No. 1,062.—"Description of the Centre Pier of the Saltash Bridge, on the Cornwall Railway, and of the means employed for its Construction." By ROBERT PEARSON BRERETON, M. Inst. C.E.

THE Author having been frequently requested to furnish a description of the means employed for the construction of the centre, or deep-water pier of the Albert Bridge, across the River Tamar at Saltash, on the design and construction of which he was engaged under the late Mr. Brunel (V.P. Inst. C.E.), the Engineer of the Cornwall Railway, has prepared the following narrative:—

In the year 1845, the Cornwall Railway Company applied to Parliament for an Act to construct a Railway from Plymouth to Falmouth. The locality selected for crossing the River Tamar was at the town of Saltash, about 3 miles north of Plymouth, at a place where the river narrows to 1,100 feet wide, with precipitous banks, and has a depth of 70 feet, from the surface of the water to that of the mud.

It was at first proposed, that the bridge should consist of seven openings, one of 250 feet, and six of 100 feet each, of a uniform height of 70 feet; but in consequence of objections raised by parties interested in the navigation, plans were submitted to the Admiralty with the increased dimensions of one span of 255 feet, and six of 105 feet, at a height of 80 feet above high water, all to be built with timber-trussed arches. The Admiralty, however, required that there should be four spans only, two of 300 feet and two of 200 feet each, with straight soffits, and a clear headway above high water of 100 feet. To comply with these requirements, it became necessary to apply to Parliament, for amended powers, which were obtained in 1847.

In selecting the site for the bridge, advantage was taken of a dyke of greenstone trap, which intersects the clay slate formation in the neighbourhood, and crops out to the surface above the water on the Saltash, or western bank of the river. In 1847, a general examination of the bed of the river was made, by borings. It was thus ascertained, that along the eastern side, to beyond the middle of the channel, there was rock, covered with a deposit of mud, or silt from 3 feet to 16 feet in thickness; and that from the middle of the channel the rock fell off rapidly towards the Saltash side. Attempts were made to ascertain, by borings, the figure of the surface of the rock below the silt, in the middle of the river; but owing to the depth of the water and the strength of the current, sufficiently reliable information could not be obtained. It was discovered by divers, that on the Saltash side, the surface of the rock presented a precipitous decline towards the river, but that it was free from chasms, and in the inshore part was favourable for the construction of a pier. In 1848, Mr. Brunel determined on a thorough examination of that part of the bed of the river, where the centre pier would probably be built. This was effected by means of a cylinder of wrought iron, 6 feet diameter, and 85 feet long, which was slung between two gun-brig hulks moored in the river, and the bottom edge of which was lowered a few feet into the mud. Early in 1849, the bed of the river for a space of 50 feet square, had been carefully examined by one hundred and seventy-five borings, made inside the cylinder at the thirty-five different places where it had been pitched. On the last occasion, the cylinder was sunk to the rock, the water was pumped out, to test the water-tightness of the mud, and the material was excavated from the inside. Masonry was then built upon the rock, up to the level of the bed of the river, and the cylinder was withdrawn. From the information thus obtained, an exact model of the surface of the rock, which had been examined, was prepared, showing the irregularities and the fissures that were to be expected.

By this time the construction of wrought-iron railway bridges had become general; and in the cases of the Conway and the Britannia Bridges, spans up to 460 feet had been obtained without difficulty. In determining the dimensions of the bridge at Saltash, it was considered whether it might not, with advantage, be constructed with only one pier in the deep water, instead of three, as would have been necessary for the spans required by the Admiralty; and the experience obtained of the nature of the foundations, having shown that the rock was favourable for the construction of the piers for a span of 465 feet over the western half of the river, designs were made in 1850 for a bridge with two main spans of 465 feet each. In 1852, when it was determined to proceed with the building of the bridge, it was considered practicable to reduce the spans to 455 feet each. The drawings from which the bridge was executed were prepared accordingly, and early in 1853 the work was commenced.

The total length of the bridge, including the adjoining land openings, is 2,200 feet. It has two spans of 455 feet, two of 93 feet, two of 83 feet 6 inches, two of 78 feet, two of 72 feet 6 inches, and nine of 69 feet 6 inches The centre, or deep water pier, which carries the weight of one half of each of the two main spans, consists of a column, or circular pillar, of solid masonry, 35 feet diameter, and 96 feet high from the rock foundation to above high-water mark. Upon this are placed four octagonal columns of cast-iron, 10 feet diameter, carried up to the level of the roadway, which is 100 feet above high-water mark. Upon the tops of these columns, cast-iron standards are fixed, for receiving the ends of the tubes and chains, which constitute the trusses of the bridge. The weight at the bottom of the masonry foundation is about 9½ tons per square foot, increased, when the bridge is loaded by passing trains, to about 10 tons per square foot.

For the construction of the masonry pier, a wrought-iron cylinder, of boiler plates, 37 feet diameter and 90 feet in length, and open at the bottom, was sunk through the mud of the bed of the river to the rock (Plate 4, Figs. 1 to 8). The water was afterwards pumped out, and the mud excavated; the masonry column being built up inside, and the cylinder above the ground being afterwards removed. From the experience obtained in sinking the 6-feet cylinder for making the borings, it was expected that, with the compression of the mud outside the 37-feet cylinder, by a bank thrown round it, after it was sunk to the rock, it would be rendered sufficiently water-tight for the execution of the masonry. But to provide for the contingency of excessive leakage, it was determined, in designing the cylinder, so to construct it as to admit of the application of air pressure in the inside, which had been successfully employed, in sinking the cylinders, for the bridges at Rochester and at Chepstow. The shape of the bottom of the cylinder was obtained, by applying it to a model of the surface of the rock, which had been prepared from the previous borings. This surface, although very irregular and ragged, showed a general dip, of about 6 feet, to the south-west, and the bottom of the cylinder was formed with a corresponding slope, one side being 6 feet longer than the other. A dome, or lower deck, was constructed inside, at the level at which the mud of the river bed would be, when the cylinder was sunk in position; and an internal cylinder, 10 feet in diameter, open at the top and the bottom, connected the dome with the top, or upper deck, of the cylinder. Further to allow of the application of air pressure, the 6-feet cylinder, previously used for boring, was fixed excentrically inside the 10-feet cylinder, and an air-jacket, or gallery, making an inner skin round the bottom edge below the dome, was formed of plates, intended to be used in the roadway girders of the bridge. The air-jacket was about 4 feet in width, divided by partition plates into eleven compartments, or cells, and connected with the bottom of the 6-feet cylinder by an air passage below the dome. It was intended, that the lower part of the cylinder, below the ground, should be filled in with solid masonry, and that it should not be withdrawn. The upper part, 50 feet in length, was constructed in two pieces of larger diameter than the masonry, with vertical separating joints bolted together, so as to be capable of being removed after the completion of the pier.

In the spring of 1853, the cylinder was commenced. It was built upon the beach, or shore of the river, with its lower end towards the water, and with its axis at an inclination of about 1 in 6. It was designed to float at that inclination when empty, and to draw about 15 feet of water forward, as shown in Fig. 4. Whilst the cylinder was being constructed, four wrought-iron pontoons, intended for floating the large spans of the bridge into their places, were moored in the middle of the river, round the intended site of the centre pier, and four mooring anchors and cables were laid out, ready to receive the cylinder.

In May 1854, the cylinder was launched, by being hauled down to low-water mark on launching ways, and it was floated off by the rising tide. It was then towed to the pontoons, and placed between them, and some water was admitted to bring it into its proper position, with the upper deck well out of the water. The mooring chains were taken on board, rove through sheaves, fixed at four points low down in the cylinder, and brought to the purchases on the deck. After the cylinder was secured between the four pontoons, water was gradually let in, till it floated in a vertical position, as represented in Fig. 5. It was then brought to the intended site, and sunk early in June, by gradually admitting water into the inside. The cylinder penetrated about 13 feet through the mud at the bottom of the river, and landing on some irregularities upon the rock, its top heeled over from the vertical, about 7 feet 6 inches towards the east. Preparations were then made for resorting to the use of air pressure, in order to reach the bottom edge, and to bring the cylinder into an upright position. A pneumatic apparatus and air pumps, which had been used at the Chepstow Bridge, were obtained, and fixed to the top of the 6-feet cylinder; two engines of 10 H. P. were placed upon the upper deck to work the air pumps, and two 13-inch water pumps were fixed inside the 10-feet cylinder. Meanwhile, steps were taken for forcing down and righting the cylinder, by water pressure upon the dome, or lower deck, and by loading the higher side with iron ballast. Gravel was thrown down round the cylinder, to secure the surface of the mud from scour, but the quantity was too small to interfere with the 'righting' of the cylinder.

At the end of June, the cylinder forced its way through the obstructions at the bottom edge, and went down 3 feet, taking a nearly upright position. Early in July, the air and water pumps were set to work. In August, the greater part of the mud and oyster shells, which filled the compartments of the air-jacket at the bottom, had been cleared out, and the irregular surface of the rock was being excavated. The water pumps were used for lowering the surface of the water inside the 10-feet cylinder, thereby diminishing the pressure in which the men were obliged to work; the bottom of the cylinder being then 82 feet below the high-water level.

Between August and November, a leak having broken out, through a fissure in the rock on the north-east, or higher edge, great difficulty was experienced, in maintaining sufficient pressure with the air-pumps, to keep the water down, and the bottom dry, for the men to work, while excavating the rock. The leakage was at length considerably reduced, by driving close sheet piling into the fissure.

In February 1855, the cylinder was sunk to its full depth, in an upright position; its bottom being everywhere down to the rock, and 87 feet 6 inches below high water at the lowest place. Before the final dressing of the rock at the bottom, a hemp gasket was worked under the edge of the cylinder, all round the outside, to assist in making it water-tight. The bottom edge, both on the up and on the down stream sides, was also secured to the rock, by lewis bolts, so as to steady it against the action of the current and the tides. In March, the rock was levelled in all the compartments of the air-jacket, and its surface cemented over. The cutting away of the rock was a very tedious operation, as in some parts, as much as 6 feet in depth had to be taken off with chisels, the trap being of such hardness, that tools could with difficulty be got to work it. In April, a ring of granite ashlar masonry was commenced in the air-jacket, and in May, it was completed all round. The granite ring was 4 feet thick, and averaged about 7 feet in height, as shown in Fig. 6. Whilst the masonry was being proceeded with, a bank, about 10 feet high, of heavy material, composed of slag and sand, was thrown round the outside of the cylinder, to compress the mud. The operations with the air-jacket were thus completed, the greatest pressure having been with 86 feet head of water. From thirty to forty men were engaged inside.

Early in June, the air-apparatus was removed from the 6-feet cylinder, the water was pumped out of the body of the cylinder below the dome, and the excavation of the mud had been commenced; but at the end of the month a leak broke out. As the pumps were unable to remove the water, two additional engines and 13-inch pumps were provided, and in the interval, until September, efforts were made to diminish the leakage, with varying success, by throwing more material round the bank outside the cylinder. The leakage, however, continued to such an extent, that even with the two additional pumps, which were got to work in October, the water could not be kept down. In November, it still required the four pumps to keep the water down to 54 feet, in spite of incessant pumping and throwing additional material round the outside. It was therefore thought, that recourse must be had to air pressure in the body of the cylinder below the dome, and preparations for its application were made.

As the 10-feet cylinder, for 50 feet in length at its upper part, was not constructed with plates of sufficient thickness to support, with safety, the pressure when filled with air, a 9-feet cylinder, with thicker plates, and about 50 feet in length, was constructed to be slipped inside, and to be secured at the bottom to the 10-feet cylinder, by a shelf riveted to it, about 50 feet from the top, to which level the four pumps were able to keep the water. Two pairs of new 12-inch air-pumps were provided, in addition to those hitherto used, and commodious wrought-iron air locks, or cages, were constructed, for attaching to the top of the 9-feet cylinder. By the middle of November the shelf was fixed, and the 6-feet cylinder was removed.

To provide against the buoyancy, or upward pressure against the dome and cover of the 9-feet cylinder, it was necessary to load the 37-feet cylinder, in addition to its own weight of 290 tons, with about 750 tons of ballast. Of this about 350 tons consisted of pig iron and kentledge, stacked upon the shelves of the 37-feet cylinder, near the top, and upon cross girders under the upper deck. The remaining 400 tons were placed upon the dome; 100 tons of this consisted of sand in bags lowered through the water, and uniformly distributed, and 300 tons of pig iron, afterwards thrown in upon it. These operations were not completed until the middle of December, when everything was ready for fixing the 9-feet cylinder. The pumps were then brought into good order, and by continued pumping, the water was kept down. The mud was excavated, the cylinder below the dome securely shored across, as shown in Fig. 7, Plate 4, and the rock levelled. The masonry in the body of the cylinder was commenced early in January 1856. A leak was discovered to have again broken out at the same fissure as before, and it had torn away the rock underneath the masonry of the air-jacket and the bottom edge of the cylinder; but the masonry itself was not disturbed.

As soon as the rock was reached, holding-down lewis bolts were let into it, with ironbars to be built into the masonry, and attached to the bottom of the 10-feet cylinder, as a further precaution in case of any sudden influx of water. The water from the leak, and from some smaller fissures, was carefully collected in pipes, and conveyed to two cast-iron wells, which were formed in halves and placed round the suctions of the water-pumps, the whole being then built into the solid masonry.

By incessant pumping, the water was kept down, so that by the end of February, the masonry, in thin courses of granite ashlar in cement, had reached the level of the air-jacket ring. The masonry was then thoroughly bonded together, the plates of the air-jacket being cut out as it proceeded. Upon the top of the bonding-course, two courses of hard brickwork in cement were laid, making a perfectly water-tight floor over the whole surface of the section, which was there 35 feet in diameter. Meanwhile, the masonry of the air-jacket, where the leak occurred, was taken down, and the leak was diminished by additional sheet piling at the edge of the cylinder, so that one engine and pump could be dispensed with. The water was collected in a pipe having a sluice valve, which on being closed early in March reduced the leakage by about one third. In the middle of March the water was drawn off above the dome, the ballast was removed, and the 37-feet cylinder above it properly shored. Early in April, the masonry had reached the springing level of the dome, or 20 feet in height. The dome was then cut away, as well as the bottom of the 10-feet cylinder. Two pumps were now sufficient to keep the water down.

By the middle of April, one of the pump-wells was filled up with cement concrete. Early in June, one pump was found sufficient to keep the water down, the masonry being 43 feet high, and proceeding at from 5 feet to 7 feet in height per week. In the middle of June, the masonry being then 46 feet in height, the influx of water was entirely stopped, by filling the remaining pump-well with cement concrete, and closing the top of it.

The masonry was completed to the top of the plinth, or cap of the pier, by the end of October; and in the middle of November, the upper part of the cylinder was unbolted, at the separating joints, and floated to the shore with the pontoons, and the iron made use of, for the decking of the pontoons which were to be used in floating the bridge.

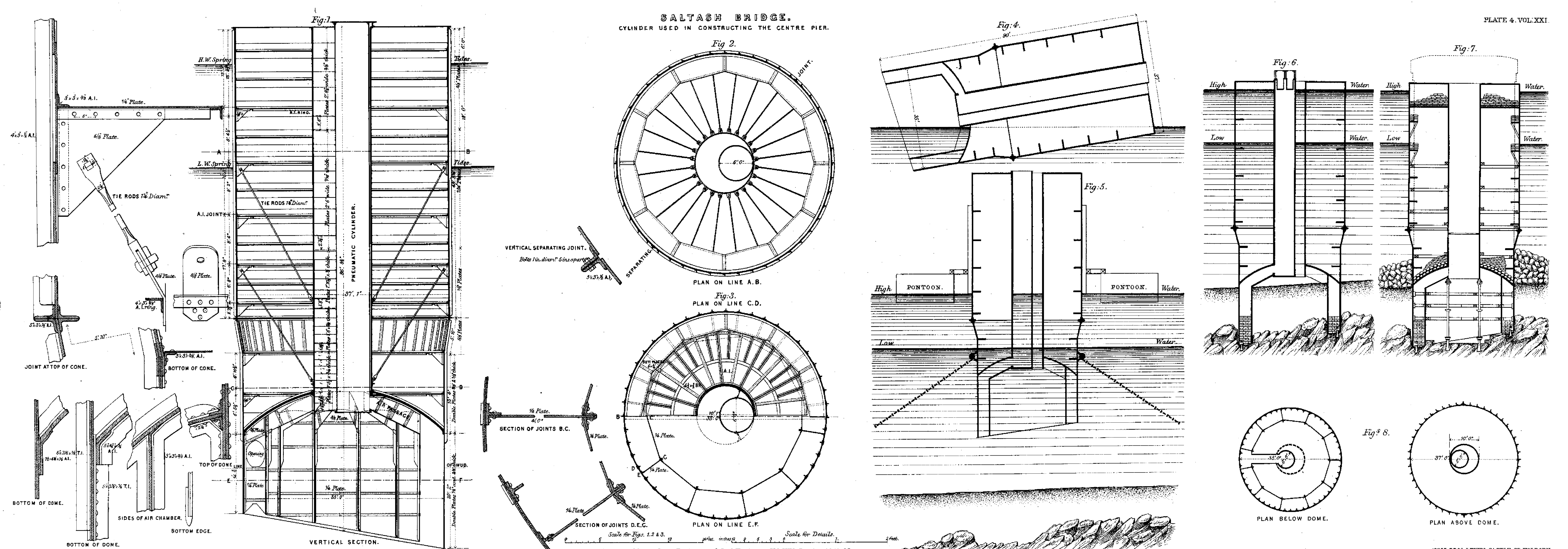
All that then remained to be done, was to fix the bases of the cast-iron columns to the masonry, and to erect the columns themselves for receiving the ends of the bridge when floated into its place. This was accomplished, with the first span, over the western half of the river, in September, 1857; and with the second, or eastern half, in July, 1858.

The Paper is illustrated by a series of diagrams from which Plate 4 has been compiled.

[Mr. BRERETON

SALTASH BRIDGE.

CYLINDER USED IN CONSTRUCTING THE CENTRE PIER.



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