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"Keyham Dockyard Extension."

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BEFORE any dockyard existed at Devonport, advantage was taken of the sheltered inlets opening into Plymouth Sound for repairing and building ships. At an early date there appear to have been facilities for building and repairing ships at Saltash, on the Tamar, and also in the Cattewater, on the east side of the Sound. It is also recorded that in 1677 establishments existed for repairing the King's ships; but until William III came to the throne there appears to have been nothing at the port to justify its being called a naval arsenal. It was rather a shipping-station where fleets could conveniently assemble.

The first plan of the dockyard was prepared in 1689, and the first charge in the Navy estimates appears in 1690. The work of constructing the dockyard was commenced in 1691, when the basin dock and certain storehouses and workshops were completed. The southern boundary of the yard at this time was at the Camber. In 1728 an addition was made increasing the area of the yard to 54 acres, and this was still further increased to 59 acres in 1761, and again in 1765 to 70 acres. The present area of the yard at Devonport is 71½ acres. When steam-power was introduced into the Navy the available space at Devonport was found to be insufficient, and therefore in 1844 land was purchased at Keyham for the purpose of constructing a steam-yard and factory. The works were commenced in 1846, and were completed in 1853. This yard, the area of which is 54 acres, contains two basins, an entrance-lock, and three graving-docks; also very extensive engine- and boiler-shops, stores, and foundry and other workshops. In

1854 an Act of Parliament was passed to construct a tunnel about ½ mile in length connecting the steam-yard at Keyham with the yard at Devonport, which tunnel was subsequently constructed. No further extension of the dockyard was made until the works described in this Paper were commenced in 1896.

Meanwhile, the ships of the Navy were rapidly increasing in size, and although docks were constructed at Portsmouth and at Chatham to accommodate these large ships, at Devonport there were no docks large enough to receive several of the latest additions to the Navy. It had for some years been realized that an extension of the dockyard at Devonport was absolutely necessary, especially as, being situated near the entrance to the channel, the position of the port rendered it important for the repairs of ships engaged at any time in a naval war. In 1894 the first active measures were taken to prepare plans for the Keyham extension works. These plans were so far completed by October, 1895, as to enable the Admiralty to invite tenders for the construction of the work; and in January, 1896, the tender of Sir John Jackson having been accepted, the work was begun at once. The arrangement of the basins and docks finally adopted was practically the same as that proposed by Messrs. Coode, Son and Matthews, who had previously been consulted by the Admiralty and had submitted a general plan for the works.

Description of the Works.

The site of the Keyham Dockyard Extension is on the east side of the Hamoaze, adjoining the existing Keyham yard on the north side (Fig. 1, Plate 1). The area of the extension is 118 acres, of which 41 acres were above high-water mark, and 77 acres between high- and low-water marks, the western limit of the area being practically situated at the low-water line of spring-tides. The area above high-water mark was ground which had been reclaimed at the time when the Keyham yard was made in 1856, the materials excavated from the docks and basins being tipped on the mud foreshore and thus forming a considerable area of ground, which was partly occupied by the naval barracks, and partly by coal-stores and boat-sheds, and was used for dockyard purposes in general. The area below high-water mark consisted of the mud foreshore, the mud varying in depth from 30 feet to 100 feet. The formation below the mud is clay slate rock of the Devonian period. All the walls of the docks and basins, the dock-floors, and the outer wall, are founded on the rock.

The works (Fig. 1) consist of three graving-docks, two of them opening into a tidal basin of 10 acres at the south end, and all of them opening into a closed basin of 35½ acres at the north end. There is also a lock giving access to the closed basin. The total area occupied by the docks, lock, and basins is 55 acres, thus leaving 63 acres for quays and ground for dockyard purposes. As the ground forming the parade- and recreation-ground of the Royal Naval Barracks, which adjoins the dockyard extension on the east side, is 12 feet above the level of the dockyard, a retaining-wall has been built along the east boundary of the new works. A valley extends inland from the site of the tidal basin, and down this valley is constructed a large main sewer which formerly discharged the sewage of the district into the Hamoaze at low-water mark through cast-iron pipes supported on piling across the mud foreshore. This main sewer has been diverted and a new outfall has been provided at the extreme south end of the extension-works. A new branch sewer was also constructed, connecting the naval barracks with the new main sewer.

In preparing the general scheme for the works, it was decided to enclose the whole area with a coffer-dam, so as to exclude the tidal water from the works during their construction. As it was considered important that the construction of the graving-docks and lock should be commenced as soon as possible, it was decided to enclose the area to be occupied by these docks by constructing two cross dams from the main coffer-dam to the shore, so that this part of the work could be commenced without waiting for the completion of the whole length of the coffer-dam. A considerable saving of time was thus effected, as the length of the cross dams was less than half the remaining length of coffer-dam, and they were in shallower water. The positions of the main coffer-dam and the cross dams are shown in the general plan (Fig. 1).

The total length of the main coffer-dam was 5,576 feet; the lengths of the two cross dams were 1,033 feet and 1,009 feet. The cross dams were removed as soon as it was considered desirable to construct those portions of the outer and basin walls which they crossed. Certain parts of the permanent works which were situated above high-water mark were carried out during the time occupied in erecting the coffer-dam; these included the diversion of the sewers, the retaining-wall adjoining the naval-barracks ground, the east walls of the two basins, and graving-dock No. 4.

Materials.

The total quantity of granite used in the work was 2,342,000 cubic feet, of which 1,500,000 cubic feet were obtained from Cornwall and 842,000 cubic feet from Norway. Of limestone, 172,000 cubic feet, obtained from local quarries, were used for facework in some of the walls. A quantity of limestone was also broken up for making small concrete blocks, which were faced with granolithic concrete and used in various parts of the works.

The Portland cement used in concrete and mortar amounted to 220,800 tons and was submitted to the following tests: briquettes placed in water 24 hours after being made and kept there 6 days had to sustain before breaking a weight of 350 lbs. per square inch, the stress being applied at the rate of 100 lbs. in 15 seconds. The specific gravity, when the cement was freshly burned and ground, had to be not less than 3·15. The time of setting had to be not less than 10 minutes nor more than 3 hours. The whole of the cement had to pass through a sieve of 2,500 meshes per square inch without residue, and through a sieve of 5,776 meshes per square inch with a residue not exceeding 15 per cent. by weight, the meshes to be made of brass wire 0·005 inch in diameter. The cement was also subjected to chemical analysis. On delivery at the works it was stored in bulk to a height of 4 to 5 feet in two large stores, each capable of holding about 6,000 tons, and was left for 3 weeks before being used, during which period it was turned over three times so as to ensure complete aeration.

The mortar was of two qualities, 1 of cement to 1 of sand and 1 of cement to 2 of sand, the stronger quality being used generally in the lower parts of the work and where the circumstances required extra strength. The concrete used in the various parts of the works was mixed in the following proportions, forming three qualities. Quality A: 1 part cement, 1½ part sand, 5 parts broken stone or rough shingle. Quality B: 1 part cement, 2 parts sand, 6 parts broken stone or rough shingle. Quality C: 1 part cement, 3 parts sand, 8 parts broken stone or rough shingle. Broken stone was very little used except in the making of small blocks for facing some of the walls. Shingle was obtained first from Start Bay and afterwards from a shoal near the Needles off the Isle of Wight. It was found that the shingle as dredged up contained 32·6 per cent. of sand. After the sand had been removed, the various sizes of the stones were in the following proportions:—

	Per Cent.
Stones retained on sieve with meshes of 1 square inch . . .	22
Stones passing 1 inch mesh but retained on ½ inch mesh . .	30
Stones " ½ " " " " " ¼ " " . .	28
Stones " ¼ "	20
	100

It was ascertained by experiment with the sand and shingle mixed together as delivered on the works that 6·15 parts contained

$1\frac{1}{2}$ part sand and 5 parts rough shingle when separated; also 7·5 parts contained 2 parts sand and 6 parts rough shingle; also 10 parts contained 2·67 parts of sand and 8 parts rough shingle, as required for qualities A, B, and C, respectively, when additional sand had been added to the latter to make up the 3 parts required. The concrete-mixers, of which there were nine located in various parts of the works as required, were turned by oil-engines. The maximum quantity of concrete mixed in 20 hours, being a day and a night shift of 10 hours each, was 1,755 cubic yards, of which 1,150 cubic yards were mixed in the day shift with six mixers at work, and 605 cubic yards in the night shift with three mixers at work. The maximum quantity mixed by one mixer in a day of 10 hours was 318 cubic yards. Small concrete blocks were used instead of stone for facework in parts of the walls. These blocks were formed in moulds, the face being upwards; the concrete was made of 1 part cement, 2 parts sand, and 6 parts limestone, crushed to pass through a ring 1 inch in diameter. The mould was filled to within 4 inches of the top with this concrete, the remaining space being filled with concrete made of 1 part of cement and 2 parts of granite crushed to pass through a sieve of $\frac{3}{8}$-inch mesh. This face of granolithic concrete was added while the lower concrete in the mould was still wet and was well beaten into it.

Tidal Basin.

The tidal basin is situated at the extreme south end of the extension works, and adjoins the old Keyham Yard. The section of the walls is as shown in Figs. 2, Plate 1. With the exception of the north wall, the walls were constructed in timbered trenches, being everywhere founded upon the solid rock. These walls, as well as those of the closed basin, were founded at 2 feet below the level of the bottom of the basin where the rock was found to be above that level; but where the rock was reached at a lower level than the bottom of the basin the foundation was taken to a depth of 2 feet below the level at which the rock was found to be solid and firm. From the foundation to 3 feet 6 inches below low water of spring-tides the walls are formed of concrete, quality B, the exposed surface above the bottom of the basin being faced with quality A concrete to a thickness of 12 inches, all formed in situ. The concrete forming the face was carefully deposited against timber shutters, the placing and fixing of which was very accurately executed, and no further work of any kind had to be done upon the face of the wall after the shutters were removed. At first a composition of soap, etc., was used to prevent the concrete from adhering to the frames, but afterwards it was found that covering the surface of the frames with a thin coating of liquid mud applied with a brush answered every purpose without in any way discolouring the concrete. From 3 feet 6 inches below low water up to the coping, the face is formed of granite ashlar set in regular courses in 2-to-1 cement mortar, and finished with a rock face; the concrete backing to the ashlar is of quality B below high water of spring-tides, and above that level it is of quality C. The upper part of the face of the wall to 28 feet below coping is formed to a batter of 1 in 8, and for 10 feet above the bottom of the basin to a batter of 1 in 4, the intermediate space of 16 feet being formed to a curve of 135 feet radius. The face of the portion of the wall carried below the bottom of the basin is vertical.

On the west side of the basin two arms are constructed, each 60 feet wide, having an opening 120 feet wide between them, forming the entrance to the basin. The end of each arm is formed into a circular head of 30 feet radius, which connects the inner and outer walls of each arm. The walls of these arms were constructed in timbered trenches, except the circular head of the north arm, where the rock dipped to a depth of 70 feet below the surface of the mud. The mud was found to be very soft and wet at this part, and the position of the head was close to the coffer-dam; it was therefore considered unsafe to attempt opening a trench to such a depth south of the line of sheet-piles of the cross dam. Concrete columns, as used for the foundations of the outer wall, were therefore sunk through the mud to the rock, the mud being afterwards removed from the spaces between them, and these spaces filled in with concrete, thus binding the columns together. Afterwards the front, or exposed, portions of the columns above the level of the bottom of the entrance were removed, and a face of concrete was built on to the columns up to the level of 3 feet 6 inches below low water. The sheet-piles of the cross dam were left in until the foundations of the head were completed; they were then drawn, and the side walls of the arm were connected with the head. The details of construction of this head are shown in Figs. 3, Plate 1. Four sets of landing-steps are provided in this basin, two at the east end, and two close inside the entrance.

The depth of the bottom of the basin is 32 feet below low water of spring-tides and 55 feet below coping-level, the entrance being 4 feet deeper. On the north side of the basin the rock was at an average level of 15 feet above the bottom of the basin, and on the south side 30 feet above the same level. From these two sides the rock sloped down towards the middle of the basin, reaching depths of 25 feet below the bottom on the east side and 35 feet below the bottom at the entrance. In the construction of the east wall, for a length of 150 feet the rock was found to dip suddenly from 60 feet to 80 feet below the surface of the ground, which at this part corresponded with coping-level. The thrust on the struts of the trench was very severe, and it was considered unsafe to attempt to remove the lower struts as the concrete was deposited; they were therefore left embedded in the concrete forming the foundation of the wall. After the wall had been constructed, a trench 40 feet wide was opened at the back of the part where the rock was so deep, and the mud was removed and replaced with a backing of rubble. In the construction of this basin 403,000 cubic yards of mud and 200,000 cubic yards of rock were excavated and removed. Fendering of Tasmanian blue-gum timber is attached to the face of the walls.

Closed Basin.

The closed basin is situated at the north end of the extension work; it is 1,550 feet in length and 1,000 feet in width. Sections of the walls are shown in Figs. 2, Plate 1. For a depth of 16 feet from the coping the facing is limestone, and below that concrete, the walls being formed generally as described for the tidal basin. With the exception of the south wall, the walls were constructed in timbered trenches, and were founded throughout on the solid rock. The east wall was founded generally at 2 feet below the level of the bottom of the basin, which is 32 feet 6 inches below low water of ordinary spring-tides, and 55 feet 6 inches below the level of the coping. The north wall is founded at the level of 57 feet 6 inches below coping for a length of 650 feet; from this point westward, a length of 350 feet, the rock dips until, at the north-west corner of the basin, it reaches a depth of 100 feet below the coping. The west wall is founded 57 feet 6 inches below the coping, except for a length of 250 feet at the north end, where it joins on to the west end of the north wall; also a length of 600 feet at the south end, where it reaches a maximum depth of 108 feet below the coping. The south wall also is founded at a level of 57 feet 6 inches below the coping.

It was found necessary in parts of the north and west walls, where the mud exceeded 50 feet in depth, to reduce the depth by excavating over and on each side of the site of the trench before driving the sheet-piles for timbering, so as to reduce the strain upon the timber due to such excessive depths of mud. This occurred for a length of 600 feet at the north-west corner, and a length of 600 feet at the south end of the west wall, where a maximum depth of 85 feet of mud was met with. Seven sets of landing-steps are provided in this basin. In its construction 2,195,000 cubic yards of mud were excavated and removed, and 470,000 cubic yards of rock were excavated. From the centre of the north wall of the basin a pier is constructed. The side and end walls are constructed of quality B concrete with a facing of quality A, and with a coping of granite; the walls are formed on the face with a batter of 1 in 8, the upper parts being protected by a fendering of creosoted pitch-pine. Subways are provided in the side walls, similar to those referred to later on as being constructed in the basin and outer walls.

Entrance to Closed Basin.

Near the middle of the west side of the closed basin an entrance is provided direct from the Hamoaze. This is to enable vessels to pass in and out of the basin at high water without using the lock. The width of the entrance is 95 feet at the coping, and the depth of water on the sill is 32 feet below low water of spring-tides. This entrance is provided with a sliding caisson and also with a floating caisson. If, during the process of warping a ship through the entrance, the tide should commence to fall, and cause a difference of level in the water inside and outside the basin, there might be difficulty in moving the caisson into position across the entrance. In order to provide against such a possibility, four large sluices have been constructed near the entrance, by which water can be discharged from the basin. These sluices will also be available for restoring to the basin at high water any water that may have been withdrawn from it by admitting ships through the lock.

Graving-Docks and Lock.

As soon as the cross dams and that portion of the main coffer-dam which enclosed the site of the graving-docks were completed, the west wall of the lock was commenced. It was necessary that this wall should be constructed first, so as to retain the mud between it and the main coffer-dam before the remainder of the site could be cleared of mud. A trench was opened for the whole length of this wall and the mud was excavated down to the rock on which the wall was founded. For a length of about 120 feet the rock dipped to 60 feet below the surface of the mud, which at this part was very wet, and the sides of the trench began to move inwards at the bottom from the pressure of the mud; this occurred when the excavation had reached a depth of 30 feet from the surface.

As it was not safe to excavate further, concrete cylinders were made, 7 feet in external diameter, so as to fit between the timber struts supporting the sides of the trench. These cylinders were formed of rings 2 feet 6 inches deep and were sunk from the bottom of the trench to the rock; four cylinders occupied the width of the trench, and when they had reached the rock the upper rings were removed as the struts were placed in position. This was continued until the tops of the front row of cylinders were at about 70 feet below coping, those of the other cylinders varying from 66 feet below coping at the back to 62 feet below coping in front. Then, the mud having been removed from the interior of the lengths of cylinders left in, the rock was excavated to a depth of 3 feet below the cylinders; after which the interior was filled with concrete and the wall was built resting upon the cylinders. While this wall was being constructed, mud was being excavated from the site of the lock and of Docks Nos. 5 and 6. In the case of Dock No. 4, which was situated above the original high-water line, the side walls were begun before the completion of the coffer-dam, and were constructed in timbered trenches; and afterwards the central portion was excavated and removed, the floor being the last part to be completed. As regards the concrete and masonry the same method of construction was followed as for the other docks. After the mud had been removed, the rock was excavated to such extent and depths as were required for the walls and floors, and below the surface of rock thus formed, key-trenches were cut, 3 feet wide and 1 foot 6 inches deep, spaced 12 feet apart longitudinally and transversely, and extending over the whole area of the floor. The transverse trenches were continued under and at the back of the side walls as far up as the rock extended. The surface of the rock was thoroughly cleaned and covered with a coating of neat Portland cement 2 inches thick, and the concrete was then deposited over and against the coating of cement before the latter was set.

In depositing the concrete to form the floors of the docks and lock, the width of the floor was divided into three parts as shown by dotted lines in Figs. 4, Plate 1. The centre portion, 24 feet wide at the top, was first formed, frames being set up to form it in lengths of about 30 feet; and the joint at the end of each length was formed in steps similar to the sides. When one of these lengths had been commenced it was continued day and night until completed, so that it should be one compact mass without joints from bottom to top. The top surface was formed in grooves longitudinally arranged to fit the beds of the granite blocks forming the surface of the floor. When the concrete for the centre portion was completed, the portions on either side were constructed in a similar manner, and extending under the side walls, the ends of the side blocks being arranged to break joint with those of the centre blocks. The average depth of concrete under the centre part of the floor is 14 feet, and under the side parts 12 feet 6 inches; these depths were increased where the depth of excavation was increased owing to the depth and quality of the rock.

After the concrete of the floor was completed, the side walls were commenced, the concrete being deposited over the full width of the wall in layers about 12 inches thick. The layers were well rammed as deposited in suitable lengths, the total depth deposited each day being about 4 feet. During the operation of building, every surface of concrete that had become hard, whether vertical or horizontal, was covered with a layer of cement ½ inch thick immediately before any fresh concrete was placed against it: this applied to concrete generally as used in various parts of the works. As the beds of the face-stones in the side walls, up to the level of the first broad altar, are not horizontal but radiate, the concrete at the back of each course was first deposited against framing formed to the shape of the back of the stones, and the latter were afterwards set with a mortar joint against the concrete. In the upper part of the walls, where the face-stones were set with horizontal beds, they were backed with concrete as each course was set. The floor-stones were laid on a bed of cement mortar 2 inches thick, being in courses 4 feet 6 inches and 3 feet 6 inches deep alternately for the centre part, and 2 feet 6 inches and 1 foot 9 inches deep alternately for the sides. The upper walls of all the docks and the lock are faced with concrete blocks having a granolithic surface as already described. Each dock is provided with steps and timber-slides.

Figs. 4, Plate 1, show the dimensions of the cross section of Dock No. 6 and the lock. These dimensions, and the methods of construction illustrated, apply also to Docks Nos. 4 and 5, except that in the latter the depths to the upper and lower broad altars, from the coping, are 10 feet less than in Dock No. 6 and the lock, i.e., are 13 feet and 36 feet respectively. All the entrances are fitted with sliding caissons. For a width of 10 feet in the centre the floors are level, and then fall 6 inches on either side to the gutters; there is also a fall of 12 inches longitudinally from the centre to each end, except in Dock No. 4, where the fall is from the head of the dock to the entrance. In Docks Nos. 4 and 5 the average level of the centre part of the floor is 49 feet below the coping, and in Dock No. 6 and the lock it is 59 feet below the coping. The upper and lower broad altars have a fall of 1 inch on the surface to drain the water off them. From the lower to the upper broad altars, which are of granite, are five altar courses, which are formed of three courses each in height, the upper and lower being of granite and the middle one of granolithic-faced concrete blocks. Above the upper broad altar the wall is vertical and is faced with granolithic concrete blocks except the bottom course and the coping, which are of granite. The lengths of the docks are:—

	Feet.
Dock No. 4, from sliding caisson to head of dock	650
Dock No. 5, between sliding caissons	745
Dock No. 6, ,, ,, ,, ...	741
Lock, between sliding caissons	730

And the depths on the sills are:—

	Ft.	Ins.
Docks Nos. 4 and 5, at low-water of ordinary spring-tides .	20	6
Dock No. 6 and Lock, ,, ,, ,, .	32	0

Docks Nos. 5 and 6 are each divided by a floating caisson into two separate docks, the lengths of divisions between caissons being 462 feet and 253 feet for Dock No. 5 and 469 feet and 250 feet for Dock No. 6. By placing a floating caisson in the outer stop in Dock No. 4 and in one of the outer stops of Docks Nos. 5 and 6 and the lock, the lengths may be increased to 692 feet in Dock No. 4, to 787 feet in Dock No. 5, to 784 feet in Dock No. 6, and to 773 feet in the lock. The recesses into which the floating caissons are fitted are shown in Figs. 5, Plate 1, and sections of the caissons are given in Figs. 6, 6*a*, and 7. The lock forms a passage from the Hamoaze into the closed basin, available at any state of the tide; it is provided with a sliding caisson at each end, and is constructed so that it can be used at any time as a graving-dock.

The floors of all entrances are level, and the side walls are formed with a batter of 1 in 12 and faced with granite, the floors and side walls being connected by a curve of 5 feet radius. Connecting the floor of the entrance with the floor of the dock are five granite steps set to form a curve on plan, the top step being to a radius of 46 feet with the joints all radiating to the centre of the curve. The stones forming the steps nearest the entrance are 4 feet 6 inches in depth and are bonded into the stones forming the floor of the entrance (Figs. 4). The next two steps are formed of one course of stones and the two lower steps are also formed of one course, all 4 feet 6 inches deep; and at the foot of the steps the gutter-stones are placed radiating to the same centre as the steps, and at the level of the floor of the dock, thus forming a continuation of the gutters on each side of the dock-floors.

Outer Wall.

This wall forms the west and north limit of the extension works; it faces the Hamoaze and Weston Mill Lake, and extends from the south end of the lock to a point near to and north of the Royal Naval Barracks. The total length of the wall is 4,730 feet, and it is founded throughout on the rock. Over half the length the depth of mud varied between 30 to 60 feet, and over the other half it varied from 60 to 100 feet. With such a depth of mud to be penetrated in order to reach the rock, and with the coffer-dam close outside, it was evident that the excavation of an ordinary trench would not be possible, and that some special form of cylinder or column must be used and sunk through the mud. The shape of column which was adopted is shown by Figs. 8, Plate 1.

The columns were made of concrete, quality B, the rings or courses being 2 feet 6 inches thick and jointed so that segments in adjacent courses should break joint. Projections 4 inches high were formed on the top surface of each ring, which fitted into corresponding recesses formed in the under surface of the course above. The weights of the segments forming each ring varied from 4 tons to 7½ tons. The segments were constructed in moulds on a prepared floor in the yard, where they were afterwards stacked till required. The base of each column was provided with a cutting ring of concrete (quality A) which was 5 feet in depth, and was formed in one piece in a mould on the site for sinking the column, a layer of ashes 12 inches thick having first been placed on the mud. In this cutting ring were embedded two frames of iron bands 4 inches by ¾ inch encircling the three wells, so as to strengthen the ring and to prevent any parts from being forced outwards if vertical cracks should occur during the process of sinking. The cutting rings were left for 4 weeks to harden before sinking-operations were commenced.

The ring was first sunk under its own weight, by excavating the mud and ashes from the interior of the wells, until the whole ring was embedded; three or four rings of concrete were then built on the cutting ring, each ring being laid on a bed of cement mortar. On the top of the length of column thus built, weights in the form of cast-iron rings were placed, and the mud was then excavated from the interior of the wells by grabs worked either by 10-ton derrick-cranes, or by 10-ton travelling cranes; when the latter were used they were mounted on a staging in order to obtain sufficient head-room over the top of the columns for working the grabs. By this process of adding rings and loading the sinking was continued until the cutting edge reached the surface of the rock. Then men were lowered into the wells to clear the surface of the rock and render it level, and the wells were filled with concrete.

It happened frequently that the surface of the rock was found to be very irregular, a difference of level of more than 10 feet occurring in some instances in the space occupied by one column. In such cases it was necessary to keep back the mud from the space between the cutting edge and the lowest part of the rock; this was generally effected with timbering supported by struts fixed from the interior of the well. In many cases, however, the mud was so soft and the pressure so great that timbering in the ordinary manner was insufficient; cylinders were therefore made of 3-inch planking secured to bands inside, formed of iron 4 inches by $\frac{3}{4}$ inch. These cylinders were 5 feet 6 inches in outside diameter, and were lowered into the wells and forced through the remaining mud to the rock, the base of the cylinder having been roughly formed to the shape of the rock surface. Mud was then excavated from the interior of these cylinders and the cylinders were filled with concrete which was carried up to the top of the wells. Subsequently, when the spaces between the columns were excavated, the mud was removed from under the columns where the timber cylinders had been used, and the whole space outside and around the cylinders was filled with concrete, the wood casing being left embedded in the concrete. The columns in the front row were sunk first, and, as it was found that the difficulty of sinking was diminished by increasing the space between the columns, alternate columns in the row were sunk first and then the intermediate columns.

Wherever the depth of mud did not exceed about 60 feet, a single row of columns was found to be sufficient (Figs. 9, Plate 1), and an ordinary timbered trench was opened at the back, the columns in the front row forming one side of the trench, in which the back part of the foundation was constructed by depositing concrete in the spaces between and around the columns, and thus forming a solid mass. The level of the top of the front row of columns when sunk was about 28 feet below coping-level. Where the depth of mud exceeded 60 feet it was necessary to sink a double row of columns (Figs. 9). Before sinking the back row the mud was excavated to a depth of 38 feet below coping, and for a width of 20 feet at the back of the front row, and thence sloped back. From this reduced level the back row of columns were sunk, each column being placed behind one in the front row, leaving a space of about 3 feet between them transversely. At first the columns in each row were spaced 6 feet apart longitudinally; this was afterwards increased to 10 feet, as it was found that the operation of sinking was facilitated by so doing. There would have been great difficulty, however, in timbering the spaces between the columns if 10 feet had been exceeded. When a sufficient number of both rows had been sunk, the mud was excavated from the spaces between them, timber sheeting, supported by framing, being placed across the 10-foot spaces between the columns as the excavation proceeded; struts were also placed between the columns transversely and longitudinally, to prevent them from being moved out of position by the weight of the mud. These timber struts were removed as the concrete was filled in. The excavation of mud was continued until the rock was reached, and generally the surface of the rock was removed and levelled to a depth of 3 or 4 feet. Very little water was met with in excavating the mud from the pockets until the rock was reached, and then a small pump was quite sufficient to keep down the water. For a length of about 900 feet at the south end a bed of gravel was found overlying the rock to the depth of 8 to 15 feet (Fig. 10). This gravel was very compact and hard, and was charged with water. It was impossible to sink the columns through the gravel by means of the grab, and the water did not permit of its removal by hand; it was therefore decided to let the columns rest on the gravel, and when the pockets between them were afterwards excavated, the gravel was removed from the whole area of each pocket, and the excavation was continued well into the surface of the rock. When the excavation extended below the level of the base of the column, the gravel on which it rested was supported by boarding, so that it was not disturbed, but was entirely enclosed by the concrete deposited in the pockets. A few of the columns, which for various reasons failed to reach the rock and could not be timbered from the inside of the wells, were successfully underpinned with concrete when the adjoining pockets were excavated. The time occupied in placing the weights on the columns, in taking them off again to add concrete rings, and in building the rings, was nearly equal to the time occupied in actually sinking the columns. In order to reduce this time as much as possible, the columns were sunk in pairs, so that while one was actually sinking the other was having rings built on and was ready to receive the weights as they were removed from the first for the purpose of building on more rings.

The average speed at which the columns in the front row moved while the operation of sinking was being carried on was about 3 inches per hour where derrick-cranes were used, and this speed was nearly doubled where travelling cranes could be employed, working from a staging. From a depth of 50 feet to the maximum depth of 100 feet the speed of sinking was generally about the same. In the columns in the front row where derrick-cranes were employed, the rate of sinking, including the whole time occupied not only in the actual movement of the column but also in building and in shifting the weights and in other incidental work, averaged $1\frac{3}{4}$ inch per hour. The columns in the back row took a longer time to sink than those in the front row; this may be accounted for partly by the circumstances connected with the position of some of them, which rendered them difficult of access, and partly by their proximity to the front row, by which the mud became consolidated, with a consequent increase in the skin-friction.

The maximum weight used, on one of the deepest columns, was 900 tons. Many of the columns did not remain perpendicular during the operation of sinking. When this occurred transversely to the line of the wall, the top of the column in nearly every case was forced to the back of that line, only a few projecting a few inches. In all cases the concrete in the 10-foot spaces between the columns was brought up from the rock at the base to the true line of the wall and formed a series of piers, and where any column was behind this line it was either corbelled out at the top gradually to the line, or an arch of concrete was formed from pier to pier in front of the column, thus bringing the line of wall to its proper position before the bottom course of the granite facing was reached, and below low water of spring-tides.

After the columns had been sunk and the spaces between them had been filled with concrete, the upper portion of the wall was constructed upon this foundation (Figs. 9). This upper wall is 12 feet wide at the top and is widened out by steps at the back to 20 feet at 38 feet below the coping, which is the average level of the top of the back row of columns. Such portions of the front row as were above this level were built into and formed part of the upper wall. The wall is faced with concrete up to the level of 26 feet 6 inches below coping, and above that level granite ashlar, rock faced, forms the facing of the wall, which is vertical. The coping is of granite. The wall as completed varies in height from foundation to coping between 50 feet and 120 feet, a length of 1,600 feet being more than 100 feet in height (Fig. 10). Fendering of Tasmanian blue-gum is attached to the face of the wall.

Permanent Piling.

At the back of the outer wall and of the north and west walls of the closed basin the mud was found to be soft, and for the most part of such a depth that it was not possible to remove it and replace it with dry filling. Piles were therefore driven from the surface of the mud down to the rock. They were of pitch-pine, averaging 12½ inches by 12½ inches, and scarfed in two or three lengths as the depth of mud required; they were placed 5 feet apart between centres. When they had been driven and the heads had been cut off to a level, timbers 12 inches by 6 inches were fixed by iron dogs on the tops of the piles in longitudinal and transverse rows; the whole of these timbers were then covered with mud, and the dry filling was tipped on top of them. The weight of the filling is thus carried by the piles, instead of causing a severe thrust against the walls, as would be the case if the weight rested directly on the mud. Where the mud was more than about 70 feet in depth the surface was lowered by excavation before the piling was commenced, so as to keep the piles within a reasonable length and thus ensure their being properly driven.

Culverts and Subways.

For filling the docks with water two culverts are provided at each end, which are 8 feet high and 6 feet wide, semicircular at top and bottom, and have vertical sides. They are formed in the solid concrete of the side walls, and are lined with blue bricks set in cement mortar. They are carried through the south wall of the closed basin, discharging close inside the north caissons, and through the north wall of the tidal basin, discharging close inside the south caissons. Culverts 7 feet in diameter are constructed round the ends of the intermediate caissons in Docks Nos. 5 and 6, so that when the caissons are in place water can be passed to or from either division into which the docks are divided by the caissons. For emptying the docks two main suction-culverts, 7 feet in diameter, are constructed. The one at the north end commences at the lock, and, passing under the entrances of the lock and the docks successively, then runs direct to the engine-house, which is situated near the south end of Dock No. 4. The other emptying-culvert is at the south end, passing under the south entrances of the lock and of Docks Nos. 6 and 5 to the engine-house. Each culvert is formed of concrete with a lining of two rings of brickwork, the inner ring being of blue brick. The two culverts meet at a large chamber outside the engine-house, and about 90 feet below the surface of the ground. From this chamber the water is drawn to the pumps through branch culverts so arranged that the water can be shut off from or admitted to both pumps or either pump singly. The main pumps discharge into a chamber constructed above the suction-chamber, and thence the water is discharged through two culverts into the tidal basin. As these discharge-culverts are below the level of high water, the connections between the discharge-chamber and the pump-shafts are provided with tide-flaps to prevent the tidal water from flowing into the pump-shafts. There is also another discharge-culvert 7 feet in diameter leading from the discharge-chamber to the south-east corner of the closed basin. The drainage-pumps discharge direct through a culvert into the tidal basin. Communication between the docks and the two main emptying-culverts is provided by two branch culverts at each end of the lock and docks; they are 6 feet high and 3 feet 6 inches wide, are semicircular at top and bottom, and are formed in the concrete of the walls of the docks with a lining of two rings of brickwork, the inner ring being of blue brick. A circular culvert 7 feet in diameter is also provided, connecting the main emptying-culvert at the north end of the docks with the closed basin, which by means of this culvert can be pumped dry if required at any time. All the culverts are provided with shafts in which penstocks are fitted to control the flow of water through the culverts. The penstock-doors are raised or lowered by means of small engines fixed in engine-pits at the head of the shafts, and worked by compressed air conveyed in pipes from the engine-house. Arrangements are also made for working the penstocks by hand if required.

At the back of the coping of all the basin walls, and of the outer wall, a subway 5 feet high and 4 feet wide is constructed in the wall. The bottom and sides are formed of concrete; the top is a semicircular arch of three rings of brickwork, the inner ring being of blue brick (Fig. 2). Starting from the engine-house, the subway branches off in two directions: one branch leads to the north-east corner of the tidal basin, and is taken thence in one direction along the east and south walls of the tidal basin, and in another direction along the north wall of the tidal basin to the outer wall, along which it proceeds as far as the new pier for the Naval Barracks. The other branch from the engine-house leads to the south-east corner of the closed basin, and is carried thence along the four sides of the closed basin. Where the line of subway crosses the entrances to the docks and to the closed basin, it is carried down a shaft on each side of the entrance and under the entrance. The length connecting the two shafts is formed of a cast-iron tube, 5 feet in diameter, encased in concrete. In one of the shafts at each entrance a small pump is fixed, which is worked by compressed air, to remove any water which may find its way into the shafts or lower subway. The pipes laid in the subways are: a cast-iron main, 15 inches in diameter, conveying compressed air from the air-receivers in the engine-house to be used for working the caissons, penstocks, capstans, and other machinery; and two 9-inch water-mains. One of these water-mains conveys salt water from a large tank on the top of the engine-house, to which the water is raised from the tidal basin by pumps provided for the purpose in the engine-house, to supplement the fresh-water supply in cases of fire, and for various cleaning purposes; the other pipe is for fresh water obtained from the Devonport town supply. Hydrants are placed at intervals along the basin and dock walls for distributing both salt and fresh water.

Caissons.

The sliding caissons at the entrances to all the docks, the lock, and the closed basin are box-shaped (Figs. 6 and 6*a*, Plate 1) and are constructed of mild steel. They are strengthened internally by two water-tight decks, and by horizontal and vertical bracing. Their buoyancy is controlled by pig-iron, burr concrete and water-ballast, the latter being contained in tanks at each end. The caissons slide into and out of the cambers, resting partly on the granite sliding-ways and partly on a cast-steel roller-path laid along the bottom of the camber and entrance. They are capable of being floated out of or into position in the entrances, the hauling being done by chains worked by a pair of compressed-air engines. Each engine is capable of exerting a pull on the caisson of 35 tons at a speed of 25 feet per minute, with an air-pressure of 75 lbs. per square inch. The same engines are used for lifting the camber-deck to the extent required to enable the caisson to be hauled into or out of its camber.

The floating caissons (Figs. 6*a* and 7) to be placed in the recesses provided for them in Docks Nos. 5 and 6, and also in the entrance to the closed basin, are of mild steel. Each caisson is divided into five chambers by two water-tight decks and by water-tight bulkheads. The caissons are raised or lowered by adjusting the water-ballast in the tanks. The caisson in Dock No. 5 can be fitted to the outer stop in Dock No. 4 and at either end of Dock No. 5. Those in Dock No. 6 and the entrance to the closed basin can be fitted to the outer stops of Dock No. 6, the lock, and the entrance to the closed basin.

Pumping-Engines and Machinery.

The main pumps for emptying the docks are in duplicate, and are of the vertical-spindle, balanced, single-inlet, centrifugal type, revolving horizontally. The vertical spindle is driven direct by a horizontal two-cylinder compound steam-engine, the cylinders being at right angles. The diameter of the high-pressure cylinder is 28 inches, and that of the low-pressure cylinder 50 inches; the stroke is 2 feet. Each centrifugal pump has a gun-metal impeller of 108 inches diameter firmly secured to the spindle, and so arranged that it can be conveniently removed, if required, for examination or repair. The impeller-casing is of cast iron and is fitted with suitable guide-blades. The drainage-pumps are in duplicate. Each set consists of three single-acting lift-pumps, with independent valve-boxes worked from a three-throw crank-shaft, with cranks at equal angles. Each set of pumps is worked by a set of vertical compound engines. When discharging at the full rate the speed of the engines is not to exceed 90 revolutions per minute, the speed of the pumps being reduced by gearing to thirty double strokes per minute. Each of the drainage-pumps is capable of lifting and delivering 1,500 tons per hour at a lift of 53 feet.

At the trial of the main pumps working together with the drainage-pumps, Dock No. 6, filled up to high-water mark and containing 117,526 tons, was pumped out in 3 hours 53 minutes, being at an average rate of 6,610,830 gallons per hour. The pumping commenced at low water, and ended with pumping against a head of 52 feet 6 inches. The main engines made 110 to 138 revolutions per minute, the total power of each being 1,120 to 1,200 I.HP. The revolutions of the drainage pumps per minute were 76 to 83. The total power of each was 90 to 135 I.HP. The steam-pressure was 122 lbs. per square inch. The work of all the pumps quite fulfilled the requirements of the contract. Two duplex pumping-engines, each capable of pumping 100 tons per hour, lifting from a depth of 20 feet below its suction-valves and discharging at a height of 60 feet above its discharge-valves, are provided for filling a tank fixed on the roof of the engine-house, and holding 82,000 gallons. This water is pumped from the tidal basin, and is used for fire-extinction and other purposes in the Dockyard. In addition to this pumping-machinery the engine-house also contains two air-compressing engines, with receivers in which the compressed air is stored and from which it is distributed in cast-iron pipes to the engines for working the caissons, capstans, penstocks, and other machinery. Adjoining the engine-house is the boiler-house, which

c 2

contains ten cylindrical return-tube boilers, each 10 feet in diameter and 9 feet 6 inches long. Each boiler may be used independently, and is capable of carrying steam of 125 lbs. pressure per square inch.

Dredging.

In front of the outer wall, from the entrance to the lock and about 400 feet east of the extreme north-west projecting angle, the mud has been dredged to a depth of 32 feet below low water of ordinary spring-tides. From that point eastward the depth to which the mud will be dredged varies from 20 feet to 15 feet below low water, the latter being the depth in front of the new landing-stage for the Naval Barracks. Outside the entrance to the lock and at the entrance to the tidal basin the depth is increased to 36 feet below low water, which depth is continued into the north-west part of the tidal basin to form a berth for the floating caissons when taken out of Docks 5 and 6. The dredging of mud in front of the south portion of the outer wall was carried out by the contractor; the removal of the remainder of the mud, as well as of rock, is being executed by the Works Department.

Retaining-Wall.

As already mentioned, the level of the parade- and recreation-grounds of the Naval Barracks adjoining the extension works on the east side is about 11 feet above the level of the dockyard. A retaining-wall has therefore been built along this boundary. It is formed of concrete (quality C, with a facing, 9 inches thick, of quality A); it was constructed in situ in frames, the faces of which were wrought smooth, with fillets of wood attached to form V-shaped horizontal and vertical grooves in the face of the wall, to represent beds and joints of blockwork with headers and stretchers alternately. The coping is of concrete, the 9-inch thickness of A quality being continued along the top of the wall throughout its whole length. The coping-course is 2 feet deep and has no vertical grooves in the face. The wall is 3 feet wide at the top, increasing to about 5 feet at the ground-level in front. Below the level of the ground the foundation of the wall is formed of concrete 2 feet deep and 6 feet wide. The front of the wall is formed to a batter of 1 in 12. The wall is backed throughout with dry rubble filling, drains 4 inches in diameter and spaced 30 feet apart being formed through the wall near its base.

Reclaiming Ground in Weston Mill Lake.

As there proved to be a large quantity of rock excavated from the docks and basins in excess of what was required for filling behind the various walls, some of this surplus material was tipped on the mud in Weston Mill Lake north of the Naval Barracks (Fig. 1). An area of about 6 acres was thus formed at a level of 17 feet above high-water mark of spring-tides. This ground has been covered with soil and sown with grass, and will form a recreation- and drill-ground attached to the Naval Barracks.

Landing-Stage for Naval Barracks.

As the construction of the closed basin necessitated the removal of the landing-pier for the Naval Barracks it became necessary to provide a new landing-stage. The site of this is shown in Fig. 1. It is facing the Weston Mill Lake at the east end of the north portion of the outer wall, and close to the Barracks. This landing-stage is formed of timber, the piles and lower frames being of Tasmanian blue-gum and the upper framing and deck of creosoted pitch-pine. There are two recesses in the front of the stage, into which fit two landing-pontoons which rise and fall with the tide; the steps from the pontoons are at the back of the recesses. By this arrangement the landing from boats and steam-launches will be facilitated, and the landing-pontoons will not project beyond the face-line of the stage, and therefore will not be in the way of any steamer or craft landing stores. For this latter purpose a small 1-ton crane, worked by an electric motor, has been erected on the stage, and a light, narrow-gauge railway has been laid from the landing-stage to the Naval Barracks.

The whole of the work included in the contract, together with additional work in extending the outer wall at the north end, was completed by the 31st December, 1906. The work has been carried out by the Works Loan Department of the Admiralty. Major Sir Henry Pilkington, K.C.B., R.E., was the Civil Engineer-in-Chief. Mr. C. Colson, C.B., M. Inst. C.E., was the Deputy Civil Engineer-in-Chief. The Author was the Resident Superintending Civil Engineer, with the able assistance of Mr. H. Sadler, Assoc. M. Inst. C.E., and others. Mr. G. H. Scott, M. Inst. C.E., has been Sir John Jackson's Agent and Engineer throughout the whole of the work, and the quality of the work and the manner in which it has been carried out reflect great credit upon the firm which he represented.

The Paper is accompanied by four tracings from which Plate 1 has been prepared. [Appendixes.

APPENDIXES.

APPENDIX I.

Concrete made from Shingle dredged from Start Bay.

From samples taken from each cargo as delivered from 1897 to 1902, the interstices in the sand screened from the shingle through a sieve of 100 meshes per square inch averaged	37·42 per cent.
The interstices in the shingle, without the sand	35·50 ,, ,,

In Quality A Concrete:—

1·50 cubic foot of dry sand mixed with 1 cubic foot of cement produced 2·15 cubic feet of mortar, or the percentage of the bulk of mortar compared to the bulk of sand used is

Mortar.		Sand.
143·33	:	100

In Quality B Concrete:—

2 cubic feet of dry sand mixed with 1 cubic foot of cement produced 2·50 cubic feet of mortar, or the percentage of the bulk of mortar compared to the bulk of sand used is

Mortar.		Sand.
125	:	100

Calculations based on the above results to ascertain if the mortar fills the voids in the shingle are as follows:—

(1) *Concrete, Quality A:—*

	Parts in Gauging.	
1 cement	4·30 cubic feet	
$1\frac{1}{2}$ sand	6·45 ,, ,,	when mixed bulked 26·25 cubic feet
5 screened shingle	21·50 ,, ,,	

6·45 cubic feet sand, 4·30 ,, ,, cement when mixed $= \frac{143 \cdot 33}{100} \times 6 \cdot 45 = 9 \cdot 24$ cubic feet

Interstices in 21·50 cubic feet shingle $= \frac{35 \cdot 50}{100} \times 21 \cdot 50 = 7 \cdot 63$,, ,,

1·61

The excess of mortar beyond that required to fill the interstices in 21·50 cubic feet of shingle is 1·61 cubic feet, or 7·53 per cent.

(2) *Concrete, Quality B:—*

	Parts in Gauging.	
1 cement	3·50 cubic feet	
2 sand	7·0 ,, ,,	when mixed bulked 26·25 cubic feet
6 screened shingle	21·0 ,, ,,	

7·0 cubic feet sand, 3·5 cubic feet cement when mixed $= \frac{125}{105} \times 7 = 8 \cdot 75$ cubic feet

Interstices in 21 cubic feet shingle $= \frac{35 \cdot 50}{100} \times 21 = 7 \cdot 45$,, ,,

1·30

The excess of mortar beyond that required to fill the interstices in 21 cubic feet of shingle is 1·30 cubic feet, or 6·19 per cent.

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APPENDIX II.

Experiments to Test the Expansion of Portland Cement due to Aeration.

The cement was spread out and left for 26 days, being turned over six times at intervals of about 4 days. The four samples were taken from different consignments of cement.

Number of samples	1	2	3	4
Weight per cubic foot in lbs. when spread	79·50	80·25	81·58	79·89
,, ,, ,, at 13 days .	75·00	73·50	75·16	76·06
,, ,, ,, at 26 ,, .	74·75	71·50	74·06	75·08
Bulk in cubic feet when spread . . .	30	30	30	30
,, ,, at 13 days	31·90	32·96	32·77	31·63
,, ,, at 26 ,, ...	32·25	34·08	33·38	31·73
Residue left on sieve of 2,500 meshes .	a trace	a trace	a trace	a trace
,, ,, ,, 5,776 ,, .	5%	2½%	3¼%	6½%

APPENDIX III.

Quantities of Work Executed and Materials Used.

Excavation—		
Made ground overlying mud . . .	740,000	cubic yards.
Mud	4,322,500	,, ,,
Rock	1,286,500	,, ,,
Total excavation . . .	6,349,000	,, ,,
Concrete	1,230,500	,, ,,
Granite	2,342,000	cubic feet.
Limestone	172,000	,, ,,
Portland stone	33,000	,, ,,
Concrete blocks	504,500	,, ,,
Portland cement used	220,800	tons.

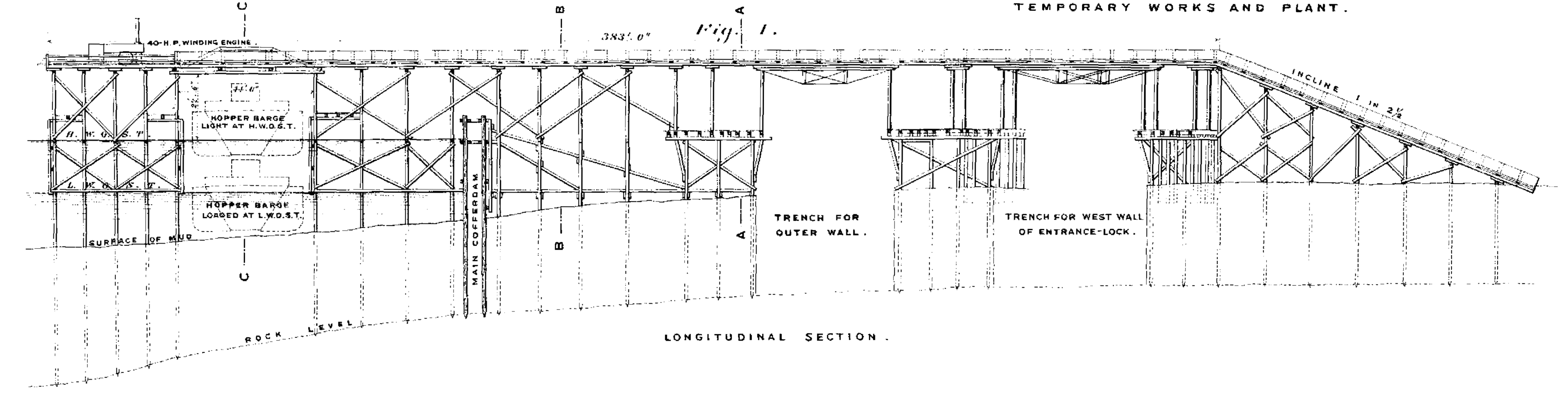
KEYHAM DOCKYARD EXTENSION.

PLATE 1.

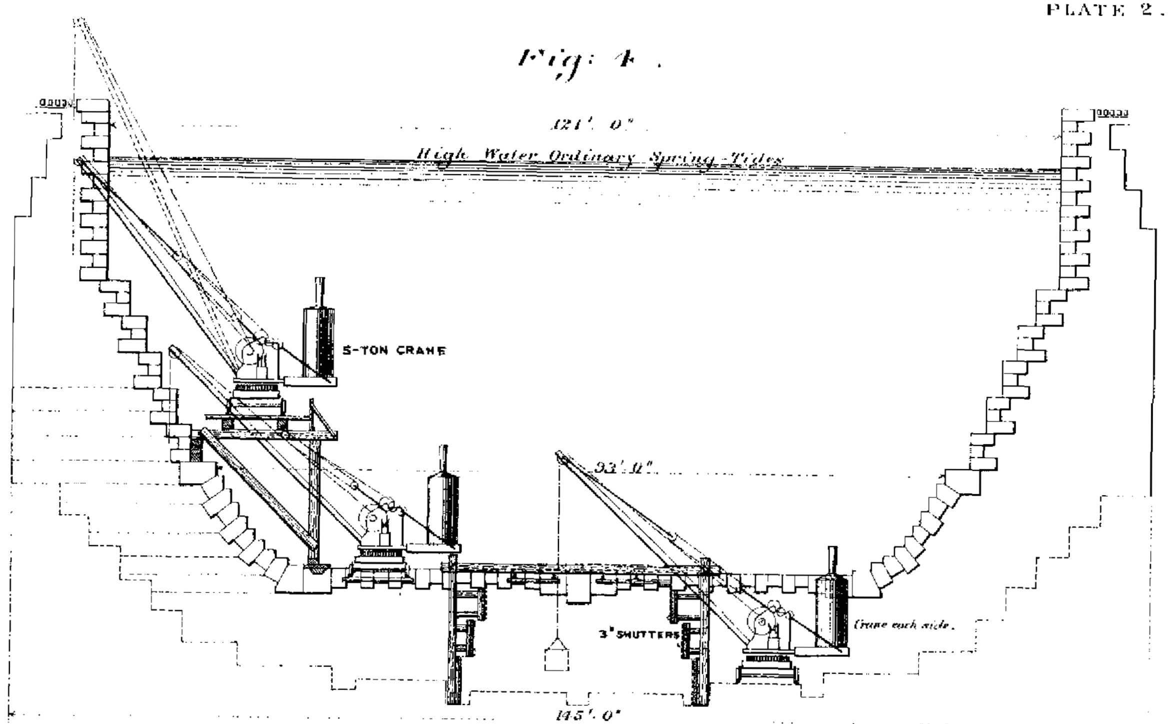
KEYHAM DOCKYARD EXTENSION
TEMPORARY WORKS AND PLANT.

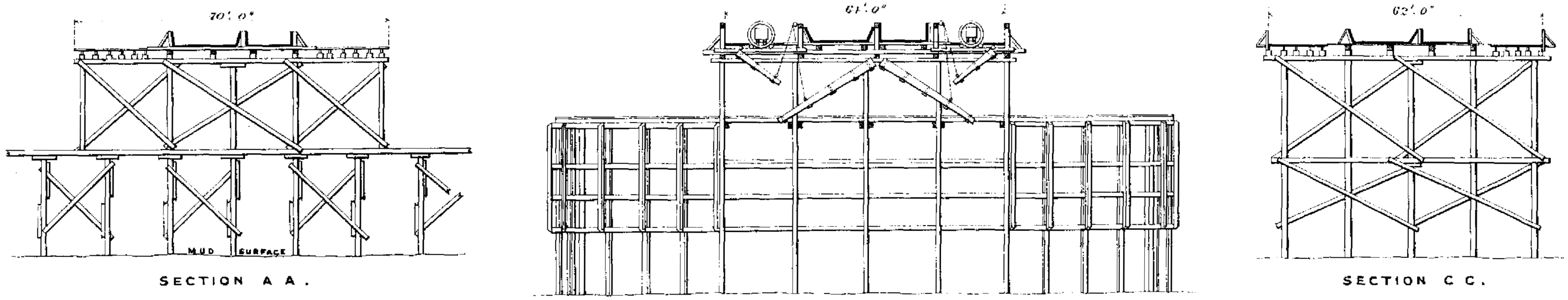
PLATE 2.

Fig: 1.



LONGITUDINAL SECTION.





SECTION A A.

SECTION B B.

SECTION C C.

STAGING FOR CONVEYING EXCAVATION TO BARGES.

SCALES.

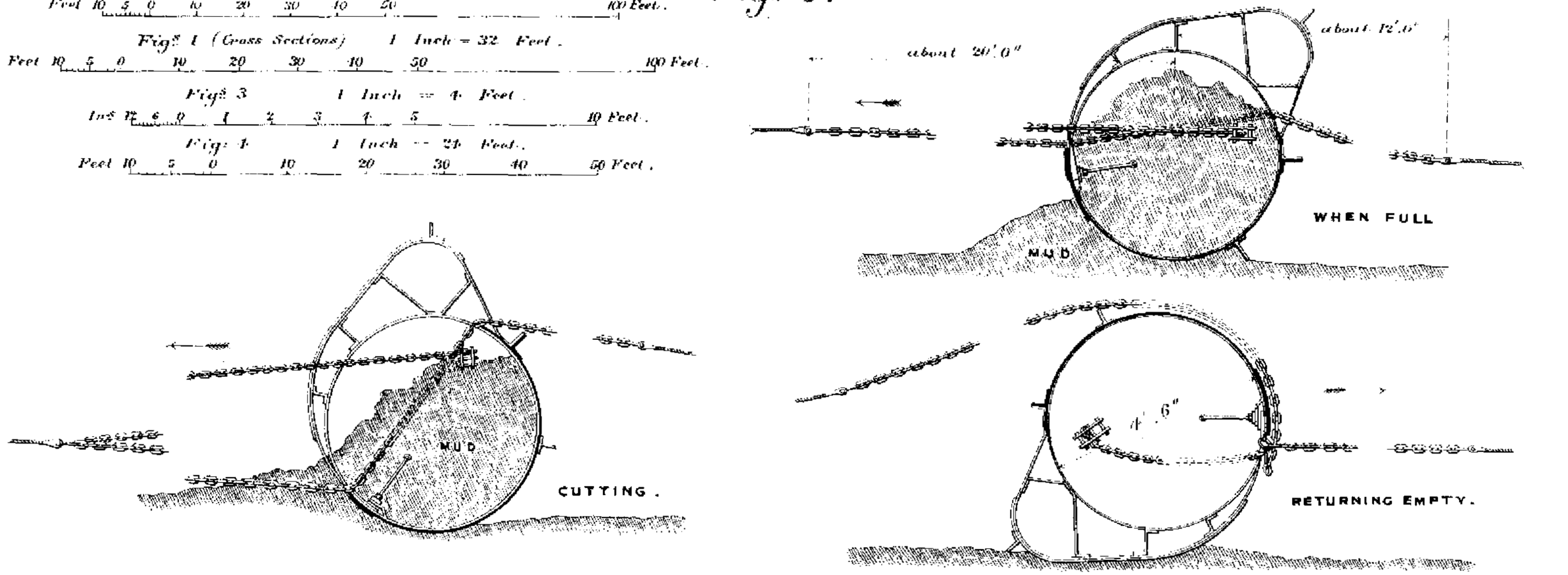
Figs. 1 (Longl. Section) 1 Inch = 40 Feet.
Feet 10 5 0 10 20 30 40 50 100 Feet.

Figs. 1 (Cross Sections) 1 Inch = 32 Feet.
Feet 10 5 0 10 20 30 40 50 100 Feet.

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

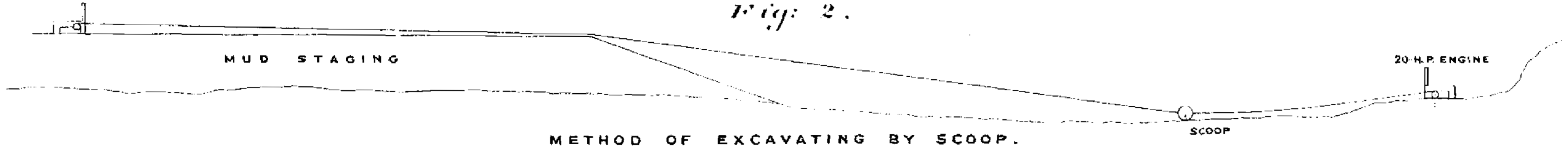
Fig. 4 1 Inch = 24 Feet.
Feet 10 5 0 10 20 30 40 50 Feet.

Figs. 3.



MUD SCOOP.

Fig: 2.



METHOD OF EXCAVATING BY SCOOP.

G.H. SCOTT.

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