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The Canadian Society of Civil Engineers.

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ADVANCE PROOF *(Subject to revision)*

DESCRIPTION OF THE NEW HARBOR, WET DOCK, AND GRAVING DOCK AT AVONMOUTH, BRISTOL, ENGLAND, SHOWING THE MOST MODERN PRINCIPLES OF CONSTRUCTION AND EQUIPMENT OF DOCKS AS ADOPTED IN GREAT BRITAIN.

By A. D. Swan, M. Can. Soc. C. E.

(To be read before the Ordinary Meeting, 16th December, 1909.)

A glance at the map of England is sufficient to show why hundreds of years ago Bristol became a great port. It largely owes its greatness to its geographical position and natural harbour.

It will be recalled that it was from Bristol that John Cabot, the explorer, sailed in 1497 and planted the flag of England on the coast of North America.

The first graving dock was constructed at Bristol in the year 1625, the dimensions being 100 feet long by 34 feet wide, and it is explained in the ancient records that the dock was made of this large size so as to take in the King's ships.

The construction of the first wharves there was begun on April 27th, 1240, and since then the facilities of the port have constantly improved until they have now culminated in the construction of the great new docks at Avonmouth.

Bristol is situated on the tidal River Avon, which originally flowed through the heart of the city, but in 1809 a new course for the river was formed and the old waterway converted into a floating harbour, which is now equipped with modern wharves, elevators, transit sheds, cranes, railways, etc. The Portishead and Avonmouth Docks are situated at the mouth of the river, about five miles below the city. There are five graving docks at Bristol, and a floating pontoon dock and one masonry graving dock at Avonmouth.

The new works at Avonmouth received Parliamentary sanction in 1901, and the first sod was cut by His Royal Highness the Prince of Wales on March 5th, 1902.

Principal Features.—The general plan is shown on Fig 1, from which it will be seen that a very large area of land was acquired in proximity to the new works to provide for future extensions and the erection of factories. Before the docks were completed, flour mills and other industrial works were already in course of construction, showing that, if proper facilities are provided, commercial enterprise at once follows.

The entrance channel or outer harbour is formed by two piers, 1,200 feet and 900 feet long, respectively, with a width between the pier heads of 700 feet, narrowing to 250 at the entrance lock.

The entrance lock is large enough to take any vessel yet built for the Navy or Mercantile Marine. Its dimensions are 875 feet by 100 feet, divided by an intermediate pair of gates into sections of 300 feet and 575 feet long, respectively. There is a depth of 46 feet of water on the sill at mean spring tides.

The main basin of the wet dock is 1,120 feet by 1,000 feet, with two branches, each 1,800 feet long by 300 feet wide, and another branch 700 feet by 250 feet wide, from which latter there is a connection called the junction cut, 550 feet by 85 feet between the new and old docks.

To the north of the entrance lock the new graving dock is situated, and this has also been designed with a view to modern naval requirments, altar courses having been constructed at a low level in order to suit the great beam and square midship section of modern armoured ships. It is 875 feet long by 100 feet wide at entrance, and the floor is divided by an intermediate caisson into sections of 547 feet and 328 feet, respectively, with 34 feet of water over the sill at ordinary spring tides. The pumping plant is capable of emptying the dock in two hours.

Along the foreshore of the River Severn a great rubble wall or reclamation embankment, 6,000 feet long, was constructed, behind which for a width of about 2,000 feet the reclaimed land has been laid out for railway terminals.

Similarly, alongside the River Avon, from the south pier to the old dock entrance, another rubble wall was constructed, having for 700 feet of its length a concrete monolith toe, 25 feet wide, sunk to a depth of about 40 feet below low water.

Construction General.—The course to be pursued in the construc-

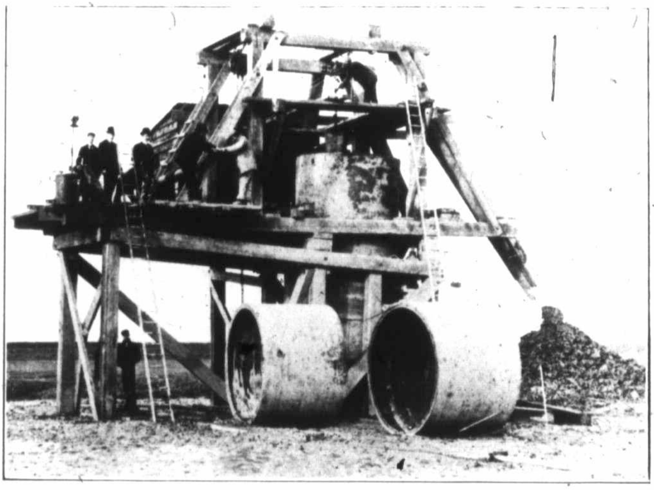

Fig. 2


Avonmouth Dock Works
Timber Breastwork N. Pier
17th January 1904

Fig. 11

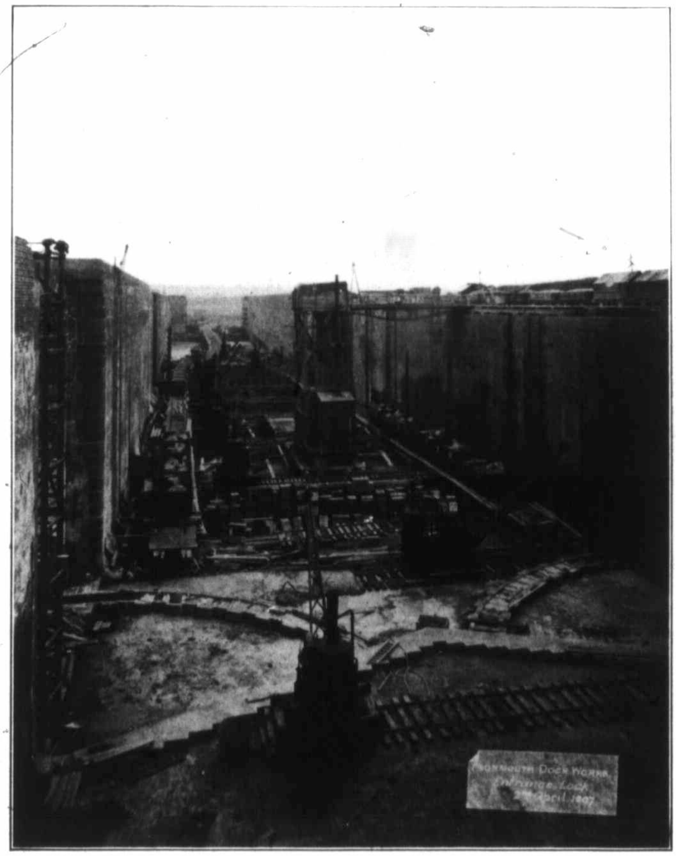

Fig. 28

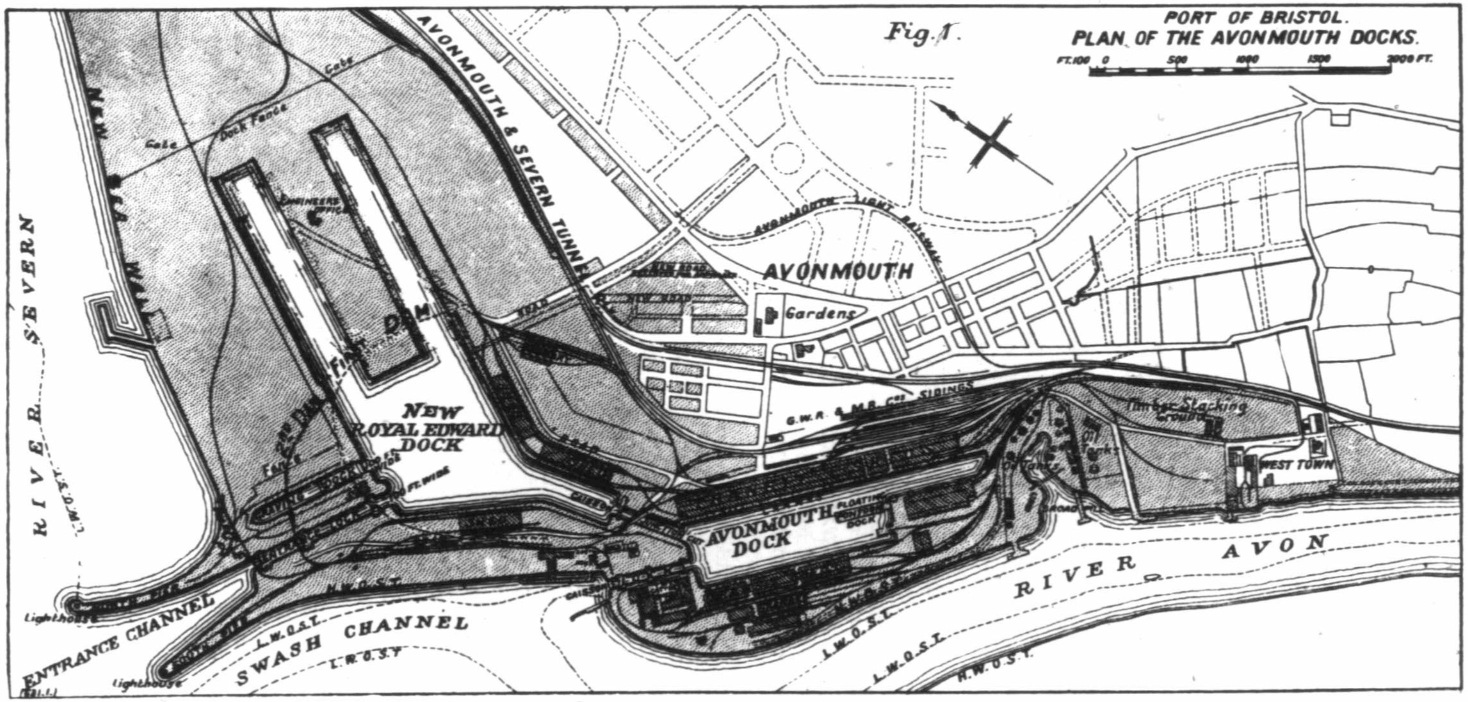

Fig. 1. General Plan of Works.

tion of a large dock or harbour scheme requires special care, great experience, and attention, not only that some parts of the permanent work may be commenced with the least possible delay, but that the subsequent portions may be taken in hand in regular order in accordance with a prearranged plan, without calling for extensive and costly alterations in the general arrangements and in the disposition of the temporary works and plant. The success of the undertaking, from an engineering and financial point of view, is largely dependent on these arrangements.

Sinking Trial Cylinders.—Previous to the exact site of the works being finally settled, two cast-iron trial cylinders, each 8 feet in diameter, were sunk, one about the middle of the dock and the other at the entrance channel, so as to make absolutely certain of the nature of the various strata to be passed through before a rock foundation could be reached, and, although this may seem to have been an expensive operation, the information so obtained paid for itself a hundred fold. Fig. 2 shows the cylinder in process of sinking.

Setting out Works, Progress Plans, and Measurements.—The main lines were set out with two 12-inch theodolites, both of which were specially made. The steel measuring bands employed were always checked before use, and the proper allowance for expansion and contraction due to change of temperature made, as in works of this description one-eighth of an inch is of importance. Great difficulty was experienced in getting the pegs marking the principal lines to remain stationary. At many places a cluster of four 12-inch piles, about 80 feet long, had to be driven, and, in two instances, even these moved. Parallel section lines, 100 feet apart, were set out on the ground from end to end of the works and correct measurements made along them for the purpose of making the monthly progress measurements, the results of which were shown in colour on the plans, and, in addition, detailed quantities were taken out.

Great Variation in Tide Level.—The main difficulties of construction to be overcome were:

(1) The enormous variation of hydraulic pressures, the range of the tide being 42 feet.

(2) The great depth to which the walls had to be carried before reaching a solid foundation

(3) The fact that the old dock walls were founded on sand in close proximity to the new works and at a much higher level.

Temporary Dams.—The first work undertaken was to close out the sea from the site of the works, and this was done by excavating the high ground at the east side and tipping an embankment of muck, as shown by the dotted line on the general plan. Some diffi-

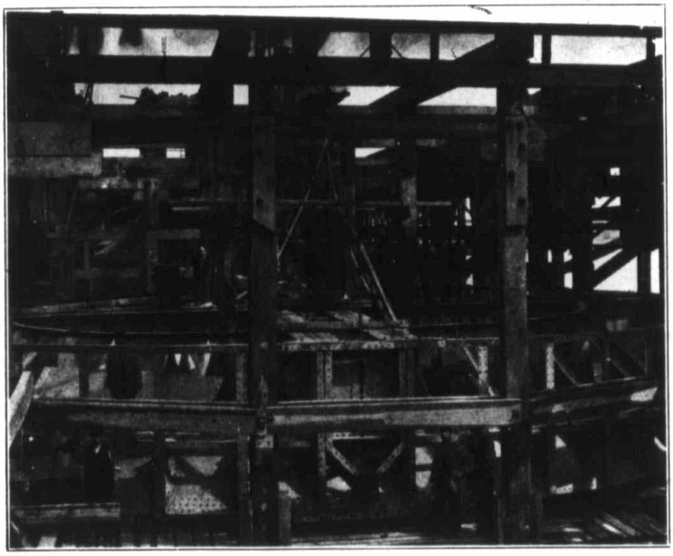

Fig. 24

Fig. 29

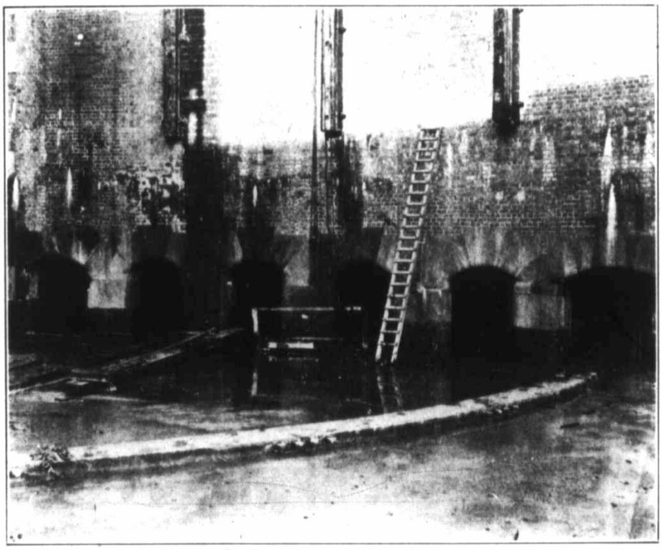

Fig. 30

Fig. 31

culty was experienced in this, owing to the mud being so soft that sometimes tipping from wagons would go on for days without making the slightest difference, and then the ground would probably spue up and disgorge the material 100 yards away. This trouble was overcome by placing in the embankment great quantities of brushwood made into bundles. Two 3 feet diameter C.I. pipes, with sluices, were laid through this embankment, to drain off the water, and at low tide the sluices were closed and the sea shut out.

A large drainage well, about 20 feet square, was then sunk about 80 feet to the rock, and any surface leakage water was led to it in open channels about 18 inches broad.

Later, a second embankment dam was constructed in a similar manner, farther out, as indicated on the plan, and last of all a concrete monolith dam was constructed across the extreme outer end of the lock, as described later.

Excavation.—The scheme of construction was to excavate the whole site of the dock in the dry, down to a level of + 14 O.C.B. = about 24 feet below cope, at which level the trenches for the dock walls were commenced, the "dumpling," about 20 feet deep, being left in until the walls were completed. Some 4,000,000 cubic yards had to be excavated, mostly silty mud, yet of sufficient consistency to bear the steam excavators on rails on a close-tied bed. The whole of the excavation was done by mechanical means, excepting the heavily timbered trenches of the walls, which were excavated by hand. The material excavated was hauled in wagons partly by two standing engines, but mostly by locomotives (of which there were 37 employed during the work), and tipped towards the north. The land thus reclaimed from the sea was afterwards used for terminal facilities.

Rock Breakers.—In this instance practically all the excavation was of soft material, but where excavation is in rock below water, instead of using explosives to break up the rock before dredging, what is known as a Lobnitz rock breaker, which does the work without explosives, is used. It consists of a heavy chisel of compressed steel, of which the weight is from 10 to 15 tons. This chisel is fitted with a hard-cutting point, and is allowed to fall by its own weight through 6 to 10 feet from a suitable height on to the clean surface of the rock. The cutter breaks its way into the surface rock, partly pulverising it and partly breaking it. The whole force of impact thus concentrated on a very small surface, and has been proved to crush or disintegrate the hardest rock. If the depth of rock to be broken up is more than 3 feet, it is best to break it in horizontal layers. A single cutter machine will break up 100 cubic yards per day in average rock at an expenditure of one ton of coal, wages of four men, and the cost of oil, stores, and repairs, which does not exceed the outlay for coal and wages.

It has also been proved beyond doubt that the rock broken up by this machine can be afterwards dredged at less cost than rock which has been blasted.

Wet Dock Walls.—The trenches for the walls of the main basin were excavated between 12 x 6 pitch pine sheet piling, with 12 x 12 inch main piles at 9 feet centres, with transverse struts, etc., as shown on the section. (Fig. 3.)

In excavating the silty mud, iron skips with hopper bottoms were filled by hand labour, raised by crane, tipped into wagons, and the material conveyed to the reclamation ground. The trenches were excavated to the rock at an average depth of about 54 feet.

The walls were then constructed of concrete, prepared by Taylor mixers, which travelled on rails along the entire length of the walls, as shown on cartoon drawings Nos. 4 and 5. These mixers discharged concrete through chutes directly into the trench in the proportion of 6 to 1 in the bottom and 8 to 1 on the top, with a facing of 4 to 1 up to a height of about 14 feet below cope level.

There is at this level a corbel course of masonry projecting 4½ inches from the lower part of the wall, which has a slight batter from the toe. The upper part of the wall is vertical, faced with brindle brick work and finished with a granite cope. This construction, of which a cross-section is shown in Fig. 4, prevents ships from rubbing against the concrete facing below the corbel.

At the back of the wall near the surface there has been constructed a culvert, 5 feet wide, with manhole openings at 100 yards intervals for the accommodation of hydraulic mains, fresh water pipes, gas and other mains, and electric cables, so that easy access might be had at any time to each or all of these.

This culvert is continued in a cast-iron pipe tunnel, 6 feet in diameter, down the walls and under the bottom of the junction cut between the old and new docks, and under the floor of the graving dock and entrance lock.

A change in the method of constructing the dock walls was necessary at the north side, where the old river channel had crossed the site of the works some 30 years ago, and where the material was exceptionally soft. It was deemed inexpedient to risk building any part of this north wall in open trench, and, for a length of 700 feet, concrete monoliths were sunk similar to those at the piers now to be described.

Entrance Piers, Monolithic Structure.—As the construction of a coffer dam to enclose the site of the entrance piers would have involved an enormous expense and considerable time, it was decided to construct the piers of concrete monoliths, as shown in Figs. 5 to 10 and cartoon drawing No. 6. These monoliths were mostly rectangular, 25 x 30 feet in plan, placed about 5 feet apart, and sunk

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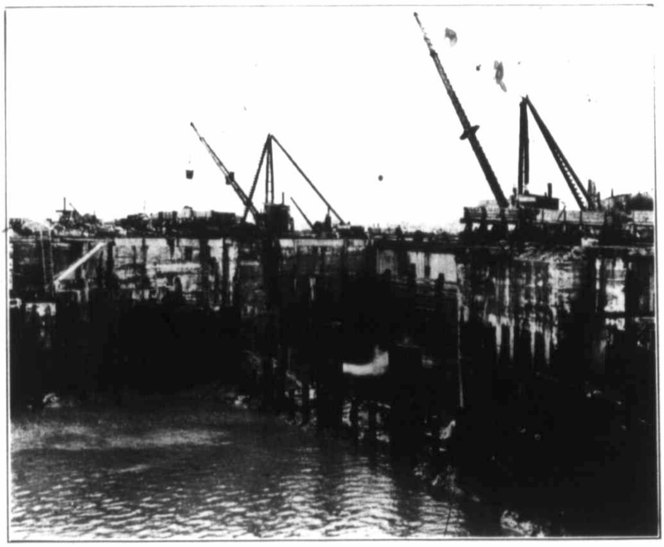

Fig. 32

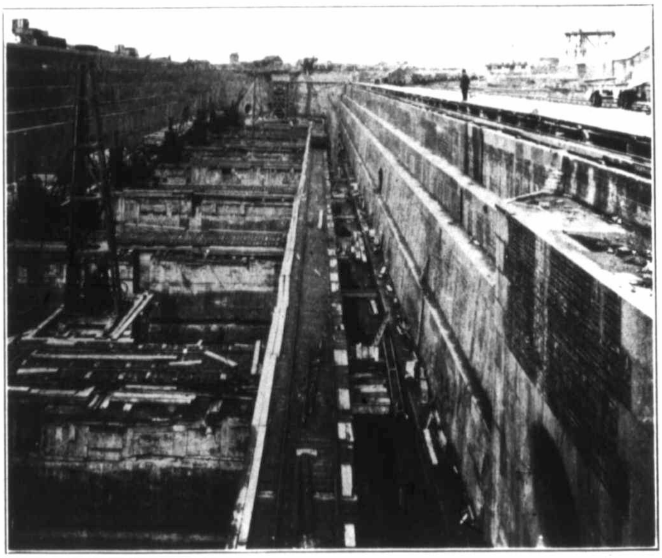

Fig. 39

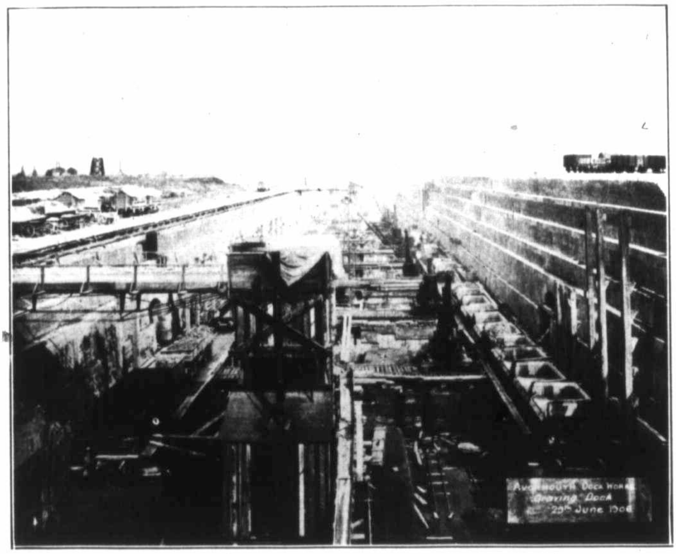

Fig. 40

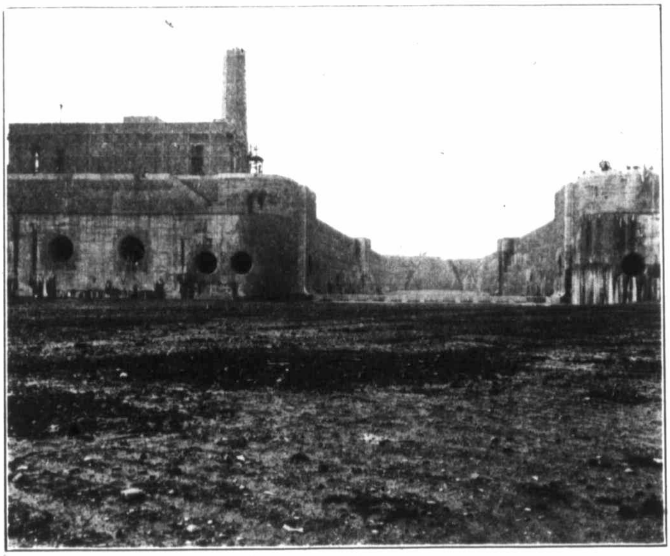

Fig. 41

from the surface of the ground to the rock, an average depth of about 80 feet below cope. Each monolith had four pockets or openings about 6 feet 6 inches x 8 feet 6 inches, and in starting the construction a steel, or, in some instances, a timber, shoe shod with steel was set level in its correct position on the ground, upon which the massed concrete was deposited in 3-feet layers inside wooden shutters.

As each succeeding layer of concrete was added, the increased weight caused the monolith to sink into the mud, which was forced up through the four pockets and removed by "grabbing."

Considerable care had to be exercised to see that the "grabbing" in any one pocket was not carried too far in advance of the others, otherwise the monolith would get out of level and give much trouble.

In many instances the water was pumped from the interior, but in bad ground this was sometimes inexpedient. When the frictional resistance on the surface of the monolith prevented it being sunk by its own weight, "kentledge" was added as required. In some instances as much as 1,300 tons of "kentledge" was used on one monolith, giving a frictional resistance per square foot of about 2,000 lbs.

The question of pumping out the water was a very delicate one indeed, and great judgment had to be exercised, for, if too much should be removed, the muck surrounding the monolith would, in all probability, burst in under the shoe and fill up the monolith. This would mean the re-excavation of the pocket, the subsidence of the adjacent ground carrying the timber staging along with it and the probable upsetting of the steam crane thereon.

In some instances a water jet is used to disintegrate the material at the cutting edge of the monolith, and so assist the process of sinking. This is most easily applied when the material consists of fine sand, but the process sometimes proves very inconvenient, and tends to extract more material than desired, thereby disturbing the surrounding ground.

When the monolith had been finally sunk on a hard foundation, the insides of the pockets were cleaned out either in the dry or by divers. The bottom was then sealed with concrete of good quality, and the remainder filled with concrete of less rich quality. The intervening spaces of about 5 feet between adjacent monoliths were excavated by hand and filled with concrete, which bonded into grooves formed on the outer adjoining walls of the monolith. The piers as finished are shown in Fig. 11.

The writer had some experience on other works of attempting to sink a monolith 80 feet long by 18 feet wide with three circular pockets, but it was so difficult to control that the design was not repeated.

Many different designs of concrete monolith walls have now been carried out, such as single cylinders, double and triune cylinders, as shown in cartoon drawing No. 7.

For the round heads of the two piers circular monoliths were adopted. These monoliths were 55 feet 6½ inches in diameter, and they are probably the largest of the kind ever sunk. The success of the operation depended on the design of the steel shoe, a drawing of which is shown in Figs. 12 to 23.

The process of sinking was exactly similar to the other monoliths, and proved highly successful. A photograph of this shoe is shown in Fig. 24.

Entrance Lock.—The entrance lock was constructed, as shown in Figs. 25 to 27, in three parts, each at different levels. The trenches for the walls beginning at the inner end, started about 18 feet below the original ground surface, and at the outer end, near the sea, the trenches were started at the surface of the ground and carried to a depth of about 65 feet.

The lock was constructed of concrete, faced with brindle brick work in panels, which was always built 3 feet in advance of the level of the concrete.

The side walls were constructed first within timber trenches in a manner similar to the dock walls, already described, skewbacks being formed at the toe to ensure a proper bond with the floor or invert. At the extreme outer end concrete monoliths similar to the pier structures were sunk from the surface of the ground right across the entrance to act as a coffer dam, and on the completion of the works the upper part down to invert level was blasted and removed, the lower part being left in to form an apron. The construction of this monolithic dam, with huge discharge culverts passing through it, was one of the most interesting and difficult parts of the work.

Along the centre of the north wall of the lock, a suction culvert, 7 feet in diameter, was constructed of brick work for pumping up the dock from the outer end when necessary, and for other purposes. After the side walls were completed, the "dumpling" between them was excavated by steam shovels to invert level. Below this, at intervals of 40 feet, trenches 15 feet wide were excavated from wall to wall for putting in the floor of the lock. The material between the trenches prevented any movement of the side walls from pressure behind. After the concrete in the 15 feet wide trenches had set, the remaining 40 feet spaces were similarly excavated. Figs. 28 to 31 show this work in progress.

Caisson stops were built beyond the end gates, so that the lock might be closed at any time by the floating caisson provided for the graving dock, as it is the same width as the graving dock.

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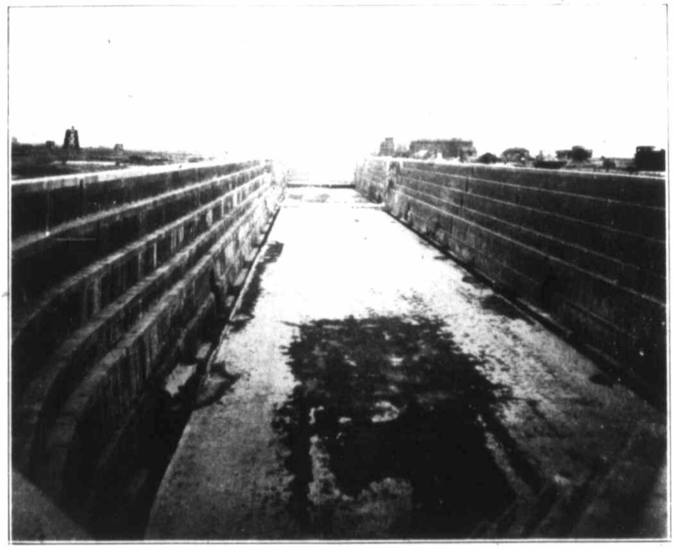


Fig. 42

Fig. 43

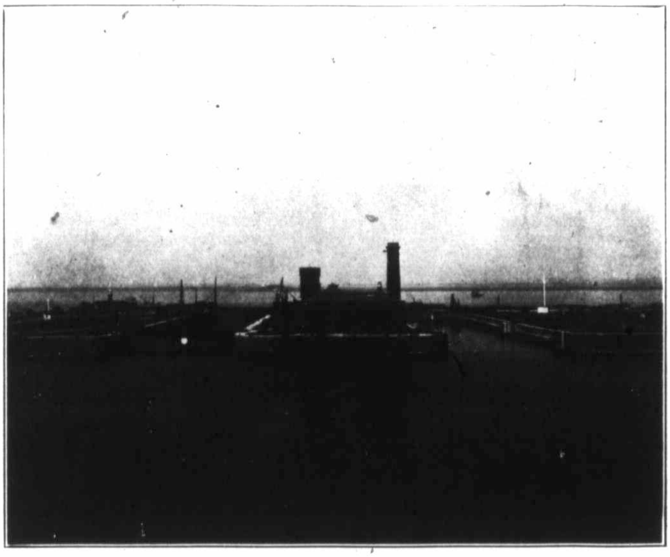


Fig. 44

Fig. 45

In fact, the caisson was placed against the outer stops during construction to enable the outer monolithic dam, as shown in Figs. 32 to 34, to be removed simultaneously with the building of the lock gates in position.

By this means the work was completed at a much earlier date than would otherwise have been the case.

Graving Dock.—The graving dock has a length of 850 feet on the keel blocks, by 100 feet wide at the entrance and floor. Figs 35 to 38 show plan and sections of the dock, from which it will be seen it is constructed of concrete with brick facing, and masonry altars, with granite for the dock coping.

In constructing the walls and invert, the procedure corresponded exactly with that adopted in the case of the entrance lock.

The graving dock is founded on a mixture of sand and gravel, the trenches in this instance not being carried down to the rock, as in the case of the wet dock walls. It was discovered, however, during construction, that there was a slight subterranean current of water from north to south underneath a vast area of this sand and gravel strata. In order to cut this off, and thus prevent any tendency to wash out the sand below the foundation, a line of cast-iron interlocking sheet piling was driven down to the rock longitudinally from end to end of the dock, making a continuous water-tight wall from the entrance to the north pier. Figs. 39 to 44 show this work.

A very elaborate system of large culverts was devised, so that the sluices in them, which are all constructed of green-heart timber, and operated by hydraulic machinery, might be made to serve many purposes.

The following list shows the duties which can be fulfilled by the system of sluices in connection with the graving dock and entrance lock:

(1) To pump both compartments or the whole of the graving dock and discharge into the wet dock.

(2) To pump the inner compartment only of the graving dock and discharge into the wet dock.

(3) To pump the outer compartment only and discharge into the wet dock.

(4) To run off the water by gravitation to the sea without pumping from the whole of the graving dock, or to fill the graving dock from the sea.

(5) To run off the water by gravitation to the sea from the inner compartment only, or to fill the dock from the sea.

(6) To fill the graving dock from the wet dock.

(7) To pump from the sea to raise the wet dock level.

(8) To pump from a high-level intake of the lock to the wet dock, to return the locking water to the dock.

(9) To fill the lock from the wet dock.

(10) To run off the water from the lock to the sea.

The Junction Cut Between the New and Old Docks.—A more than usually interesting part of the work was the construction of the junction cut between the old and the new docks. (See Fig. 45.) Great care had to be taken to avoid any risk of water from the old dock breaking through to the new works, as the old dock walls had been founded at a much higher level than the base of the new walls.

In order to isolate the new basin from the old, a section of the wall nearest the new dock was first carried down to the rock on the trench system and completely concreted. The sliding caisson chamber was then built immediately at the back thereof, and the caisson constructed in place before any further excavation was made adjacent to the wall of the old dock.

The caisson thus became an effective barrier to the flooding of the main dock in the event of the old wall collapsing, but this fortunately did not happen.

Between the caisson chamber and the old dock walls the monolithic system of construction was again chosen as a precautionary measure, in preference to open trench work. The work was conducted silmilarly to the pier construction, but special provision was made in the design of the shoes for the monoliths near the old walls, so that air locks could be used if ultimately found desirable. Although as much as from 1,200 to 1,300 tons of artificial weight had to be used to sink these monoliths, no resort to the pneumatic system was necessary.

On the completion of the side walls, the old dock wall at the end was cut through, blasted with tonite, and removed. Divers, diving bells, and dredgers were used for this portion of the work.

There is a swing bridge over the junction cut, which was completed at an early stage, as passenger and railway goods traffic had to be maintained over this part during the whole progress of the works. The bridge has a double line of rails, with footpath on each side, and is of the parallel lattice girder type and operated by hydraulic machinery.

Dredging of Entrance Channel.—The dredging of the entrance channel, comprising some 600,000 cubic yards, was sublet to a firm of Dutch contractors, who used a centre ladder dredger. The material dredged was delivered into hopper scows and towed out to sea a distance of some 4 miles. The whole of the crew lived on the barges, and worked regularly and cheerfully 16 hours every day, so that the contract was most expeditiously carried out. There is a considerable formation of silt at Bristol during every tide, and the culverts of the entrance lock are so designed as to scour out the channel at low water.

Fig. 47

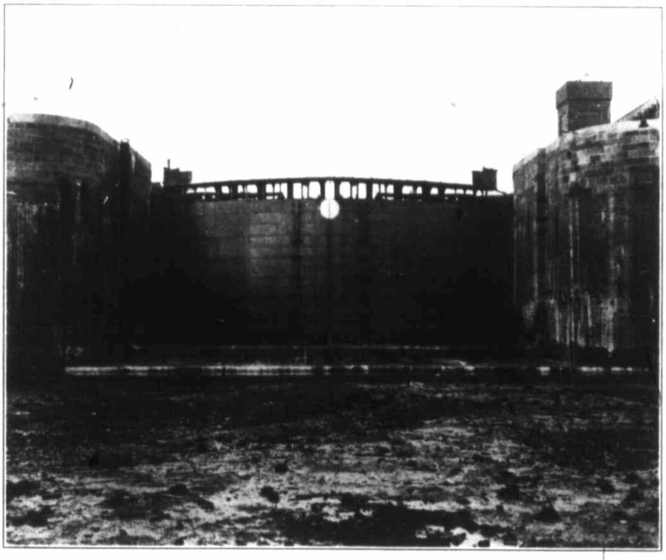


Fig. 48

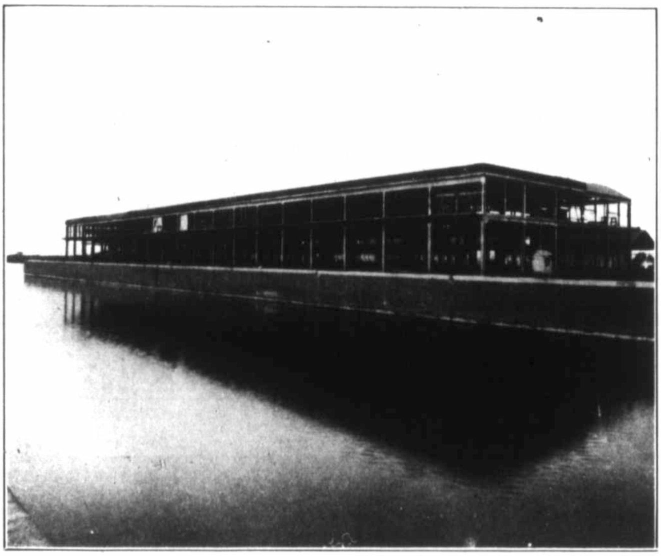


Fig. 53

Lighthouses.—At the seaward end of each of the new piers there is a lighthouse constructed of granite masonry, as shown in Fig. 46.

At the north pierhead the lighthouse shows a white flashing light every 10 seconds, and a subsidiary fixed red light. The lighthouse at the end of the south pier shows a green light, occulting every 30 seconds, and here there is also a fogbell. All the stones for these lighthouses, as, indeed, for the whole of the granite work used in the dock, were hewn and dressed exactly to the finished dimensions at the quarries in Norway from drawings prepared by the engineers, and the greatest credit is due to the Norwegian workmen for the accuracy displayed in working to those most intricate drawings.

Railway Terminals.—As previously mentioned, a great area of land (over 200 acres) has been reserved for railway terminal and commercial facilities in close proximity to the dock, and meanwhile 20 to 30 miles of railway sidings and shunting yards have been laid down. This part of the work required much study, so as to effectually serve all the different parts of the docks, and give rapid connection to the various railway companies' main lines to London and other centres.

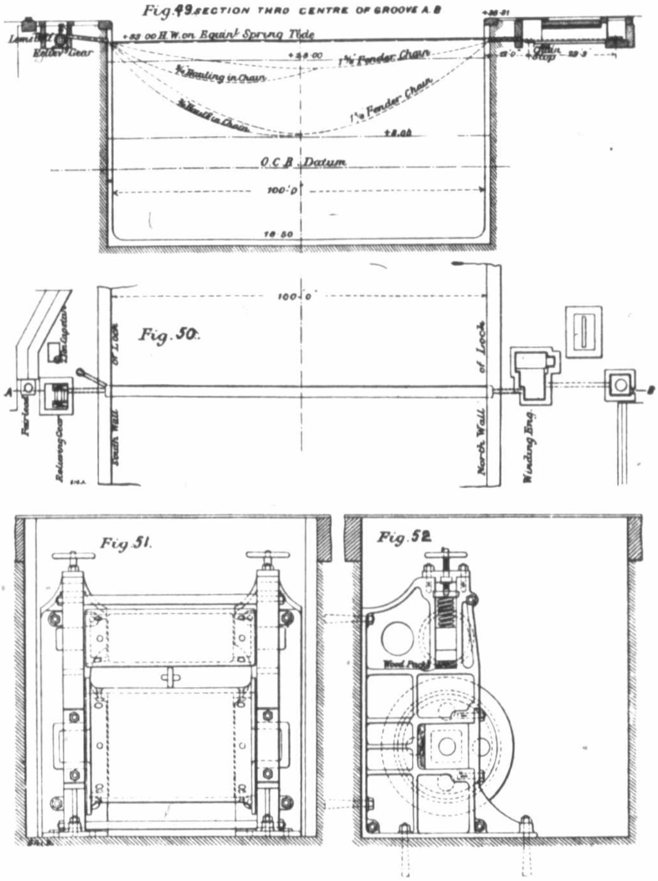
Lock Gates.—The entrance lock is closed by gates of great height, the adjacent walls being 54 feet 4 inches from cope to outer sill level. So far as the author is aware, they are the largest and heaviest gates ever constructed, each half weighing about 250 tons. Three pairs of gates are provided, dividing the lock into an outer section of 300 feet, and an inner of 575 feet between heel posts. Figs. 47 to 48 show the gates under construction and when completed.

The gates are constructed of steel, with iron plates and rivets outside. The heel posts, mitres, and sills are of green-heart, and on the back of the gates the iron skin is protected by cresoted memel fenders. The gates are opened and closed by direct acting hydraulic rams, working through a built-up cross head and connecting beam to the gates.

Boom-Relieving Chain Protection for Gates and Lock.—Across the lock, near the gates, there are fender relieving chains to protect each pair of gates when closed from collision with an approaching ship, as shown in Figs. 49 to 52.

This protection chain consists of 1⅝-inch stud link fender chain, and is designed to take up the thrust of the ship gradually. To do this it has to oppose a steadily increasing resistance to the moving vessel.

When the gates are opened the chain is lowered to the bottom of the lock. Below the surface of the quay, in cast-iron boxes, there is fitted on one side an ordinary hydraulic winding engine, from the drum of which a light chain, travelling over a sheath, is attached to one end of the boom chain and passed through a steel chain stopper, the upper jaw of which is raised or lowered by a lever in order to



Chain Protection for Lock-Gates.

allow or prevent the chain paying out. In the latter case the chain stretches right across the lock with a slight sag. The chain is carried through a cast-iron hawse pipe to the relieving gear. This

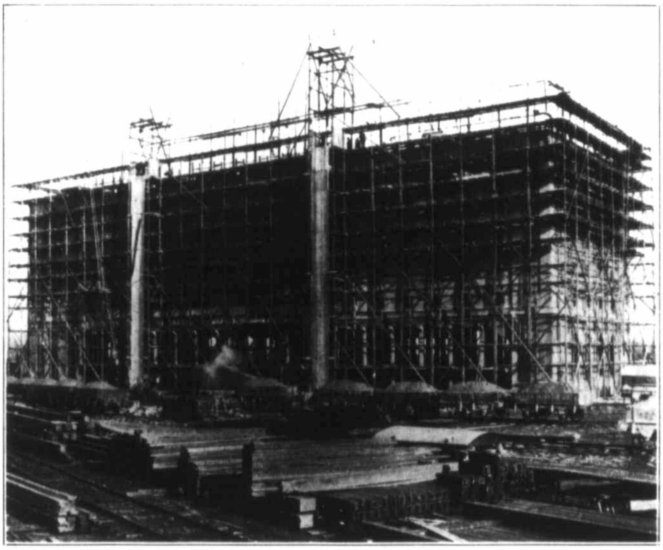


Fig. 60

Fig. 61

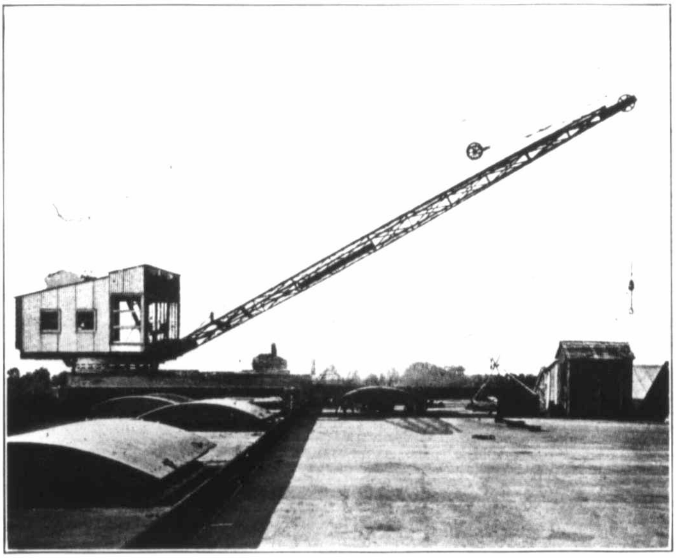


Fig. 62

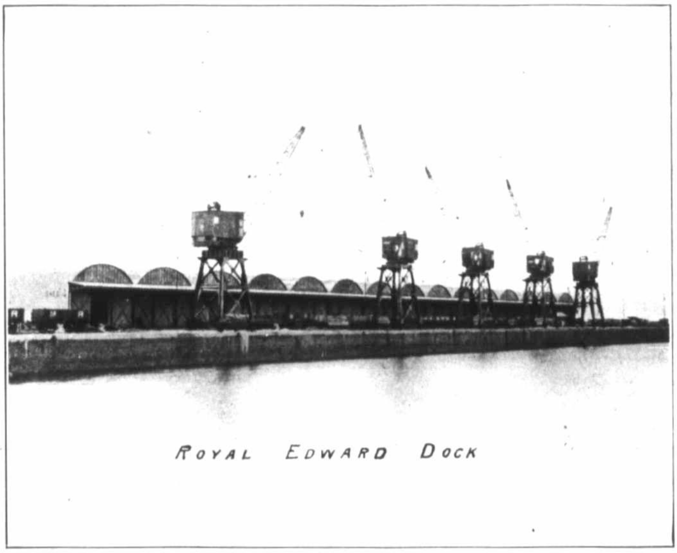


Fig. 63

consists of a fixed drum, above which is a smaller cylinder free to move vertically; between them the boom-chain is passed.

Over each end of the cylinder is a volute spring adjustable by hand wheels and screws, by which a moderate pressure is brought to bear upon the chain. Two turns of chain are wound round the fixed drum, and a length of 10 or 12 feet of slack chain is then lightly stoppered back. The third and fourth turns are then taken in the same way with a corresponding slack of 20 or 30 feet, respectively. The end of the chain is shackled to a stout bolt secured in the masonry. The total slack must fall somewhat short of the extra length of fender chain required to traverse the distance from its original position to the lock gates. A vessel moving towards the lock gates, on coming into contact with the chain, would cause it to fleet round the drum, part the stopping, and take up the first bight of slack, thus forming three complete turns of chain round the drum and greatly increasing the frictional resistance. If this is insufficient to stop the vessel, then in like manner the fourth turn is taken up. But should the fourth turn fleet, then the last of the slack would be taken up and the fixed end would tighten all the turns on the drum, and the maximum strength of the chain would be finally exerted. Before this a vessel, with ordinary way on, would have been brought up. When it is necessary for shipping to pass in or out of the lock, the chain is lowered. When the stopper is raised, the chain passes from the winding engine round the sheave, and falls to the bottom of the lock, but to assist its fall, as well as to guide it into a groove, there is a small hydraulic capstan alongside the relieving gear, which winds in a ¾-inch hauling chain attached to the centre of the boom chain. The time occupied in lowering the chain to allow a vessel to pass and to readjust it afterwards is only a matter of a minute or so, and the protection given to the gates by means of this gradually applied increasing resistance of from 40 to 60 tons through a distance of about 50 feet is far superior to anything hitherto used.

This relieving gear has been patented by Messrs. Brown, Lennox & Co., of London, and is now being fitted to nearly all the large locks in Britain, and, it is understood, in India also.

Caissons.—The caisson for the junction cut is of steel, with iron plates designed to slide on green-heart sills in polished granite grooves, and is actuated by hydraulic machinery. The caisson for the graving dock is of the floating type, somewhat after the design of a turret-built ship. Electric pumps are fitted inside the caisson for regulating the water ballast, and it is moved out or into position in a few minutes by hydraulic capstans on shore.

EQUIPMENT

Pumping Plant.—The pumping plant for emptying the graving dock and for other purposes is situated between the lock and the graving dock, and is designed to empty the dock (3,350,000 cubic feet) in two hours. There are three vertical coupled compound centrifugal engines, each about 850 I.H.P. The centrifugal pumps, which are coupled direct to the engines, have cast-iron impellers, 87 inches in diameter, keyed on steel spindles. The discharge branches are 54 inches diameter, and there are two suction pipes, 38½ inches diameter. Each delivery branch is fitted with a hydraulic sluice valve operated from the engine bed-plate, the maximum lift of the pumps being 38 feet. Two of the engines are non-condensing, having cylinders 22 inches x 38 inches diameter, with a 24-inch stroke. The third engine is used for keeping up the level of the water of the dock, and is arranged for economy to run condensing. The working steam pressure is 135 lbs. Two 12-inch drainage pumps are provided, one worked by a compound engine, the other by a Siemens motor.

The power is supplied from two Lancashire boilers, each 30 feet x 8 feet 6 inches, fitted with super-heaters and economisers, and three Babcock boilers for the non-condensing engines.

Passenger Station.—A commodious passenger station, with customs baggage examining rooms and passenger waiting rooms, is provided on the south pier, at which steamers can land their mails and passengers at any state of the tide before entering the dock. Trains from this station can reach London in about two and a half hours.

Import Sheds.—The import sheds have been constructed of reinforced concrete on the Hennibique principle. There are two double story buildings, each 500 feet long and 125 feet wide, having at the rear a covered way 34 feet wide over a double track loading way. Fig. 53 shows this work, and Figs. 54 to 59 show sections of the sheds.

The foundations consist of reinforced concrete piles in groups of 2, 3, 4, and 5, respectively, from the rear to the front of the building. Each cluster of piles is braced at the top by longitudinal and transverse tie beams, which carry the columns supporting the first floor and the roof above it.

The side walls are of galvanized corrugated sheets, with continuous sliding doors. A considerable part of the roof is flat, and is used for the storage of non-perishable goods. The roof also carries the electric cranes. The part of the roof farthest from the quay face is built up of light principals and galvanized sheets. The first floor extends over the loading way at intervals, forming platforms with hatches, so that goods may be lowered into the railway wagons

Fig. 64

Fig. 66

below. A tilting platform is provided on the side of the building next the quay at the level of the first floor, on which goods may be deposited by the crane for distribution on this floor, but hatchways are also provided along the crane track.

Export Shed.—The export shed on the south side is 450 feet long by 100 feet wide, with a covered way along the back of the shed, 31 feet wide, with a loading platform. It is a single story building of iron and steel founded on timber piling. The roof is in transverse bays of 30 feet span, carried on steel stanchions. These latter are 12 feet 6 inches apart, and this space is spanned by 16-inch joists, which carry a gutter of built-up steel channel section. This carries the galvanized iron roof and dispenses entirely with roof principals and purlins.

From gutter to gutter there are $\frac{7}{8}$-inch tie rods with central $\frac{3}{4}$-inch king bolts. This, it will be recognized, is an extremely simple and economical construction, and it has proved quite effective, as no movement was observed during the most severe gales. The end of the roof is covered with rough plate-glass. Along the sides of the sheds there is a continuous lateral girder which gives longitudinal stiffness. On the sides of the shed next to the dock this lateral girder carries cantilever brackets, with corrugated sheets to form a verandah roof.

Granary or Elevator.—The granary is erected about 400 feet back from the quay wall, the object being to permit of more sheds being constructed beside the wall.

The grain is conveyed to the granary in reinforced concrete tunnels underneath the ground. The granary is also constructed of reinforced concrete on the Hennibique system, as shown in Figs. 60 and 61, and is capable of holding 500,000 bushels of grain. It is divided into three portions, one with six floors, each having an area of 4,200 square feet, and designed to carry at least 5 feet depth of grain; the second comprising 78 silos, 9 feet 6 inches by 11 feet 3 inches, and 50 feet 4 inches deep; and the third containing an elevator and weigh-house section. Underneath there is a sacking-off floor. with a distributing tunnel below, and above all a machinery floor, with conveyer bands, etc.

This building is founded on reinforced concrete piles, driven 50 feet into the ground, which are in clusters of three under the silos and of five under the columns, the groups being at 10 feet intervals. These piles are braced together by longitudinal and transverse beams, and carry the columns to support the grain floors and the silos. The outer walls are 9 inches thick normally, and rest on longitudinal beams carried on the piles.

Grain-Conveying Tunnels and Machinery.—Reinforced concrete tunnels are constructed and run continuously along the back of the dock wall in front of the transit sheds, with another tunnel branching off nearly at right angles, and leading to the granary. The tunnel in front of import shed No. 1 is 11 feet wide, and accommodates two grain-conveying bands. That in front of import shed No. 2 is widened out to take four bands. These bands are 22 inches wide, and run at a speed of 650 feet per minute. The grain is conveyed to them from the ships through chutes, and is delivered by them to four weighing machine elevators at the eastern end of the granary. These discharge into automatic weighers, which take 3,000 lbs. of grain per turn of the scale, and discharge each successive load into a boot, whence it is again raised by one of four elevators, having a capacity of 100 tons of wheat per hour. These deliver the grain to conveyer bands on the top floor, which are fitted with movable throw-offs, so that the grain can be passed into any of the 78 silos or other part of any of the six grain floors.

Chutes enable the grain to be put into sacks on the ground floor, or to be passed to conveyer bands in a tunnel under the basement, which communicates with the grain elevators. This admits of grain stored at any one point being removed automatically to any other point.

For the despatch of grain by rail, loading ways, 26 feet 6 inches wide, covered by lean-to roofs of galvanized iron, have been built on the sacking-off floor level, on each side of the granary. For shipping grain into barges and coastwise craft, an overhead conveyer has been constructed from the granary to the dock. This will take sacks or grain in bulk, and has a capacity of 800 sacks per hour, with a belt speed not exceeding 250 feet per minute.

Electric and Hydraulic Cranes.—On the roof of each of the import sheds six movable electric jib cranes have been erected, which, from their position, can either

(1) Take cargo from the hold of the vessel and deposit it direct into cars on the quays;

(2) On to the ground floor of the shed;

(3) On to the second floor of the shed;

(4) On to the roof of the shed if non-perishable, or can transfer goods from any part of either of the floors to the floor above or below it. These cranes are shown on Fig. 62, and have a radius of 60 feet maximum and 24 feet minimum; lift 100 feet; hoist 1½ tons at 250 feet per minute; slew 1½ tons 450 feet per minute; luff in and out 90 feet per minute. On the export quay there are two 10-ton electric cranes, two 3-tons, and one 1½-tons, as shown in Fig. 63. At the graving dock there is a 25-ton crane and two 3-ton cranes.

Electric and Hydraulic Capstans.—A large number of electric and hydraulic capstans, varying from 2 to 11 tons, are provided all round the docks. These are used mostly for hauling cars, thereby saving a vast amount of locomotive shunting.

Coal Tip.—A typical hoist, as used for loading coal into vessels for exportation, is shown in Fig. 64. The loaded cars run by gravitation from the terminal storage area on to a hydraulic turntable in front of the hoist, which automatically tips up slightly and sends the car on to the hoist cradle. The whole car, weighing from 20 to 30 tons, is then lifted by hydraulic power to a height of 40 feet above quay-level, if necessary, and the contents tipped down the chute into the hold. The empty car is then run off by gravitation at a high level while the next loaded car is being got into position. In this way about 250 tons an hour is loaded.

MATERIALS

Cement Concrete.—The proportions of cement to broken stone, sand, and gravel varied from three to one to fifteen to one of cement. It is not necessary to describe all the various proportions. Suffice it to say that the great bulk of the walls were constructed of eight of broken stone and sand to one of cement, with a 6-inch face of four to one.

The stock of cement was never allowed to be less than 6,000 tons in store, which, when delivered on the works, was emptied out of the bags and kept thoroughly dry and well aerated in sheds specially constructed for the purpose. Cartoon drawing No. 1 shows a cross-section of a cement shed specially designed for this purpose on other works, which, however, the author considers much too expensive a structure for such purpose.

In the interior of this shed there were three floors, one above another, on which the cement was spread. The floors were formed of 12-inch x 3-inch planks, suspended at each end by a pivot placed a little out of the centre of the plank end, so that when thus suspended the flat sides of the planks were vertical. By a mechanical contrivance, as shown in cartoon drawing No. 2, hand wheels on the outside of the shed were made to raise the planks to a horizontal position when cement was to be laid on them, or to lower them to a vertical one when it was required to drop the cement to a lower floor. Beneath the bottom floor were large hoppers, which discharged into wagons for delivery on the works. Cartoon drawing No. 3 shows a cross-section of the sheds and the system adopted at Avonmouth, where the cement was aerated by compressed air. The bins were constructed of timber in the usual manner, but the sides were pierced with holes 1½ inches diameter, 20 inches apart, in two rows near the bottom of the bin. Compressed air was supplied from a compressor to each shed by means of a pipe running the whole length of the building, with connections at intervals, to which an indiarubber pipe was attached. A wrought-iron pipe, 1 inch diameter, was provided of somewhat greater length than the width of the bins. This pipe had a solid point at one end and a stop valve and connection for the indiarubber pipe at the other end.

The operation of aerating was performed by inserting the iron pipe into the cement through one of the holes near the bottom of the bin. The air was then admitted by opening the stop valve sufficiently until the air escaped from the cement at the top of the bin. The pressure was usually about 5 lbs. to the square inch.

Washing Sand and Ballast.—As showing the practical effect of having absolutely pure sand or ballast for concrete, some 6-inch cube blocks were tested, one-half of which were made of natural, moderately clean ballast and cement in proportions of three to one, while the other half consisted of ballast from the same heap, but washed perfectly clean and mixed with the same proportion of cement. After a month the blocks were tested, and the unwashed material began to crack at an average of 13.30 tons, and crushed completely at 15.18 tons, while the washed material began to crack at an average of 20.24 tons, and crushed completely at 29.66 tons, or practically double the strength of the unwashed. The water used for mixing the concrete was fresh, and averaged about 21 gallons to the cubic yard.

Note on Decay of Concrete in Contact with Salt Water.—Where concrete is being deposited in sea water, as in the construction of a pier, there is still some difference of opinion, even amongst our most eminent engineers, as to whether the sea water in such an instance is injurious to the cement or not, and it is probably better practice to use clean fresh water. The decay of concrete in contact with salt water is due to the substitution of the calcium or lime salts by those of magnesia, the magnesia being a constituent of sea water. This action does not take place, or only to a very small extent, when the cement used is good and the concrete is sound and impervious.

Displacers or Plums.—In nearly all the walls large, rough stones called "displacers" or "plums" were embedded in the concrete, as shown in Fig. 65, to reduce the cost of the work, the saving thus effected being as much as from $1.00 to $1.25 per cubic yard, and there is also the further advantage that the more displacers the greater the weight of the wall. Where the concrete was being deposited in heavily timbered trenches, with struts at about 9 feet centres, the timbers prevented the displacers being laid regularly along the length of the wall, and confined the extent to which they could be used to about 6 to 8 per cent. of total bulk. In open work the author has seen from 20 to 35 per cent. used.

Admission of Water to Docks on Completion of the Works.—The water was admitted to the docks through two 3-feet diameter cast-iron pipe syphons, laid from the entrance channel to the nose end of the graving dock, at high tide, so as to prevent excessive silt from getting in. Approximately, about one foot depth of water was admitted each day. This represented about 35,000 tons weight.

Cost of the Works.—The total cost of the works was about £3,500,000, but, taking the relative cost of work in this country for comparison, this would have been fully double, or approximately about $35,000,000, in Canada. When the works were in full swing, about $10,000 worth of work was executed each day.

The principal contractors were:

Messrs Sir John Aird & Co.—General work.

Messrs. Sir W. G. Armstrong, Whitworth & Co.—Lock gates.

Messrs. The Motherwell Bridge Co.—Caissons.

Messrs. Tannett Walker & Co. — Penstocks and hydraulic machinery.

Messrs. Tangyes, Limited—Pumping plant.

Messrs. T. B. Cooper & Co.—Railway terminals.

Messrs. Alex. Findlay & Co.—Swingbridge.

Messrs. Brown, Lennox & Co.—Fender chains and relieving gear.

Messrs. Carrick & Wardale—Caisson hauling machinery.

Messrs. Musker & Co.—Capstans, etc.

Messrs. The New Conveyer Co.—Grain conveying machinery.

Messrs. Higginbottom & Mannock, Limited.—Electric roof cranes.

Messrs. Stothert & Pitt—Shore cranes.

Messrs. Johnson & Phillips—Electric lighting.

For several years over 2,000 workmen of all classes were employed daily, and a large staff of assistant engineers, pupils, and inspectors.

Engineers.—The engineer for the works was Mr. W. W. Squire, M.I.C.E., engineer to the Bristol Docks Committee, through whose courtesy the author is permitted to give this paper. The consulting engineers were the late Sir Benjamin Baker, K.C.B.; Mr. Hurtzig; Sir John Wolfe Barry, Bart.; and Mr. Brereton. The author was resident engineer in charge of the works.

Opening Ceremony by T.R.H. King Edward and Queen Alexandra.—The new docks were opened by Their Majesties King Edward and Queen Alexandra on board the Royal yacht, "Victoria and Albert," on 9th July, 1908.

THE ROYAL EDWARD DOCK AT AVONMOUTH, BRISTOL;

CROSS SECTION OF IMPORT SHED.

Fig. 54

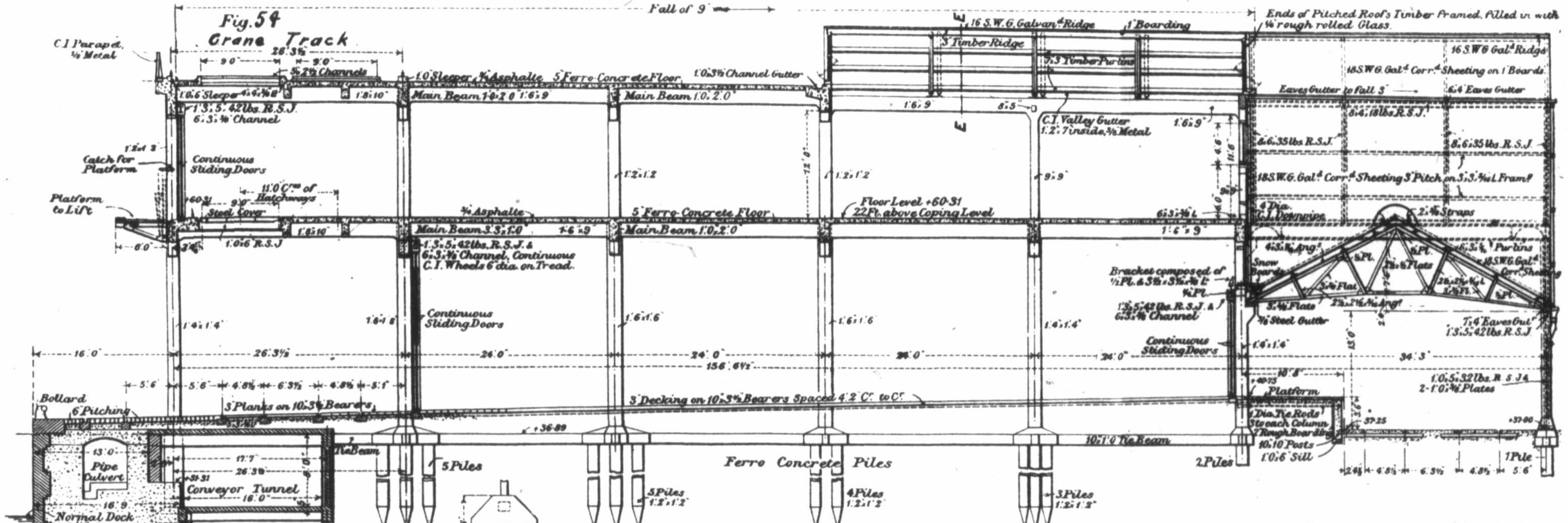


Fig. 55

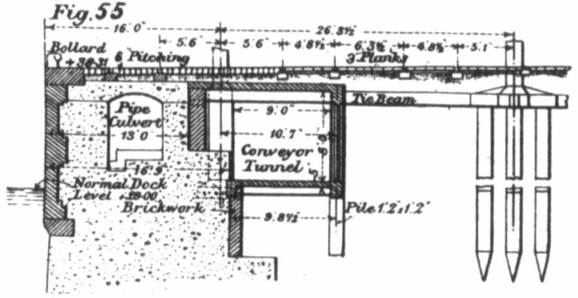


Fig. 56

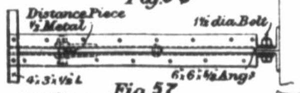
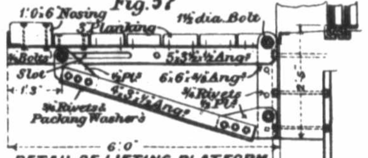


Fig. 57

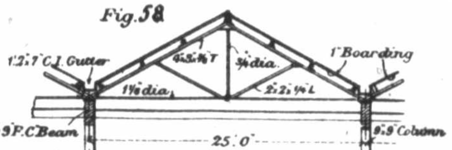


DETAIL OF LIFTING PLATFORM
Scale: ¾" = 1 Foot

CROSS SECTION

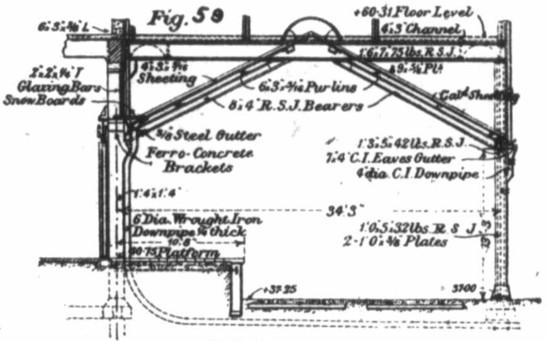
0 5 10 20 30 40 Feet

Fig. 58



SECTION ON LINE E–E

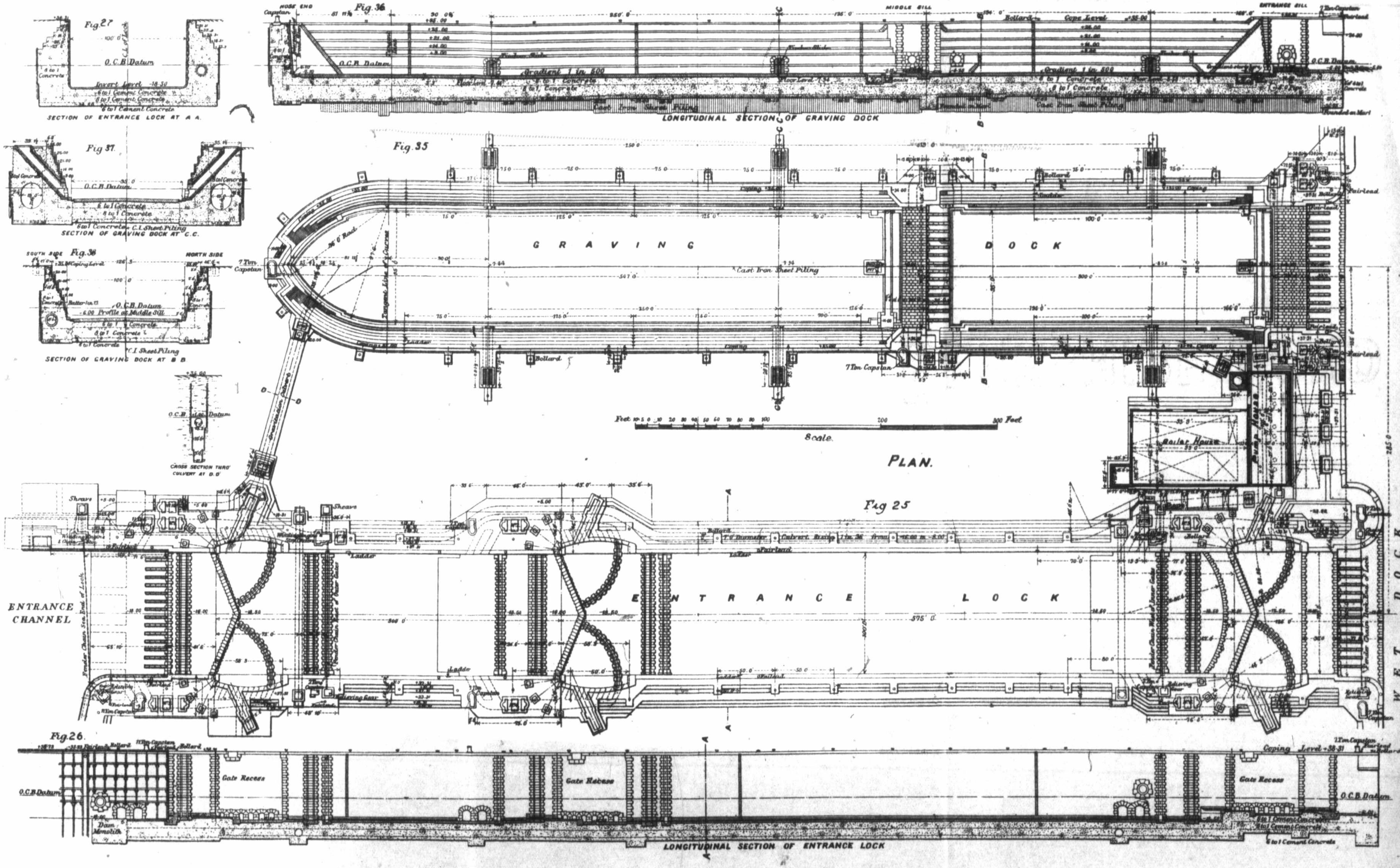
Fig. 59



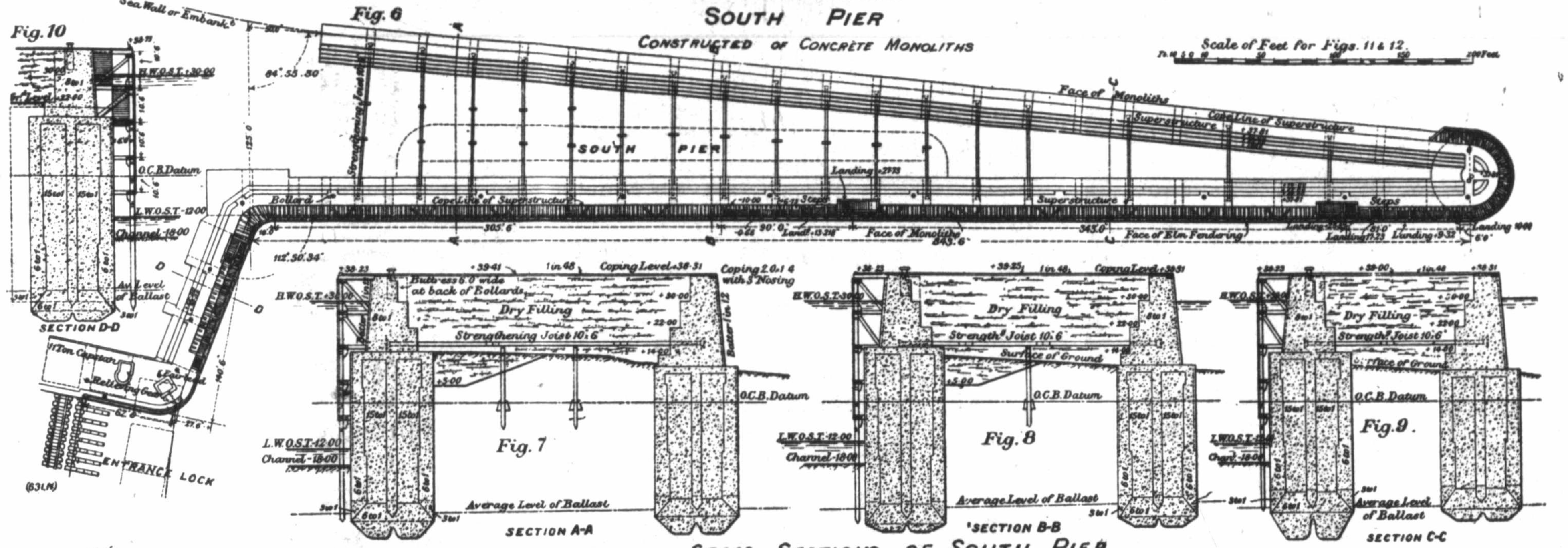
SECTION AT HOOD

A

THE ROYAL EDWARD DOCK AT AVONMOUTH, BRISTOL; THE ENTRANCE-LOCK AND GRAVING-DOCK.



DEVELOPED ELEVATION

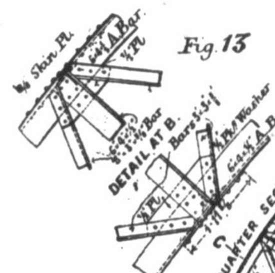


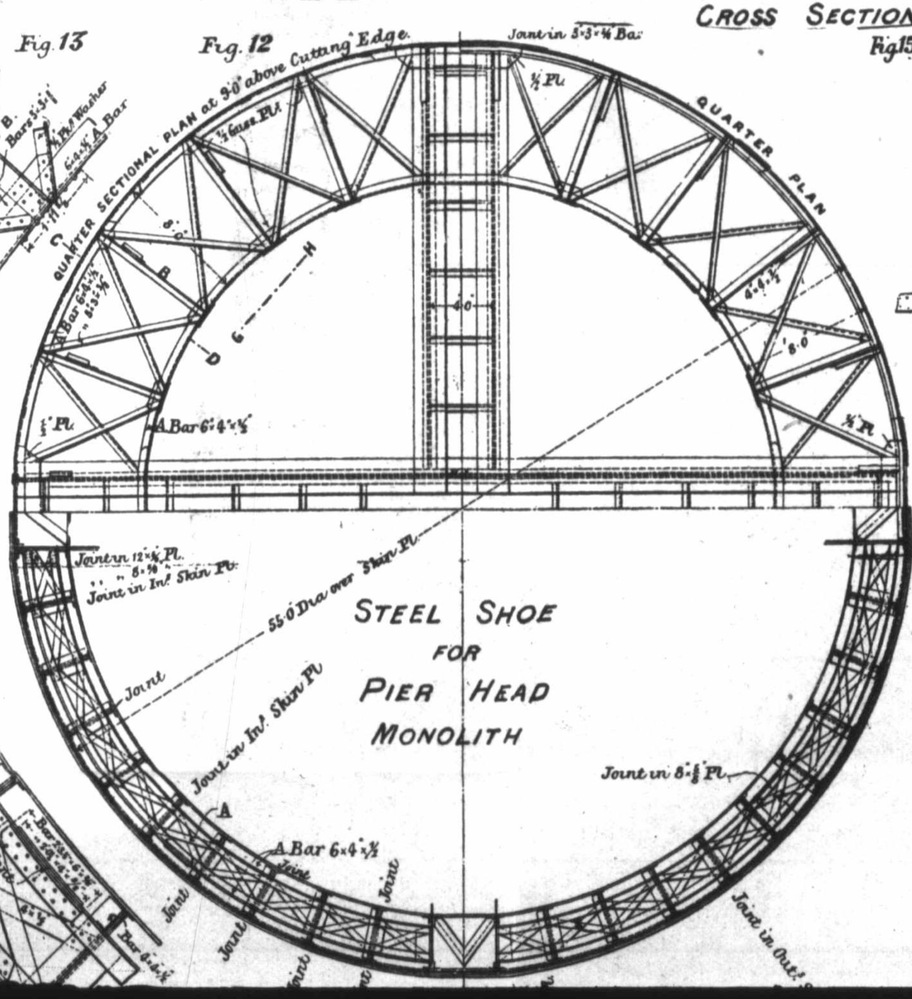
SOUTH PIER

CONSTRUCTED OF CONCRETE MONOLITHS

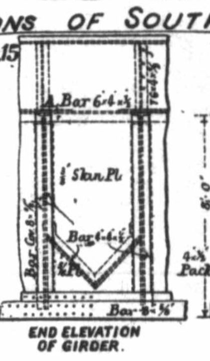
Scale of Feet for Figs. 11 & 12.

CROSS SECTIONS OF SOUTH PIER.

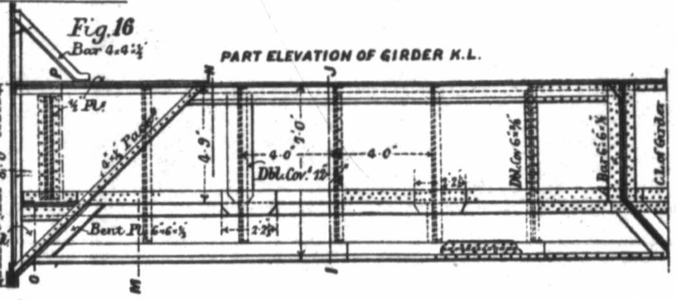




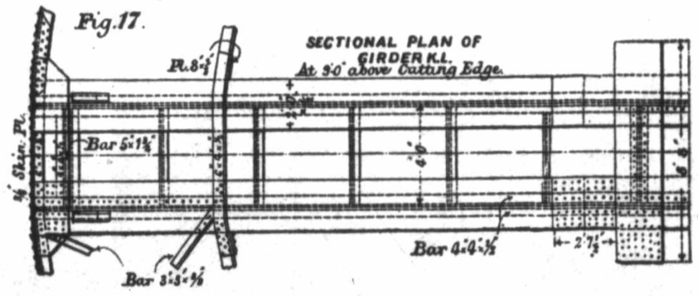
STEEL SHOE FOR PIER HEAD MONOLITH



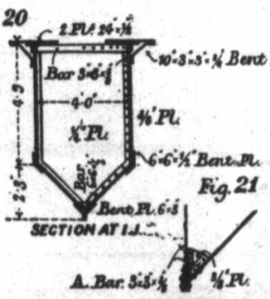
END ELEVATION OF GIRDER.



PART ELEVATION OF GIRDER K.L.

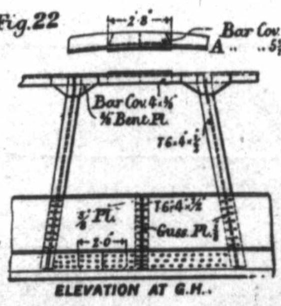


SECTIONAL PLAN OF GIRDER K.L. At 9'0" above Cutting Edge.

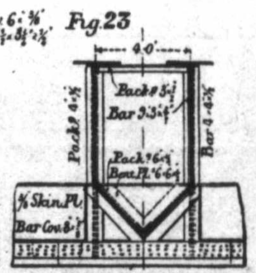


SECTION AT I.J.

INTERMEDIATE STIFFENER.



ELEVATION AT G.H.



SECTION AT M.N.

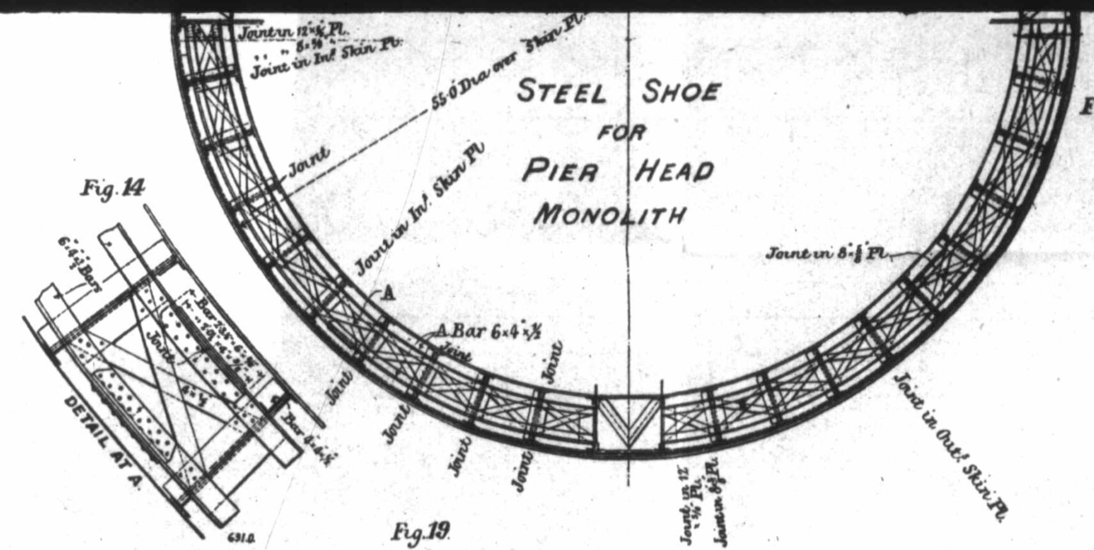
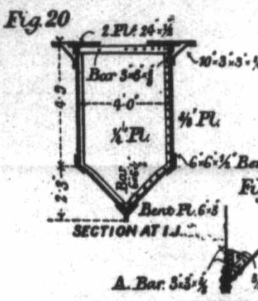
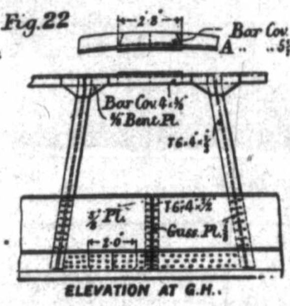

STEEL SHOE FOR PIER HEAD MONOLITH

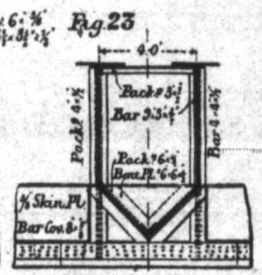
Fig. 14

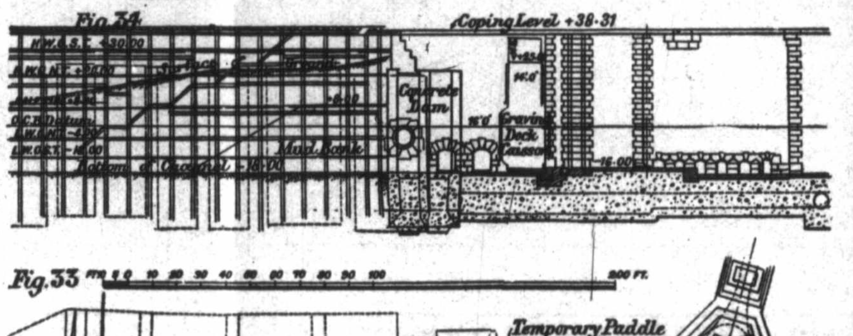
DETAIL AT A

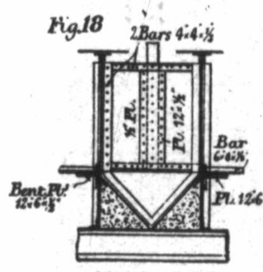

SECTION AT I.J.

INTERMEDIATE STIFFENER.

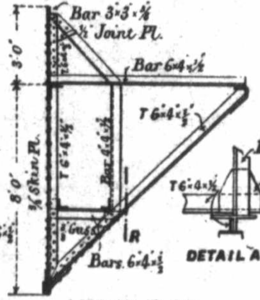

ELEVATION AT G.H.


SECTION AT M.N.

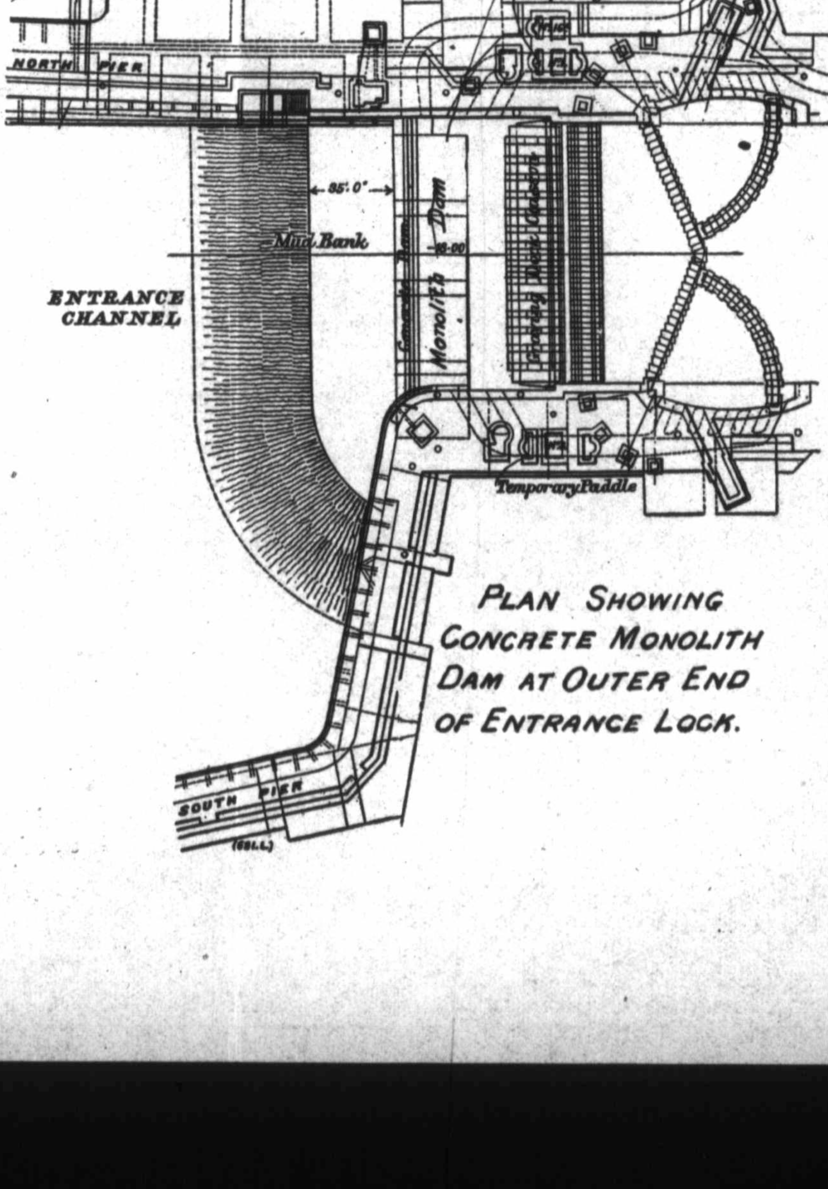




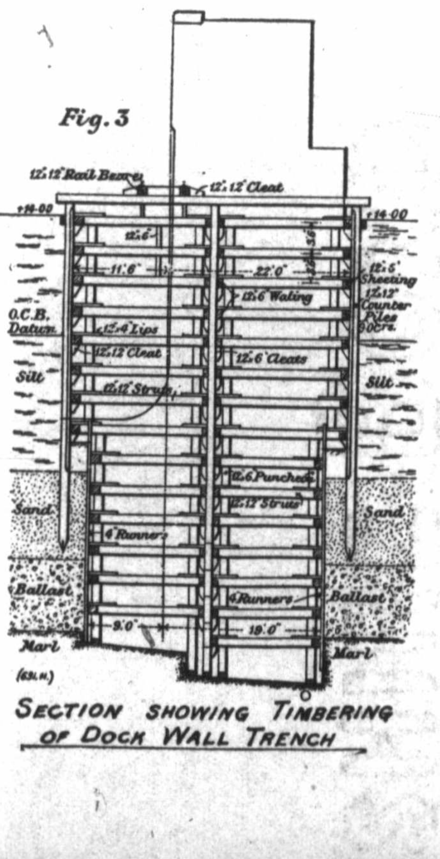
SECTION AT O.P.



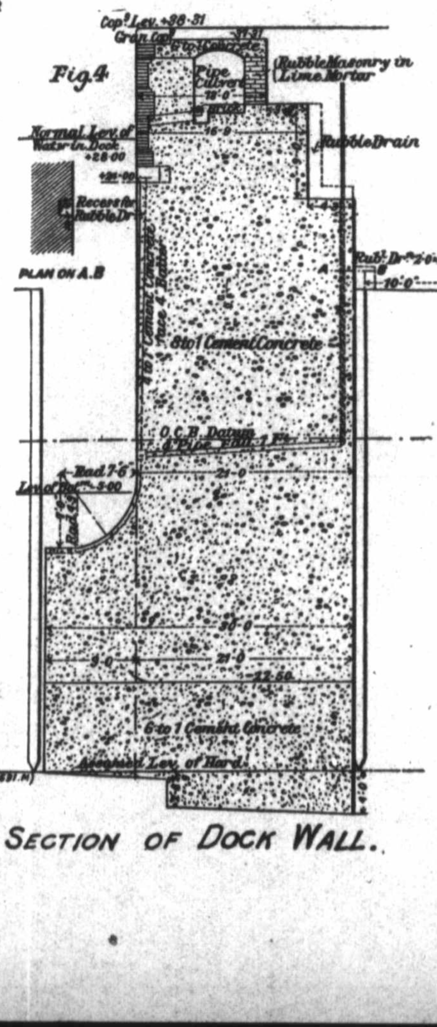
SECTION AT C.D.



PLAN SHOWING CONCRETE MONOLITH DAM AT OUTER END OF ENTRANCE LOCK.



SECTION SHOWING TIMBERING OF DOCK WALL TRENCH



SECTION OF DOCK WALL.