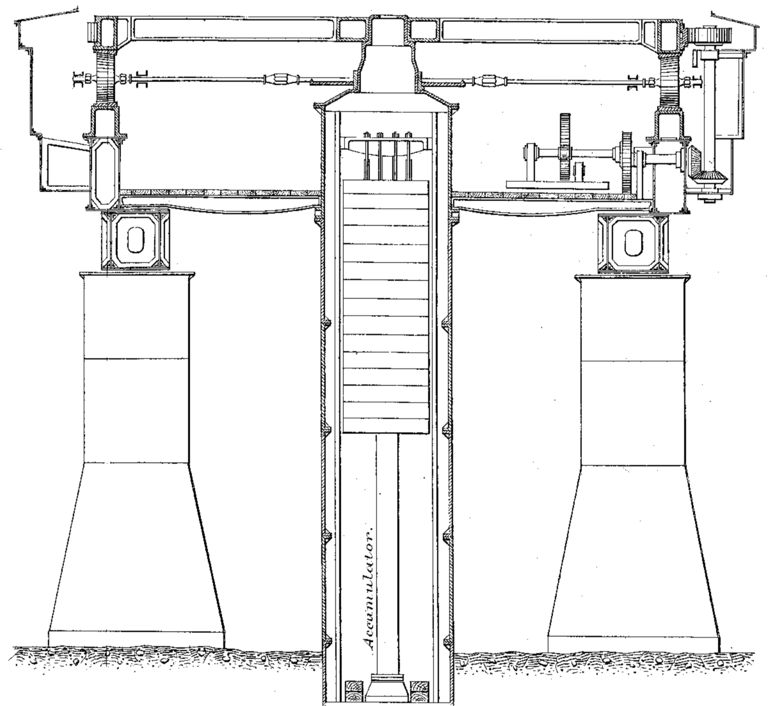
SAMPLE JOINT IN BOOM.

Fig: 39.



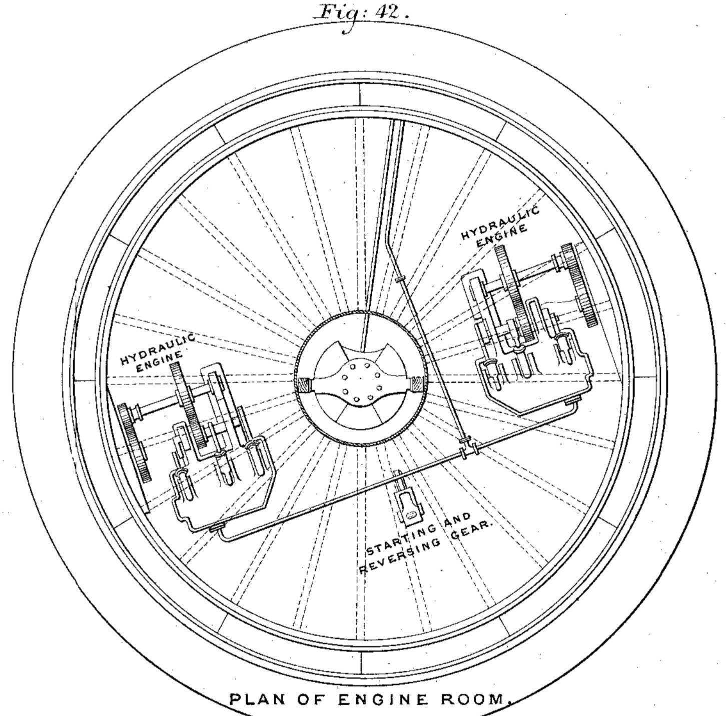
CROSS GIRDER.

Fig: 40.



CROSS SECTION AT CENTRE OF BRIDGE.

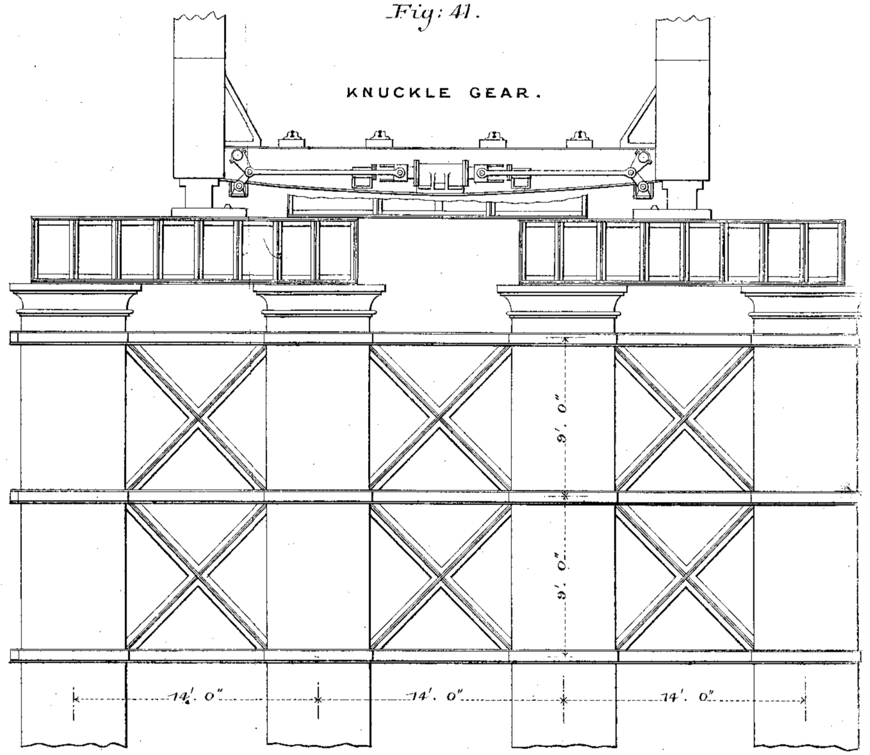
Fig: 42.



PLAN OF ENGINE ROOM.

Fig: 41.

KNUCKLE GEAR.



INTERMEDIATE PIER.

Scale 11 Feet = 1 Inch for Figs 40, 41, & 42.

Feet 10 5 0 10 20 25 Feet

Scale 45 Feet = 1 Inch for Figs 31 & 32.

Feet 50 0 10 20 30 40 50 100 150 Feet

Scale ½ Inch = 1 Foot for Figs 33, 34, 35, 36, 37, 38, & 39.

Ins. 12 6 0 1 2 3 4 5 10 Feet

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