ON THE PUMPING MACHINERY FOR EMPTYING THE DRY DOCKS AT CHATHAM AND AT RIO DE JANEIRO.

BY MR. GEORGE B. RENNIE, OF LONDON.

The new Dry Docks at Chatham and the works in connection with them, for the repairs of the ships of the Royal Navy, adjoin the old Dockyard, which is situated ten miles up the river Medway, near the mouth of the Thames, as shown by the light shaded area in the accompanying general plan, Fig. 1, Plate 40, and dates its existence from the time of Queen Elizabeth, shortly before the Spanish Armada in 1588; it was improved in the reigns of James I and Charles I, and the first dry dock is said to have been constructed there in the latter period. In 1667 the celebrated Dutch Admiral De Ruyter sailed up the Medway, and after destroying several of the largest ships of the English navy was stopped at Upnor Castle, just before reaching Chatham Dockyard. Subsequently the dockyard was enlarged and improved at various times, until it extended for more than three quarters of a mile along the south bank of the river, and covered an area of about 80 acres. It contained four small dry docks of wood up to the year 1820, when a fifth of larger size was constructed by the late John Rennie, of granite, and more suitable for the largest class of vessels then in the navy.

The breadth of the Medway opposite the dockyard is only 1250 ft. at high water, and 950 ft. at low water, with a depth of 14 to 20 ft. at low water of spring tides; and this depth is scarcely increased for a distance of two miles down the river to Gillingham Reach. In a report made to the Admiralty by John Rennie in 1814 the disadvantages of the position of a dockyard so far up a river as Chatham, or as Woolwich and

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Deptford, were clearly pointed out; but as it was determined to retain these dockyards, it was suggested in this report that the best mode of remedying the evils of shallow water and difficult navigation would be by making a direct communication with Gillingham Reach, thus saving the round of two miles in shallow water; "for the great detention and hazard of bringing ships up the Medway lies between Gillingham Reach and the dockyard." A more detailed report was made some years later, with estimates for the required works; but the proposal fell through, and the system of patching and altering the old dockyard and enlarging the old dry docks went on from time to time, until eventually it was determined to enlarge the dockyard considerably, and to construct new basins and dry docks on the adjoining mud flats known as St. Mary's Islands, covering the area shaded dark in the plan, Fig. 1, and to make two entrances, one near the old dockyard and the other at Gillingham Reach.

The plans for the new works were prepared about 1860 by the Admiralty Director of Works, Colonel Green; but these were considerably modified by his successor, Colonel (now Sir Andrew) Clark. The plan finally adopted and now in course of execution, as shown in the general plan, Fig. 1, comprises three basins; first the Repairing Basin of about 21½ acres, with one entrance into the river near the dockyard, and the other end communicating with the second basin of about 20 acres, called the Factory Basin, which is also in connection beyond with the third or Fitting-out Basin of about 33 acres, with an outlet from this into Gillingham Reach. Thus after a lapse of some sixty years the proposal of John Rennie is now being carried out, so far as the main point is concerned of placing the dockyard in direct communication with Gillingham Reach, though his plan for doing this has been modified.

On the south side of the Repairing Basin four large Dry Docks have been constructed of granite, as shown at D in Fig. 1, each 468 ft. length by 108 ft. breadth on the ground line, with a total depth of 41½ ft. These works have been constructed under the superintendence of Lieut.-Colonel Pasley, R.E., assisted

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

by Mr. Bernays. At present only the Repairing Basin and the Dry Docks are in use; the Factory Basin is nearly completed, and the Fitting-out Basin is in course of construction. The principal part of the labour is done by convicts, who are now employed in excavating the Fitting-out Basin. At the Gillingham Reach entrance there will be two locks, in order to give facility for passing ships into and out of the basin simultaneously at most periods of the tide, without waiting for high water.

In 1869 plans and estimates were submitted to the Admiralty by the writer's firm, for the Pumping Machinery required for emptying the two graving or dry docks then in course of construction, and to be available also for the two other docks to be afterwards constructed. These plans were eventually adopted at the recommendation of the Committee specially appointed to examine the whole question; and the work has been carried out accordingly by the writer's firm. The following conditions were required to be fulfilled in the design for the pumps. They were to be capable of removing the water from the two docks simultaneously in four hours, pumping into the basin and without discharging into the river, the water in the docks and basin standing at 27 ft. above the sills of the dock entrances at the commencement of the pumping. The pumps were also required to raise water from one foot below the bottom of the dock culvert, and discharge into the basin; or to pump from the river into the basin direct, in order to raise the level of the water in the basin when wanted. It was also considered desirable that in emptying the docks the water should be lowered as rapidly as possible to the level of the "broad altar" course, shown in the transverse section of the dock in Fig. 4, Plate 42, this depth being 15 ft. below the top or 27 ft. water level, and estimated to contain about 18,000 tons of water. The remaining depth from this point to the floor or bottom of the dock is $15\frac{1}{2}$ ft., containing about 12,000 tons of water; so that the total quantity of water to be pumped out in four hours was 60,000 tons, the lift increasing from zero to $30\frac{1}{2}$ ft.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

The condition of discharging the water rapidly from the top or 27 ft. level down to the broad altar course was considered to be best met by the adoption of two centrifugal pumps, as the maximum lift would be only 15 ft., and that class of pump is found to be peculiarly adapted for the work of discharging large volumes of water at low lifts. But the form of pump and size of suction pipes required for discharging a large volume of water with a low lift are very different from those required for discharging a small volume with a high lift. This has been shown in the experiments made on centrifugal pumps, such as those for emptying the dry docks at Portsmouth, where at 12 ft. lift the useful effect is 33 per cent., and at 19 ft. lift only 20 per cent.; and it would consequently be very small at 30 ft. lift.

With respect therefore to the lower part of the dock, containing a smaller quantity of water, with a lift varying from 15 ft. to 30½ ft., it was considered that the size, form, and velocity of pumps suitable for the upper portion would be ill adapted for the lower portion, if each pump were to draw and discharge independently, as in the upper portion. It was also desirable to arrange so as to have as little variation as possible in the indicated horse power of the engines throughout the work, as well as in the speed of the engines and pumps. These requirements have been met by having recourse to dividing the lift for the lower portion into two parts, by placing the two pumps at different levels, each pump lifting the water through only half the total height, so that neither of them has to discharge against a greater head of water than about 15 ft.

This arrangement renders it necessary for each pump to be placed in a separate well, with separate suction and discharge culverts, but with a communication between the two wells above the discharge of the lower pump into the suction of the upper pump; and with the means of opening or closing this communication at pleasure by a sluice or penstock. The culvert from the docks to the pump suction is 7 ft. diameter, and about 1050 ft. length, as shown at C C in the section and plan, Figs. 2 and 3, Plate 41, branching just outside the pumping-engine house into two culverts A A, Fig. 6, each 7 ft. high by 3 ft. wide; a sluice is fixed in the

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

main culvert at the junction, as well as an independent sluice in each branch culvert. The pump wells B B are $11\frac{1}{2}$ ft. diameter, with a total depth of $55\frac{1}{2}$ ft., and are constructed in brick, with granite copings and foundations.

The centrifugal pumps and wells are shown in the section and plan, Figs. 5 and 6, Plates 43 and 44. The pumps E E work horizontally upon vertical shafts F, which have bevel wheels 5 ft. 8 in. diameter fixed on their upper ends, driven by 6 ft. wheels upon a horizontal shaft G. The pumps are carried by collars on the shafts and are keyed upon them; the pumps and shafts are held central by girders fixed across the wells and stayed by short girders at right angles. The lower bearings of the shafts are cased with gunmetal, and work in lignum-vitæ bushes without any end bearings, as shown at H in Fig. 7; and the bearings at the upper ends of the shafts are formed of a series of collars working in gunmetal, as shown at I in Fig. 5, which carry the weight of the pumps and shafts and of the column of water in the centre opening of the pump. By means of screws the level of the pumps can be adjusted so as to give a minimum clearance between the rotating part of the pumps and the fixed part, with the least loss from clearance and the least amount of friction.

The form and arrangement for working the pumps are the same as in the large centrifugal pump made by the writer's firm for H.M. Dockyard at Keyham, but with a larger proportion in the size of the suction pipe to the size of the pump. The pumps are $8\frac{1}{2}$ ft. diameter, and the suction pipes $4\frac{1}{4}$ ft., increasing to 6 ft. diameter at the rose end. The pumps are of cast iron, and of a form that has been adopted by the writer for some time, as shown in Figs. 7 and 8, Plate 45, as he considered and has since found by experiment that the ordinary form of centrifugal pumps with the outflow abruptly at right angles or nearly so to the inflow causes a considerable loss in the delivery of the water. For the purpose of testing this point he had two small model pumps accurately made, as shown half full size in Fig. 9, Plate 46, exactly alike in size, and in number and form of arms, but one with the flow at

A 2

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

right angles, and the other in a curved form as in the Chatham pumps. The experimental pumps were $5\frac{7}{8}$ in. diameter, and the suction pipes $3\frac{1}{4}$ in. expanding to 5 in. diameter at the suction end; the discharge well was $8\frac{1}{2}$ in. diameter. Three experiments were made with each pump, and the time required to fill a tank containing 104·8 cub. ft. was ascertained; the actual lift between the suction water level and the discharge was 8 ft. 3 in.; and the velocity of the pump was kept practically the same throughout all the trials, by means of a pair of cone pulleys. The mean result was found to be that the pump with right-angled flow took an average of 4 min. 48 sec. to fill the tank, and the one with curved flow filled it in 3 min. 52 sec. It is quite possible that much of this difference is due to the high velocity of the water through so small an orifice, the velocity being as much as 380 ft. per min. in the pump with flow at right angles, and although increased in the curved pump to 470 ft. there was an advantage of nearly 20 per cent. in the curved form; but on a larger scale of pump, where the area of orifice is in a much larger proportion to the quantity of water passing through it, the difference would be less marked. At all velocities however some difference would no doubt be shown, as in the case of water passing through different curved bends in pipes.

Having thus ascertained the best form for the pump as regards the vertical section, several experiments were made by the writer as to the number of the arms and their best form in the horizontal section. Three different lifts of 8 ft. 7 in., 14 ft. 2 in., and 30 ft. 4 in. were tried, and indicator diagrams were taken from a small portable engine that worked the pump, and the revolutions of both engine and pump were recorded by a counter. The result was found to be that at all heights the percentage of duty was the greatest when the arms had a curve formed by the resultants of the circumferential velocity at any point and the radial velocity of the water at that point. This curve was consequently adopted for the arms of the Chatham pumps, as shown in the sectional plan, Fig. 8, Plate 45; and it has a close resemblance to the curve advocated by the late Mr. Appold.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

The operation of emptying the docks is performed as follows. At the commencement of the pumping, the water standing at the same level in the dock as in the basin, namely 27 ft. above the sill and 30½ ft. above the floor of the dock, the sluice K between the two pump wells is closed, as shown in Fig. 5, Plate 43, and each pump has then a separate suction from the main culvert of the docks, and discharges independently into the basin; but both pumps are driven at the same velocity by the engine and first motion shaft. This continues until the water is lowered the first half depth of 15 ft. down to the broad altar level; the suction of the upper pump from the main culvert C is then closed by the sluice L, Fig. 6, and the sluice K between the two wells is opened, so that the lower pump drawing from the main culvert discharges into the suction of the upper pump, which in its turn discharges into the basin. Thus although the total lift for pumping out the dock increases from zero up to 30½ ft., each pump can be proportioned as regards both size and velocity for a lift increasing from zero up to only about 15 ft.

With this arrrangement the average discharge per minute for each pump, as the water falls through successive depths of 5 ft. from the highest level, was estimated to be as follows:—

1st 5 ft.,	pumps making about	70	revs. per min.	discharge each	245 tons per min.
2nd 5 ft.,	,,	80	,,	,,	206 ,,
3rd 5 ft.,	,,	94	,,	,,	147 ,,

The total quantities of water to be discharged for emptying each dock through the successive 5 ft. depths are about as follows:—

1st 5 ft.,	6,300	tons, occupying	26	min.
2nd 5 ft.,	5,980	,, ,,	29	,,
3rd 5 ft.,	5,720	,, ,,	39	,,
Total	18,000	tons, occupying	94	min.

Consequently the docks would be emptied the 15 ft. depth down to the broad altar level in less than 1¾ hours, when the two docks are being pumped out together by the pair of pumps.

The quantities of water to be discharged for emptying the lower half of each dock through successive 5 ft. depths were estimated to be as follows:—

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

1st 5 ft.,	4,600 tons, occupying	38 min.
2nd 5 ft.,	4,200 ,, ,,	41 ,,
3rd 5 ft.,	3,200 ,, ,,	44 ,,
Total	12,000 tons, occupying	123 min.

The discharge of the two pumps together through this lower portion was estimated to be equal to the discharge of each of them separately through the upper portion, making the time about $2\frac{1}{4}$ hours for emptying the lower half of the two docks from the broad altar level to the bottom of the docks. The total time estimated for emptying the two docks was thus 4 hours.

The following are the results of the actual working, in pumping out No. 4 Dock shown in the general plan, Fig. 3, Plate 41; this dock, as well as No. 3, is somewhat larger than the size upon which the estimate was made, containing 20,000 instead of 18,000 tons of water in the upper half, and 13,830 instead of 12,000 tons in the lower half. The trial was made on 4th March last, and the pumps were started at 12.34 p.m. and emptied the water down to the broad altar level by 1.19 p.m., being 45 min. pumping. The change of sluices was then made for pumping out the lower half, causing a delay of 5 min., and the pumping was completed at 2.42 p.m., being 78 min. pumping for the lower half, and a total time of 2 hours 8 min. for the whole work. This exceeded by 8 min. the estimated time of 2 hours for one dock or 4 hours for two docks; but by a little increase of steam pressure and a consequent increase in the speed of the pumps the time was brought within the estimate, notwithstanding the increase in size of dock.

This is shown in a further trial on 10th March, when the pumps were started at 12.55 p.m., and emptied the water out of the upper half of the dock down to the broad altar level at 1.34 p.m., being 39 min. pumping; and then after a stoppage of 1 min. for the change of the sluices the pumping was completed at 2.35 p.m., being 60 min. pumping for the lower half, and a total time of 1 hour 40 min. for the whole work, or 20 min. less than the 2 hours allowed. The mean Ind. H. P. was 1019, the steam pressure 52 lbs., and the

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

total revolutions 9724, or $97\frac{1}{4}$ per min. In the previous trial the mean Ind. H. P. was 820, the steam pressure 42 lbs., and the revolutions 86 per min. during the first portion, the speed being afterwards increased to 88 revolutions. The water level of the basin rose 15 in. during the time of emptying the one dock; and a considerable obstruction to the flow of water from the dock was caused by the keel blocks having come adrift and floated over the suction culverts.

During the first 30 min. in the second trial the two pumps were throwing more than 490 tons or nearly 18,000 cub. ft. per min., with a velocity of flow of about 625 ft. per min. through the suction pipes of the pumps and 468 ft. per min. through the main culvert. These speeds for the flow of the water are however too great to get a very economical result, considering the great length of the culvert, and the sharp bends and passages at the heads of the docks and in the discharge culvert, which latter has also the disadvantage of being $10\frac{1}{2}$ ft. below the level of the water in the basin. The result obtained was however as much as 47 per cent. useful effect in the trial, when pumping with a total lift of $26\frac{1}{2}$ ft. These trials were made solely to test the working of the engines and pumps, and to ascertain the shortest possible time required for emptying the dock; but when the dock has to be emptied for the purpose of docking a large ship, nearly one third of the total quantity of water is displaced by the ship, and from the time required for fixing the shores and from other causes there will be no necessity for the use of so great an amount of engine power or speed of pumps and velocity of water through the culverts. The result with the Chatham engines at $26\frac{1}{2}$ ft. total lift on the double-lift system compared favourably with that at Portsmouth with 19 ft. single lift.

On 13th July a further trial was made by pumping out the two docks Nos. 3 and 4 at the same time, under the superintendence of Mr. Eames, the Engineer-in-Chief of the dockyard. The time of emptying the two docks down to the broad altar level was 1 hour 24 min., with an average of $85\frac{1}{3}$ rev. of the engines per min., discharging 40,000 tons of water at a height varying from 1 ft. to 17 ft. 7 in.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

total lift. From the broad altar level down to the floors of the docks the time was 2 hours 11 min. 20 sec., discharging 27,660 tons at a height or total lift varying from 17 ft. 3 in. to 34 ft., with an average of 89 rev. of the engines per min.

The engines for driving the centrifugal pumps at Chatham dockyard were originally intended to be an old pair of marine non-condensing trunk engines as used on board H.M.S. "Forth;" but a compound condensing engine was adopted on the writer's recommendation as the main working engine, the old pair of marine engines being fitted as a reserve engine in case of necessity. The compound engine is of the overhead marine type, with two cylinders 43 and 75 in. diameter and $2\frac{3}{4}$ ft. stroke, adapted to make about 96 revolutions per minute, and to indicate from 800 to 1000 Ind. H. P. The high-pressure cylinder has a variable expansion valve; the engine has a surface condenser with vertical tubes, the condensing water being circulated outside the tubes by a centrifugal pump driven by a small independent engine.

The boilers are Cornish double-flued, seven in number, including one spare boiler; they are $6\frac{1}{2}$ ft. diameter and 28 ft. length, working at 50 to 60 lbs. pressure. Two similar boilers are added for supplying the large hydraulic engine for working the sluices and capstans. The flues of the nine boilers have a total area of 44 sq. ft. at the entrance of the chimney, and the chimney has a total flue height of 150 ft. The pumping machinery, consisting altogether of two main engines and pumps, a drainage engine with pumps, and the hydraulic engine with pumps and accumulator, is contained in a handsome building, 51 ft. wide by 180 ft. long, surrounded by an arcade, and having a light iron roof over the boilers, and over the engines a large cast-iron tank of 13,000 cub. ft. capacity, which serves for the fresh-water supply to the dockyard.

The basins and dry docks are provided with hydraulic capstans for warping and other purposes. The hydraulic power for opening and shutting the different sluices and working the capstans is obtained by means of a horizontal steam engine with a cylinder

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

21 in. diameter and 2 ft. stroke, working two pumps $5\frac{1}{16}$ in. diameter, which supply an accumulator loaded to a working pressure of 700 lbs. per sq. in. This power is estimated to work eight hydraulic capstans hauling 10 tons each at 18 ft. per min. or 5 tons each at 36 ft. per min., as well as four sluices at the same time.

The Sluices with the exception of two are single-faced, of cast iron with gunmetal faces, as shown in Figs. 10 and 11, Plate 46. The hydraulic cylinders by which the sluices are worked are proportioned so that any sluice may be raised or shut in about two minutes; the cylinders are lined with copper and are double-acting. Wherever the height above the head of the sluice is limited by the ground level, the hydraulic cylinders are placed horizontally underground, as shown in Fig. 11, and the sluices are then weighted sufficiently to shut them against the pressure of the head of water. Where the pressure from the head of water in the culverts may be in either direction, two separate sluices are used in the same well, with their faces in opposite directions; excepting in the case of the sluice K, Fig. 6, between the two pump wells, and also the one situated at L in the branch suction culvert to the upper pump, where special and somewhat novel arrangements are adopted.

The sluice at L, Fig. 6, in the branch suction culvert to the upper pump, is made with two parallel faces, as shown in Fig. 14, Plate 47, with a small clearance between these and the iron frames fitted in the masonry, in order that the sluice may go down easily into its place; the pin-joint in the rod working the sluice is also made with a similar clearance, so that the sluice door is free to close tight upon the face against which the pressure forces it. By this arrangement considerable economy is effected, as an additional ram is saved and there is also somewhat less cost in the manufacture of the sluice thus made than in making two independent sluices.

The other double-faced sluice, situated at K between the pump wells, Figs. 5 and 6, is made of a wedge shape, as shown in

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Figs. 12 and 13, Plate 47; it is fitted with hard wood on the bearing surfaces, resting on granite facings. The hydraulic cylinder for this sluice is horizontal and single-acting, the weight of the sluice being sufficient to close it.

For drainage purposes, a separate well is provided at M, Fig. 6, Plate 44, containing two bucket-lift pumps of 20 in. diameter and 33 in. stroke, worked by a small pair of engines with 14 by 18 in. cylinders. These are almost constantly at work for pumping out the water leaking into the emptied docks; a pair of sluices at N N, Fig. 6, worked by hand, admit the water from the branch suction culverts A A to the drainage well M. These pumps also give the means of emptying the two main pump wells, so that the main pumps can be left dry and accessible at all times when they are standing. Self-acting flap-valves opening outwards, made of wood and leather, are placed at P P in each of the main discharge culverts, for preventing the discharged water from returning into the pump wells.

The same system of pumping out the docks as that adopted at Chatham has also been applied by the writer's firm at the new dry docks in course of construction at Rio de Janeiro for the Brazilian Government, as shown in Fig. 16, Plate 48; the capacity of each dock is estimated at 21,600 tons with a depth of water of 29 ft., and the time required to empty the dock is 3 hours. The pumps and wells are shown in section and plan in Figs. 17 and 18, Plates 49 and 50. The pumps are $6\frac{1}{2}$ ft. diameter, and are driven by a pair of horizontal compound engines, of 300 Ind. H. P., with tubular boilers.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Mr. Rennie mentioned that the hydraulic rams for the sluices described in the paper at the Chatham docks had been supplied by Sir Wm. Armstrong and Co., and fitted up in place by his own firm. As an example of the amount of friction of the water in passing through the culverts, it might be stated that in a recent trial, in pumping out Nos. 3 and 4 docks at the same time, it was observed that in about $\frac{1}{4}$ hour after the pumping had commenced there was a difference of 5 in. between the levels of the water in the two docks; this difference was maintained until the velocity of the water in the culverts was reduced, when the levels gradually became more nearly equal. This could only be accounted for by the friction of the water passing through the portion of culvert intervening between the two docks. With such a difference as was thus shown, due to so short a length of culvert, it was manifest that a considerable allowance in the results given in the paper must be made for the true duty of the pumps, on account of the power absorbed by the friction of the water in passing through the whole length of the culvert from the docks to the pumps, which was over 1000 ft.; besides the several sharp bends, which could not be obviated.

Mr. E. A. Cowper said that in reference to the proper curve for the arms of centrifugal pumps he had come to the same conclusion as had been stated in the paper. It was an involute curve, such as would be described by a point in a string unwinding from a cylinder; and although any two knots made in the string would remain the same distance apart, yet the curves described by them would not be exactly parallel or equidistant throughout, because the string was never at right angles to the curves it was describing at any moment. Consequently the distance between the arms in the pump was not the same from the centre to the circumference; and in order to preserve a uniform area of passage, the width of the arms themselves had therefore to be tapered gradually towards the circumference, according to the shape shown in the diagrams.

As it appeared the friction in the short length of culvert between two adjacent docks was sufficient to produce 5 in. difference of

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

level in $\frac{1}{4}$ hour, the increased friction due to the total length of the 7 ft. culvert, together with the high velocity of 468 ft. per min. which was stated to have been maintained through the culvert, seemed to him enough to account for a considerable reduction in the useful effect obtained, as measured by the actual quantity of water pumped. He enquired whether there was any special advantage in employing a number of collar bearings at the top of the pump shaft, as shown in the drawing, instead of placing a fixed cover-plate immediately above the pump to take off the pressure of the column of water on the top of the pump. He asked also why the wedge-shaped double-faced sluice, shown in Fig. 13, Plate 47, was faced with wood, while the other double-faced sluice, shown in Fig. 14, was fitted with metal faces.

Mr. Rennie replied that the object of placing the collar bearings at the top of the pump shaft was to provide the means of adjusting from the top of the well the clearance of the pump when working, so that its bottom face should be made to run always just clear of the top of the suction pipe underneath it; the weight of the column of water above the pump did not seem to be so excessive as to prevent its working most satisfactorily. The wedge-shaped sluice with wood faces was used only in the intermediate culvert between the two pump wells, where there was scarcely space enough for putting in an iron framing for the sluice; the wood faces bearing against the granite faces of the chamber had proved sufficiently tight with the wedge-shaped sluice.

Mr. Jeremiah Head enquired whether there was any liability of the bottom of the groove into which the sluice fell getting choked with sand or dirt. Being so small, it appeared to him that it might very easily get choked up, and so prevent the sluice from closing.

Mr. Rennie replied that no difficulty or inconvenience had been experienced from that cause at present. It was quite possible that any grit contained in the water might be washed into the groove; but if so, it would only be necessary to lift the sluice when there was no water in the pump wells, and the groove could then be easily cleaned out.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Mr. Benjamin Walker said he had had great pleasure in seeing the pumping engines at Chatham, described in the paper, and they were certainly fine specimens of mechanical skill and workmanship; they were very solid and substantial, and the various contrivances connected with them were well adapted to their purposes. He understood Mr. Rennie had made some careful experiments as to the amount of power developed in the engines, by measuring the quantity of water from the surface condenser, so as to ascertain exactly how much steam had been used in the engines; and it would be very interesting to have the particulars of the results obtained by this mode of ascertaining the power developed in the working of a steam engine.

Mr. G. D. Hughes enquired whether the consumption of fuel per thousand tons of water pumped out of the docks by these engines had been ascertained.

The President observed that this information was given in the paper in the form of the percentage of useful effect realised by the pumps; and as it was generally known what was a fair and proper consumption of coal for a well constructed steam engine, the actual consumption for the work done could be readily calculated from those data.

Mr. Rennie said that in a recent trial of a pair of very similar marine engines in a vessel of their own make, supplied with steam by tubular boilers instead of the Cornish boilers, the consumption had been 2·07 lbs. of coal per Ind. H. P. per hour, the speed of the engines being 87½ rev. per min., instead of 86 to 88 as named in the paper, and the mean Ind. H. P. very nearly the same as in the pumping engines at that speed.

The measurement of the quantity of water from the surface condenser had been carried out in the trial recently made of the Chatham pumping engines, and he would supply the particulars.*

* Particulars of the trial made on 13th July to ascertain the amount of steam used in pumping out two docks, Nos. 3 and 4, containing together 67,660 tons of water, by measuring the total water condensed in the engines during the work. The feed pipe was disconnected from the hot-well, and all the water condensed in the surface condenser, in the steam jackets of the

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Mr. W. H. Maw enquired whether any endeavour had been made to determine the friction of the water in the culvert by running the water back through the culvert into the dry dock, so as to refill the latter after it had been emptied. If this could be done, and the time required for so filling the dry dock to various depths were recorded, an exact measure would be obtained of the loss of power caused by the friction in the culvert and the contractions at the sluices.

Mr. Rennie replied that no experiment of that kind had been made, and it would not be easy to arrange such a trial, owing to the difficulty of letting the water run back through the pumps, on account of the self-acting flap-valves in the discharge culverts from the pumps, which prevented the return of the water. Each dock was filled by admitting the water direct from the basin through two separate short passages, each 3 ft. wide and 6 ft. high; and the time occupied in filling the docks in this way by gravity was

---

cylinders, and in the steam pipes, was discharged into measuring tanks. The mean indicated horse power was ascertained by taking indicator diagrams every ten minutes.

3 hours 32½ min.,	time of working engines full speed.
3 hours 40 min.,	total time of working engines.
891·5 Ind. H. P.,	mean total power of engines.
87·6 rev. per min.,	mean speed of engines (taken by a counter).

60,228 lbs.	water collected from hot-well.
1,312 lbs.	" " " steam jackets.
315 lbs.	" " " steam pipes.
61,855 lbs.	total condensed water.

Consequently 61,855 lbs. of water was used by the engines in doing the work, equivalent to 18·92 lbs. per Ind. H. P. per hour. The coal used in the trial was Fothergill's Aberdare, and taking the evaporative duty according to the Admiralty returns at 9·73 lbs. of water per lb. of coal, the consumption of coal would be equal to 1·94 lbs. per Ind. H. P. per hour. The consumption of coal during the trial was approximately estimated at 5½ tons; but the time of the trial was too short to estimate the actual amount, and to get the fires in the same state on completing the trial as at the commencement.

The surface condenser contains 2407 vertical copper tubes of 5 ft. 3 in. length and ¾ in. diameter, with a total condensing surface of 2480 sq. ft., the steam being inside the tubes and the water outside; the temperature of the condensed water in the hot-well during the trial was 92° Fahr.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

about the same as that occupied in emptying any one of them by the pumping engines.

The PRESIDENT remarked that the paper now read was interesting, as showing how a uniform power could be applied to work against a head that varied considerably. From the result it appeared that 47 per cent. of the indicated horse power of the engines had been utilised in the water delivered. From the indicated horse power however must first be deducted from 16 to 20 per cent. for the friction of the engines themselves; and after making that deduction the percentage of useful effect was a very considerable one. Moreover there still remained the loss from the friction in the passage of the water through the culvert and bends. The velocity in the culvert during the first half of the pumping was 468 ft. per min.; and the friction at that speed being about 3-7ths lb. per square foot of wetted surface would account for a great deal of the unutilised power. The remainder must be attributed to the defect in the centrifugal pump itself; but it must be borne in mind that in all pumps, whether reciprocating or chain pumps, there was loss; and thus it was only the excess of loss in the centrifugal as compared with other pumps that could properly be charged as a disadvantage attendant upon its use. Considering the loss incidental to the centrifugal pump, the result of 47 per cent. useful effect was not unsatisfactory; and although such a percentage did not appear very high, it must be borne in mind that in the present instance the pumps were applied to empty dry docks, and to do it rapidly and not often. They were seldom wanted, and it seemed one of those cases where it was better to do the work with a simple machine, although not a very economically working one, than with a complex and costly machine standing idle for most of its time, which might cost more, in the loss of interest upon the heavy outlay required by its complicated construction, than would be saved by its more economical performance during the short periods of working. In selecting a machine for any particular purpose it was necessary to consider what was most desirable under all the circumstances, and not merely what was the most perfect mechanically. Such

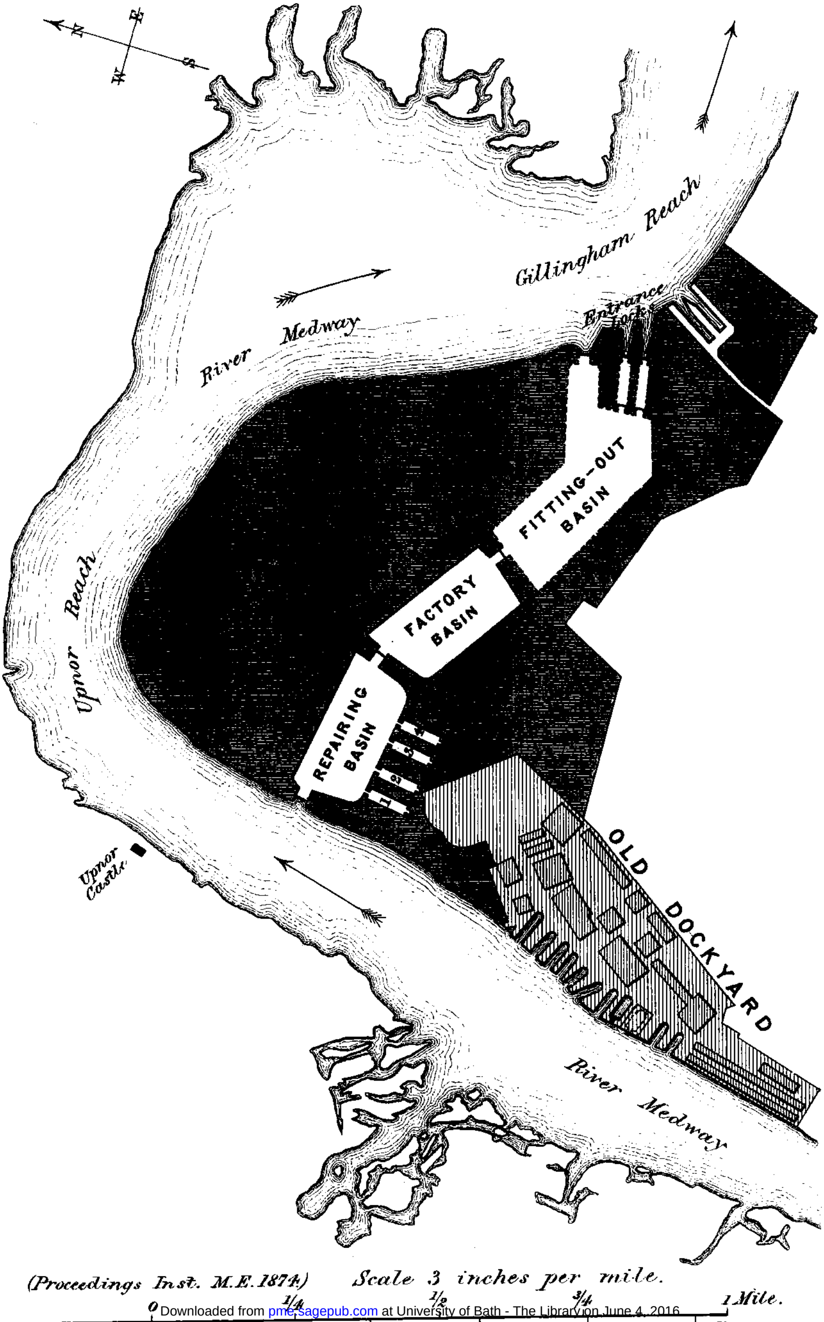
Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

consideration appeared to have been given in this instance by Mr. Rennie, who had successfully grappled with the difficulty of the varying head of water.

The PRESIDENT then proposed a vote of thanks to Mr. Rennie for bringing the subject before the Institution; this vote was passed.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Fig. 1. *Plan of Chatham Dockyard.*



(*Proceedings Inst. M.E. 1874*) *Scale 3 inches per mile.*

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

DOCK PUMPING MACHINERY.

Plate 41.

Chatham Dockyard.

Fig. 2. *Transverse Section of Dry Docks, along line of Suction Culvert.*

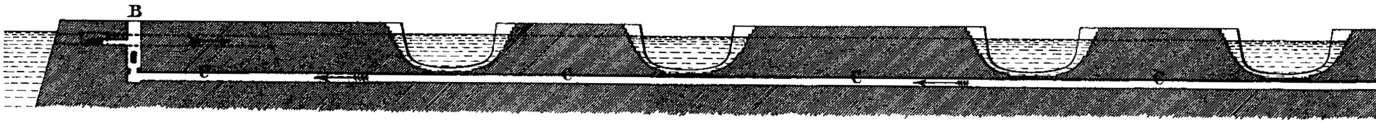


Fig. 3. *Plan, showing Suction and Discharge Culverts and Pump Wells.*

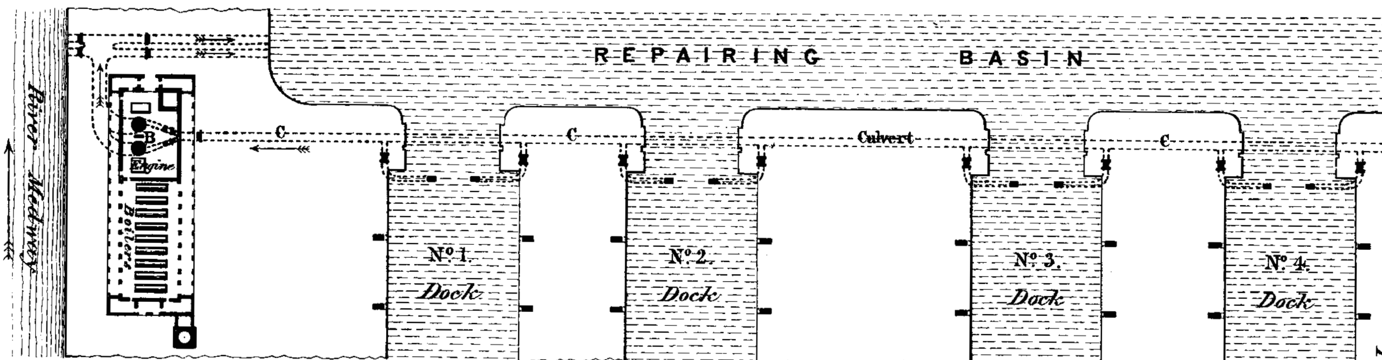


Plate 41.

(*Proceedings Inst. M. E. 1874.*)

Scale 1/2000th.

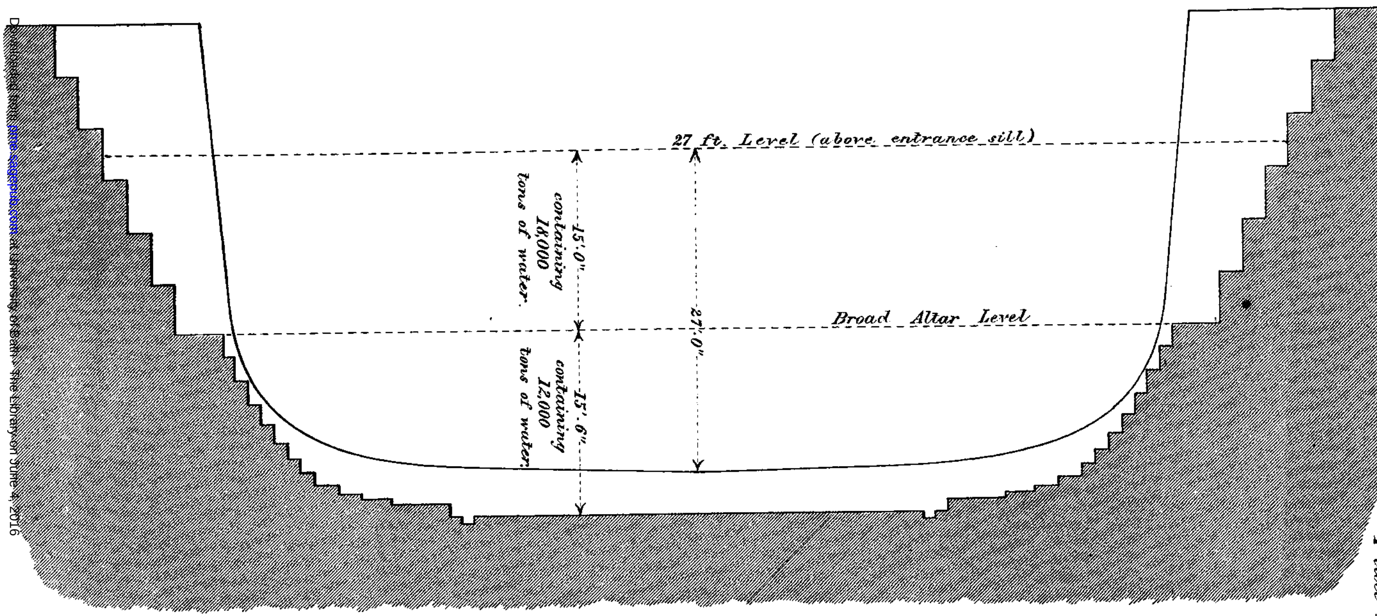
0 100 200 300 400 500 Feet.

Plate 42.

DOCK PUMPING MACHINERY.

Chatham Dockyard

Fig. 4. *Transverse Section of Dry Dock.*

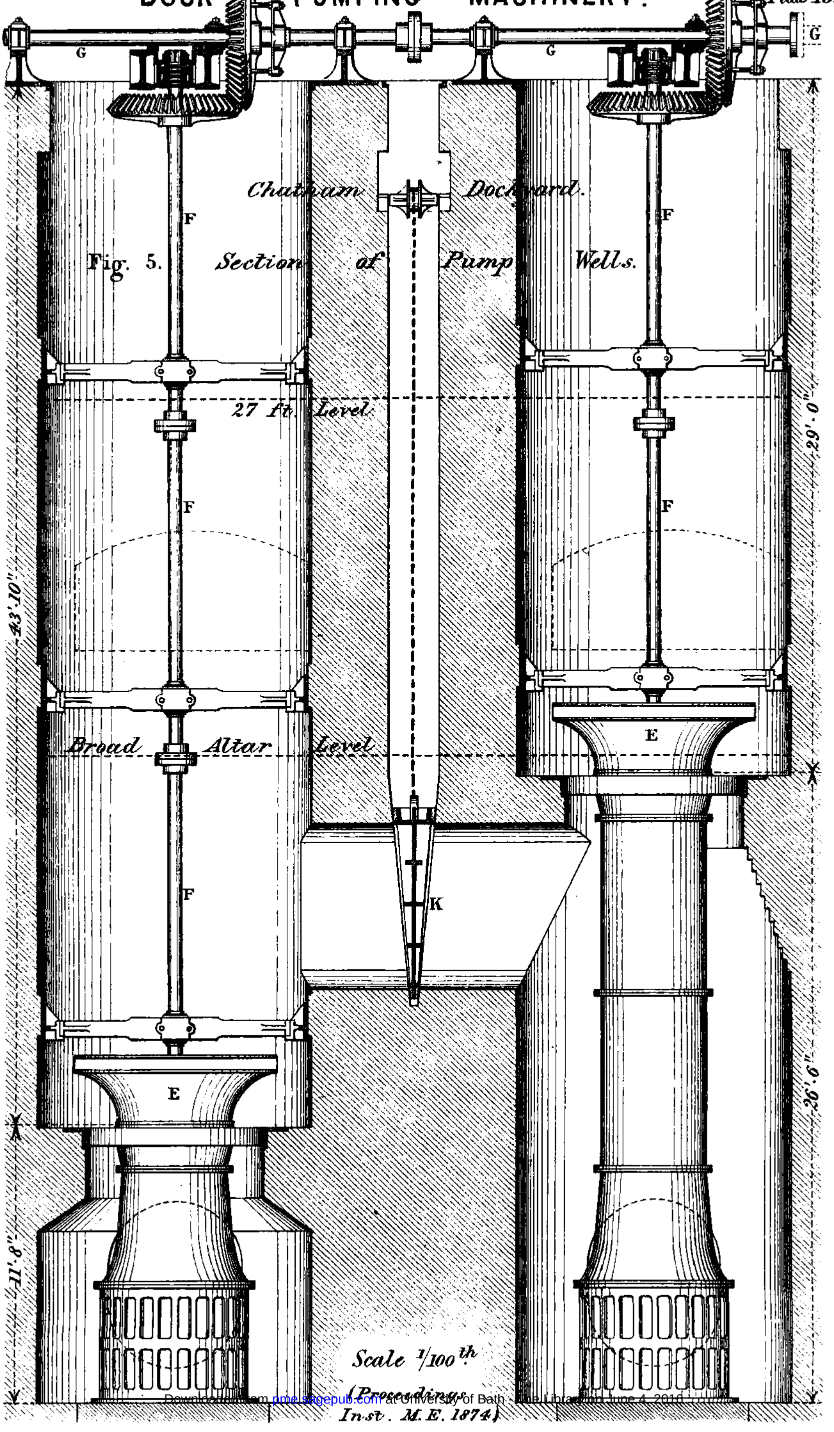


Scale 1/200th

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

(Proceedings Inst. M.E. 1874.)

Plate 42.



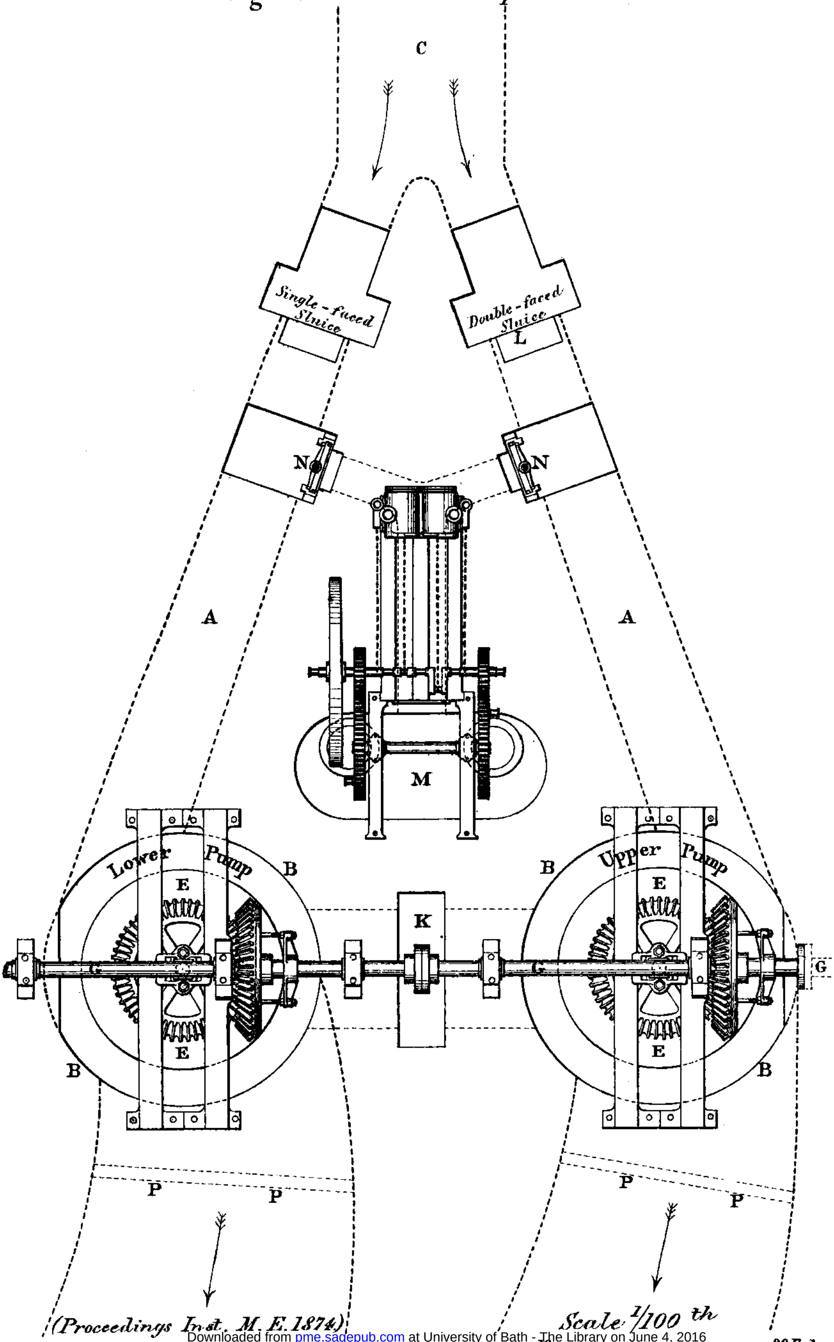
(Proceedings Inst. M.E. 1874.)

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

DOCK PUMPING MACHINERY. *Plate 44.*

Chatham Dockyard.

Fig. 6. *Plan of Pump Wells.*



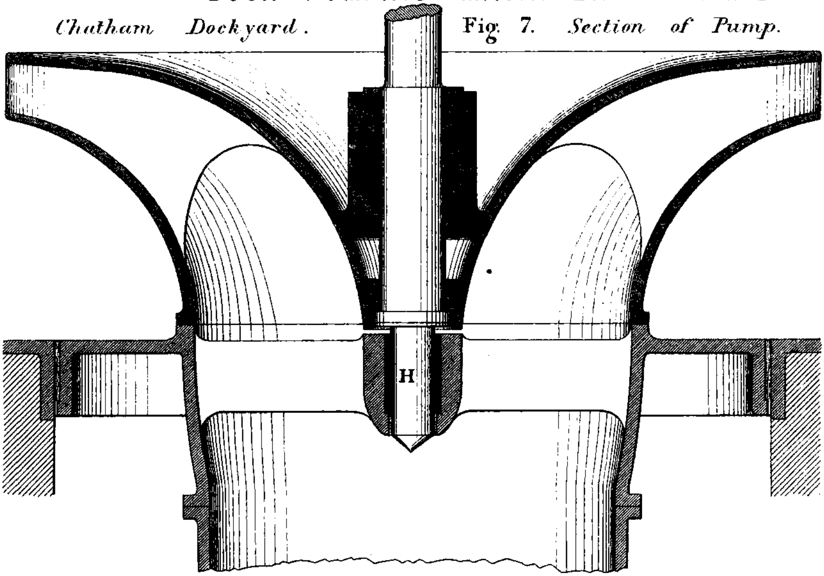
(Proceedings Inst. M. E. 1874) *Scale 1/100 th*

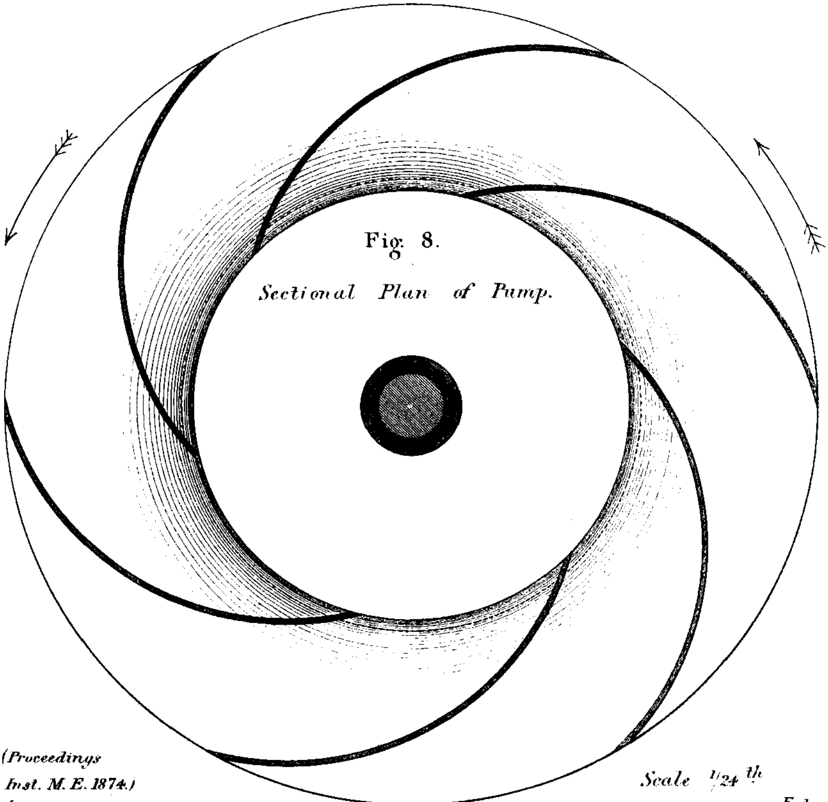
10 5 0 10 20 Feet.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

DOCK PUMPING MACHINERY. *Plate 45.*

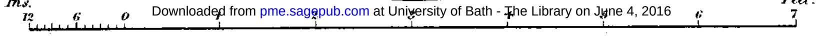
Chatham Dockyard. Fig. 7. *Section of Pump.*





(Proceedings Inst. M. E. 1874.)

Scale 1/24 th



Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

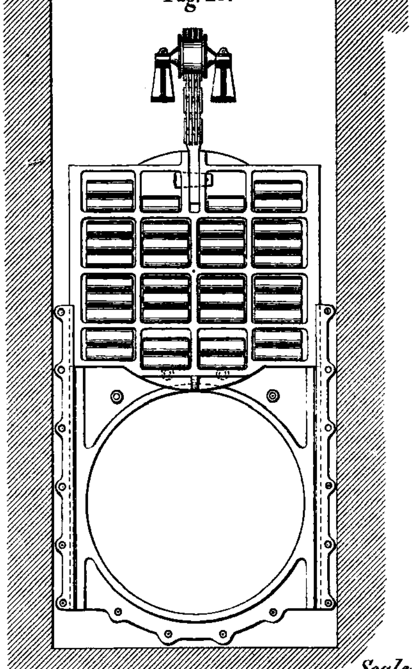
DOCK PUMPING MACHINERY.

Chatham Dockyard.

Single-faced Weighted Sluice.

Plate 46.

Fig. 10.



Scale 1/70th.

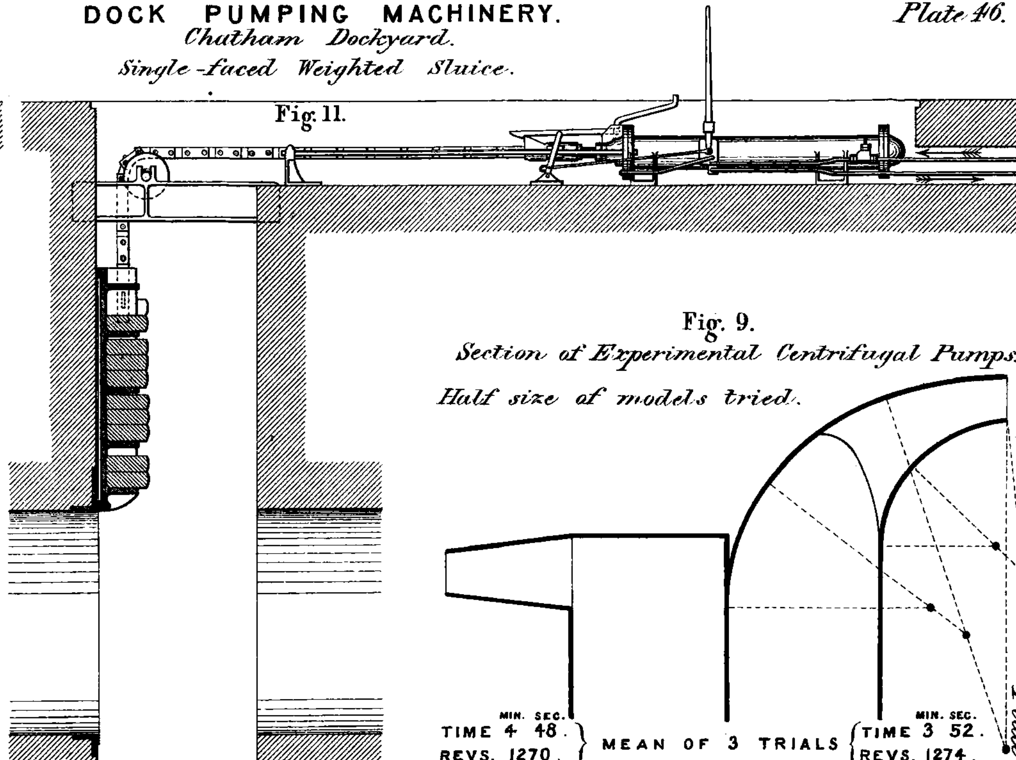
0 5 10 15 20 *Feet.*

Fig. 11.

Fig. 9.

Section of Experimental Centrifugal Pumps.

Half size of models tried.



(Proceedings Inst. M. E. 1874.)

Plate 46.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

DOCK PUMPING MACHINERY. *Plate 47.*

Chatham Dockyard.

Fig. 12. *Double-faced Wedge Sluice between Pump Wells.*

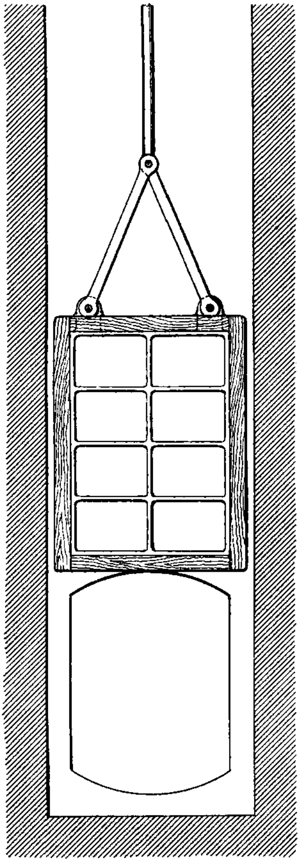


Fig. 13. *Transverse Section.*

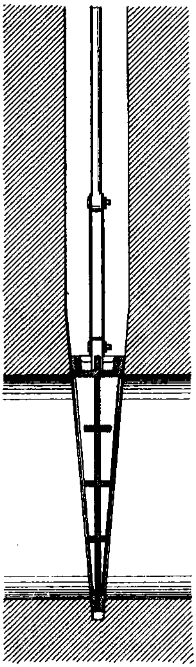


Fig. 14. *Double-faced Sluice in branch suction culvert to Upper Pump.*

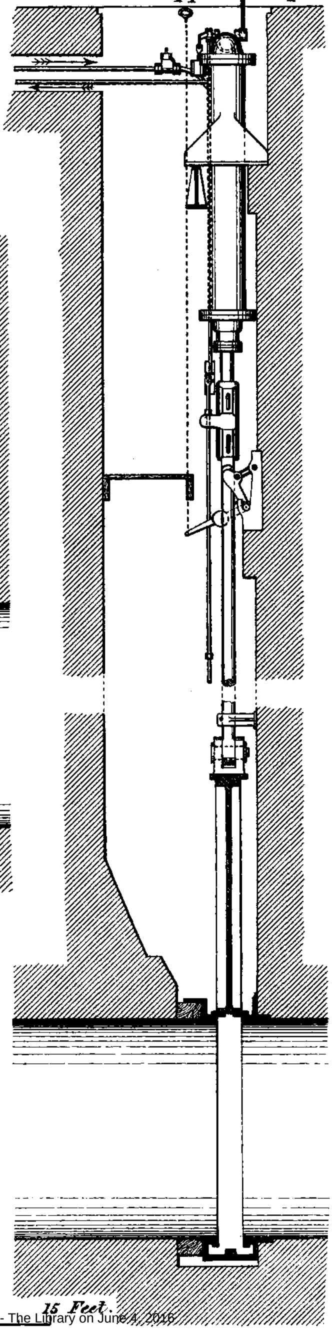
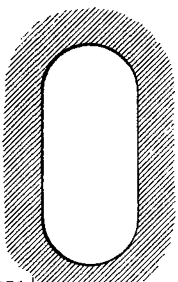


Fig. 15. *Transverse Section of Branch Suction Culverts to Pump Wells.*



(Proceedings Inst. M.E. 1874.)

Scale 1/70 th

0 5 10 15 Feet.

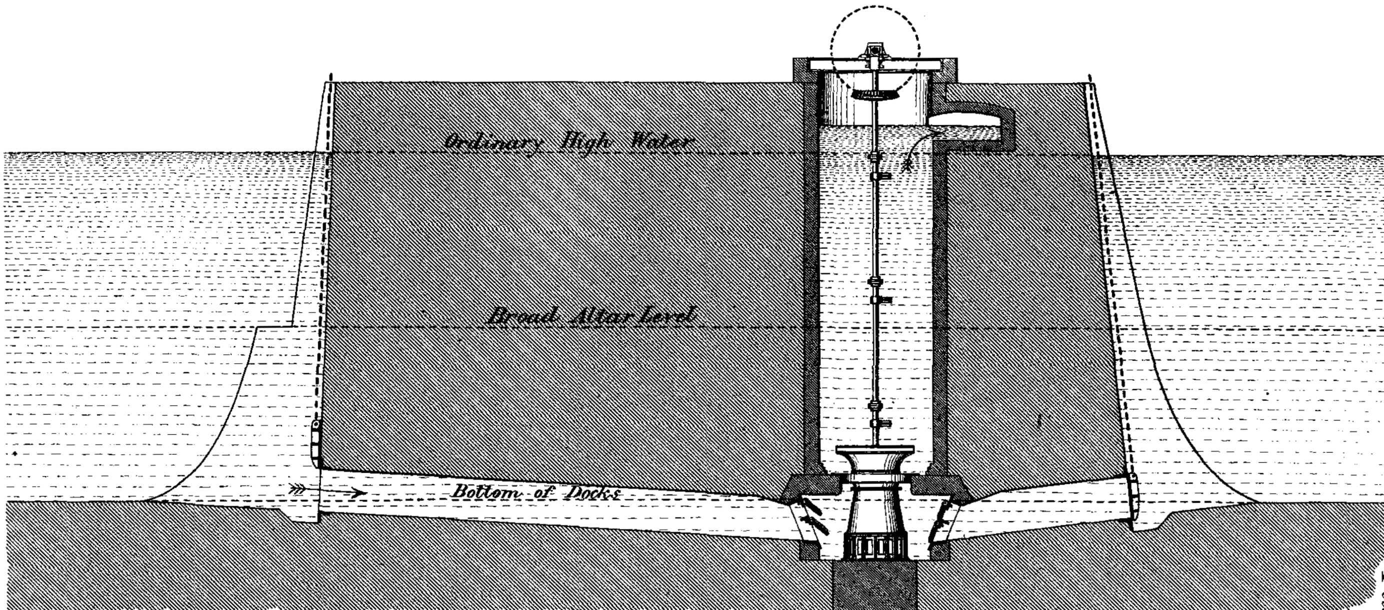
Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

DOCK PUMPING MACHINERY.

Plate 48.

Rio de Janeiro Docks.

Fig. 16. *Transverse Section through Dry Docks and Pump Well.*



(Proceedings Inst. M.E. 1874.) Scale 1/200th. 10 5 0 10 20 30 40 50 Feet.

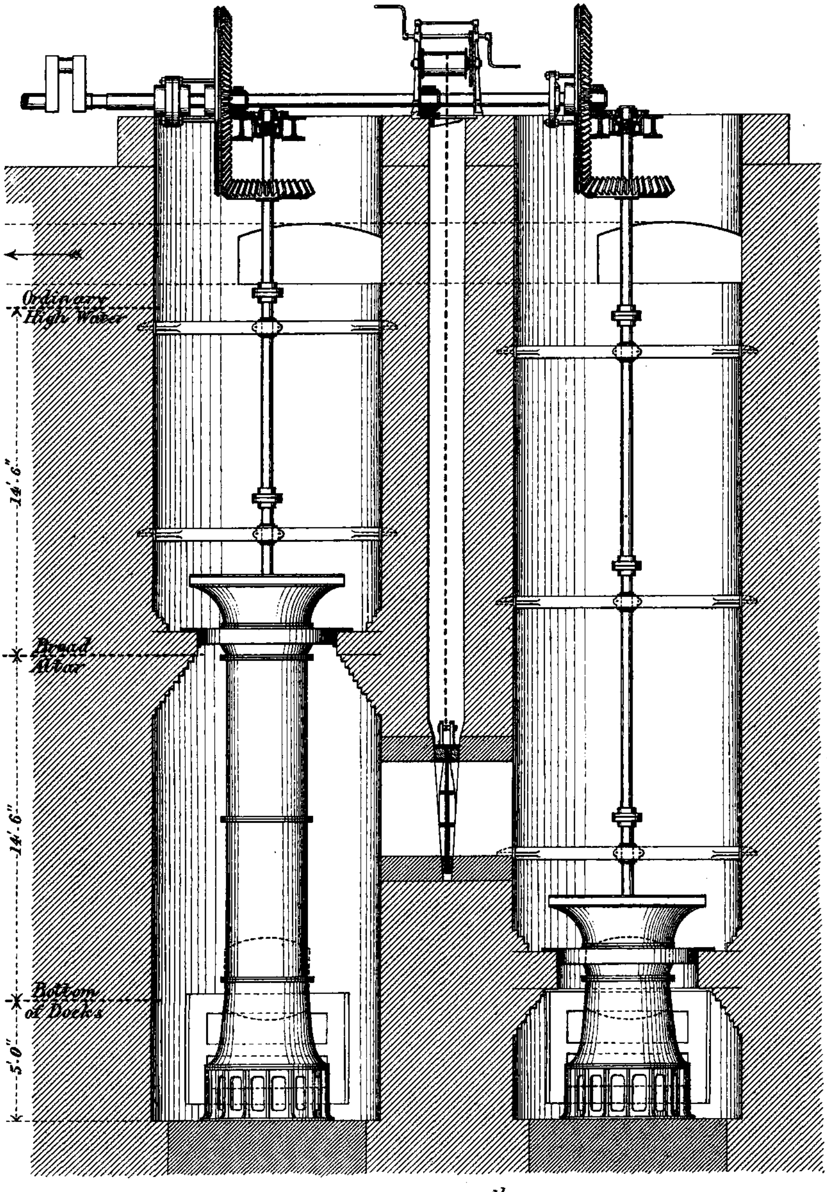
Plate 48.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

DOCK PUMPING MACHINERY. *Plate 49.*

Rio de Janeiro Docks.

Fig. 17. *Section of Pump Wells.*



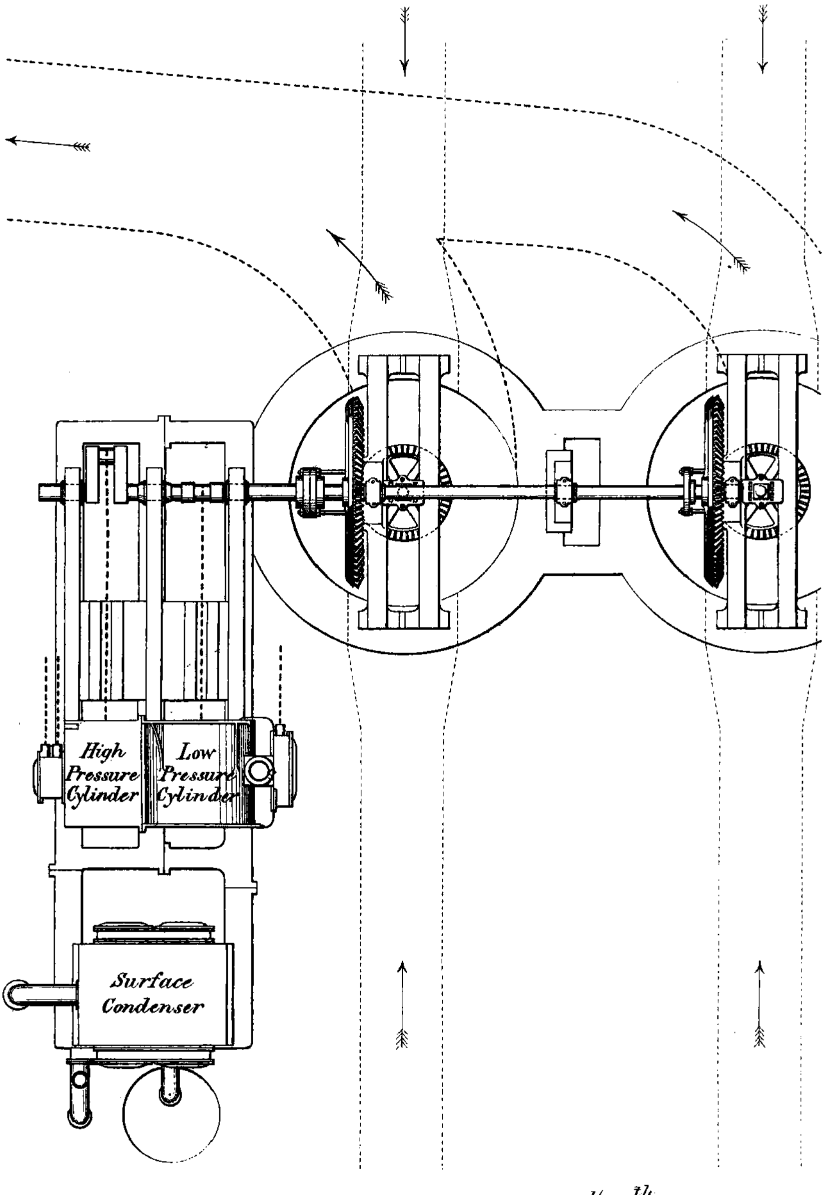
(Proceedings Inst. M.E. 1874.) *Scale 1/100th.*

10 5 0 10 20 Feet.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016

Rio de Janeiro Docks.

Fig. 18. *Plan of Pumping Engines and Wells.*



(Proceedings Inst. M.E. 1874.)

Scale 1/100th.

10 5 0 10 20 Feet.

Downloaded from pme.sagepub.com at University of Bath - The Library on June 4, 2016