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(*Paper No. 4605.*)

"H.M. Dockyard, Rosyth."

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IN 1903 it was decided that a large dockyard was necessary on the East Coast of Scotland, capable of docking any ship of the British Navy. A site, therefore, was purchased on the north side of the Firth of Forth, west of the Forth bridge (Fig. 1, Plate 1). The rocks underlying the site belong to the Calciferous Sandstone series which occurs at the base of the Carboniferous strata and lies immediately above the Old Red Sandstone. They include beds of sandstone, limestone, and shale, which have been considerably disturbed by the intrusion of large irregular masses of igneous rock. The igneous rocks at certain points cropped out at the surface, but elsewhere were covered with various thicknesses of glacial deposits.

The site was explored by sinking 208 bores, aggregating in depth more than 11,000 feet. Since the materials passed through were found to lie in lenticular beds, the variation between adjacent bores was often considerable. The character of the strata as a whole is probably best given by the following average analysis of the bores on the site of the permanent works:—

Strata Bored Through.	Percentage of Total.
Silt	12·82
Sand	25 57
Clayey sand, stones and gravel	6·36
Sandy clay	19·73
Puddle clay	19·40
Boulder clay (medium and soft)	6·36
Boulder clay (hard)	8·84
Boulders	0·71
Rock	0·21
	100·00

In order to obtain more reliable data by observation of the strata in position, a cast-iron cylinder, 8 feet in diameter, was sunk to a depth of 101 feet below sea-bed (Fig. 1). This cylinder passed through the following strata :—

	Feet.	Inches.
Silt	12	0
Stones (old beach)	2	7
Sandy clay, with stones, very stiff and compact	3	5
Soft clayey sand, with small stones	2	9
Stiff brown puddle clay	11	3
Soft red clay	18	0
Fine sand, waterbearing and running	2	3
Soft red clay	2	9
Fine sand, waterbearing and running	1	0
Dark purple clay, containing stones up to 9 inches in diameter	4	6
Fine sand, waterbearing and running	0	6
Stiff red clay	9	0
Stiff sandy clay, with angular stones up to 12 inches across	5	0
Sand	3	0
Red clay	8	6
Coarse sand	2	6
Soft red clay	1	0
Soft boulder clay	6	0
Hard clay and boulders	5	0
	101	0

The boulder clay, where hard, made a good foundation for heavy works. Dark bluish-grey shale (locally known as "blaes," or as "fakes" when containing sand) made an excellent foundation, except where the stratified beds were too steeply inclined and not confined on all sides. The igneous rock, which was a dolerite (known locally as "whinstone"), and a large proportion of the sandstone were suitable for use in the works as concrete aggregate, pitching, etc.

The tidal range at Rosyth is as follows :—

Mean High Water Springs	8·75	feet above Ordnance datum.
,, Low ,, ,,	7·55	,, below ,, ,,
,, High ,, Neaps	5·15	,, above ,, ,,
,, Low ,, ,,	3·40	,, below ,, ,,
The chart datum is	8·75	,, ,, ,, ,,

While the borings were in progress a number of different schemes for the design and lay-out of the dockyard were prepared and submitted to exhaustive examination and discussion. It is not necessary to review these steps in the progress towards the design ultimately adopted, beyond stating that they included a close examination of the relative values of "cross stream" and "up and down stream" entrances to the lock, also of floating docks and graving-docks. The final scheme, which was drawn up in 1908, provided for a complete Naval Establishment on such lines that a portion could be built for immediate use and added to subsequently as need required. The first portion constructed is shown in Fig. 2, Plate 1.

It was hoped that the data which accumulated during the progress of the undertaking would serve as the basis of a Paper dealing adequately with the problems which arose in the design and execution of the work. Circumstances, however, precluded such a Paper from being written, and the following outline of the undertaking is presented mainly with a view to evoke criticism of the main features of the design and works.

The tender of Messrs. Easton Gibb & Son, Ltd., for the execution of the works comprising the first section of the scheme was accepted in February, 1909. Under the contract the works were divided into two sections, namely:—

Section I.—Basin for submarines and approach.
Electric generating-station.
Pumping-station.
Boat-house and slipway.
Reclamation in neighbourhood.

Section II.—Main basin.
Dock and lock.
Dockyard area.

The works in Section I were required to be completed within 4½ years from the date of signing the contract, and Section II within 7 years from that date, subject to the usual conditions for extension of time. The Admiralty reserved power under the contract to order a second graving-dock; this order was given, and a third dock, and other works, eventually formed the subjects of supplementary contracts.

The contract with Messrs. Easton Gibb & Son was for the main works only. The caissons and penstocks, the dredging for the outer part of the approach channels, the erection of workshops, etc., were provided for by separate contracts, which were let at the latest date consistent with completion in time for use with the main works.

General Description of Works.

The primary aim of the design was to provide an establishment for the economical and rapid execution of all work required to keep the Fleet in an efficient condition; that is to say, the dockyard is a repairing base and not a shipbuilding yard; neither is it a transit establishment comparable with commercial ports dealing with a flow of passengers and goods. Subject to these conditions, the design was drawn up to make the best and most economical use of the site; this may appear obvious, but it was difficult to apply.

At the outset, when the sketch designs were being prepared, the rocky island of Dhu Craig was regarded as a feature which spoilt a good site and which would be best left alone. It was not until the lock was put through the centre of it that the designing difficulty was overcome.

Although the basin proved to be small for the work which was done in it during the war, it is larger than was originally contemplated. The dimensions originally proposed were increased after examination of the results yielded by the borings, which showed that, owing to the costly nature of foundations on the lines which had been tentatively selected, a larger basin could be obtained without additional expenditure if its north wall and the docks behind were sited farther to the north.

The south-west corner of the basin was cut off because the borings showed that a right-angled corner would project into a deep bed of sand. This sand would probably have carried the basin-walls, but it was felt that there would be a danger of leakage from the basin when it was low water outside if the walls were not taken through the sand to the boulder clay below. By cutting off this corner the boulder clay was met with at a much more favourable depth, and not only was a considerable economy effected, but serious constructional difficulties were avoided.

It was laid down in the main contract that the construction of the works, with a few specified exceptions, should be "in the dry," but the contractor was not allowed to surround the whole site with a dam. Owing to the great depth to which it was essential to go before good foundations could be reached for the outer sea-wall it was necessary to employ monoliths for this part of the work, and such foundations support the external southern wall and the adjacent walls of the establishment from the outer end of the entrance-lock to a point about the middle of the west wall of the main basin. It was intended that these walls on monolith foundations should be used as part of the complete dam to enclose the area of the works during construction. As the work advanced, it was found that the rate of progress in monolith sinking was too slow to permit this, and additional temporary clay dams were formed to avoid delay in the completion of the whole of the works.

To comply with the contract conditions clay dams were also formed, enclosing, in the first instance, the work comprising Section I of the contract, and thereafter, in succession, various other areas as the work advanced. *Fig. 3* shows the successive areas thus enclosed and the date upon which each was pumped out.

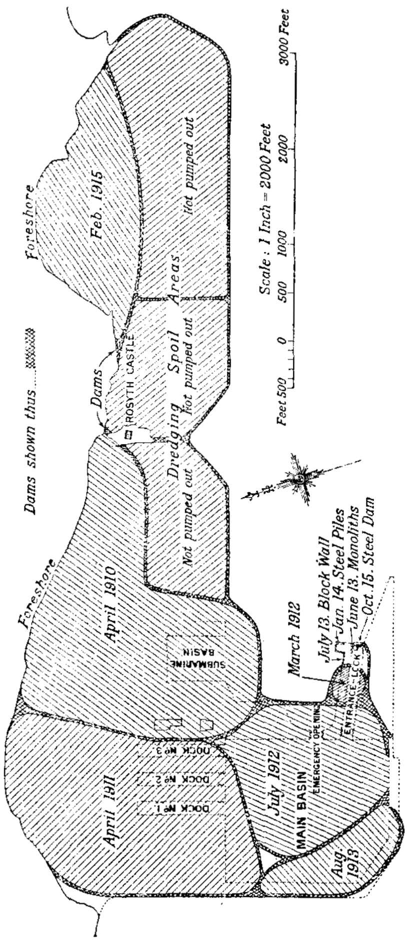


Fig. 3.

Construction Dams.

Basin for Submarines and Adjacent Works.

By April, 1910, the embankment round Section I had been completed and the enclosed area pumped out. Timbered trenches for the walls of this basin were then sunk from the level of the original sea-bed. The concrete walls (Figs. 4, Plate 1) were then constructed in the trenches. The excavation of the basin area enclosed by the walls was executed at a later date, the spoil being used for filling behind the basin-walls and reclaiming the foreshore in the vicinity.

Two reinforced-concrete jetties projecting from the north side of the basin were constructed when the excavation had been sufficiently advanced. Details of one of these jetties are shown in Figs. 5, Plate 1, Projections from the jetty and wall were provided to keep a small floating dock in position in the space between the eastern jetty and the adjacent basin-wall. A boat-house with slipway was built on the eastern side of the basin.

Graving-Docks, Entrances, and Pumping-Station.

While work on the submarine-basin was in progress, a clay embankment was formed round the site of the graving-docks and north wall of the main basin. The area enclosed by this dam was pumped out by April, 1911, and the excavation for the north wall and for docks Nos. 1 and 2 was put in hand. By the end of 1911 the north wall of the main basin was practically completed from the north-west corner of the basin up to the entrance to dock No. 1. The construction of docks Nos. 1 and 2 was begun as soon as the excavation for them had been completed. Dock No. 3 was built at a later date.

Figs. 6, Plate 1, show one of the three docks, which, as regards internal dimensions, are identical. The differences between the docks are that No. 1 dock is divided into two unequal parts by a floating caisson placed 600 feet from the outer sliding caisson, whilst No. 2 has a recess in the head into which the bow of a ship can project, so that a vessel slightly longer than the normal working length of the docks (for example, H.M.S. " Hood ") can be docked. Space is reserved at the head of each dock for a lengthening of 150 feet, if required at any time in future.

Few points of particular interest arose during the construction of the graving-docks. In the case of dock No. 1 the walls were built first, the floor being laid subsequently in strips at right-angles to the line of the side walls. The floors of docks Nos. 2 and 3 were, on the contrary, laid first and in blocks, about 24 feet square on plan, over the whole area excavated, the walls being subsequently built up upon the floor thus completed.

At the floor-level of No. 1 dock and at the same level in the southern half of No. 3 dock good sandstone rock was found. This only required to be excavated sufficiently to get in the granite keelblocks and to provide a level floor for working purposes. As the sandstone rock was pervious and the thin floor laid upon it was not designed to withstand upward hydrostatic pressure, the rock immediately below the floor was well drained with 4-inch earthenware pipes discharging into drainage-sumps through non-return valves. The northern half of No. 3 dock and the whole of No. 2 dock were founded on a sandy shale, locally called "fakes." Upon this inferior foundation a thick floor capable of resisting the full hydrostatic head was formed, and no drainage-pipes were provided. Fig. 7, Plate 1, indicates how the thickness of walls and floors varied according to the nature of the foundations.

In all the graving-docks and in the lock means for rapidly flooding the magazines of ships in dock are provided, for use in case of fire. Crane-tracks of 21 feet gauge carrying 30-ton travelling cranes are laid along both sides of each dock.

The outer or river entrance to the lock is generally similar to the entrances from the main basin into the docks and lock, but it has a depth of 37 feet 9 inches over the sill at L.W.O.S.T. Details of the emergency opening showing the provision made for constructing a future lock are shown in Figs. 8, Plate 3. The emergency opening is 125 feet wide at coping level, all other entrances being 110 feet wide.

The docks and lock (which latter can, in emergency, also be used as a dock) are emptied by means of a central pumping-station, to the pump-wells of which the water flows by gravity through culverts. The pumps raise the water-level in the wells, the discharge flowing out near the top to either the main basin or the tideway through non-return valves. The pumps are steam-driven, actuated by vertical steel shafts fixed in the pump-wells. The arrangement of culverts, etc., below ground is shown in Figs. 9, Plate 2. The topping-up culvert serves to raise the water-level in the basin by pumping water into it from the sea or when unwatering docks, necessity for which might arise during neap tides.

Monolith Foundations

The original scheme provided for 127 monoliths in the positions shown in *Fig. 10*. Of these only 120 were sunk. Typical sections of some of the larger monoliths are given in Figs. 11, Plate 1.

It having been the intention, as previously explained, that the walls on monolith foundations should form part of the dam to exclude water during the execution of the enclosed works, the work of monolith sinking was put in hand as early as possible. The construction of a temporary timber staging leading westward from the island of Dhu Craig was begun about October, 1909, the first portion being erected along the line of monoliths at the south-

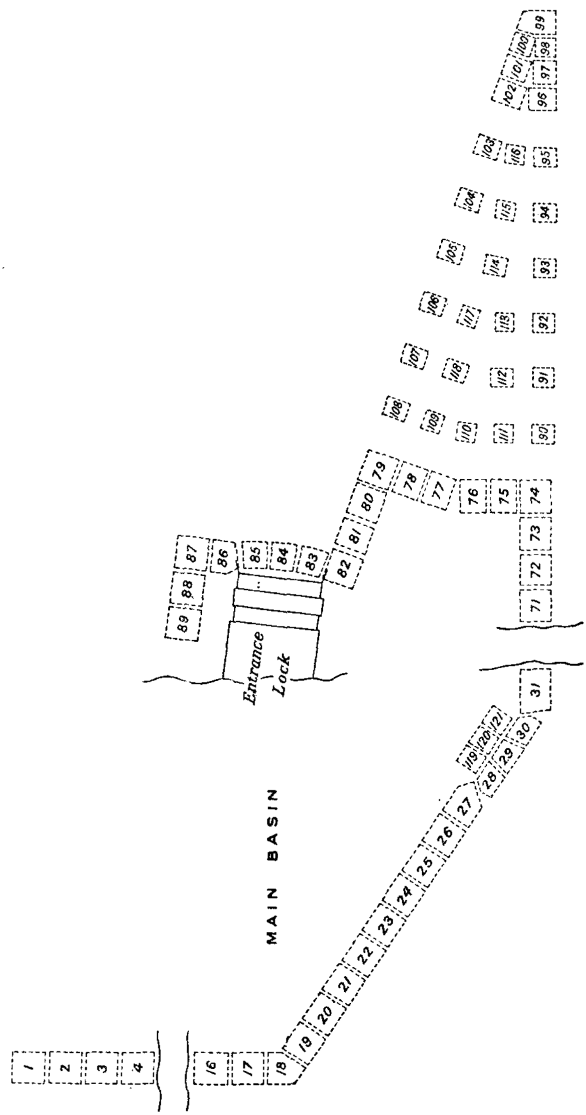


Fig. 10.

Layout of Monoliths.

east corner of the main basin. The method of sinking the monoliths and the details of the temporary staging are shown in Figs. 12, Plate 2.

The steel shoes of the monoliths were constructed on the shore of the Forth at a point about ½ mile east of Rosyth Castle. On completion, they were run down temporary slipways on to pontoons, upon which they were transported to the place where they were to be sunk. There they were lifted by cranes and deposited on a bank of firm material which had previously been tipped for the purpose with its surface 4 feet 4 inches below Ordnance datum.

The contractors decided to apply kentledge for sinking purposes by lining the interiors of the wells with blocks of concrete. This involved a restriction in the area of the wells, as will be seen by comparing Figs. 12, Plate 2, with Figs. 11, Plate 1, which represent the contract section. Kentledge in the form of well-lining blocks could only be made fully effective by pumping out the wells. To enable this to be done without reflooding at each successive tide, steel cylinders extending above high-water level (Figs. 12) were, as a rule, fixed at the top of each well. By means of grabbing, pumping out the wells, hand excavation, and blasting at or near cutting-edge level, the monoliths were sunk to their final founding levels. The wells were then filled with 1 : 4 : 10 concrete, the cylinders were removed, and the construction of the superincumbent wall was put in hand; the lower courses of the wall were put in behind half-tide dams formed with material excavated from the monolith-wells. The lining blocks remained in the wells as part of the well-filling. The spaces between the monoliths (specified to be 5 feet wide, but, in reality, varying widely on completion owing to lateral drift) were afterwards excavated and filled with concrete. Steel sheet piles were driven across the two ends of the spaces before excavation was begun, and were drawn after the concrete had been put in.

The first monoliths to be sunk were those on the south side of the main basin. As the work of monolith sinking proceeded, the temporary staging was extended westward along the south, south-west, and finally along the west wall of the basin; and by September, 1911, monolith sinking was proceeding along the full length of staging provided, from monolith No. 1 to monolith No. 54 (*Fig. 10*).

Serious difficulties were experienced in sinking the monoliths in the vicinity of the south-west side of the basin: waterbearing sand and other unstable materials were encountered; numerous "blows" into the wells occurred, and the staging sank repeatedly at various points. Finally the contractors were forced to enclose the whole area from monolith No. 1 to monolith No. 38 with a clay dam. When the area had been laid dry, the sinking of these monoliths was completed under more favourable conditions.

The staging which had been erected for the monoliths surrounding the main basin was dismantled when no longer required, and re-erected for the sinking of the remaining monoliths east of the basin. Foundations on solid rock were secured for monoliths Nos. 38 to 66. Eastward of the latter, treacherous and difficult material was again met with, particularly from monolith No. 68 to monolith No. 82. The strata were very unstable, and it was found impracticable to excavate some of the closing spaces between the monoliths to the full depth and width required by the contract.

The monoliths to which consideration has so far been given measured, for the most part, 43 feet by 43 feet in plan. The smaller isolated monoliths which support the reinforced-concrete superstructure and timber deck of the entrance-pier were 30 feet by 30 feet and 30 feet by 25 feet, but, like the preceding, they were formed with four wells. The method of applying kentledge by lining the wells of these monoliths with blocks being inapplicable owing to their smaller area, they were sunk, by grabbing, by pumping out the wells, and by blasting, through soft clay until, at a considerable depth, a hard stratum of gravel was reached, upon which they were founded. A number of these monoliths during the progress of sinking deviated considerably from the vertical, and efforts to correct this before they were founded proved ineffectual.

As monolith sinking proceeded, the contractors developed a method of blasting for sinkage, known on the works as "bomb-firing." Charges up to about 4 or 5 lbs. each of "blastine" (the explosive in general use on the works) were placed in tin canisters, lowered through the water, and exploded at or about the level of the steel shoe. The concussion of the explosion shook the monolith and the material in which it was embedded. Sinkage was thus obtained in many instances when other methods had proved ineffective. To sink monoliths by concussion in this manner involves risk. After some damage had been caused, the contractors were required to limit the charges and also the head of water in the wells above the charge at the time of explosion. Excavation by hand in the wells after they had been pumped dry was adopted in many cases. It was necessarily risky work, for blows into the well of sand, mud, or water often occurred with but little warning. Fortunately no fatal accidents resulted from these blows, though the workmen on several occasions had narrow escapes. The responsibility for deciding when any monolith had been sunk to a sufficient depth and to a sufficiently firm stratum rested with the Admiralty engineers. Where possible the monoliths were founded upon rock. The rock surface was often found sloping steeply towards the river. In such cases underpinning was resorted to, as illustrated in Figs. 11,

Plate 1. No movement has occurred in monoliths founded on rock. After the wells had been excavated, a number of the steel shoes were found to have been crumpled up and twisted by contact with the rock.

At the south-west side of the basin, where the strata were somewhat unstable and where the foundations were not rock, the monoliths tilted sideways slightly when the spaces between them were being excavated. In such circumstances the top of the monolith moved towards the side where excavation was proceeding, and, if the closing space on the other side had previously been filled with concrete, it parted from the latter, leaving a crack measuring 1 inch or less in width at the top. Since these cracks were thought to be due to the temporary weakening of the foundation and to the increase of pressure upon it caused by the excavation in progress, they were not regarded as being of any moment. They were grouted up and, as no subsequent movement has occurred, this view has been confirmed.

The contractors were not restricted in the number of monoliths which they might sink at the same time, except that the specification required that monoliths should be sunk alternately, and those first begun should be founded before the sinking of the intermediate ones was begun. Owing to the slow progress of monolith-sinking this requirement was withdrawn in April, 1911, and after that date the sinking of the intermediate monoliths was permitted to proceed before the adjacent monoliths were founded, on the understanding, however, that the cutting edge of the intermediate monolith should be kept at least 30 feet above those of the two adjacent monoliths belonging to the first series.

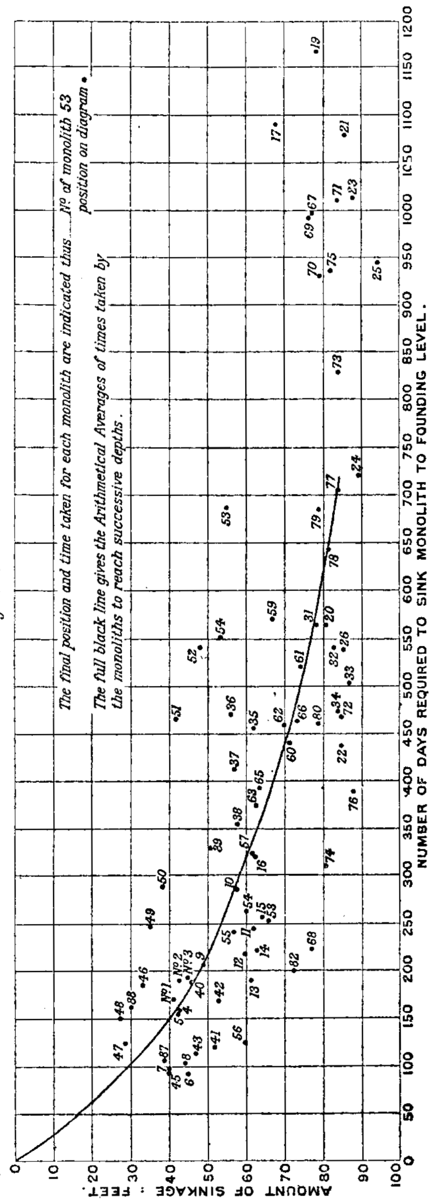
The average rates of sinking the largest monoliths at the various depths is shown in *Fig. 13*.

ENTRANCE-LOCK.

The lock (Figs. 14, Plate 3) is designed for use as a dock. The larger vessels of the Fleet may be so damaged in war time as to arrive at their docking port drawing up to 10 feet more than normal. In this condition they could not pass over the high-level sill at the basin end of the lock or enter the basin through the emergency entrance. The deep entrance at the river end of the lock, however, permits a damaged ship to be docked in the lock. Temporary repairs would then restore the normal draught and allow the ship to proceed to one of the ordinary graving-docks.

In selecting the rocky island of Dhu Craig as the site for the lock, regard was had to the prospect of utilizing the rock excavated as aggregate for concrete and also to the economy which could be effected in the thickness of the concrete walls and floor. The site

Fig. 13.



RECORD OF MONOLITH SINKING.

was, in the first instance, partially enclosed by a clay dam, and excavation of the rock was begun in March, 1912. The greater part of the rock was hard dolerite (whinstone), very suitable for concrete.

It was originally intended to construct the caisson-camber at the river (or east) end on the south side of the lock. It was found, however, during the sinking of monolith No. 82 in the immediate vicinity, that, even at a depth of 90 feet below cope-level, the clay was too soft to be suitable as a foundation. The design was therefore altered, and the camber was constructed on the north side, where good foundations were available at the required depth.

The original design also provided for dovetail chases in the solid rock, for the attachment of the thin concrete facing which formed the walls and floor. Owing to the exceptional hardness and fractured character of the rock the dovetails were omitted, and under the floor a layer of neat cement was substituted for them to ensure proper adhesion between the rock and the concrete facing. At the same time the thickness of the concrete was reduced to a minimum of 9 inches. Before the change was made, adhesion tests were carried out which showed that the adhesion between the ordinary concrete (1 : $1\frac{1}{4}$: 4) and the rock was 3·6 tons per square foot; by the addition of a 2-inch layer of neat cement this figure was increased to 4·7 tons per square foot.

Cement rendering of the rock surface was not used for the side walls, but steel bars were inserted in the rock face, grouted into position, and left with their ends projecting into the concrete. Owing to the great pressure which had to be borne by the inner sill of the river entrance when the lock was pumped dry, the concrete under this sill was made thicker than had been originally proposed, and a number of 2-inch steel bolts were inserted to secure it to the underlying rock. The outer sill was similarly strengthened with steel bolts.

The rock remaining after excavating the site for the lock was not free from cracks and fissures, but very little water entered the excavation through them. It was thought prudent nevertheless to provide weep-holes in both the walls and the floor to prevent damage by hydrostatic pressure. Drain-pipes, 4 inches and 6 inches in diameter, were placed at intervals in the side walls and also under the inner sill of the river entrance.

Three small monoliths (Nos. 83, 84, and 85) were sunk at the river end to form, with embankments at either end, the dam to exclude water from the site during construction. These monoliths were filled with clay above sill-level (45 feet below Ordnance datum) and upon their tops, after they were founded, a temporary wall of concrete blocks was carried up to above high-water level. The three monoliths, down to sill-level, and the temporary block wall which surmounted them, were subsequently removed.

The rock surface at the south-east corner of the lock dipped steeply to a great depth. The eastern end of the south wall of the lock for a length of 200 feet (measured from monolith No. 82, previously founded) was therefore constructed in a heavily timbered trench, of a maximum depth of 90 feet below coping.

MAIN BASIN.

This provides an area of water, 56½ acres in extent, maintained at an approximate depth of 38 feet above the level of the sills of the docks, inner end of the lock, and emergency entrance. Ships may thus enter or leave the basin at high water by the emergency entrance, or at any state of the tide by the entrance-lock.

The original design included a pier 600 feet long projecting into the basin from the west side so as to increase the ratio of wharf-length to water-area. In the interval between settling the main lines of the design and the date when the progress of the works permitted the construction of this pier to be commenced, dimensions of ships had so increased that it became evident that the pier would form a serious obstruction in the basin, and it was omitted. The original design provided an emergency opening at the south-west corner of the basin so that, in the event of the lock dock being occupied by a disabled ship, the ships in the basin could be brought out. During the course of the works it was decided to build the basin entrance of one of the future lock docks on the east side of the basin. This emergency opening, which has been referred to already, is shown in Figs. 8, Plate 3. It can be used for egress or ingress at any high water.

Early in 1914 a further substantial alteration in the design of the basin was decided upon. It has already been explained that the strata in the south-west corner of the basin had proved difficult to work in and that the contractors had, in consequence, been compelled to tip a clay dam outside the monoliths being sunk there. It was consequently decided to build the south and south-west walls of the basin on the monolith foundations and not, as originally intended, as independent walls about 60 feet north of, and parallel to, the north face line of the monoliths. To give sufficient space for railways, roads, etc., the above-mentioned temporary clay dam was retained and extended along the south side of the monoliths as a permanent part of the works, with the addition of pitching and a toe of large rubble.

It has already been stated that the construction of the north wall of the basin advanced, under the protection of a clay dam, concurrently with that of the graving-docks. It soon became evident that, owing to the slow progress of monolith-sinking, further areas would require to be enclosed if the construction of other works was not to be delayed. An additional dam (*Fig. 3*) was therefore tipped across the basin area from near its north-west corner to monolith No. 38, connecting at that point with the river wall which had already been built from there to near the south-east corner of the basin. The area enclosed by this additional dam, by the abovementioned wall, and by other embankments extending on the east side of the basin northward to the original dam surrounding Section I, was pumped out in July, 1912.

The excavation of the portion of the basin area thus laid dry was begun at once and was extended at an early date to the adjacent area at the south-west and west sides of the basin when that had also been enclosed and pumped out. When the excavation had been carried down to the full depth of the basin (31 feet 8 inches below Ordnance datum) a timbered trench was sunk for the construction of the portion of the east wall extending from the emergency opening to the north-east corner of the basin. This trench at one place reached a depth of 70 feet below Ordnance datum. The section of wall employed there is shown in Figs 4, Plate 1. The portion of wall extending from the north-west corner of the basin to monolith No. 1 was also constructed in trench, in this case sunk from the original sea-bed level.

At the south-east corner of the basin the excavation laid bare a large area of whinstone rock, the surface of which had been rubbed smooth by glacial action. The striæ indicating the direction in which the glacier had moved were clearly visible, and were pronounced by an officer of the Geological Survey to be the finest that had been seen in Scotland. The rock upon which a number of the monoliths were founded presented similar characteristics.

The clay excavated from the basin was used for reclamation. The rock was used for concrete.

Dredging.

The extent of the dredging carried out at Rosyth is shown in Figs. 1 and 2, Plate 1. Approximately 12 million cubic yards of material was dredged and either used for reclamation or deposited at sea. The work was divided into two parts. A quantity of about 4 million cubic yards from areas in the immediate vicinity of the entrance-lock and basin for submarines was included in the main works contract. The dredging of the main approach channel was carried out under a separate contract. The depth obtained in the main channel was 45 feet below Ordnance datum. The depth of the channel to the emergency opening and of the berth along the south river wall was 31·66 feet below Ordnance datum. The area in front of the basin for submarines was dredged to a depth of 27 feet below Ordnance datum, the basin itself having been excavated 2 feet deeper in the dry. At the west end the approach channel also was widened on the north side by Admiralty departmental dredgers, so as to form part of the future tidal basin.

For the main contract dredging the bucket-dredgers "Venezia" and "Ierland," and three suction reclamation dredgers "Wilkinson Nash," "Edinburgh," and "Belfast," were employed. The latter vessels pumped out dumb barges which had been previously loaded under the shoots of the bucket dredgers and towed to the place where the suction dredgers were moored and used for pumping the spoil ashore. The approach channels were dredged by the bucket-dredgers "Gadsden," "Merwede," and, at intervals, on the gravel and boulders, the "Devon." For conveyance of the spoil to sea six 600-ton steam hopper-barges were used.

The materials dredged comprised a top layer of mud, silt, and shells ranging from 5 to 10 feet in depth. Beneath this was a layer of gravel in which were embedded numbers of large glaciated boulders. Below the gravel was a deep bed of soft red clay extending far beneath the bed of the dredged channel. In the vicinity of the lock-entrance and basin for submarines hard boulder clay was found when the lower levels were reached, and this material at times proved difficult to remove by means of the lightly constructed belt-driven dredgers employed. It was remarkable how, with skilful handling, these dredgers could raise boulders which were so large that they could only just pass between the suspension links on the end of the ladder. In only one case was a boulder encountered which was too large to be dredged. This was broken by explosives. In another case the dredger succeeded in raising a boulder which could not be passed up the ladder on the buckets. This was brought to the surface resting on the buckets over the lower tumbler, slung by chains over the stern of a steam hopper, and so conveyed to sea.

Disposal of Dredged Spoil.—The contract for dredging the main approach channel provided for the spoil being deposited at sea in deep water between Oxcars and Inchcolm, 6 miles east of the works. After the outbreak of war the defence measures adopted for the security of the port involved the abandonment of the Oxcars dumping-ground, so that during the war a deep depression around the Beamer rock immediately to the west of the Forth bridge was used instead.

The smaller volume of dredged spoil arising from the main contract was, in accordance with the provisions of the contract, used to reclaim the area to the east of the dockyard for future extensions of the establishment. Banks were tipped in the neighbourhood of Rosyth Castle (*Fig. 3*) to form a series of ponds in which the dredged material settled after being pumped out of the barges. The surplus water escaped over weirs. The large quantity of water required to break up the material when it was being pumped from the hopper-barges to the reclamation, and the action of the pump itself, reduced much of the clay to slurry. The result was that stones and heavy material were deposited in the immediate vicinity of the discharge-pipe outlet, forming ridges of hard material across the reclaimed areas, whilst between these ridges and at the extremities of the ponds there were large areas filled with extremely soft slurry.

At the time when these arrangements were made it was not anticipated that the areas would be required for many years. Owing to the war, however, several of these slurry areas had to be utilized for naval purposes before the material had consolidated. An attempt to dry an area by drains led into a well which was kept constantly pumped down was only successful after some years of operation. This, under the conditions then prevailing, was too slow to meet the requirements. The particles in the slurry retained their moisture even under favourable drainage conditions. In the absence of any rapid method of consolidating these areas they were covered with a blanket of dry material which sank into the soft material and in the worst places attained a thickness exceeding 10 feet.

All buildings on this pumped reclamation had to be carried on piled or pier foundations, whilst very great difficulties were, and have since been, experienced with roads, railways, drains, water-mains, etc., because the material under the blanket has remained soft. In these circumstances it will readily be understood that the cost of rendering the pumped reclamation available for use within 2 or 3 years of its formation was excessive. The extra cost has to be set against the original saving made by using pumping as the method of putting the material on shore. The dockyard area proper was all reclaimed with material excavated and deposited in the dry.

Output of Dredging Plant, etc.—As might be expected from the double handling of the material on the main contract, the output per dredger on this section fell considerably below that on the contract for dredging the approach channels. When the material was suitable for pumping ashore, the three stationary suction reclamation dredgers could keep pace with the two bucket dredgers, but when clay and stones were dredged, the progress of reclamation was retarded, not only by the stickiness of the clay, but also by stones becoming jammed in the pump-casings.

Some remarkable outputs were obtained from the plant on the approach-channel dredging, when the size of the dredgers and of their buckets is taken into consideration. On one occasion over a period of 5 weeks the dredger "Gadsden" maintained an average output of 55,000 cubic yards in barge per week, whilst in several individual weeks outputs exceeding 60,000 cubic yards in barge were obtained.

Over a very large portion of the area the depth of water at low water was only 1 to 2 feet, so that at the outset advantage had to be taken of every high tide to dredge as much as possible, in order to secure sufficient depth for the hopper-barges to come alongside the dredgers.

Apart from the two or three occasions when the bucket-chains parted, there were only two serious accidents to the plant. The dredger "Merwede" sank in the main channel, owing to her hull being torn on one side of the well by a lost anchor brought up by the buckets. The master's efforts to pull the dredger over on to the shallow bank by means of the side chains were unavailing, and the vessel turned turtle and sank. Pending her recovery, arrangements were made for the use of the "Dredgewell," a large vessel of similar type. In 6 months the "Merwede" was salved, repaired, and at work again. The dredger "Venezia," employed on the main contract dredging, sank near the lock-entrance, and as the date for completion of this work was near at hand she was slung from barges, towed under water, and grounded on the sloping bank of the approach channel. Salvage operations were subsequently conducted there.

Progress of Construction.

Situation at the Outbreak of War.—While the Rosyth works were under construction the German Government had put in hand the deepening of the Kiel canal, which, when completed, would give the German Navy the advantage of being able to transfer warships rapidly between the North Sea and the Baltic; while their opponents would have to take the longer and, under war conditions, more dangerous passage through the Kattegat and Great Belt. It is understood that the deepening of the Kiel canal was completed in July, 1914; and a state of war, so far as this country was concerned, came into force on the 4th August, 1914.

The situation which arose at Rosyth on the outbreak of war was serious. The new dockyard was two-thirds complete, but no part of it was available for the use of H.M. ships. The basin for submarines was finished, but the entrance to it was closed by a clay dam. The pumping- and electric generating-stations were built and in process of being equipped, but there were no facilities in the shape of roads, railways, electric and water mains, etc. Graving-docks Nos. 1 and 2 were practically complete, and the building of No. 3 was well advanced, but access to any of them was impossible, because the excavation of the main basin and the construction of the emergency opening were still far from complete. The excavation for the entrance-lock had made good progress, but practically nothing had been done towards the construction of the floor and walls, and the approach channels had not been dredged. The sinking of the monoliths round the basin (Nos. 1 to 54) was approaching completion, and the work of building the basin-walls was well advanced. The sinking of the monoliths east of the basin was about half completed.

Measures were at once taken to bring the completed basin for submarines into use, although for other purposes than those for which it was originally designed. On the 12th August the pumping of water into it was begun, and by the 20th it was flooded to mean sea-level. On the 25th the breaching of the enclosing clay dam was begun by a ladder dredger, and on the 2nd September H.M.S. "Aquarius" entered the basin and was berthed alongside one of the jetties. From this date onwards the basin for submarines was brought into increasing use as an auxiliary base for small craft.

The main contractors pressed on at utmost speed with the work in Section II of the contract, but during the autumn and winter of 1914–15 the conditions, as to both supply of labour and the procuring of materials, became steadily more unfavourable, and, early in 1915, the position had to be faced that early completion of the works, which had become of vital importance and inestimable value to the Navy, could not be achieved unless special arrangements were entered into.

The main contract provided for an extension of time in the event of war. Owing to the enlistment of men for the Army and the rapidly advancing cost of materials the contractors could not, except with special facilities for recruiting labour and obtaining materials, and at greatly increased cost, continue to press forward the works to such early completion as national interests required. The Admiralty had thus open to them two alternative courses of action: (1) To close down, or greatly reduce the rate of progress on the works and divert the labour and materials to other purposes. The advocates of this policy held that this would give a more immediate return and would shorten the duration of the war. (2) To co-operate with the contractors in a scheme put forward by them for accelerating the works to the utmost possible extent with a view to bring them into use for some period of the war. After much discussion, the latter policy prevailed. It was decided to abandon, temporarily, the aim of completing simultaneously the whole of the establishment and to concentrate all efforts on the task of giving the Navy the essential portions of the works, that is, the full use of two graving-docks and the main basin, at the earliest date possible. The contractors in effect took upon themselves to accelerate and carry out this work to completion by an early agreed date at their contract schedule rates plus the estimated extra cost of wages and materials, with the important proviso that, if they failed to complete these essential works within the promised time, they were to forfeit half of the extra cost of wages and materials. They succeeded in their task. The contract was unbroken, and the essential portions of the works were in full use 21 months before the contract date for completion of the works as a whole. Very strenuous team work by the staffs of the Admiralty and contractors was necessary to achieve this satisfactory result.

Completion of Graving-Docks.—The small amount of outstanding work on docks Nos. 1 and 2, such as the dressing of the axed meeting faces for caissons, the setting of bollards, etc., was completed without difficulty in advance of the flooding of the main basin.

At the outbreak of war dock No. 3 was nearly half completed. The floors had been laid, the walls on the east and west sides were, for three-quarters of the length of the dock, built to broad altar level. Without prejudice to the acceleration of the more urgent items of work already defined, the construction of dock No. 3 was pushed forward as rapidly as possible. Before the flooding of the main basin took place the dock-entrance and caisson-camber had been completed; and, after the flooding, when the caisson had been placed in position across the entrance, the area of the dock was pumped out, and the remaining work was completed.

Completion of Main Basin.—The completion of the excavation of this large area was the crucial point in the project for bringing the essential part of the works into use at the earliest date possible.

Before August, 1914, 1,290,000 cubic yards had been excavated out of a total of 2,100,000 cubic yards, of which total approximately 6 per cent. proved ultimately to be rock. Steam-navvies were used for the excavation of soft material, the underlying rock being subsequently broken up by blasting. By the 16th September, 1915, the whole area had been excavated to the required level (31·66 feet below Ordnance datum) and the surrounding walls had been completed. At 9.30 p.m. on that date flooding began, the water being, in the first instance, admitted through the culvert leading from the basin for submarines. At a later stage water was admitted through the basin sluices. By 9 p.m. on the 17th the whole area (including that of the docks and lock) had been flooded to a depth of 37 feet. The sluices and penstocks were then closed, as the tide had reached its maximum height. The main pumps in the pumping-station were set to work, and the depth was increased to 39 feet 6 inches. This depth was necessary to float the deep sliding caisson for the outer end of the lock which, with three other caissons, had been built in the basin. The three sliding caissons were then placed in position across the inner and outer ends of the lock and across the emergency opening. When this had been done, the lock area and the space enclosed by a clay dam east of the emergency opening were pumped dry to permit remaining work in those situations to be completed.

Completion of Entrance-Lock.—Between the date of the outbreak of war (4th August, 1914) and that of flooding the main basin (16th September, 1915) the floor of the lock had been laid, both entrances (including sliding ways, cambers, and contiguous masonry) had been completed, and the side walls and altars of the lock had been partly built.

The dredging of the approach channel was completed by the 25th March, 1916. On the 27th March H.M.S. " Zealandia " passed through the lock and was subsequently docked in No. 1 dock. Within the succeeding month H.M. ships " Dominion," " Calliope," " Constance," " Tyne," " Dreadnought," and " Invincible " entered the basin, and on the 27th April H.M.S. " New Zealand " was docked in No. 2 dock. The new establishment was thus, though far from complete, available from this time onwards for the use of the largest ships of H.M. Navy.

On the 31st May, 1916, the battle of Jutland was fought. On the 1st June H.M.S. " Warspite," and on the following day H.M. ships " Princess Royal," " Tiger," and " Southampton," entered the basin through the entrance-lock. All these ships had suffered considerable damage in the battle, and on the 5th June

H.M.S. "Lion," in a similar state, came in. The necessary repairs and refit of these damaged ships were carried out in the docks and basin.

When the lock had been brought into use it was found that, at certain states of the tide, the cross currents running through the entrance-pier were sufficiently rapid to cause anxiety when ships were entering the lock from the river. The open spaces between the monoliths for the full length of the entrance-pier were therefore closed by driving a close screen of reinforced-concrete piles. This remedy has proved effective, and ships now enter the lock from still water.

Completion of South River Wall, Entrance-Pier, and Minor Works.—These outstanding items had necessarily suffered delay in the acceleration of the more essential works described above. Their completion calls for but little comment. The original design of the entrance-pier provided for a timber deck supported by reinforced-concrete arches resting upon the monolith foundations, but eventually heavy reinforced beams were constructed instead of the arches. Details of the superstructure as completed are given in Figs. 15, Plate 2.

Monoliths which, during sinking, had drifted or tilted inwards were corbelled out at the top to the true line. The faces of those which projected into the fairway were cut back as necessary.

MATERIALS.

Concrete.—The following classes of concrete were specified :—

Quality.	Portland Cement.	Sand.	Broken Stone.
A	1	1¼	4
B	1	2	5
C	1	2	5½
D	1	3	7
E	1	4	10

These proportions were designed to give a volume of mortar 10 per cent. in excess of the interstices in the broken stone. Though various alterations were made, broadly speaking these different qualities were used in the following positions :—

A.—Walls of monoliths including seal at toe and caps. Mass concrete work below the level of 4 feet 4 inches below Ordnance datum. Mass concrete in closing spaces between monoliths if deposited under water.

B.—Mass concrete between 4 feet 4 inches below and 9 feet above Ordnance datum. All facing blocks for walls. Mass concrete in closing spaces between monoliths if deposited in the dry.

C.—Mass concrete between level 9 feet above Ordnance datum and coping level (15 feet above Ordnance datum). Foundations for buildings.

D.—Foundations for isolated bollards, etc.

E.—Interior filling of monoliths.

Displacers of hard rock were permitted in concrete not deposited under water; the best results were obtained with large displacers of 3 to 5 tons weight placed in the wet concrete by a crane. Stone was obtained from quarries on the Admiralty property, from the excavation for the entrance-lock, and from other rock excavations on the works. Sand was brought by rail from the sea coast near Kinghorn. Just before the outbreak of war the contractors had completed arrangements for obtaining a supplementary sand supply by dredging from the Drum sands, a shoal lying immediately east of the Forth bridge. This scheme, however, had to be abandoned in consequence of war restrictions on shipping in the Firth of Forth.

The quantity of sand obtained from the stone broken in the stone-crushers fluctuated within wide limits, and this had such a disturbing effect upon concrete gauging that eventually it became necessary to screen out all fine material from the crushed stone. This fine material was deposited in the sand-bins and was added to the gaugings as part of the specified proportion of sand.

All Portland cement was specified to be in accordance with the British Standard specification and was sent by sea from works on the Medway belonging to the Associated Portland Cement Manufacturers and Messrs. Martin, Earle & Company. The cement was stored in bulk to a depth of about 4 feet on the floors of special sheds built for the purpose, aerating being done by means of compressed air.

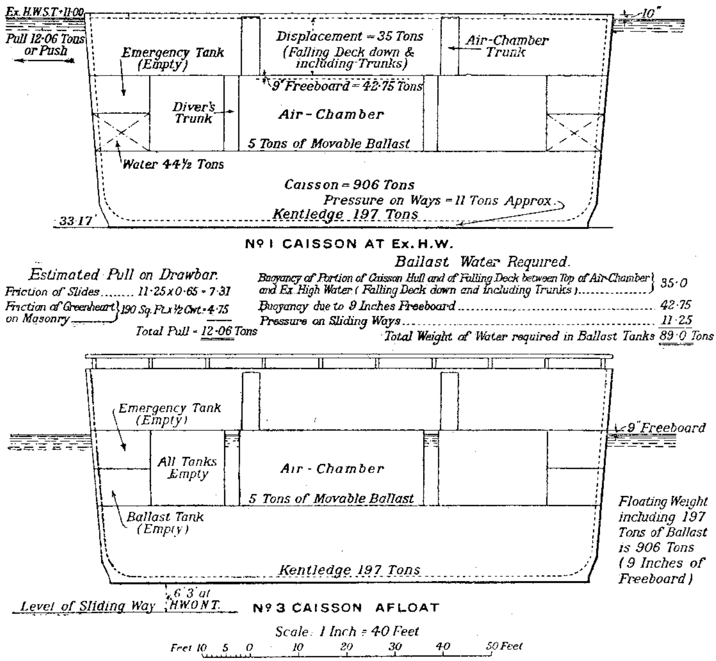
Concreting during frosty weather was, as a broad rule, allowed when the temperature exceeded 22° F. if salt, or 28° F. if fresh, water was used. This rule was not applied with rigidity. The circumstances of each case governed the decision; for example, substantial masses of concrete deposited under tidal conditions, which, shortly after deposition, would be covered by the tide, were clearly in a different category from reinforced concrete or concrete paving.

Reinforced Concrete.—The reinforced-concrete jetties in the original contract were designed to carry the worst possible combination of the following loads :—

(1) Live deck load of 3 cwt. per superficial foot.

(2) Load on train rails, namely, an unlimited train with an axle-load of 10 tons and a wheel-base of 7 feet. The latter was assumed to occupy a width of 9 feet. Within this width no simultaneous

Figs. 18.



Normal Working Conditions of Caissons.

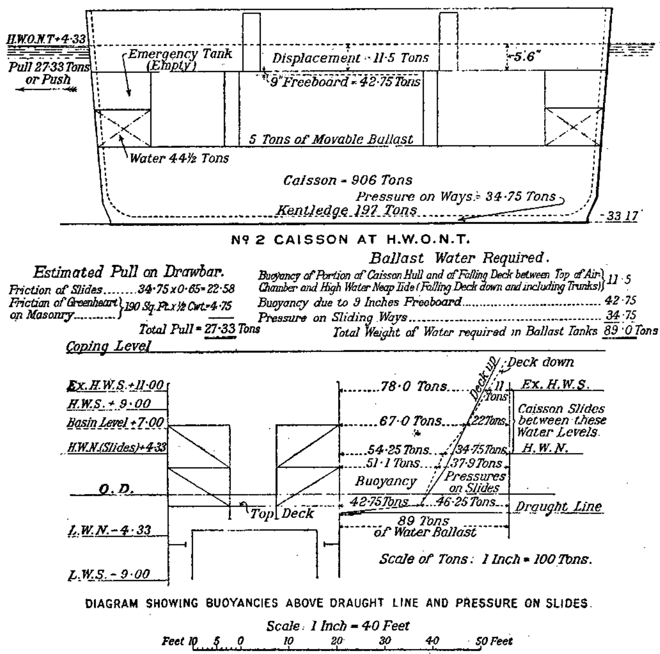
The lowest tide at which the caisson will be hauled out of its camber is H.W.O.N.T. The ballast-tanks when completely filled with water (89 tons) produce a minimum pressure on the sliding ways of approximately 11 tons at a tide-level of 11 feet above Ordnance datum. As the ballast water remains permanently in the end tanks, except when the caisson is floated out of its groove

floor load was taken. Provision was also made for shocks caused by ships.

The concrete for reinforced concrete was composed of 4 parts of broken granite ($\frac{1}{2}$ inch to $\frac{3}{4}$ inch), 1 part of cement, and sufficient fresh-water sand to fill voids.

As already stated, the superstructure of the entrance-pier was finally designed as a series of large-section reinforced-concrete beams carrying a timber deck, the whole being required to support a working load of 2 cwt. per square foot of superficial area, together with the weight of the structure itself, and to resist shocks from battleships alongside. The concrete was composed of 1 part of Portland cement, 1½ part of sand, and 4 parts of broken whinstone (1¼ inch and less). Difficulties were experienced while the work was

Figs. 18.



for repairs, the pressure on the sliding ways is approximately 35 tons at H.W.O.N.T. When it is required to examine and paint the lower ballast-tanks, the emergency tank can be filled with sea-water by gravitation and the ballast-tanks pumped out. The ballast-tanks and emergency tanks are filled from the sea valve in the bottom of the air-chamber.

in progress owing to oil fuel floating on the surface of the water. The oil coated the unprotected steel reinforcement between high and low water and had to be removed by the use of petrol.

Granite.—All granite used on the work was obtained from Norway. It was cut and dressed to sizes at the quarries and was ready for use in the work on arrival at Rosyth. Fortunately, practically the whole quantity had been delivered when war broke out. The decision to use foreign granite was made on grounds of economy, the price being lower than that of British granite. The Norwegian granite proved to be of generally satisfactory quality, but in landing-steps some spalling of edges has been caused in use. For such situations a tougher granite would have been preferable.

CAISSONS.

With the exception of the caisson which divides dock No. 1 into two portions and the second caisson at the emergency opening, which are both of the floating type, all the caissons are of the sliding type, with decks which are lowered automatically as the caisson is drawn into its camber. The sliding caissons are operated by electric power generated in the dockyard, but in an emergency can be hauled by hand power. Details of the design of the caissons will be found in Figs. 16 and 17, Plate 3, and particulars of their operation are given in *Figs. 18*.

Four of the caissons were, as already stated, built in the main basin. The remainder were constructed lying on their sides on slipways at North Queensferry, and, after being launched in the sideway position and brought upright while afloat, they were towed to the dockyard.

BASIN SLUICES AND PENSTOCKS.

Six large sluices were placed at the south-east corner of the main basin for the regulation of the water-level in that basin. A caisson which has one face exposed to tidal water, as for example that at the emergency opening, can only be operated when the water-levels on the two sides of it coincide. By opening the basin sluices the time of coincidence of level to suit movements of ships through the entrance can be varied as desired, provided the depth of water in the basin is not reduced too much. Further, in a basin with only one entrance open, the rise or fall of the tide outside produces a current which is liable to embarrass the movements of large ships passing through that entrance; when the basin sluices are open this current is reduced.

The penstocks in culverts are operated electrically, but have alternative gear for hand working.

WATER-SUPPLY, SEWERAGE, ETC.

When the Admiralty purchased the site in 1903, the water-supply of the district was insufficient and the prospect of a large Naval establishment made the provision of additional supplies imperative. Eventually the Admiralty became partners with the Dunfermline District Committee of the County Council in a scheme to form a reservoir, etc., utilizing a catchment-area in the Ochil Hills, about 25 miles distant from Rosyth, and to bring in an entirely new supply. The Admiralty share of this water is delivered into a service-reservoir adjacent to the dockyard and at an elevation of 240 feet above it. Thence it is distributed throughout the establishment for all purposes, including supplies to the Fleet.

To provide for the prospective increase in the population of the district the Dunfermline Town Council constructed a sewer discharging into the sea at North Queensferry. The Admiralty contributed £10,000 towards the cost of this main sewer and laid a branch sewer to it about 1½ mile in length, for draining their own property. Owing to the relative levels of the dockyard and the ground immediately behind it, the sewage from the dockyard area has to be lifted about 30 feet vertically by ejectors and pumps before it can be discharged into the Admiralty branch sewer.

General.—To complete the equipment of the establishment for the service of the Fleet it was necessary to provide, in addition to what has already been described, an electric generating-station, workshops, storehouses, dockside sheds, a foundry, a torpedo-depot, roads, railways, residences for officers and workmen, etc. The main contract for the works made no provision for many of these subordinate but essential services, the original intention having been to place contracts for their execution at the latest date which would permit of their being ready for use when the main works were handed over. The war altered this arrangement, and most of these items were ordered as soon as the state of other works permitted their execution.

The total expenditure upon works in the new dockyard, including the subsidiary works, but exclusive of all machinery, was £6,920,000.

The Authors are indebted to the Lords Commissioners of the Admiralty and to their Civil Engineer-in-Chief, Mr. L. H. Savile, C.B., M. Inst. C.E., for permission to present this Paper.

The original design was prepared, and the main contract entered into, under the direction of Colonel (now Brigadier-General) Sir Edward Raban, K.C.B., K.B.E., R.E., then Director of Works. When Sir Edward Raban retired, Mr. (now Sir) Thomas Sims, C.B., M. Inst. C.E., succeeded to the position of Director of Works. Mr. F. W. Kite, C.B., was, under the Director of Works, responsible for all work at Rosyth.

Colonel S. H. Exham, C.B., C.B.E., R.E., was Superintending Engineer on the site until 1912, when he was succeeded by Mr. H. Cartwright Reid, C.B., M. Inst. C.E.

The Managing Director of Messrs. Easton Gibb & Son, Mr. (now Sir) Alexander Gibb, G.B.E., C.B., M. Inst. C.E., resided on the works and personally directed the work entrusted to that firm.

The caissons and basin sluices were provided, under contract, by Messrs. Sir William Arrol & Company. Messrs. Sir W. G. Armstrong, Whitworth & Company were the contractors for the penstocks and basin sluice-machinery. The contractors for the approach channel dredging were Messrs. Topham, Jones & Railton.

It will be understood that works of such magnitude, extending altogether over a period of about 14 years, necessarily required the services of a large number of engineers (too numerous to mention individually) who were employed either by the Admiralty or by the various contractors. Many of these gentlemen, though not in supreme control either at the Admiralty or on the site, were yet responsible for the design or execution of important, and often very difficult work.

Rosyth Dockyard is memorable as a great engineering work, but unique as an example of a modern naval port brought to virtual completion under the stress of war. It is a sufficient testimonial to the efficiency and enterprise of the contracting firms employed that the establishment was, in spite of great difficulties, far enough advanced to be of substantial service to the Fleet during the war.

The Paper is accompanied by twenty-nine sheets of drawings, from some of which Plates 1 to 3, and the Figures in the text, have been prepared.

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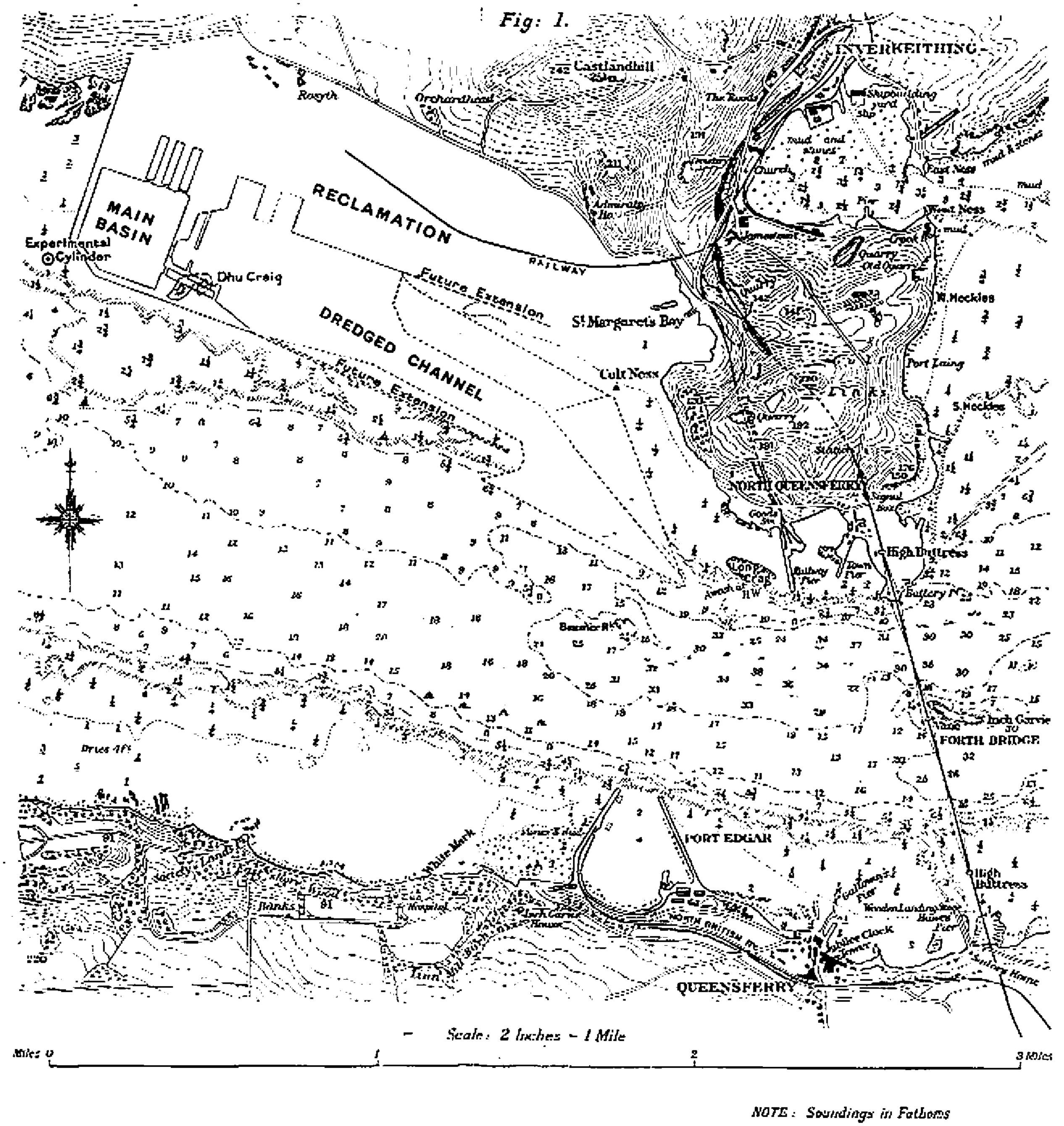
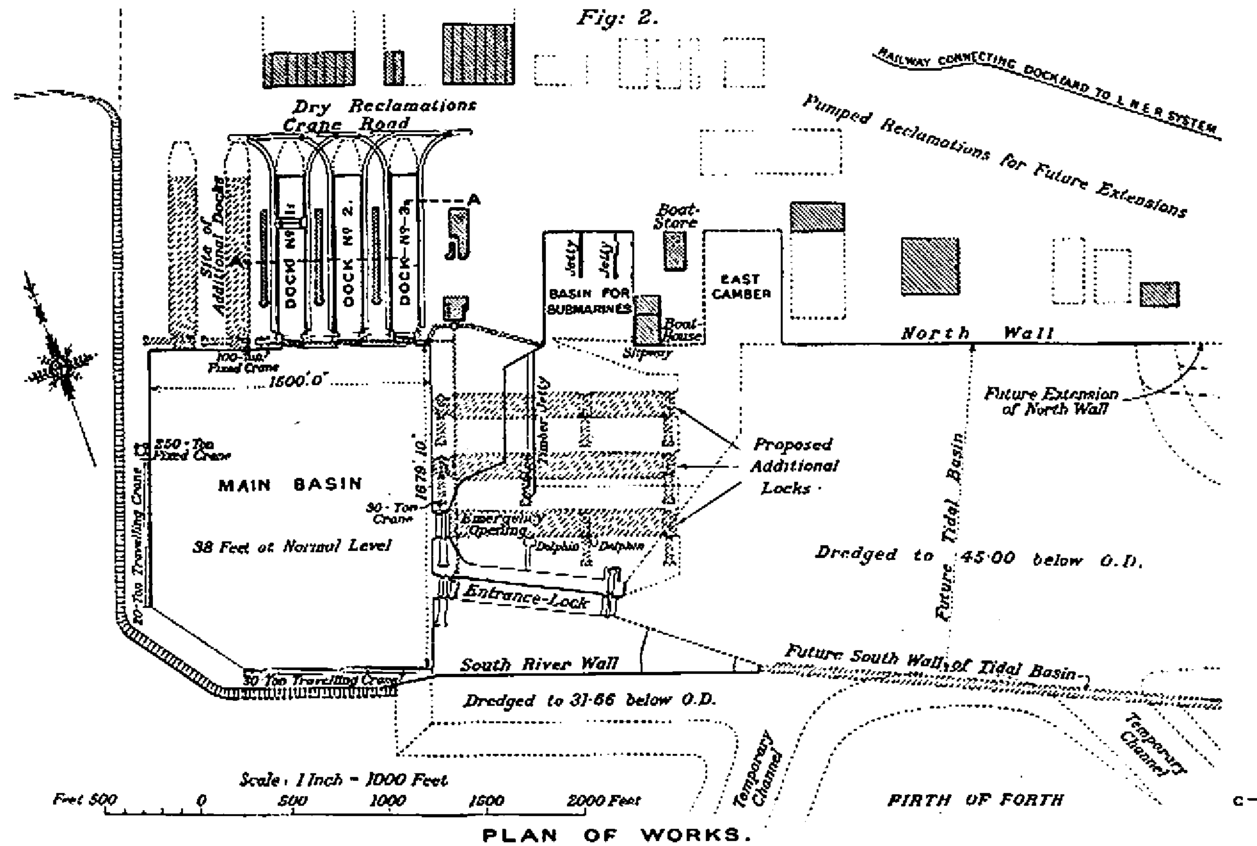
Fig. 1.



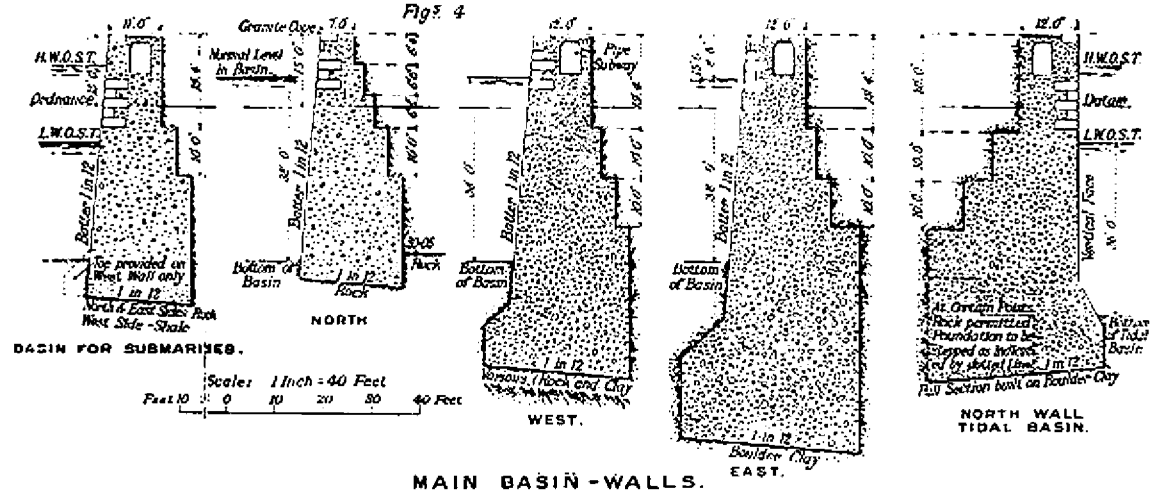
SITE PLAN.

Fig. 2.



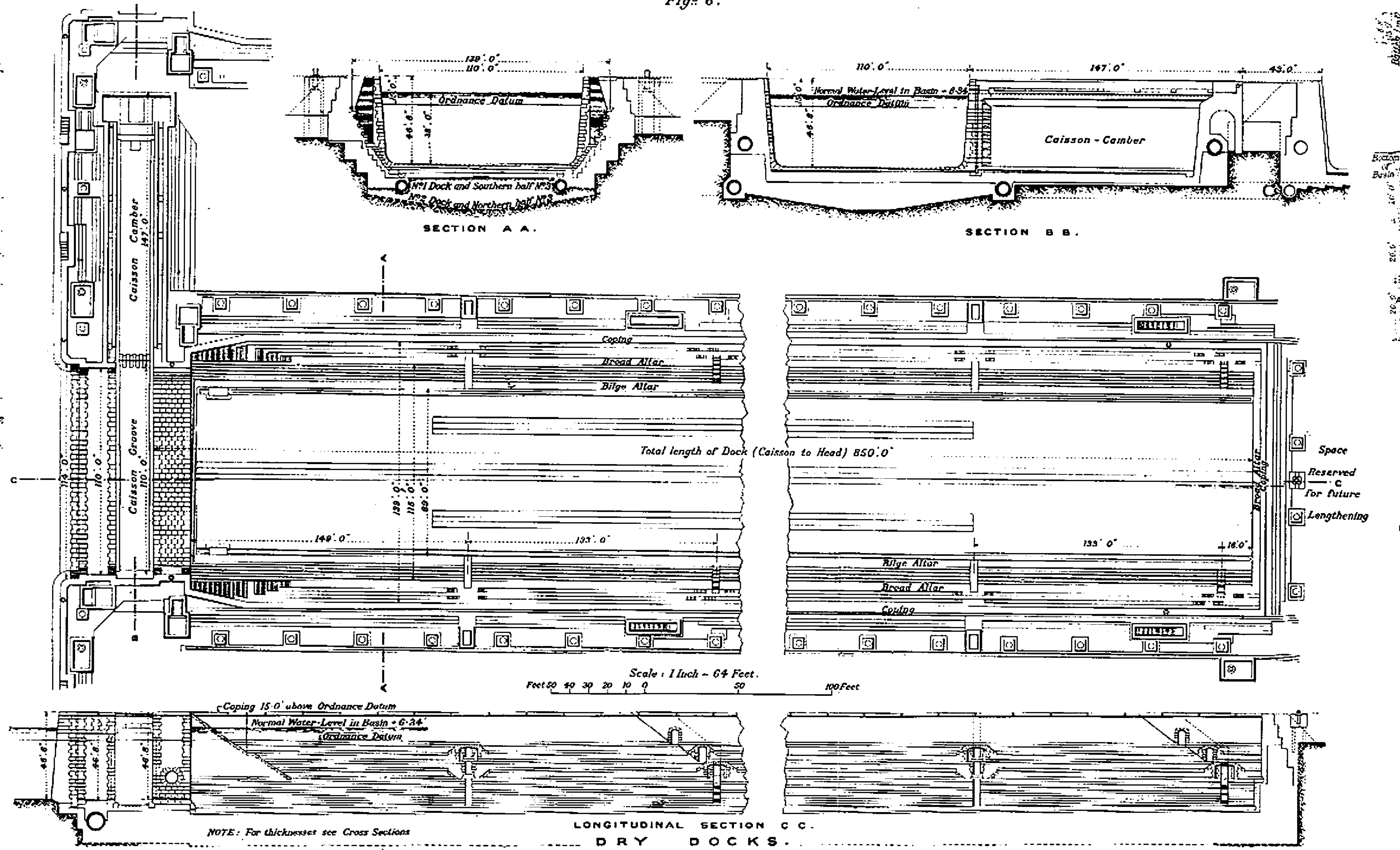
PLAN OF WORKS.

Fig. 4.



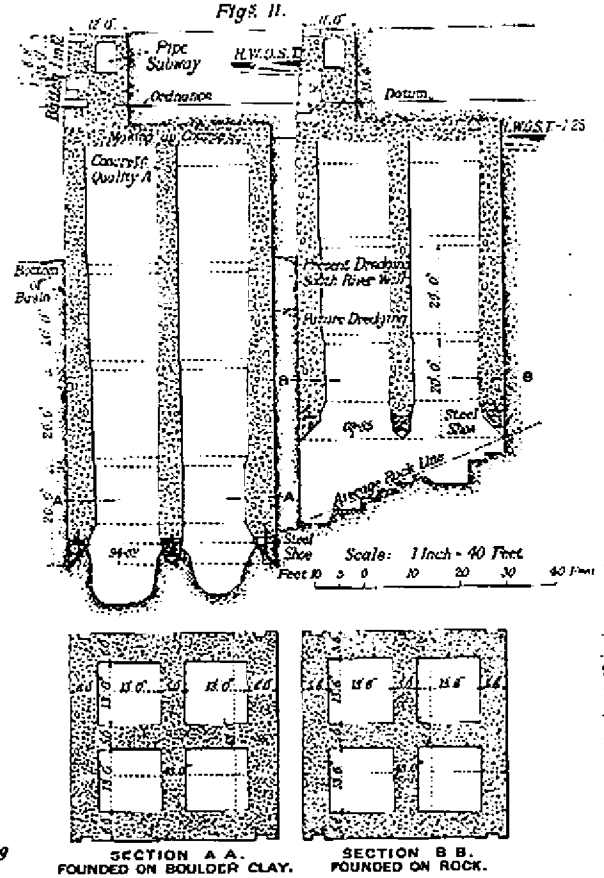
MAIN BASIN-WALLS.

Fig. 6.



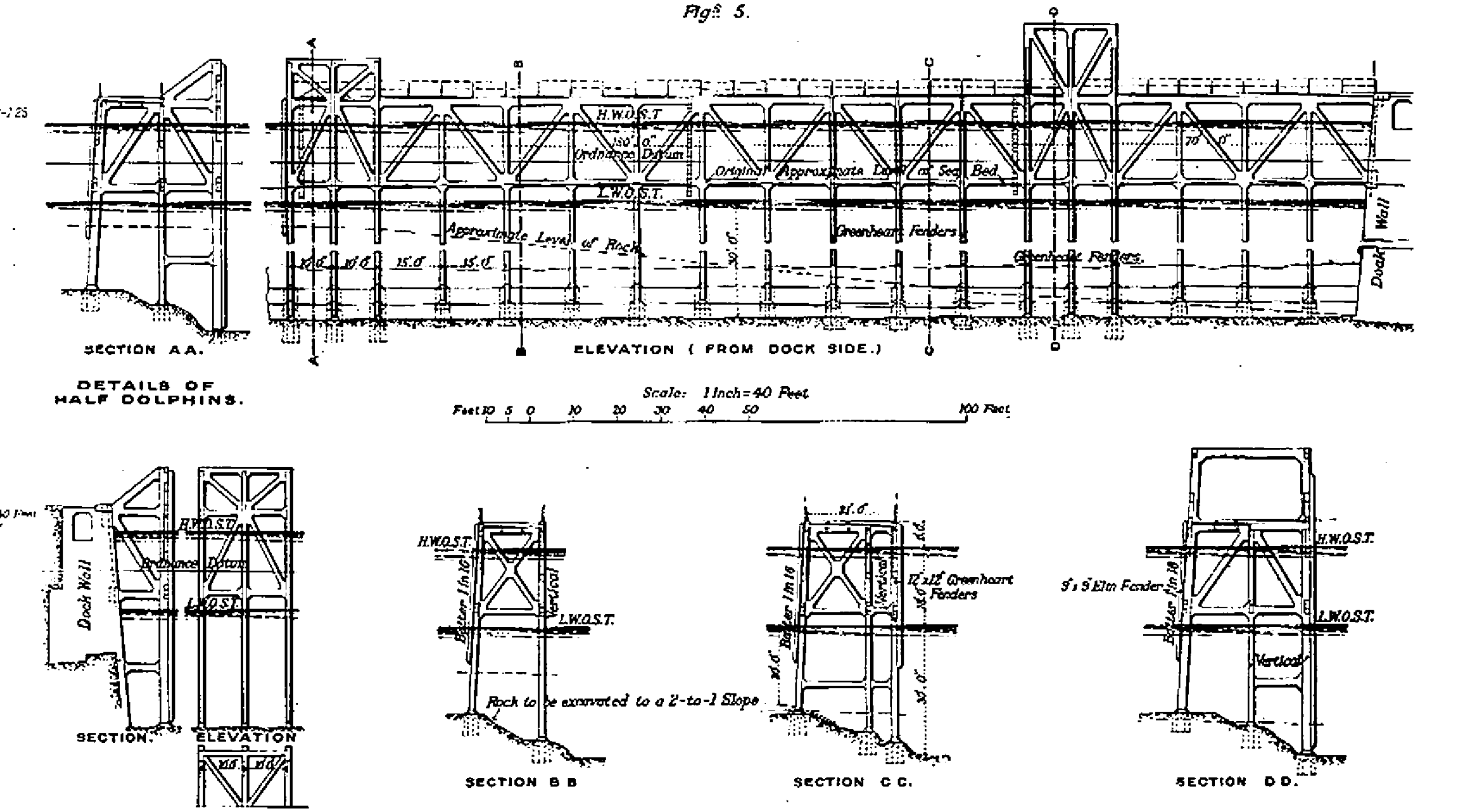
DRY DOCKS.

Fig. 11.



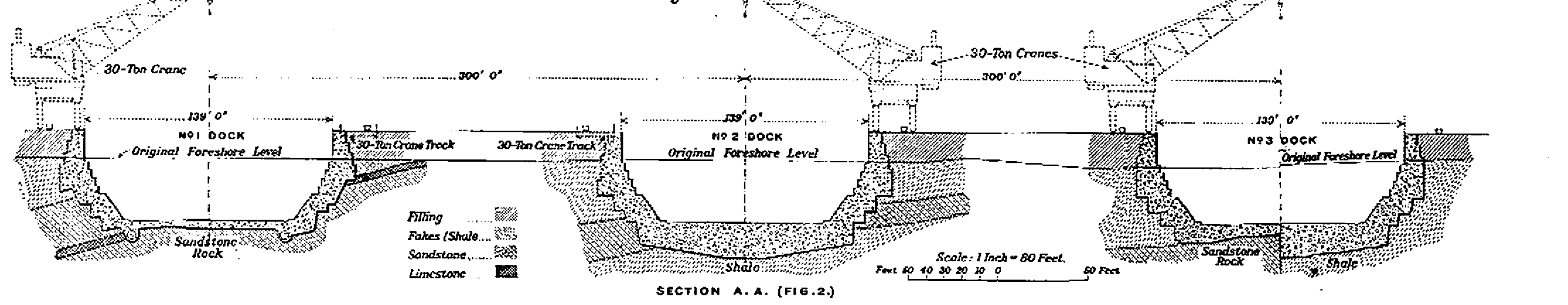
MONOLITHS.

Fig. 5.



JETTY IN BASIN FOR SUBMARINES.

Fig. 7.



SECTION A.A. (FIG. 2.)

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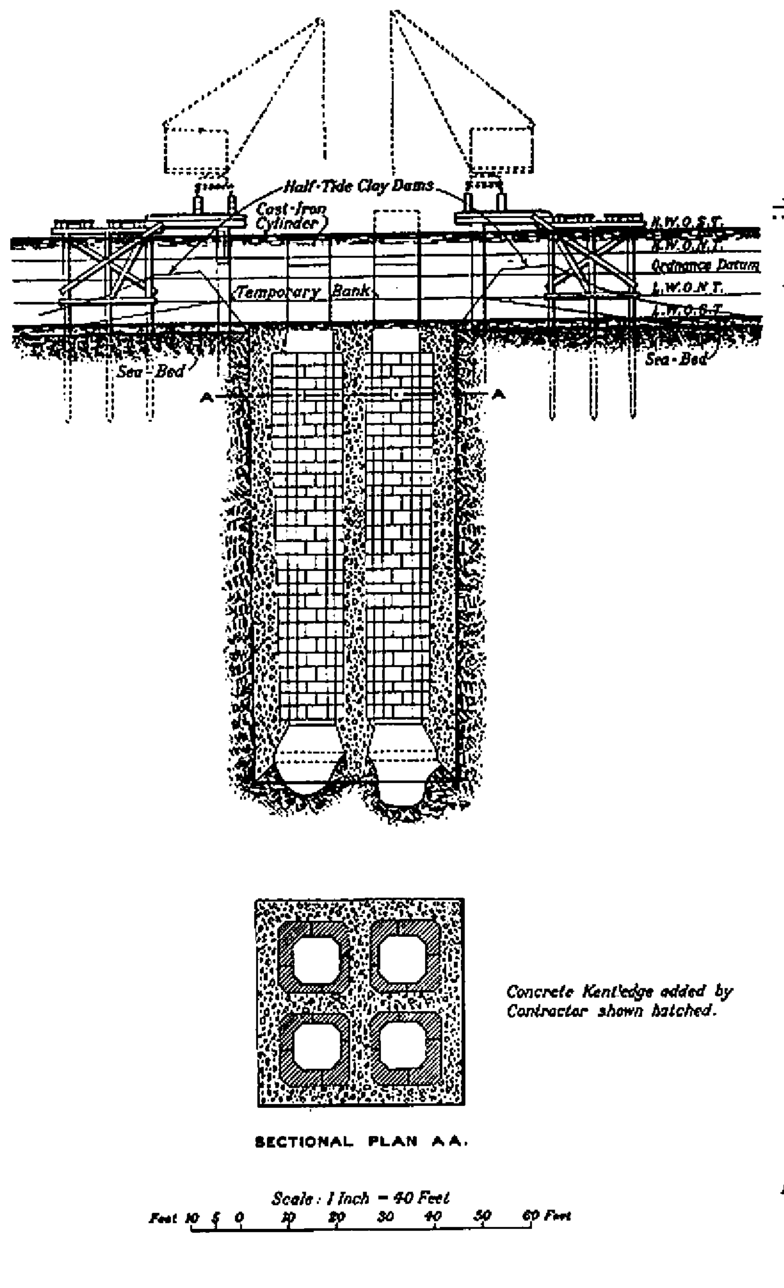
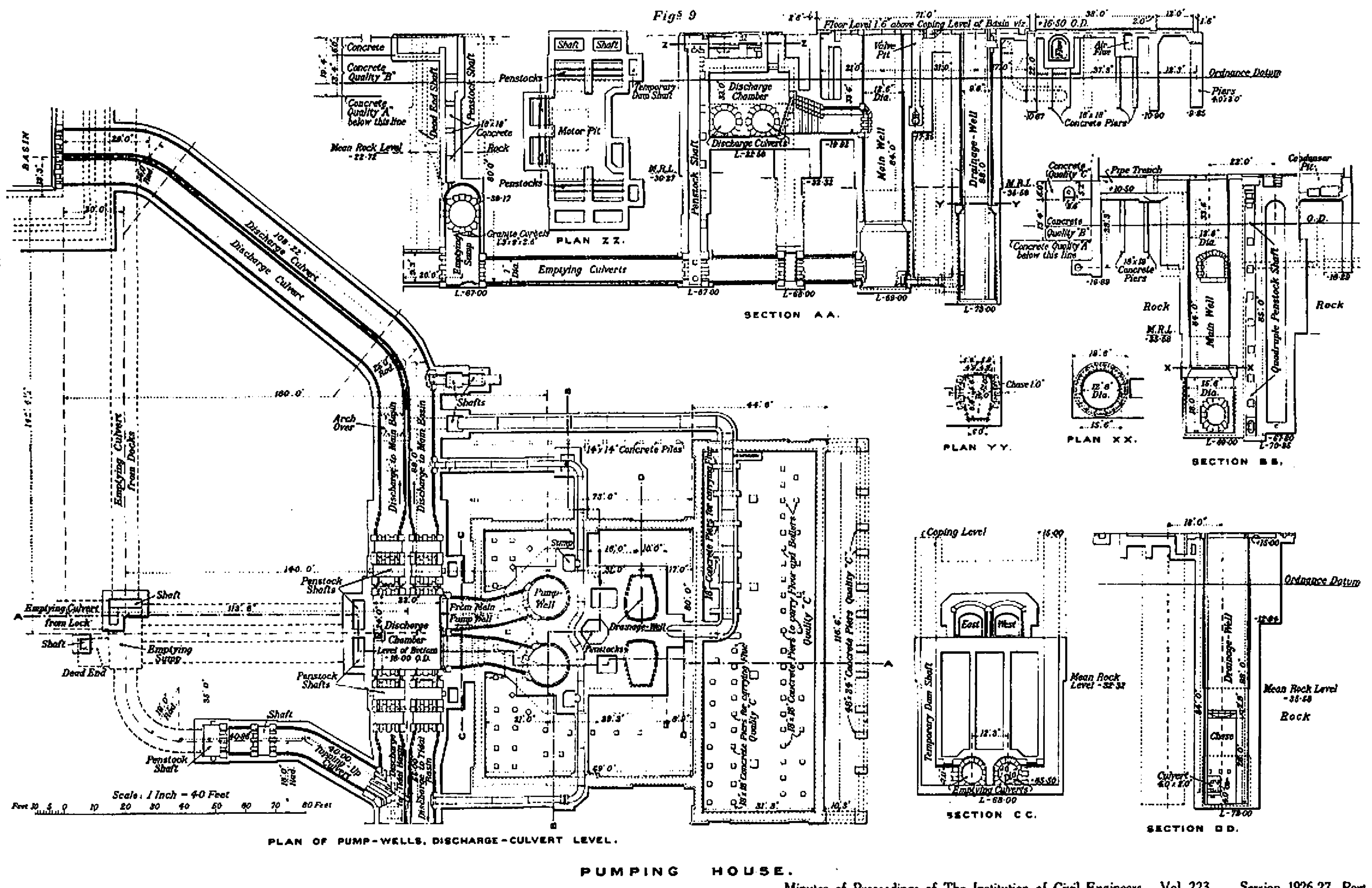
Fig. 12.



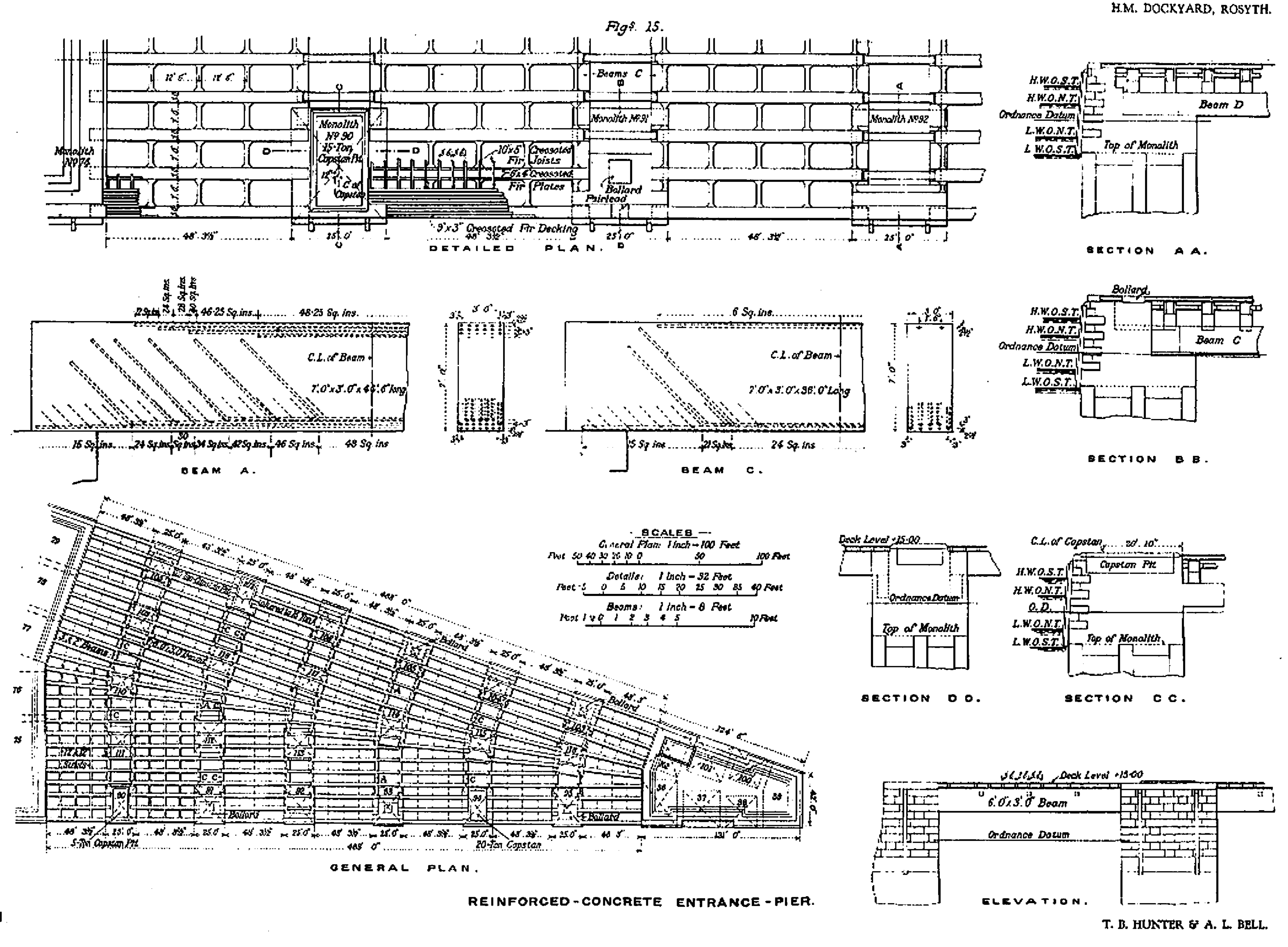
MONOLITH SUNK READY FOR FILLING.

Fig. 9.



PUMPING HOUSE.

Fig. 15.



REINFORCED-CONCRETE ENTRANCE-PIER.

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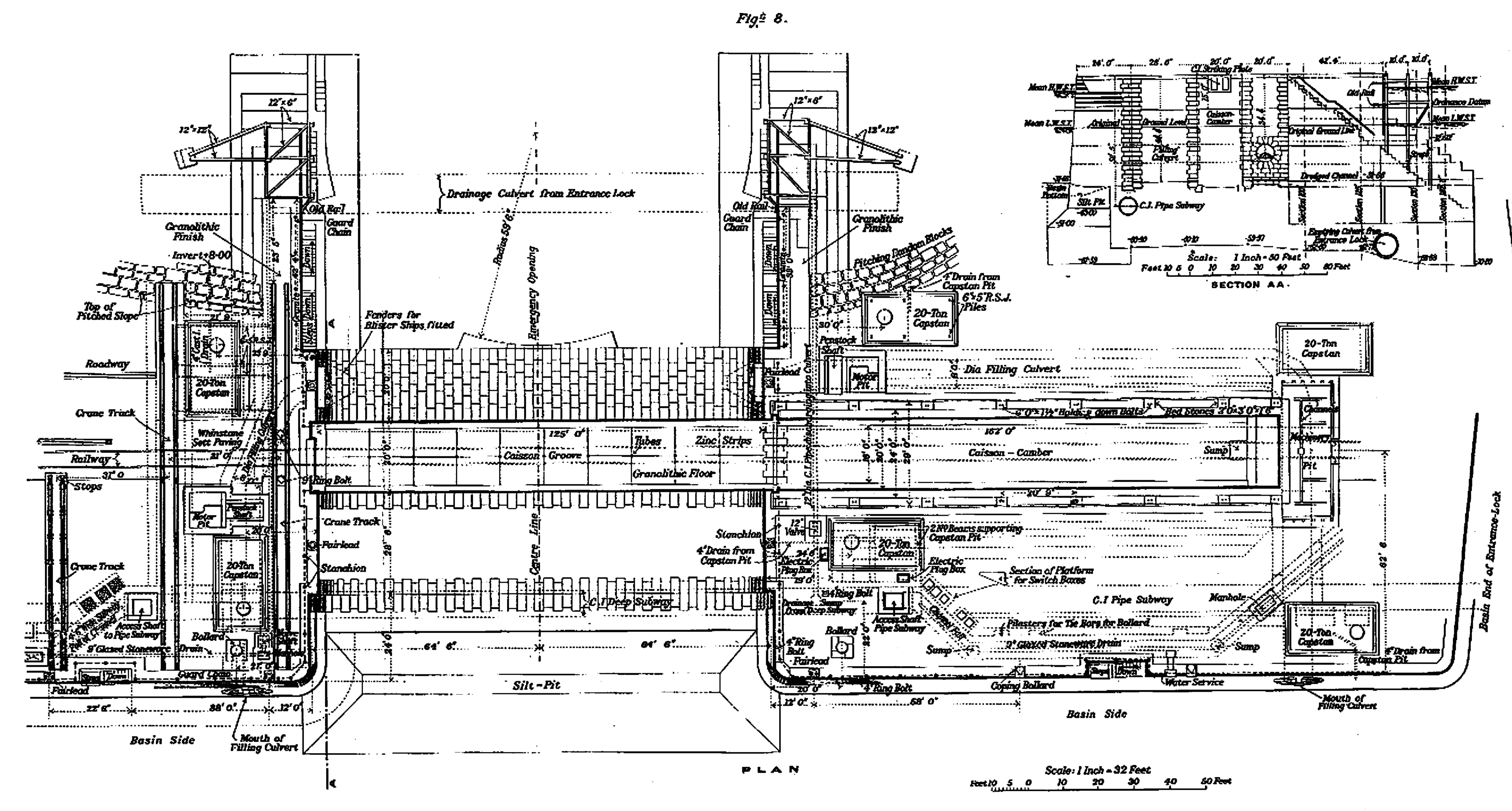
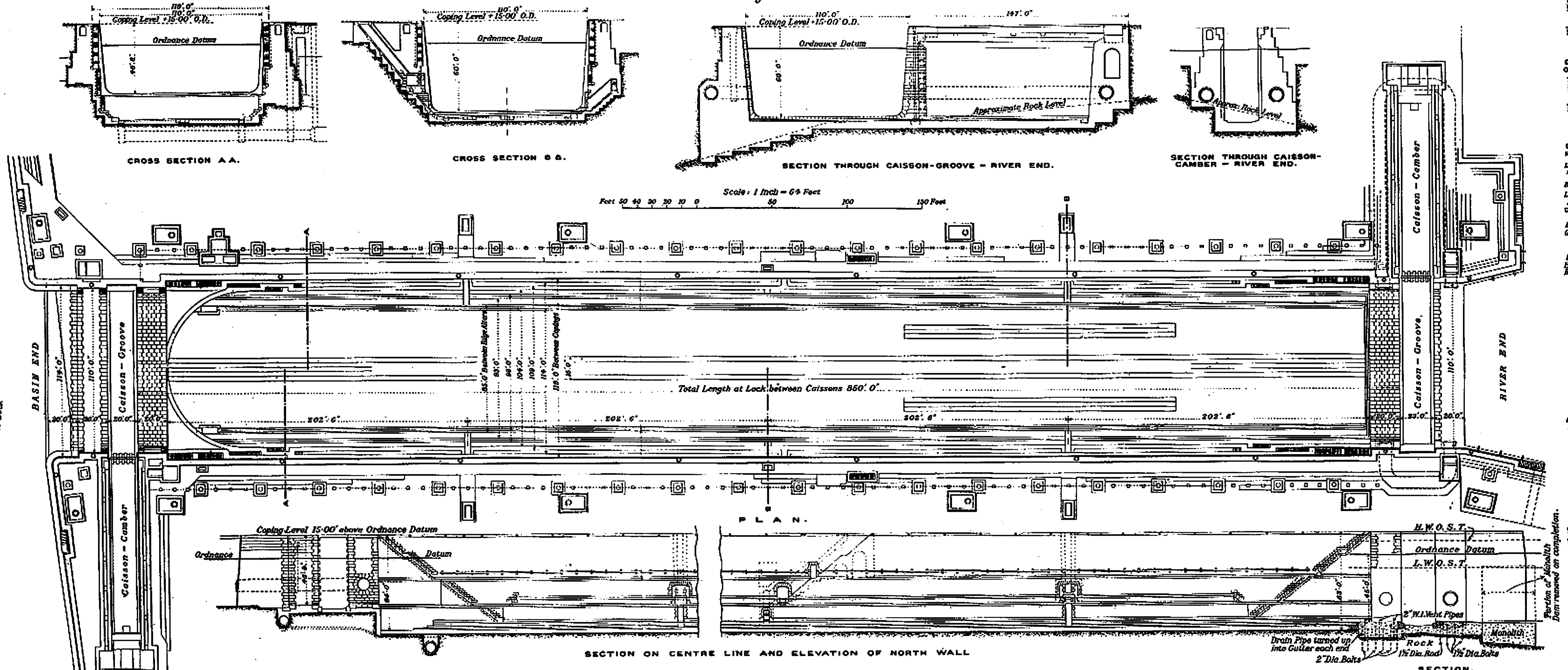
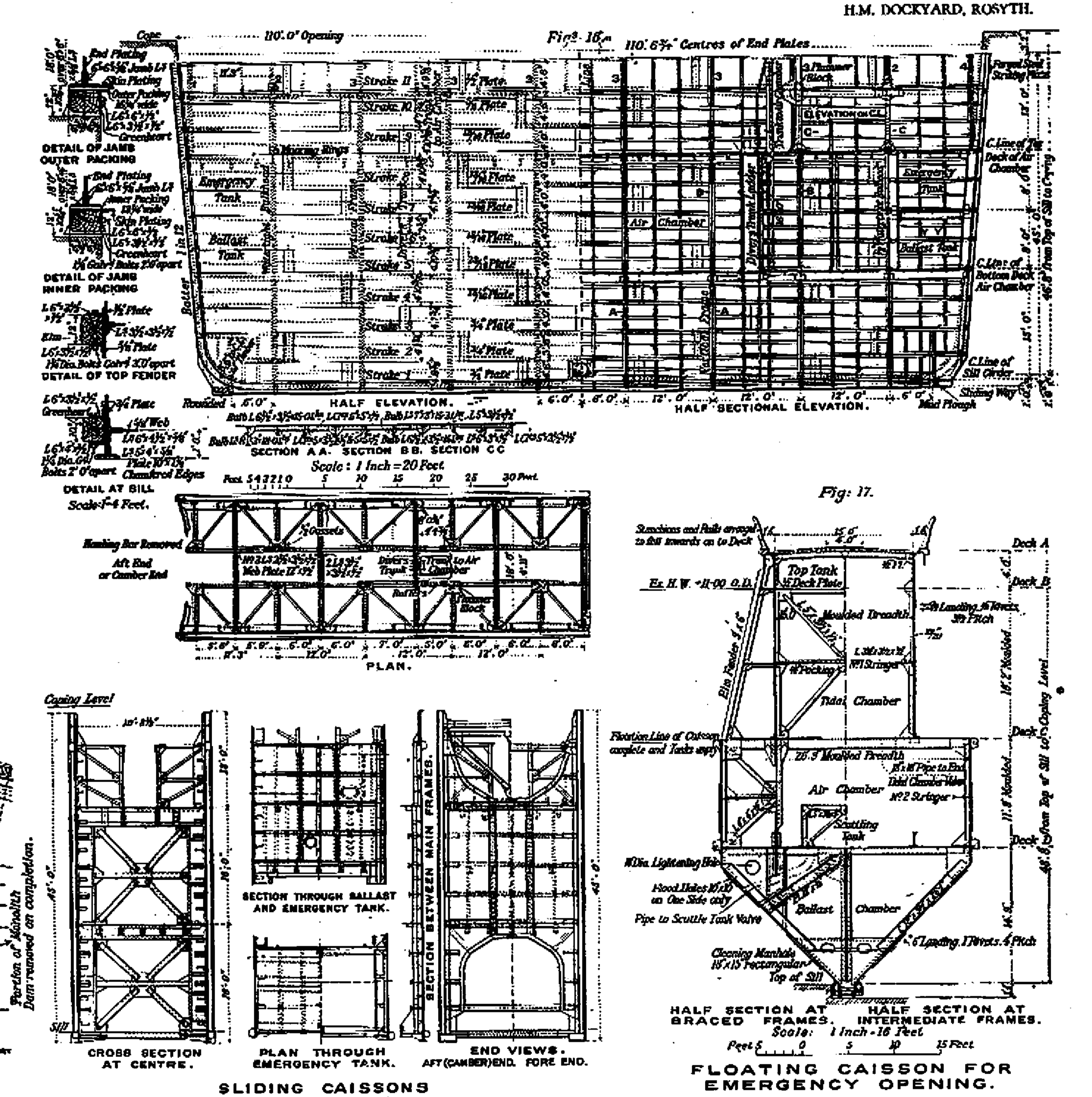


EMERGENCY OPENING.



ENTRANCE—LOCK.



SLIDING CAISSONS

FLOATING CAISSON FOR EMERGENCY OPENING.

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