May 6, 1856.

ROBERT STEPHENSON, M.P., President,
in the Chair.

The following Candidates were balloted for and duly elected :—
GEORGE ABERNETHY, FREDERICK JOSEPH BRAMWELL, DAVID
STEWART DYKES, WILLIAM HUMBER, and ALEXANDER WRIGHT,
as Associates.

No. 950.—“ On the Progressive Construction of the Sunderland
Docks.”¹ By JOHN MURRAY, M. Inst. C.E.

PART I.

THE shipping trade of the Port of Sunderland was formerly conducted in the tideway of the River Wear. The water surface of the harbour from near its mouth, for a distance upwards of about two miles, comprised an area of about 60 acres; but at low-water, the channel was reduced to about 40 acres, often much contracted by the shipping. When the tide was out, nearly all the vessels took the ground, and they were, in consequence, frequently strained and otherwise injured. During floods, especially if accompanied by ice, they sometimes broke adrift from their moorings, and did much damage to themselves and to other vessels.

To prevent the continual injury arising from these causes, Docks in which the shipping could at all times lie afloat and in safety, had been often proposed, and numerous designs had been suggested by Engineers of eminence. Among others, Dodd, so long ago as 1794,—Jessop, in 1807,—Stevenson, of Edinburgh, in 1829,—Giles and Brunel, in 1831,—Rennie and Walker, in 1832,—were consulted on the subject, and some of the schemes were investigated by Parliamentary Committees. None of them were, however, executed, till 1838, when a dock of about 6 acres, with a tidal harbour attached, of about an acre more, was constructed on the north side of the river, by a Company under the direction of Mr. Brunel, as the Engineer. It afforded some relief to the larger class of shipping; but the principal collieries of the district being situated on the south side of the river, where the chief ship-owners and merchants reside, as well as the great mass of the inhabitants, further accommodation became absolutely necessary. For want of

¹ The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

docks, the trade of the port was being gradually diverted to other places; on the one side, Seaham and Hartlepool were flourishing, and on the other, the River Tyne, with its projected docks, was a formidable rival.

This inadequacy of accommodation in the Port, indicated the necessity for a change of system, and in 1846, a Company, with Mr. G. Hudson, M.P., then at the head of the railway interest, as Chairman, obtained Parliamentary powers for the construction of commodious docks, the site of which was a range of rough rocks on the sea-shore, between the South Pier and Hendon Bay. The designs were made by the Author, who had, for many years, conducted the consecutive improvements in the Port and in the River Wear. Mr. Robert Stephenson, M.P., (President Inst. C.E.,) was associated with him in conducting the Bill through Parliament, but ceased to be Engineer, on the Act being obtained. Mr. James Walker, (M. Inst. C.E.,) by instructions from the Admiralty, reported on the proposed plan, when the Bill was in Parliament, and the opinion of Mr. J. M. Rendel, (M. Inst. C.E.,) was taken, at the request of the Directors, previously to the commencement of the works.

The general form of the dock, with its basin and approaches, will be readily understood from Fig. 1, page 420, which is a copy of the Parliamentary plan of 1846: several modifications have, however, been introduced during its construction. The northern basin, communicating with the River Wear, was intended to have two passages; that to seaward to be 45 feet wide, and the other, pointing up stream, to be 80 feet wide. The basin was intended to have an area of $2\frac{1}{2}$ acres, and to be connected with the dock by two entrances of 45 feet and 60 feet wide, furnished with gates. The area of the wet dock was $27\frac{1}{2}$ acres. At the southern end, it was intended to have a half-tide basin, of about 4 acres, with two gate openings of 45 feet and 60 feet, and similar openings and gates to connect this basin, in Hendon Bay, with a tidal harbour, protected by rubble-stone break-waters; that on the east side, being nearly parallel with the entrance, whilst that on the west side, was in connexion with the land. The total water area proposed to be formed, amounted to about 47 acres.

The dock was chiefly intended for the shipment of coals, which is the staple business of the port. The quantity brought to the river at Sunderland, in the year 1846, was about 1,500,000 tons; the greater part of which, it was considered, would ultimately be transferred by railways to the dock, at the level of the adjacent table-land of the Town Moor, and be connected with it by staiths of timber. The depth of 6 feet under low-water of ordinary spring-tides, was presumed to be sufficient in the dock, and its sides were, for economy, to be made sloping, and to be pitched with

Fig. 1.

rubble-stone. A long timber jetty was to be placed in the southern part of the dock, if additional berths were required for the shipment of coals. The cost was estimated at £300,000.

Even after the project had received the sanction of Parliament, doubts were entertained, as to the practicability of the work:—1st. As regarded the efficacy of the groynes, in maintaining a beach, or barrier against the inroads of the sea; 2ndly. As to the possibility of keeping down the water, during the execution of the works, situated, as they were, within the influence of the tides;—3rdly. Whether the water could be retained in the dock, after its completion.

The previous construction of the dock on the north side of the river, and near its mouth, executed upon the same formation of marly magnesian limestone, solved the two latter points; the first, however, still remained doubtful. For the purpose of testing that principle of construction, it was suggested, that three groynes should be erected at the northern end. If they should have the effect of creating a natural deposit between them, it was considered, that, when connected by the material excavated from the docks, a consolidated embankment would be formed by the action upon it of the waves, bringing with them, in their travel from north to south, sand and other matter, which, it was believed, would be washed into the interstices, and would ultimately form a sloping beach, impervious to water from the sea, and capable of retaining the water in the docks.

Groynes Nos. 1, 2, and 3, (Plate III.,) were, in consequence, commenced in the latter part of 1846, on the assumption, that the Parliamentary plan was to be carried out. This will account for their position so far inland, which might appear to be at variance with the situation of the southern groynes, and with the subsequent contour of the barrier embankment. The three groynes were completed in the spring of 1847, and long before that time, isolated as they were from each other, and from the Town Moor Cliff, a lodgment of sand was effected between the landward end of the south pier and groyne No. 2. At this stage of the proceedings, they were examined by Mr. Rendel, and he made the Report previously alluded to. The Directors then resolved to proceed with the execution of the dock; but it was deemed prudent to confine their attention, in the first instance, to the northern portion, and to connect it with the River Wear. It was determined, that the formation of the southern, or sea outlet should remain in abeyance, until the trade was so far developed as to warrant the expenditure. Instructions were therefore given, to alter the Parliamentary plan and to introduce a half-tide basin at the northern end; and in compliance with Mr. Rendel's views, the quay in front of the tidal basin, was entirely removed, thus doing away with the two passages

to the river, and making the entire width open to the navigable channel. This suggestion has been found useful in facilitating the access of shipping to the docks, but it has allowed a heavy roll of sea to be admitted, during stormy weather, into the tidal harbour. This heavy roll of the sea, which, undoubtedly, did not exist at the time of Mr. Rendel's Report, arises from alterations subsequently made by the Commissioners of the River, in removing some portions of the North Pier and placing a timber jetty across the Potogarth. The gates in the tidal harbour are now, during severe gales, acted upon by the waves, and at such times, great care has to be exercised in closing them.

Subsequently, the head of groyne No. 2 was connected by an embankment with the adjacent high ground, and the excavations being afterwards deposited from the Fort and the sea-shore in front, in the form of another embankment, between the south pier and the head of the same groyne, an area was reclaimed from the sea, which allowed the excavations from the beach to be performed by day-work, instead of during the intervals of the tides, and thus lessened the cost and facilitated the progress of the works.

The Directors having ultimately determined to execute the whole, as first-class docks, for the general use of commerce, as well as for the shipment of coals, the surrounding walls, in place of being made sloping as originally intended, were built very nearly upright. The depth of the dock was increased to 24 feet under high-water of ordinary spring-tides, or 20 feet 6 inches at dead neap-tides. The cills of the entrances were laid deeper than in the Parliamentary plan, viz., 20 feet 6 inches under high-water of ordinary spring-tides, or 17 feet at dead neap-tides. It was intended to open the gates, so that the water might be, for two hours before, and two hours after high-water, at one common level with the tide in the river, and thus to permit steam tugs to take a great number of vessels in and out during a tide, and avoid the usual detention of lockage.

The remaining excavations from the half-tide basin, the building of its walls, the construction of the great dock, with the coffer-dam at its southern end, and the excavations, masonry, &c. of the three entrances, were let to Messrs. John Craven and Sons, on the 17th of July, 1847. Their contract amounted to £135,000, exclusive of the gates, and the groynes of masonry Nos. 4, 5, 6, and 7, on the sea-shore, which were let, at subsequent periods, to other contractors.

Messrs. Craven immediately erected an engine of 30 H. P. on the reclaimed land, near the head of groyne No. 2, with pumps placed in the half-tide basin, and ultimately, in the northern part of the great dock. (Plate III.) They soon afterwards erected another engine contiguous to it, for drawing up an inclined plane,

from the half-tide basin, the waggons containing the excavated material, which was then tipped from the waggons running on railways, into the barrier embankment, between groynes Nos. 2 and 3. A barrier, or dam was soon after formed from the table land of the coast to the head of groyne No. 3. It was composed of timber uprights, sunk into the rock, and secured thereto by wedges, strengthened by external raking shores similarly fastened. To the inner side of the uprights, planks were fastened, and a mass of clay from the excavations at the Town Moor Cliff, was then deposited against them. The pressure of the clay being thus thrown upon the planking, the timber uprights and the outside raking shores, tightened the latter, and prevented them from being washed out by the action of the waves. By working from the landward side, it was finally united to the barrier embankment near the head of groyne No. 3, and the tide was excluded from the northern portion of the great dock. When this was laid dry, the engine near the head of groyne No. 2, drew the waggons up an inclined plane, and they were tipped in a south-easterly direction towards groyne No. 3, to widen and strengthen the embankment, while the adjacent engine had pumps attached to it, to discharge the water from the great dock into the sea. Groyne No. 4 was founded on the 30th of June, 1847, and completed on the 7th of August following. Groyne No. 5 was founded about the same time, and finished on the 16th of October of the same year.

The excavations of the half-tide basin and the northern part of the great dock having, in the meantime, been proceeded with, all was ready for laying the foundation stone of the half-tide basin. On the 4th of February, 1848, an immense concourse of people were assembled from all parts of the surrounding country, and walked in procession to the spot, from the temporary offices of the Dock Company. The stone was laid, with the usual formalities, by Mr. George Hudson, M.P., the Chairman of the Company, with the aid of the Freemasons, who mustered in a large body on the occasion.

A lime-kiln and mortar-house were erected on the land reclaimed from the sea, and as it was important to have always at command a good supply of this necessary article, of the best quality, much attention was bestowed upon its production, it being intended to make the mortar by the Company's workmen, and to sell it to the contractor at a specified price. This system having worked well, has been pursued throughout the whole of the different contracts, and an article has been formed over which the Engineer has had a perfect control, and altercations with the contractors and their workmen have been avoided.¹

¹ To obtain an insight into the best method of burning and slacking the limestone, and to make arrangements for a regular supply of blue lias stone, the

The kiln, adopted at Sunderland, had two eyes with one opening to each, the interior walls being perpendicular. The limestone when broken and burnt, was conveyed under cover into the slacking-house, and deposited in small heaps; water being then sprinkled over each, they were thinly covered with sand, and in a few hours, the powder was removed into the mixing-house, where it received its due proportion of dry sand. In that state, it was thrown into the grinding-pan, having two rollers working in it, attached to one of Gough's engines, and a due supply of water being added, the whole was readily formed into mortar and removed from the grinding-pan into a large trough, whence it was cast into tubs, or boxes placed on railway waggons at the mill door, and conveyed in them to the works. The Pozzuolana was kept at the other end of the mortar-house. This sort of mortar was used only in the entrances, groynes and other works exposed to the action of water, the joints being stopped with the best light-coloured Roman cement from Hull.

The cost of the lime-kiln and mortar-houses	£
amounted to	550
Ditto of Gough's 6 H. P. engine, mixing pan,	
rollers, &c. &c. fixed complete	360
Total	£910

If kept working at full speed, it turned out in a day of ten hours, 25 cubic yards of mortar; it often had, however, to be worked extra time, and the ordinary means of making it by manual labour, had also to be employed, as 40 and even 60 cubic yards have been used in a day. The cost to the Company of making the mortar, and delivering it to the contractor, at the door of the mill-house, including interest on capital in buildings, &c., amounted to 10 shillings per cubic yard, which made the price equivalent to about 2s. 7d. per cubic yard of rubble-masonry. The price of the

Author visited Lyme Regis in 1847. For many years previously, he had used that stone, procured from Barrow, in Leicestershire, and from Lyme Regis, (although not in such large quantities,) in the building of the north pier and other harbour works at Sunderland, and he had followed the old method of grinding it dry, conveying it in bags from the mill-house to the work, and then mixing it with sand and water into a proper consistency. It was often found, that the joints were shaken, and the lime, after being ground, was, therefore, kept for some time in store, until it had imbibed atmospheric moisture, which lessened the injury. On visiting Lyme, he learned, that it was the custom there, after burning the stone, to slack it in small quantities with a watering-pan, to cover it up immediately with a thin layer of sand, and in the morning, the heap had fallen into powder. To his surprise, he was informed, that the lime so slacked and mixed with sand, was immediately used for interior plastering, and so few particles remained unslacked in it, that blisters rarely occurred. Where great care was taken, the slacking-water was applied hot, with still better effect.

blue lias-stone at Sunderland, varied from 7 shillings to 9 shillings per ton.

A drawing engine having been placed near the head of groyne No. 3, with another incline, the waggons with the excavations were drawn up, and tipped into the embankment in a south-easterly direction towards groyne No. 4. (Plate III.). A third drawing engine was, soon after, placed a little way to the north of the last, for raising the three-wheeled waggons, which were drawn by horses over the bottom; on arriving at the top, they were conveyed by other horses into different parts, where required. The excavated material joined the head of groyne No. 4, on the 21st of March, 1848, and that of groyne No. 5, on the 31st of May following.

A quantity of rubble-stone had been previously deposited a few feet in height, between the heads of the groynes Nos. 2, 3, 4, and 5, on the surface of the rocks, to assist in the operations of warping up the sand brought in by the sea, and to prevent the finer particles of the deposited materials, from being washed on to the site of the dock. The interstices were thus soon filled with sand, gravel, and other matter, and aided, in some degree, to consolidate the lower part of the embankment.

During these operations, a second barrier of vertical timbers with raking shores and planking, backed with clay, was run out from the cliff of the Town Moor, to join the head of groyne No. 5, and thus the second area of the great dock was reclaimed from the sea. Soon afterwards, a second pumping engine of 35 H. P., was erected on the newly-formed embankment near groyne No. 5, and additional drawing engines were placed, to raise the waggons with the excavated material. Groynes Nos. 6 and 7 were both founded on the 28th of April, 1848;—the former was completed on the 29th of July, and the latter, on the 21st of September following. These two groynes were shortened at their landward ends, in consequence of an extra quantity of excavated material being brought to this point, thus rendering the masonry unnecessary.

A third barrier was, in the mean time, formed at the southern end, from the high ground of the coast, to the head of groyne No. 7, and thus before the termination of 1848, the tide was excluded from the whole area of the great dock. Within this last temporary barrier, when the rock was excavated to the full depth, a coffer-dam was erected, (Plate V., Figs. 12, 13), between the point of the jetty No. 4 and the eastern wall of the dock, for the purpose of permitting it to be lengthened at any subsequent period, without disturbing the shipping in the northern part of the dock. It was designed so as to allow the timbers and the vertical sheeting to be drawn without running off the water from the dock, and the interior clay to be taken out by dredging. The vertical timbers

were secured to cills, laid in chases cut in the rock, strutted to it at the bottom, and tied to it by iron rods, with split lewis bolts at the top; the former, with the view of removing it and the adjacent rock at a subsequent period, and the latter, to guard against the pressure of the earth forcing the upper part of the dam towards the dock before the admission of the water, and afterwards, if the water should, by any necessity, be reduced to a lower level than usual.

The groynes served to maintain the whole length of the embankment, between the south pier and groyne No. 7, a length of 1,120 yards. The actual cost was about £13 per lineal yard of coast, which is unquestionably much cheaper than any sea-wall, or glacis, could have been constructed for; and it was less dangerous to the shipping, as has been proved by the vessels which have beached on this sloping foreshore, without sustaining any great damage. It is unnecessary to give a lengthened description of the method of constructing these groynes, as full particulars may be found in a Paper communicated to the Institution in 1849, by Mr. William Brown, an assistant of the Author at that time. They were all founded on the rocks and built by tide-work; the outer coating was composed of freestone set in Pozzuolana mortar, and the hearting was formed of rubble-stone. Railways led from them, on the sea-beach, to the mortar-house and to the foot of the cliff, and for obtaining the supply of stone, they were connected by inclined planes, with the railway on the table land of the Town Moor.

The total cost of the seven groynes amounted to the sum of £14,480, being on the average, at the rate of £19 16s. 3d. per lineal yard. The general dimensions were:—

Groyne.	Lengths.	Slope of their Crests Seaward.	
No. 1	326 Feet		
" 2	326 "	1 in 18	Situating at distances from each other, varying from 350 to 450 feet.
" 3	358 "		
" 4	312 "	1 in 26	
" 5	360 "	1 in 30	
" 6	300 "	1 in 32	
" 7	210 "	1 in 30	

If the outlet had been formed in Hendon Bay, the southern groynes were intended gradually to slope and assimilate with those at the northern end, for the purpose of making the embankment convex on its seaward side, between the first and last groyne. But circumstances which will be detailed hereafter, have altered this arrangement.

At the termination of Messrs. Craven's contract, the area of the

embankment on the eastern side of the dock and half-tide basin, thus rendered available for commercial purposes, was 12 acres, exclusive of the quay and a strip of waste on the eastern side, which, it was thought, might, at times, be acted upon by the sea.

The pumping power employed to overcome the leakage and surface water was, for a long time, only a 30 H.P. engine, placed between the half-tide basin in the great dock, and working four pumps of 18 inches diameter each. This engine was fully equal to draining an area of 16 acres, including the three entrances. When, however, 8 acres more were enclosed from the sea, it was considered prudent to erect another engine of 40 H.P., which worked two pumps of 24 inches diameter, and with these engines, no difficulty was experienced in keeping down the water. It was only during rainy weather, that the two were employed; and one was frequently found sufficient for the work. In building the masonry of the trenches of the entrances, a small engine of 8 H.P. was used at each. Their great depth of 16 feet under the level of low-water, and an anxiety to keep them dry, until the mortar had become perfectly indurated in this important part of the work, was the cause of temporarily employing such assistant power; but the water was only thus raised to the level of the bottom of the dock, whence it was pumped by the other engines.

The coping of the walls of the half-tide basin, and of the northern side of the great dock, was placed at the level of 8 feet above the datum, or high-water of ordinary spring-tides;—the coping of the west wall of the great dock being fixed at 6 feet, and that of the east wall, at 4 feet above the same datum. The plan, section, and elevation of the west wall are given in Plate V., Figs. 1, 2, and 3. Below the surface of the rock against which these walls were placed, the thickness was only 3 feet, with chases 3 feet square, cut in it at intervals of 20 feet, to unite them more solidly to the rock. Above the surface, the section of the walls varied in thickness, according as its depth varied below the datum; counterforts were, in all cases, used to strengthen the walls. The method of building them will be understood by the following description.

The thickness of the walls underneath the coping, was 5 feet, battering in front one-tenth of the height; they were perpendicular behind, with offsets of 6 inches each; the highest offset was 12 inches below the datum, (high-water of ordinary spring-tides); the next was 6 feet below that level, and the next, where necessary, was 5 feet lower. The counterforts were placed at intervals of 20 feet, along the back of the wall; their length was 4 feet 6 inches, and their breadth at the root, level with the upper offset, was 4 feet, diminishing at their tail to 2 feet 8 inches, shortened by offsets, like the wall. Between each offset, the counterforts were bonded to the wall in their hearting, by large

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rough blocks, not less than 4 feet 6 inches long by 18 inches square, and by large angular stones at their intersection with it. The bottom course of the walls was a row of headers, each 3 feet 3 inches long by 15 inches thick, having an offset of 3 inches before the face of the wall. From the foundation course to a height of 5 feet 8 inches below the datum, they were built entirely with limestone rubble, having large rough blocks of limestone selected for through-stones, none of which were less than 4 feet 6 inches long by 18 inches square. The external part of the walls, up to the underside of the coping, was executed with limestone in courses, square-jointed, with headers and stretchers alternately. The rest of the backing was built with ordinary limestone rubble, similar to the lower part of the walls. Two through-stones of freestone, quarry broached, not less than 4 feet 6 inches long by 18 inches square, were laid at right angles to the face of the wall, between each fender. These fenders were composed of freestone, the external face, 18 inches broad, rising one-twentieth of their height from the level of 5 feet 8 inches below the datum. The courses varied from 18 to 12 inches in height, diminishing upwards; but in such cases, the courses of limestone were made to run level with the top bed of each fender and through-stone. The stretching fender-stones were not less than 3 feet 6 inches long, and 2 feet on the bed of the wall, and the headers were 3 feet 6 inches long, by 2 feet on the face, all of them being measured exclusive of the projection. The upper stone was of Aberdeenshire granite, 3 feet long, by 18 inches broad; the freestone coping was 20 inches thick, and of one uniform breadth of 4 feet. The whole of the rubble and other masonry was laid in blue lias mortar. A dowel of iron 6 inches long, and $1\frac{1}{4}$ inch diameter, was let into the end of each coping-stone, so that the whole length formed one continuous strong band of defence to the wall.

During the construction of the commercial quays, at the northern end of the dock, various methods for shipping coals were brought under the consideration of the Directors. It was pointed out to them, that a great length of quay would be required, if the vessels lay parallel to it; and the dock then in course of construction, would scarcely be adequate for any great extent of commercial business, and much less for accommodating, at the same time, the large quantity of coals to be shipped. It was, therefore, suggested by the Author, that the quays in the southern portion of the dock on the landward side, should be formed into a series of jetties, and by arranging the ships lying alongside of them, so that they should overlap each other, these jetties might be reduced to a minimum projection. It was shown, that four ships could thus be accommodated in the lineal length of quay, which one vessel would occupy in the ordinary way. It was, therefore, resolved,

that four jetties should be formed, capable of receiving thirteen ships to lie alongside of them, and upon these jetties, superstructures of timber, rubble walling, and arching, were erected, to carry the railways at the level of the Town Moor. Four other coal-drops were erected on a part of the commercial quay, until the warehouses should be built, making in all, seventeen coal-shipping places, in a length of 1,320 feet. It would be difficult to convey any proper idea of how the coals are shipped, without a series of drawings. The railways are laid about 30 feet above the level of high-water, and the loaded waggons run by their own gravity, to the shipping points. By means of turn-tables they run on to a cradle, suspended to the end of a double lever, the other end having a balance-weight attached to it; and the descent and ascent of the waggons are regulated by means of a break. The coals are discharged from the bottoms of the waggons immediately over the hatchways of the vessels, and the empty waggons, when brought back to the level of the superstructure, run back by their own gravity, from the shipping points, along railways to the standing-places on the Town Moor.

The gates in the three entrances all point inwards, it not having been considered necessary to increase the expense by having outer, or sea gates, to the two openings of the half-tide basin, in consequence of the tranquillized state of the lower reach of the harbour, when the works were designed. The gates were contracted for, by Messrs. Hawks, Crawshaw, & Co., of Gateshead. The frame of each is entirely of cast-iron, covered with greenheart planking 3 inches thick, placed diagonally on one side, and vertically as fender planking on the other. These gates, which are curved on plan, and are opened and shut by capstans, worked by manual labour, are strong and compact, and are put together in a sound and workmanlike manner. Across the two outer openings, are placed strong wrought-iron foot bridges, with openings of 60 feet, and 45 feet between the hollow quoins. They meet in the centre and have tail-balance weights, working on the principle of a crane, and are capable of turning either to the right hand, or to the left. The railway carriage bridge across the inner, or dock opening is not yet constructed.

This part of the Paper may be concluded with a slight description of the works, executed to effect a communication with the River Wear. A large shelf of rock existed in the bed of the river, directly in front of the tidal harbour, dipping northward and extending into the mid-channel. It was considered necessary to remove the whole of this shelf, to the depth of 10 feet under low-water of ordinary spring-tides, or 4 feet below the sills of the entrances. Figs. 10 & 11 (Plate IV.) are a plan and section of the coffer-dam used. It was similar to those which the Author

executed in the years 1837 and 1838, in a very contracted part of the tideway of the River Wear, at the Lambton and Hetton Staiths, without interfering with the shipping which passed up and down the river. Five coffer-dams were there placed for the removal of about 20,000 cubic yards of hard rock, which required to be blasted with gunpowder, to a depth of 12 feet under low-water of spring-tides. The coffer-dam at the mouth of the tidal harbour of the docks, surrounded the whole rock, at the depth mentioned, and comprised an area within it of about $2\frac{1}{2}$ acres. The method of construction was, by depositing clay in the line of the dam, and then driving through it, at intervals of 9 feet, the main piles, connecting them with walings and bolts, planking them internally and externally, and filling the space between them with clay. The area within the coffer-dam was kept dry by a steam engine of 30 H.P., working two pumps of 18 inches diameter. This engine was so placed as to be capable, without removing the pumps, of taking the leakage from the tidal harbour during its construction, and for this purpose, two additional pumps were, at a later period, connected with it. As the coffer-dam jutted out considerably into the tideway, and its continuance there until the tidal harbour had been completed, would have been an inconvenience to the shipping passing up and down the river, it was desirable to have it removed, as speedily as possible after the rock had been excavated. It was necessary, therefore, to put another dam in front of the old pier, which had likewise to be rooted out, as well as the rock on which it was founded. This was done on the line marked A B, (Plate III.,) and when executed, the outer coffer-dam was removed and the works of the tidal harbour were commenced. The material excavated from thence, as well as from within the river coffer-dam, was deposited in the embankment, between the south pier and groyne No. 3, by hauling the waggons up inclined planes, by means of a steam-engine from the bottom, and tipping them in the directions shown on Plate III. The works at the northern end of the dock, were constructed by Messrs. Thomson and Hunter, at the cost of £28,500.

During the summer of 1849, the whole of the works of the Great Dock and Tidal Harbour were prosecuted with the greatest vigour. Ten steam engines were employed upon them as follows:—

Four engines for pumping, (including the small engine at the entrances,) two of which were, however, used also as drawing engines)	108 H.P.
Five engines for drawing up the waggons from the bottom	75 „
One engine at the mortar-house	6 „
Aggregate power	<hr/> 189 H.P.

During the months of August and September in that year, twelve hundred waggons and two thousand three-wheeled (Dobbing) carts drew out daily, 4,300 yards. The number of men then employed on the whole works, including mechanics, masons, labourers, and quarrymen varied from thirteen hundred to fourteen hundred, and the number of horses was one hundred.

In June 1850, an area of $18\frac{1}{2}$ acres of wet dock, with a half-tide basin of $2\frac{1}{2}$ acres, and a tidal harbour communicating with the River Wear, of $2\frac{1}{2}$ acres more, was opened to the trade of the port, in the presence of an immense concourse of people, collected from all parts of the adjacent country.

PART II.

The southern outlet of the docks into the sea, in Hendon Bay, formed part of the original design; but after obtaining the Act of Parliament, its construction, for the reasons previously given, was postponed. The opening of the northern part of the dock, soon produced an increase of trade, and a fleet of laden vessels, detained by contrary winds, was often to be seen in it. A larger and finer class of vessels began to be built on the Wear, and to frequent the port in such increasing numbers, that it became imperative to have a connexion with the sea directly from the dock, in order to provide deeper water for their entrance and departure, than the mouth of the old harbour could possibly afford. Foreseeing that, at no distant period, this work would require to be executed, well aware of its importance, and that a false step would be fatal to the whole project, the Author, before deciding upon the situation of this outlet, urged the Directors, soon after the commencement of the works, to allow him to make a more minute and extensive survey of Hendon Bay than had yet been effected. In the summer of 1849, numerous soundings were consequently taken, in various directions over its whole extent, into deep water. These were reduced to depths under low-water of ordinary spring-tides, and being plotted upon paper, contoured and coloured, gave a clear conception of the bottom, and pointed out the foul ground existing in different parts of the bay. It was decided, that the outlet should approach the deep water under the lee of the Crab Rocks, in a south-easterly direction from the dock, although the execution of the work would be attended with more difficulty, and greater cost, than if it could have been accomplished in the comparatively sheltered situation shown on the Parliamentary plan, in the middle of the bay.

To enable this altered design to be carried out, a new series of groynes, Nos. 6, 7, and 8, (Plate III.,) was commenced in the latter part of 1850, and as the barrier embankment at the northern

end of the dock was narrow, and required strengthening, groynes Nos. 2 and 3 were reconstructed further to seaward, and made to form part of the new foreshore. The masonry of the old groynes was rooted out to assist in their construction, and emboldened by success, a much larger area of land has been reclaimed from the sea than was previously contemplated. For want of funds, the groynes Nos. 4 and 5 have not yet been rebuilt, but there can be no doubt, that the land will be gained hereafter, and the line of foreshore made uniform, from the south pier to the newly-formed outlet. The land at present reclaimed, is levelled and intersected with carriage roads and railways, and has become exceedingly valuable for commercial purposes.

When the new groynes Nos. 6, 7, and 8 had been built and a barrier of clay and stones had been formed, to connect them with the south-eastern side of the embankment, at the point A, (Plate III.,) the remaining works of the sea outlet were let on the 8th of April, 1851, to the contractors, Messrs. Pawson and Dyson, for the sum of £52,000. An engine of 40 H.P. having been previously purchased by the Company, it was erected contiguous to the proposed inner entrance, for drawing the waggons and pumping the water from it, as well as from the half-tide basin and the channel. A coffer-dam was placed on the sea-side of the inner entrance, which enabled its site to be excavated for the reception of the masonry. These contractors having, however, failed to carry on their contract with sufficient energy, it was taken out of their hands on the 4th of May, 1852, and their plant having been purchased by the Company, the plans were revised, and the works were put into a state of efficiency by the Company's men, under the superintendence of Mr. Riddell, the Clerk of the Works, and under the direction of the Author, as the Engineer.

The embankments at C, D, and E, (Plate III.,) were formed by the excavated material from the inner entrance and the enlargement of the dock at B; their seaward faces, where exposed to the action of the waves, were protected by a coating of rubble-stone. The spaces at F, F, having been filled up with ballast from the shipping, an ample area of land was reclaimed from the sea, for the workshops, and for a dépôt for stones and other materials. The inner and outer walls of the east pier, between the groynes Nos. 7 and 8 having been built, and the interval filled with rubble-stone, as shown in Fig. 4, Plate V., a mass of large stones was deposited on the seaward side, as a glacis, to break the force of the waves, which, from the proximity to deep water, here struck the foreshore with great violence. This work having been sufficiently advanced, a dam of timber and clay was put in at G, (Plate III.,) which connected the embankments C and D, on each side of the half-tide basin, and which, the sea being thus shut out, enabled the marly

rock excavated from it to be removed by waggons, drawn by the adjacent engine, up an inclined plane at H, and to be deposited to strengthen the embankments and the sea barrier between the groynes Nos. 6 and 7.

The excavation of the half-tide basin, the building of its surrounding walls, the masonry of the inner entrance, and that of the outer entrance, were let in separate contracts, and this system was pursued, till the completion of the outlet works. The foundations of the eastern pier, from the groyne No. 8, having been executed by the Company's workmen, the upper part of the masonry was also let to contractors; but in consequence of the numerous engagements of the Clerk of the Works, the seaward part has been wholly carried on by contract, the foundations being laid by means of the diving-bell and diving-dress. The head of this pier is founded on the rocks, at the depth of about 8 feet under low-water of spring-tides; the upper masonry will be completed during the ensuing season, to the height of 12 feet above ordinary spring-tides; it will be surrounded by a parapet, and it is intended to have a tide-light erected in the centre of the head. An elevation and section of the groyned pier are given in Plate V. (Figs. 6 and 7.) It is built in the cycloidal form, with the view of allowing the waves, in extreme storms, to pass over it, but under a platform, or gangway of timber, which is to give access to the head. To enable the masonry to withstand the heavy shock of the waves on its seaward side, it is strengthened by a deposit of large rubble-stones from the groyne No. 8, tailing off to some large blocks at the head.

While this work was in progress, an approach was formed from the embankment C, to the point I, (Plate III.,) to the south pier, with vertical timbers fixed into the rock when dry, at the time of low-water of spring-tides, and when beyond it, by piles driven through a mass of clay previously deposited on the rocks for that purpose, and which was likewise protected by a coating of rubble-stone. On arriving at the point I, the work was more permanently constructed. After the timber work was erected in skeleton, the piles were connected at the bottom, by inner and outer planking, between which a further quantity of clay was deposited, and its surface was protected from the wash of the sea, by rubble-stone. Proceeding in this manner, the pier-head, which is planted on a ledge of rocks, was attained. It is not yet fully completed, and the hearting of rubble-stone of the pier is, at present, only carried up to about the level of high-water of neap-tides; but during the ensuing season, it is intended to raise it, with heavier masses of rubble-stone, to the high-water of spring-tides. An elevation and section of this pier are given in Plate V. (Figs. 8 and 9.) The westward end from the point I, (Plate III.,) is intended to take a curved form to the point K, and when the whole is executed in a

durable manner, the approach, connecting it with the half-tide basin between I and C, is to be wholly rooted out. The object is to make it an isolated breakwater pier, to give free dispersion to the waves, in the tidal harbour, during stormy weather. At an after period it may be connected with the land by a slight gang-way of timber.

The tidal harbour, while these works were in course of construction, being thus, in some measure, protected from S. and S.E. gales by this breakwater pier, and from the N. and N.E. by the groyned pier, directions were given to proceed with the channel coffer-dams. No. 1 (Plate III.) was commenced early in the spring of 1853, and being gradually formed in skeleton, with a solid mass of clay at the bottom, to keep the vertical timbers and braces in their places, was closed in the month of August following. But, previously to commencing the excavations within it, and removing the coffer-dam in front of the outer entrance, it was considered prudent, in so exposed a situation, to protect the channel coffer-dam No. 1, from the shocks to which it would be subjected during the severe storms of winter, by erecting the skeleton of coffer-dam No. 2. This was commenced in July 1853, and in that state, with care and attention, it was upheld throughout the winter, and until the month of August 1854, when it was finally closed, and the sea was excluded from the second portion of the channel.

In December 1853, the old dam, in front of the outer entrance, was removed, and the excavation of the rock in the channel, within the coffer-dam No. 1, was commenced with vigour. An incline of timber had been previously formed, adjacent to the northern wing of the outer entrance at L, (Plate III.,) up which the waggons were drawn by a locomotive engine, running on the level ground at the top of the embankment, on the north side of the half-tide basin. This engine drew up, at one time, two loaded waggons, each containing 2 cubic yards, in a minute and a half, the gradient of the incline being 1 in $6\frac{1}{2}$, and the length of the plane being about 225 feet. During the twenty-four hours, (day and night,) three hundred waggons have been drawn up from the bottom: the empty waggons, taking with them the drag chain, when descending by their own gravity. The working expenses of the locomotive, including fuel, were 13*s.* 6*d.* per day. A stationary engine, capable of doing the same work, would have cost 22*s.* 6*d.* per day, so that a considerable saving was effected by the application of this system.

The leakage water was conducted through the half-tide basin, by cutting a trench to the pumping engine adjacent to the inner entrance; but as the excavations of the channel were carried to a greater depth, and the draining trench still lower, it was necessary

to place a small portable steam engine on the seaward side of the outer entrance, which raised the water a few feet, and passed it through the recess culverts, into the half-tide basin and to the large pumping engine.

For the protection of the second channel coffer-dam, the skeleton of No. 3 dam was commenced, in January 1854, and throughout the whole of that year, it was gradually proceeded with, and was maintained in that state till the end of January 1855, when a new contract was entered into for its completion, which was effected in the month of June following. Transverse sections of this coffer-dam are given in Plate V. (Figs. 14, 15, and 16.) The bed of the sea at the eastern end of the intended channel, was composed of a stratum of rough gravel and boulders, the surface of which was 9 feet under low-water of spring-tides, and the marly rock was met with at about 3 feet lower. The main piles were strongly shod with iron, tipped with steel, and firmly driven into the rock, at intervals of 9 feet from centre to centre. The inner main piles were placed opposite to the outer piles, and were connected with them by a cap-cill at the top, strapped and bolted to the piles, and by four tiers of struts and bolts between the level of the cap-cill and low-water mark. Four tiers of double walings connected the outer piles to each other, and four tiers of single walings connected together the inner main piles. A railway, for bringing materials to the spot, was laid on longitudinal beams, resting on and securely fixed to the cap-cills previously mentioned. This skeleton dam was further strengthened, by a series of raking piles driven opposite to each inner main pile, and connected to them by two tiers of struts and bolts, and to each other by two tiers of walings. For further security, strut piles, at intervals of 18 feet, were driven opposite to these raking piles. When the main piles were driven, and the railway was extended, a mass of clay was tipped into the heart of the dam, until it appeared above low-water of spring-tides, and assumed a natural slope outwardly and inwardly. It was then coated with rubble-stone, and in this skeleton state, (Plate V., Figs 14 and 16,) the dam was maintained throughout the winter.

In the spring of 1855, the outer main piles were strengthened by long and short raking shores, placed alternately against each pile; the object being to throw as great a pressure as possible against them, by the weight of the clay embankment, and thus to prevent them from being washed out by the action of the sea. The coffer-dam was gradually closed, (commencing at each outer end,) by placing planks horizontally behind the outer and inner main piles, from the surface of the clay upwards, and filling the space between them with clay deposited from waggons. In the circular end of the dam, intermediate piles were driven, between the walings of the outer row of main piles; and the remaining

spaces were filled up with sheeting piles 6 inches thick. The clay was deposited behind them as they were driven, and was gradually carried up to the full height; when completed, it took an inner slope, and covered up the interior raking piles, as represented in Plate V., Fig. 15.

Although the level of the railway on the dam, was placed at the height of 14 feet above high-water of ordinary spring-tides, yet it was considered probable, that the waves, during stormy weather, would break over the dam and thus wash away the interior clay. To prevent damage from water running down the slope, a strong bulwark of timber was raised to the height of 7 feet above the level of the railway. During storms, very heavy seas struck the outward part of the dam, with great violence, and a mass of water was frequently thrown above the bulwark to a considerable elevation, so that the spray, often attained the height of 20 feet, and sometimes even of 30 feet.

During the formation of these sea dams, a trunk was placed through each, at the level of low-water, with a shuttle therein, so arranged as to allow the water to ebb and flow through each, while open. When all was completed, advantage was taken of a low spring-tide to run off the water to the lowest level, and then closing the shuttles, the remaining quantity was pumped out by the steam engine at the inner entrance.

Upwards of 124,000 cubic yards of marly rock and other material, have been excavated from the channel, and during the whole time, the sea never made a breach in the coffer-dams, nor was the work interrupted during the heaviest gales. The depth in the middle of the channel, in its whole length, was excavated to 12 feet under the level of low-water of spring-tides. The width at the top, at the outer entrance, was 240 feet, and at its seaward end, 107 feet; the greater width was to allow of the proper admission of the water from the sluices, and it was gradually reduced in sectional area to seaward, with the intention of keeping up the force of the scouring current, until lost beyond the pier heads.

There is only a depth of water of about 4 feet on the bar of the River Wear, at low-water of spring-tides, with 14 feet 6 inches rise of tide, making a depth of 18 feet 6 inches at high-water, without any allowance for sand, or lift of sea in stormy weather; consequently, ships of large draught cannot go to sea from the river, or from the docks communicating with it, except at the top of spring-tides. If easterly, or north-easterly winds prevail, they cannot even then proceed on their voyage, in consequence of the swell upon the bar, but have to wait until the following spring-tides. During a continuance of these winds, no ships whatever can leave the port, and hence very large fleets of laden vessels are sometimes

detained for weeks together. Large laden vessels entering the harbour, with valuable cargoes, are subjected to the same disadvantages; timber ships, of which there are many belonging to the port, are often prevented by deficiency of depth of water from entering the harbour, till the spring-tides arrive, and they are frequently under the necessity of being lightened at other places, and sometimes in the adjacent roadstead, by which both ships and cargoes are exposed to additional sea risk.

The southern outlet of the docks will remedy this inconvenience, as the largest ships can proceed to sea at high-water, even of dead neap-tides, during a north-easterly gale, when all exit from the mouth of the river, is impossible. The cill of the outer gates is laid at the depth of 10 feet under low-water of spring-tides, and the channel is excavated 2 feet deeper, making 24 feet 6 inches on the cill at high-water of spring-tides, and 21 feet at high-water of neap-tides, thus giving an increased depth of, at least, 6 feet over the bar at the mouth of the river. The navigation to sea for laden vessels of the ordinary size which now frequent the port, begins two hours before, and terminates two hours after high-water, while light vessels of the ordinary class can enter, or leave the harbour at half-tide. But by the southern outlet, the time for entering and going to sea each tide, will be prolonged to ten hours, (or twenty hours out of the twenty-four,) and there can be no difficulty in admitting light vessels, even at the time of dead low-water. For after the common level ceases between the water in the dock and the sea, the half-tide basin is intended to be used as a lock, for the passage of vessels in and out during the remainder of the tide. The number that can be locked through, is calculated at from fifty to eighty sail during each tide, whilst with the water at one common level, as many as from eighty to one hundred vessels can be passed by steam tugs, before the closing of the gates. Great facilities are provided for emptying the half-tide basin in a few minutes, by drawing the shuttles of the scouring culverts, and filling it again with water from the dock, by capacious culverts.

It was a source of anxiety to the Author, how to keep the sea channel free from deposits of sand and gravel, if brought in during stormy weather. It was considered impossible to remove them by dredging, if formed during the gales of winter. Scouring, therefore, appeared to be the only available method; but to accomplish it in a depth of 12 feet at low-water of spring-tides, and at a reasonable expense, was deemed difficult of attainment. The Author, some years ago, visited the principal French, Flemish and Dutch ports, and found them entirely dependent upon a system of sluicing. He also studied the method formerly in use at Lowestoft, and at a later period, at Dover. He had likewise been engaged to ascertain the effects of the sluices at Hartlepool, and had

expressed opinions upon what could be done at Birkenhead. Combining the whole of this information into his scheme at Sunderland, he formed a series of conduits on each side of the outer entrance. The width of the apertures was, in a great measure, regulated by that of the half-tide basin, after allowing 60 feet for the width of the shipping entrance and the necessary piers of masonry on each side. He then calculated upon a discharge from 34 acres by 4 feet 6 inches in depth, that being the fall between high-water of ordinary spring-tides and the level of water to be maintained in the great dock; and he further assumed this quantity to be discharged in the space of fifteen minutes, at the period of low-water of spring-tides, which thus gave the height of the entering apertures. As the water in its passage through the culverts would be retarded by friction, their area was gradually diminished, so as to make the discharging mouths less than the area of the entering apertures. The loss in the velocity of the current through them, was, therefore, taken into account.

Water, when it enters square orifices, or those of like shape, is known to issue from them in an oblong form, of greater width than their height. It was considered desirable, therefore, to follow the same law in the transverse sections of the conduits, it being in accordance with the object contemplated, of discharging the issuing water in a continuous sheet under the low-water, at different levels, in the form of a fan. It was believed, that, by heaping up the water in mid-channel, and confining it laterally within the sloping sides of the rocky bed, it would quickly attain an altitude capable of generating a velocity, and creating a current outwards to sea. Beyond the pier heads, there is deep water, so that no deposit can take place there, in consequence of the action of the tidal currents, in and out of Hendon Bay and along the coast. By reducing outwardly the sectional area of the channel, in proportion to the retarding force of friction, it was calculated that the water would have a mean current of 6 feet per second in the minimum section, which, at the bottom, would be reduced to 3 miles an hour at the pier-heads, distant 350 yards from the discharging conduits. This current is capable of acting upon all deposits likely to take place in the channel, and yet will not tear up the bottom; but to guard against such effects in the neighbourhood of the sluices, a portion of the channel was pitched with blocks of rubble-stone, set and grouted in Pozzuolana mortar.

A plan of the outer entrance is given in Plate VI., Fig. 1, which shows the cill of masonry faced with Aberdeen granite, the levelling culverts, (extending throughout the whole length of the gate recesses, for the purpose of getting rid of the sand that might lodge there,) and the fan shape of the scouring conduits. A

longitudinal section of one of these, marked A B, with cross sections of it, is given in Plate VI., Figs. 2, 3, 4, 5, and 6; and in Fig. 8, a longitudinal section also of this entrance through its centre, showing the depth of the cill of masonry, the stop-water wall underneath it, the mouths of the emptying culverts, and the outlets of part of the scouring conduits. The other parts of them are shown in Fig. 9, which represents an elevation of the wall facing the tidal harbour. Both of these Figures give the different levels of the outlets of the scouring conduits, and in Fig. 7, is shown a transverse section of the entrance, giving the inlets of the scouring conduits, each being 8 feet 10 inches high and 7 feet wide in the clear, situated beyond the two feeding apertures in the wall of the half-tide basin.

The emptying culverts in the gate recesses of the outer entrance, have each an area of 31 square feet, and can be used for scouring purposes, if necessary. The area of the entering apertures of the main scouring conduits, is 495 square feet; they are closed by eight shuttles, four on each side of the entrance. All the shuttles work in grooves of Aberdeen granite, and can be raised by hydraulic power, either simultaneously, or separately, to their full height, or partially, at pleasure, and can be closed again in like manner.

The hydraulic apparatus was executed by Messrs. Armstrong and Co., of the Elswick Engine Works, near Newcastle-upon-Tyne. It is applied to the opening and shutting of all the sluices, the gates of the outer and inner entrances, the railway bridge, and the sluices of the filling culverts of the half-tide basin. The shuttles of the scouring culverts are each raised to their full height in less than a minute, and can be as rapidly closed, by one man on each side of the entrance. The gates of the entrances, (60 feet between the hollow quoins,) are opened in about two minutes, and closed in about the same time, by one man at each gate, to open and shut them by aid of a handle. These effects are produced by an engine of 30 H. P., situated in a building placed on the southern side of the half-tide basin, which forces the water into an accumulator, whence cast-iron pipes lead to the various rams fixed at the outer and inner entrances. The accumulator is equivalent to the force of a column of water of 900 feet in height, and it works efficiently and economically, considering the vast and multifarious duties it has to perform.

A wrought-iron bridge has been placed across the inner entrance, by Messrs. Armstrong and Co. It is 16 feet wide, and is capable of carrying railway and ordinary carriage traffic. The weight of the bridge, including the balance load, is nearly 200 tons. When required to be opened, it is raised vertically, about 18 inches, by hydraulic power, and is then drawn back by the same means, on

railways, in about two minutes and a half. It can be shut again by the same power, in the like time.

The gates in the outer entrance point inwards; those in the inner entrance point both ways; all of them were constructed by Messrs. Butler and Co., of Stanningley Iron Works, near Leeds. The frames are entirely of cast-iron, and the planking of East Indian teak. The rollers are placed as nearly as possible under each gate, and, consequently, work with great freedom. This is attained, by having the lower rib of greater width than those above it; and to it is also attached a closing rib of teak timber, for the purpose of producing throughout a water-tight joint, with the cill of finely-axed Aberdeen granite. The hollow quoins are also of Aberdeen granite, and the whole masonry of the entrances is executed in a sound and workmanlike manner.

The sea outlet is situated near the brink of deep water, and is exposed to gales from the north-east to the south-east; but the piers shelter the tidal harbour from their violence. The width between their heads is 230 feet, and the piers spread inwardly, to allow the entering waves to be dispersed over an area of about 18 acres. The east pier is built of solid masonry, only to the height of high-water of equinoctial spring-tides, to permit the waves to fall over it, and annihilate those which have a tendency to roll along its inner side. On the other hand, the upper part of the south pier is composed of open timber work, for the purpose of breaking the violence of the agitated water. The waves which travel along the deep-water channel, have again to pass through the entrance of 60 feet into the half-tide basin, before coming in contact with the sea gates of the inner entrance. In such extreme storms, the gates of the outer entrance are drawn back, and the sea gates of the inner entrance being closed, are further secured by two tiers of spars, or struts, planted against them in the recesses.

East and south-east gales are most felt in this tidal harbour, and probably, when the funds of the Company will permit the outlay, the south pier will be built of solid masonry, to the full height of the lift of the tide. Until that time, however, shall arrive, the evil consequences of gales from these points may be guarded against, by leaving in and altering some portions of the channel coffer-dams on the southern side, so as to form interior isolated piers, to conduct the channel waves from the outer entrance, and disperse them over the southern part of the tidal harbour. These coffer-dams are now being rooted out, and the effects produced by them in their existing state, are particularly studied during storms, with the view of cautiously coming to a decision upon their total, or partial removal.

PART III.

Not wishing to interrupt the foregoing description of the works of the sea outlet, the Author has refrained from alluding to those connected with the southern Extension of the Docks. While the former were in progress, a contract was entered into, in August 1853, with Mr. William Brown, (Assoc. Inst. C.E.), for the building of five groynes of masonry, excavating $13\frac{1}{2}$ acres to be added to the great dock, surrounding it with walls, and forming a timber-pond of about 10 acres southward of that extension. The total area of land and water to be reclaimed from the sea, amounted, by this contract, to about 40 acres.

By means of a dam O M P, (Plate III.,) formed with vertical timbers secured to the rocks, with planks attached to them, and backed with clay taken from the adjacent sea cliffs, an area of 7 acres was, in the first instance, reclaimed. It was kept clear from leakage, and rain-water, by the pumping engine at the inner entrance. The wag-gons containing the excavated material were drawn up inclined planes by two steam engines; one placed on the east side at M, and the other on the western side at N. The marly rock and other excavations were deposited on the seaward side of the barrier, southward of the half-tide basin. The embankment, so formed, was acted upon by the waves during every high-tide, until it took a sloping beach and became permanent, by the construction of groyne No. 1.

The timber barrier from the point M, was continued southward on the same system, but was, in some degree, protected by the excavated material which was deposited on its seaward side. During its progress, another barrier of vertical timbers, planking, and clay was constructed from the point Q, nearly at right angles with it, until both were united near the head of groyne No. 2. This junction was effected in November 1854, and soon afterwards, a timber barrier, with a mass of stones, connected it with the head of groyne No. 2, and thus the sea was shut out from the whole area of the extension. The clay from the first cross-dam was then gradually rooted out with the other material, and deposited in the barrier embankment.

The building of the walls was commenced as soon as a portion of the excavation was made, and was afterwards prosecuted with vigour. The pumping engine at the inner entrance kept the whole free from water, until the extension was nearly completed, when another engine was erected on the eastern embankment, in case of accident. The walls are nearly similar in construction to those of the old dock, with the exception of being made thicker on the eastern side, where it is contemplated to place hereafter loads of iron and other heavy articles upon the quay.

The jetties upon which the superstructures for the shipment of

coals are to be erected, are made to accord with the adjacent lines of railway: and to afford standing space for the waggons, between the points of shipment and the main lines belonging to the North-Eastern Railway Company, and a new line formed by the late Marquis of Londonderry, between Sunderland, Seaham, and the southern collieries. The erection of these superstructures and coal-drops is now about to be commenced.

The southern end of the dock has the ordinary battering-wall carried up only to the height of 1 foot under the retained water surface. From thence upwards to the level of the quay, it has a slope, or inclination of 8 horizontal to 1 perpendicular, upon which it is intended to erect timber gearing, to carry a series of travelling cranes, for the facility of delivering such timber as may be required to be piled up on land, or be conveyed direct by railways into the interior of the country. The floating timber may be passed southward into the Timber Pond, which will be divided into sections by piles and booms, and appropriated to different timber merchants, and where it may be sunk in rafts, or be kept afloat, as may best suit their convenience. Preparations are also made in this southern wall, for the entrance of a graving slip, or dock, the construction of which is contemplated.

It was deemed desirable, while the works were in progress, not to remove the whole of the coffer-dam which originally formed the end of the old dock, but to convert it into the northern side of a tongue, or extension of jetty No. 4; and a quay wall being built southward and parallel with it, four additional shipping-berths were obtained, which may be appropriated either for the shipment of coals, or for other commercial purposes. The eastern end of it will be useful, by means of bollards, for guiding ships in and out of the inner entrance of the sea outlet. It also breaks any roll of the water, or the force of the wind in so great a length of dock, and gives facility, by means of stairs and boats, to pass from one side of the dock to the other.

A coffer-dam having been driven across the south-eastern corner of that part of the old dock, at RS, (Plate III.,) the wall separating it from the extension was rooted out, and the whole of the works having been executed, with the exception of part of the coping of the quays, the water was admitted through the sluices of the inner entrance, from the half-tide basin of the sea outlet, on the 24th of October, 1855. Part of the coffer-dam above mentioned having been rooted out, ships were admitted into the dock extension, in the latter end of November.

Groynes Nos. 3, 4, and 5 are not yet constructed, nor is the timber pond yet formed, but preparations are making for this purpose, by having the barrier embankment carried southwards, as far as the head of groyne No. 3, and forming a skeleton dam, between it and the Clay Cliff, south of Hendon Baths. During

the ensuing season, it is intended to prosecute these works, so as to bring the timber pond into use, and this last section of the works to a conclusion.

A Graving Dock is now in course of construction at the northern end, communicating with the tidal harbour and the river. The width between the hollow quoins of the entrance is 45 feet. The cill is laid 16 feet 6 inches under high-water of ordinary spring-tides. The length of the dock between the point of the gates and its eastern end, is 345 feet. The length at the bottom, for the reception of the blocks, is 315 feet. The width at the bottom is 25 feet 8 inches, and at the top, 64 feet. It is founded on the magnesian marly rock, and built with granite and freestone, backed with rubble masonry, all set in blue lias mortar. The heel posts and lower ribs of the gates, are to be of cast-iron, with the remaining ribs and planking, of teak timber. The tender for constructing them is under £2,000; and the whole dock, complete with the ordinary appurtenances, including the steam engine and pumps, will cost about £16,000.

On the 31st December 1855 :—

The expenditure on the whole of the engineering works, including about £20,000 in the purchase of plant, &c., amounted to	£ 492,854
The purchase of property, valuations, arbitrations, salaries, Acts of Parliament, &c., &c.	96,940
	<hr/> 589,794
Estimated expenditure to complete the present plans	60,206
	<hr/>
Total	£650,000

The following table gives a condensed statement of the areas of the dock and basins, the breadths of the entrances, and the depths of water on the cills; with some observations on the rise and fall of the tide on the coast of Sunderland :—

	A.	R.	P.
The area of the Great Dock is now	32	0	25
„ of the Northern Half-Tide Basin	2	2	1
„ of the Northern Tidal Harbour	2	2	36
„ of the Southern Half-Tide Basin	1	2	4
„ of the Southern Tidal Harbour	18	0	0
„ of the Timber Pond (not yet completed)	9	3	2
Total Water Surface.	66	2	28
Area of Quays, Roads, and Land adjacent	80	1	12
	<hr/>		
Total Area	147	0	0

About 127 acres of the above area are gained from the waters of the North Sea.
[1855-56. N.S.] 2 H

	Ft.	In.
The Depth of Water in the Dock at ordinary Spring-Tides .	24	0
" " on the Ebbing of each Tide .	19	6
" " on the cill of the Northern 60 ft. Entrance	20	6
" " of the Southern Inner 60 ft. "	22	6
" " Outer 60 ft. "	24	6
" " in the Channel at Low-water of Spring-Tides	12	0
" " " of Neap Do.	17	0
Total Quay space in the Great Dock	7,622	0
There are fifteen Self-acting Drops now at work, and ten more are to be erected, (some of them double,) for the shipment of Coals.		

The High-water of ordinary Spring-Tides rises 14 feet 6 inches above the Low-water of the same Tides.

The High-water of an Equinoctial Spring-Tide rises 3 feet 9 inches above the High-water of an ordinary Spring-Tide.

Hence Spring-Tides rise, on an average, from 14 to 15 feet; but they vary from 13 to 18 feet.

The High-water of Neap-Tides rises 3 feet 6 inches under the High-water line of an ordinary Spring-Tide.

The Low-water of Neap-Tides rises 9 feet 6 inches under the High-water line of an ordinary Spring-Tide.

Hence Neap-Tides rise 6 feet, but they vary from 5 to 10 feet.

The Time of High-water Full and Change, is 3h. 22m.

The Winds from N.N.W. to N.N.E. make the Highest Tides, and check the Ebbs.

The Winds from S.S.E. to S.S.W. depress the High-waters, and make Low Ebbs.

The Winds from E.N.E. to E.S.E. make the Heaviest Seas.

The Paper is illustrated by a series of diagrams, whence the Plates 3, 4, 5, and 6, and the woodcut, (Fig. 1,) have been compiled.

NORTHERN PORTION CONNECTED WITH THE RIVER

SUNDERLAND DOCKS.

PLAN OF THE WET DOCKS AND TIDE BASINS 1856.

Plate presented by The Author

WEST WALL OF DOCK

SOUTH BREAKWATER PIER

RIVER COFFERDAM

DOCK COFFERDAM

CHANNEL COFFERDAM N° 3

0 5 10 20 30 40 50 Feet

Plate presented by The Author

John Murray, del.

Day & Son, Lith. to the Queen.

Fig. 2

Fig. 1 at D.

Fig.5 at E

Fig. 6 at F

Plate presented by The Author