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"Hydraulic Appliances at the Forth Bridge Works." [1]

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THE Forth Bridge, in its manufacture and erection, is a work well adapted to the use of hydraulic and other special machinery, and no opportunity has been lost by Mr. W. Arrol in the introduction of labour-saving plant. There are two forms of accumulators in use at the works, through which the high-pressure water is pumped, one form having a 16-inch cylinder loaded by dead weight, the other having an 8-inch cylinder weighted by steam. The larger one is that used for general work, the smaller, which is portable, only for isolated jobs, or in case of a break down. All the compression members of the cantilevers are tubular; the bottom members and the columns forming the main steel pier are circular in section, the struts being flattened, so as to simplify the junctions and intersections with the other parts of the triangulation.

The heaviest plates, weighing 34 cwt., are in the bottom members of the cantilevers, their dimensions being 16 feet by 4 feet 9 inches, and they are bent in the arc of a circle with a radius of 6 feet. A hydraulic press (Plate 9, Figs. 1 and 2) was made for the work, capable of putting a load of 800 tons between the cress blocks, with a pressure of 1000 lbs. per square inch on the cylinders. It has four rams 24 inches in diameter, connected at the top by a heavy cast-iron cross-head, upon which is placed the lower or concave "cress" block. Eight steel standards, 7 inches in diameter, are secured to the cylinder castings, and support the upper table, as well as form guides for the lower block while it is being raised.

The rams are packed with tallowed white rope in ordinary glands, this form of packing being very much more economical in such large diameters than any form of cup leather.

The water is controlled by two ordinary brass conical screw-down

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valves, one for admission and one for release, the exhaust water being forced out by the weight of the rams and lower table. The plates to be set are drawn from an adjacent gas-furnace, at a red heat, upon the lower cress block of the press, by means of a chain working over multiplying pulleys on a vertical hydraulic ram, and when in position are squeezed between the dies to the desired form. The plates are removed, while warm, from the press, and laid aside to cool, during which process they generally become distorted, requiring to be adjusted when cold, by placing them in the press a second time. The hydraulic cranes used throughout the sheds for handling the material, of which Plate 9, Fig. 3, is a sectional elevation, are simple in design and efficient in working. The cast-iron cylinder is let into a cast-iron box filled with concrete, forming the foundation, and is bored to $4\frac{1}{4}$ inches for the steel ram. The cantilever jib is rigidly attached to the head of the ram, and is lifted or lowered with it, transmitting the shear of its own weight and load, direct to the water in the cylinder; the bending moment being taken up by two pairs of pulleys running within the channels forming the mast. The distance between the centres of these wheels is 6 feet, being made as small as is consistent with strength to allow of as great a lift of the jib as possible. The cast-iron distance-pieces between the channels of the mast form bearings on which the crane revolves, the lower one being split embraces the cylinder just above its foundation, while the upper one works in a bearing, attached by means of a plate and long angle-stays to the roof-trusses of the sheds. The loads are slung to a small carriage, which is travelled by means of a system of chain wheels on the horizontal bottom member of the cantilever jib. A common three-way cock controls the admission and release of the water, the weight of the jib and ram serving to force out the exhaust, when the cock is turned in such a position to allow of this being done. The thickness and the number of courses of plates in some portions of the bridge is so large, and the necessity for machine-riveting therefore so great, that special plant had to be made for the work. Plate 9, Figs. 4 and 5, represent the machine used for riveting the upper and lower bed-plates, which rest upon the tops of the granite piers supporting each cantilever. The bed-plate is supported on columns about 4 feet 6 inches above its final level.

The machine is composed of two box-girders bound together at their ends by bolts and plates, and faced on their inner surfaces. Each girder is provided with a cast-steel slide, having a planed recess at right-angles to its longitudinal axis. The base of a

12-inch cylinder is contained within the slide, and can be moved transversely, or longitudinally by suitable screw-gearing.

The whole machine travels on wheels at its ends, which rest upon timber runners having "flats" spiked to their upper surfaces.

Both the cylinders are controlled by one cock, to which six pipes are attached; two of these are for the main pressure and exhaust, and two for each cylinder. Only one of the two entering each cylinder is controlled by the valve, that which enters it nearest the base; to the other the high-pressure water has constant access. The use of these two connections will be better understood by referring to Plate 9, Fig. 6, which is a section of a 15-inch hydraulic ram, used in the works for the setting of heavy plates and connected in the same way as the riveting cylinders. S, the cylinder, has two connections coming from the cock Q, one, B, on the under side of the piston, and one, C, on the upper side of the same. The lower one only can be controlled by the cock, the water being always free to enter the upper one. There are two cup leathers L, the upper one, which is always in action, faces downwards, and L′, which faces upwards, only comes into use when the water is allowed to escape from the under side of the ram R; for in that case the pressure is no longer equal on both sides of the leather, expanding it, at the same time the pressure in the annular space in the front of the piston forces in the ram. On again admitting the water to the under side of the ram, the pressure becomes equal on both sides of the lower cup leather, and the lifting area of the jack is that due to the smaller diameter.

With the above riveter eleven hundred rivets, $1\frac{1}{8}$ inch in diameter, and from $5\frac{1}{2}$ to 6 inches long, have been put in in one day of ten and one-quarter hours. In the complex junctions of the tubes, where it is impossible to work one of the ordinary riveting-machines, but where it is a matter of importance to secure the advantages of hydraulic over hand-riveted work, it was necessary to devise something entirely new. Whatever mechanism was employed would require to be of such dimensions that it would pass through a manhole 16 inches by 13 inches, and of such a weight as to be easily handled by one man. Mr. Arrol decided to adopt a high pressure with a correspondingly smaller piston area, and it was found that with a pressure of 3 tons per square inch, a riveting cylinder 4 inches in diameter was sufficiently powerful to do the work; the weight of such a cylinder and fittings does not amount to more than 40 lbs., and its overall dimensions are only 10 inches by 6 inches.

Plate 9, Fig. 7, is a section of one of two skewbacks or main junctions over the caisson piers, showing the position in which these cylinders were employed. The two cylinders are connected by small copper piping sufficiently flexible to bend easily, and provided with suitable hinged joints to one tee piece, from the third arm of which is led a copper pipe of larger diameter to the pressure multiplier, which is large enough to keep two or three pairs of cylinders in operation. Plate 9, Figs. 8, is a section of this machine, C is a brass casing or cylinder, having two diameters, the squares of which are in inverse ratio to the pressure on the two ends of the ram.

The plunger has a piston upon its end of the diameter of the lower part of the cylinder.

Referring to the diagram of the connections, Fig. 8, F is the flexible hose bringing water at 1,000 lbs. per square inch to the under side of the conical valve V, as well as leading through the branch B to the cock Q, which is an ordinary plug cock, communicating through the pipe P with the base of that part of the cylinder having the larger diameter. From the space on the upper side of the conical valve V, there are two branches, one leading into the end of the cylinder having the smaller diameter, the other controlled by the screw-down valve S, to the small riveting-rams. The cock Q being turned to exhaust, and the pressure at 1,000 lbs. filling (after lifting the conical valve V) the smaller cylinder, the water below the larger piston is forced out, and the ram brought to the commencement of its stroke. When a rivet is to be struck the screw-down valve S is opened, filling the piping and small rams with water, at 1,000 lbs. per square inch. The rivet is squeezed as far as the pressure of 1,000 lbs., on an area of 12 square inches, will squeeze it, when it is necessary to put on the higher pressure of 3 tons. This is done by turning the cock Q, which allows the water at 1,000 lbs. pressure to enter the larger cylinder, thereby increasing the pressure in C′; thus shutting the conical valve against the water at the lower pressure and preventing it from leaking back into the mains, while at the same time the rivet gets the necessary load to properly compress it. For riveting the vertical and diagonal tubes, machines of special design are employed, similar in principle to the one already described in connection with the bed-plates, but differing from it to suit the form and position of the tubes on which they work.

Plate 9, Fig. 10, is a vertical section of one of the 12-foot tubes, showing this machine in place, Fig. 9 being a sectional plan. R and R′ are two heavy steel girders, 22 feet apart, kept at their correct distance by angle-iron framing, which when covered with small mesh netting makes a complete cage, from which nothing can fall. The rings are kept at a uniform distance from the skin of the tube by hard wood wedges driven in opposite the stiffening H beams. G is the vertical riveting girder held by cast-steel clips to the outer flange of the circular rings, but it can be moved to any position in their circumference by the small hydraulic jacks C, Fig. 9. On the face of the girder, held in a cast-steel sliding saddle, is the riveting cylinder, to which there is also attached a small platform for holding the men, whose business it is to attend to the closing of the points of the rivets. The saddle, with its stage and cylinder, can be raised or lowered to any position by the small hydraulic jack B, the cock controlling which is within easy reach of the men on the stage.

Holes are provided in the faces of the girders as well as round the circumferences of the rings, against pins passed through which the rams are made to bear, either to raise the cylinder or to alter the radial position of the girder. There is then on the outside of the tube a vertical girder, movable to any position round the circumference, carrying a cylinder which is capable of putting a pressure of 40 tons on the point of a rivet on any part of a length of 17 feet. The inside girder does not travel bodily, but is made to rotate by suitable gearing, within easy reach of the men on the small lifting platform, upon trunnions at its ends (Plate 9, Fig. 10). These trunnions are held in a central position by angle-frames at the upper and lower ends of the girder, which are wedged to the faces of the longitudinal stiffening beams of the tube, and rest upon small movable brackets.

The cylinder is in this case far from its work, but is provided with a long snap, having a movable cranked end, so made to get in at the backs of the angles on the H beams (Fig. 9). The cylinder, platform, and men are raised and lowered by a small hydraulic jack, in the same way as on the outer riveting girder. There is then inside a cylinder of the same power as that without, which can be brought to bear on the head of any rivet in a length of 17 feet of the tube. The whole machine is suspended to the platform above, and is raised with it in 16-foot stages, or sufficient to put on one course of plates.

The water is admitted to both cylinders at once from one cock, but is delayed by a suitable valve from entering the outer cylinder until the rivet is well pushed into the hole from within.

The rivets are heated in a specially designed oil-furnace, just above the machine, inside the tube, and have been put in at the rate of eight hundred per day of ten hours. The machines used in the diagonal tubes are similar as far as the outer rings are concerned, except that instead of being circular they follow the outline of the flattened tubes upon which they work. The longitudinal girder is made to traverse a path at a uniform distance from the inner sides of the plates, upon raised ridges, which are attached to the upper and the lower diaphragms, forming the inner framing of the machine.

The last subject to be dealt with in this Paper is the raising by hydraulic jacks of the approach viaducts, the larger of which is 1,680 feet long, and weighs about 2,000 tons. The viaducts are in 168-foot spans, continuous over every second pier, and so closely connected at the non-continuous pier that it was decided to lift all the girders at one time. Two inverted 15-inch jacks were employed on each pier; these were fixed into a temporary cross-girder bolted to the under side of the viaduct. Four stacks of hard wood blocks were placed beneath the cross-girder, which, during the time the lifting operations were going on, were kept closely packed by means of long slip wedges. There was also placed under each cylinder a pile of blocks, against which the rams pressed while the girders were being raised. On the completion of a lift, which was always enough to allow of the building of three courses of the pier, the stacks were removed one by one, to enable the masonry to be set beneath them, being again replaced after the new work had been allowed sufficient time to set. When the three courses of the pier were finished, forty-eight hours were allowed for the proper setting of the cement, before another lift was taken. The high-pressure water was supplied at 34 cwt. per square inch, by steam-pumps, the engines of which, during the building operations, were used to work by rope-gearing the friction-hoists for setting the masonry. The rate of building and lifting, including the time allowed for the setting of the cement, was about 10 feet per month, and a lift of between 4 and 5 feet occupied about two hours. The north and south viaducts have been raised, by the means here outlined, over 100 feet without any mishap, and are now at their final level.

This communication is accompanied by several drawings, from which Plate 9 has been engraved.

HYDRAULIC APPLIANCES, FORTH BRIDGE.