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JOSHUA FIELD, President, in the Chair.

No. 813. "Description of the Cofferdam at Great Grimsby."  
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It rarely happens that in the execution of engineering works, permanent constructions can be completed, without the previous expenditure of considerable labour on preliminary, or temporary structures. This is more particularly the case with works of hydraulic engineering, where the exclusion of the water from the scene of future operations, is usually the first step requisite to be taken; whilst it not unfrequently involves as many difficulties as the subsequent permanent operations, and demands, perhaps, even more constructive skill than the latter, owing to the less ponderous character of the materials employed for such purposes. Structures of this class, therefore, well deserve the attention of the engineer, and accounts of the methods employed, particularly for works on a large scale, form valuable records for the archives of the Institution. With this view the following description has been drawn up, of the cofferdam used in the construction of the new Dock at Great Grimsby, a structure which has scarcely its parallel for magnitude, boldness of design, and exposure of position.

Grimsby, a borough and port of considerable antiquity, lies on the south, or Lincolnshire shore of the mouth of the river Humber, whose breadth at this, its widest point, is about seven miles; and at nearly the same distance south-eastward, the estuary opens into the sea. Within this area, of nearly seven miles square, is an excellent and

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\* The discussion on this Paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

capacious roadstead, possessing space and depth of water for a great number of every class of shipping, and forming a well-known and valuable anchorage for vessels navigating the North Sea.

The Humber estuary is a natural refuge harbour, protected by the configuration of the shore on both sides, and particularly by that on the north side, which terminates in a promontory, whose extremity is known as the Spurn Head. The general deficiency of ports along this portion of the eastern coast, and the great local advantages presented by the position of Grimsby, induced the construction of the new and extensive dock, which is now being carried into execution, whilst its importance has been further increased by being selected for the terminus of two railways, which place it in direct communication with London and Manchester respectively.

The new dock-works, which are now rapidly advancing to completion, were commenced in the spring of the year 1846, from the designs of Mr. Rendel, and under his direction as engineer-in-chief, and that of Mr. Adam Smith, as resident engineer.

In compliance with a stipulation on the part of the Admiralty, it was necessary, that the entrances to the docks should be in sufficiently deep water for the passage of the heaviest vessel in Her Majesty's navy; and it was considered equally important for commercial purposes, to afford sufficient depth for the entrance and exit of ordinary merchant ships, at all times of the tide. It was therefore determined to construct the dock entrance, in the deep water of the natural channel of the river, although the extreme flatness of the shore rendered such a projection necessarily very extensive.

The existing dock at Grimsby has its entrance laid at the margin of high water, and is approached along a narrow creek, or channel, which is almost dry at low water. The consequent difficulty of access to this float, even at high water, and its total inaccessibility at other times, greatly impair its utility, and render it, although 19 acres in extent, quite unfitted for large vessels. The present entrance is shown on the general plan (Plate I. Fig. 1), and it will be observed, that the new works begin at the line of high water, just where the old ones terminate. The whole area of the new enclosure amounts to 138 acres, entirely recovered from the river; the artificial boundaries measure nearly a mile and a-half, and the projection from the margin of high water is five-eighths of a mile.

It will easily be understood, therefore, in how exposed and isolated a position the coffer-dam had to be constructed. Immediately in its front, and to the eastward, there is an estuary seven miles in width, and on the north-west, the whole current of the Humber, for a reach of twenty miles in length; whilst against the front, or

outside, there is a rise of tide of 25 feet, and on the inside an excavated depth of 11 feet below low water, which is necessary for laying the foundation of the locks. To this must also be added, that the Humber is frequently exposed to violent storms, and finally, that this coffer-dam, unlike most structures of its class, must depend entirely on its own strength and form of construction for the requisite stability, as there is nothing in its whole length of 1,500 feet from which to derive support of any kind. Under such difficult circumstances, therefore, it is the more satisfactory to record, that the work has been completed without any necessity arising for altering, in the course of its execution, a single feature of the design.

The plan of the coffer-dam (Plate I. Fig. 1) is that of a compound curve, formed by two circular arcs, of 150 feet and 800 feet radii respectively, with a straight return on the west side. The versed sine of the curved portion is 200 feet, or nearly one-fifth of the span. The dam (Plate I. Figs. 2 and 3) consists of three rows of whole timber sheet piling, of Baltic yellow pine, from 13 inches to 15 inches square; the outside row batters half an inch per foot, and the other two rows are upright. The sheeting was all driven between gauge, or bay piles, placed 10 feet apart, and the power employed was that of two stationary 30 H.P. high-pressure engines, working twelve winding drums, from which the chains were led to ordinary pile engines. The three last piles driven in each bay, were accurately sawn to a taper, in opposite directions, so as to wedge the remaining piles of the bay closely together. The average length of the piles in the first row is 55 feet, and in that of the other two rows 45 feet, though many of them exceed 60 feet in length. The height of the piles above the ground is from 28 feet to 30 feet, all being driven down sufficiently far to enter a bed of hard clay. The width between the first two rows of piling is 7 feet, and that between the centre and back rows is 6 feet. The puddle clay occupying these spaces, was mixed, for the first 5 feet in height, with one-fourth part of small broken chalkstone, and perfect consolidation was insured by tipping the puddle throughout, from earth waggons, on the top of the dam; single barrow loads, even from that height, being entirely forbidden. The front and back rows of piling are secured by five tiers of whole timber double walings; but in the centre row, the three lowest tiers of waling are replaced by bands of wrought-iron, 6 inches broad by 1 inch thick, keyed together in lengths of 12 feet, and forming a continuous tie on either side of the piling, from the two extremities of the dam. In this capacity alone they must be very

serviceable, but the principal object in adopting them, was to insure an uninterrupted surface on both the sides, or faces of the sheet piling, in order that the puddle might, at all times, lie closely against it, without leaving any of those voids, which are inseparable from the use of ordinary timber walings in such situations, and which serve as channels for any water that may pass along the through bolts.

Another precaution against the admission of water, is observed in the arrangement of the long bolts, which are all distributed in such a manner as to "break joint," never passing entirely through the dam, but in every case terminating at the centre row of piling; they are screwed up against the wrought-iron plating, between which and the face of the pile, a washer of vulcanized India rubber is introduced. The long bolts are  $2\frac{1}{4}$  inches in diameter, at the lowest tier of walings, diminishing upwards to  $1\frac{1}{4}$  inch; and in every bay of 25 feet, that is, between two counterforts, there are six through bolts for each tier of walings, or thirty in each bay. The washer plates under the heads and nuts of the long bolts are of cast-iron, 10 inches square, so as to give a large bearing surface on the timber. For the purpose of distributing the pressure, a cleat of hard wood, 5 feet, or 6 feet in length, is introduced between the walings and the washers, under all the bolt-heads on the exterior face of the dam.

It is, however, in the method of giving interior support to the structure, that the greatest constructive excellence and originality of design will be found to exist. Instead of the rows of single piles, generally driven at a distance from a dam, with struts and braces carried back against them, buttresses, or counterforts, each 18 feet in depth, are introduced; they consist of close-driven rows of whole timber sheet piling, springing immediately from the back row of the main pile sheeting, and placed at intervals of 25 feet throughout the work. These counterforts are strengthened by tiers of walings, corresponding with those on the inner row of the dam, and connected with them, by strong wrought-iron angle-plates, or knees, 6 feet in length, through each of which a long bolt passes; also by horizontal diagonal struts of whole timber, from 12 feet to 13 feet in length, abutting in cast-iron dovetailed sockets, 1 inch thick; of these struts there are three rows in the height of the dam, placed 4 feet 6 inches and 5 feet apart. By this arrangement, those portions of the dam included between the counterforts, derive the full benefit of the strength of the latter, so that the whole structure may be said to stand virtually on a base equal to 32 feet,

or the width of the dam, plus the depth of the counterfort. The most decided success has attended this form of construction, for nothing can be more satisfactory, than the manner in which the coffer-dam has resisted the daily pressure of the water, for the fourteen months which have elapsed since its completion, as well as the violence of several severe storms, to which it has been exposed during that period.\*

In order, however, to test its stability, with the greatest degree of accuracy, the following arrangement was adopted. Opposite to every fourth counterfort, and at some distance from it, a single pile was driven, supporting a horizontal arm, or index, fixed at the level of high-water spring tides, while its extremity, graduated to parts of an inch, rested against the counterfort, without being attached to it, so that any motion of the latter might be observed and measured on the graduated scale. The result of the observations made in this manner, inspired perfect confidence in the stability of the work, for under the pressure of high-water spring tides, the deflection amounted only to about 3 inches; and when some rubble-stone, required subsequently for masonry on the same spot, had been deposited behind the counterforts, the deflexion was reduced to an inch, or an inch and a-half. It should be observed, that the resisting power of the dam was so great, that in severe storms, even during the late equinoctial gales, the shocks of the waves against the coffer-dam scarcely produced any visible, or sensible effect. The arrangements before described, for guarding against leakage, have been quite as effectual as those for securing strength, for the interior of the work is perfectly dry.

The reasons have already been given, for the selection of the position of the coffer-dam. An examination of the ground by borings, previous to the commencement of the works, furnished additional motives for this selection. From this examination, it appeared, that the ground on and near the present site of the coffer-dam afforded an excellent foundation, not only for the dam itself, but also for the two large locks, which were to be constructed immediately behind it. The same borings showed, that the intervening space between this position, and the margin of high water, contained ground of a very different description. It was nevertheless necessary to traverse this ground, in the formation of the wharfs and em-

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\* It may be added, that since this paper was read, the coffer-dam has been exposed to the severe gales and unusually high tide, which occurred in February, 1850.

bankments which were to complete the enclosure, and connect the coffer-dam with the shore. The foundation on the site of the coffer-dam and of the locks, consisted of an excellent hard clay, extending down to the chalk rock, which was reached at an average depth of 53 feet below the level of low water. A little nearer to the shore, this bed was replaced by a deep deposit of soft silty clay and sand, which appeared to fill the ancient channel of some creek, or outfall, that very probably once existed at this spot. Such modifications and precautions, therefore, as the treacherous nature of the ground appeared to require, were necessarily resorted to, in the formation of the works passing over it.

The structure leading to the coffer-dam on the west side, consisted of an exterior line of sheet piling, backed by a wall of chalk-stone rubble, behind which, a puddle-bank was raised. The chief precaution taken, was that of loading the soft ground as gently as possible, and avoiding any lateral pressure upon the piling. Accordingly, the base of the puddle-bank was spread over a considerable width, the bank itself was raised cautiously, in thin successive courses, and for the last 4 feet of its height, layers of fascines, mixed with small broken chalk-stone, were substituted for solid clay, and the latter was merely sloped over the fascines, to form a puddle facing; by these expedients the difficulty was successfully met.

The ground to the eastward of the coffer-dam, was of too yielding a nature to support the necessary weight, and the various methods attempted for lightening and distributing the load, all proving unsuccessful, it was determined to adopt an opposite course, and to deposit upon it, with the greatest rapidity, a mass of heavy material, which would sink until it reached a firm foundation, and would displace in its descent all the soft and yielding ground. Accordingly, a ponderous bank of chalk-stone was quickly raised, which, after causing a series of slips and subsidences, effectually came to rest, forming for itself a natural slope of about seven to one. Some fears were entertained, however, lest the puddle-wall, which was situated between this bank of chalk and a smaller chalk-stone wall, should have been severed, or compressed in the course of these slips, but by dint of constant watchfulness and caution, it was maintained unbroken. After the occurrence of any slip, every care was taken to examine the puddle throughout, and open out any portions that appeared most likely to have suffered, and when the chalk-stone bank had subsided and consolidated, the puddle was brought up, upon its slope, as a facing.

These slips, which occurred during the summer of 1848, were

mastered by the end of the autumn, when the tidal water was finally excluded from the whole enclosure, and the large area of 138 acres has ever since been completely free from all leakage, or soakage of any kind; indeed, the works were so perfectly dry, that pumps, 16 inches in diameter, working three hours, and sometimes scarcely one, out of every twenty-four, were amply sufficient for every purpose of drainage.

At the east end of the coffer-dam there is an opening, 20 feet in width, provided with a pair of flood-gates (Plate I. Fig. 4). These gates are rather peculiar in their construction, being strengthened between each bar by truss-rods, which pass over a cast-iron bridge in the centre of their length, and are screwed up at the extremities, through the heel and mitre-posts. The originality of the arrangement consists less in the form of the truss itself, than in its application to the purpose of lock-gates, the curved, or cambered form of which, render this mode of increasing their strength peculiarly suitable.

This opening was requisite for the vessels employed in conveying materials during the construction of the outer works, and was the only permanent one into the enclosure, with the exception of the two culverts in the coffer-dam, each 3 feet in diameter; when the outer works approached completion, it became necessary to close the temporary openings, which had been maintained as long as possible, in other parts of the work, prior to the final exclusion of the water, so that the whole tide had, at last, to enter and quit the enclosure, with each flow and ebb, through this single opening of 20 feet in width.

The influx of the water was unimportant, as it only occasioned external pressure, which the works were of course calculated to resist; but the efflux exposed them, on the concave and weak side, to the pressure of a head of water, 6 feet in depth. The works, however, never sustained the slightest injury from this pressure, which, while it imposed a severe test upon their strength, also afforded satisfactory evidence of their soundness and freedom from leakage.

As a practical example of the discharge of water through large apertures, it may be interesting to state the manner of its efflux. The whole quantity of water passing through the opening at spring tides, must have amounted to forty-two millions of cubic feet; during the first half of the discharge, the fall of the tide in the river exceeded that of the water through the aperture, until, as already stated, a head of 6 feet, and even once of 7 feet, had been attained in the enclosure; the order then became reversed, and during the second half of the ebb, the fall of the water in the

enclosure gained upon that of the river, until by the time of low water, an equilibrium had been restored.\*

In alluding to the nature of the foundations, the chalk rock has been mentioned, as occurring in the enclosure of the works, at an average depth of 53 feet below low water. The outcrop of this formation takes place a few miles inland, in the range known as the Wolds of Lincolnshire, and to the vicinity of which, Grimsby, in common with the surrounding district, probably owes its never-failing supply of water, which, besides overflowing in a number of natural artesian springs, may be abundantly obtained by boring from 3 yards to 10 yards into the chalk. As an example it may be mentioned, that a boring, 5 inches in diameter, yielded a continuous supply of 150 gallons per minute, at about the level of half-tide. It is quite obvious to what a variety of useful purposes this resource may hereafter be applied.

In closing this description of the coffer-dam, it may be remarked, that the permanent works for the Port of Grimsby, are designed on a scale of magnitude, commensurate with that of the structure which was formed to protect them in their growth. They include a dock, or float, of an area of twenty acres, affording an extent of three-

\* Mr. Beardmore, thinking that it might prove interesting, has subjoined the following Table, based on the formula  $8 \cdot 04 \sqrt{h}$  for the velocity in feet per second, and showing the full theoretical discharge due to the observed heads.

At the end of each Half-hour.			
Fall of Tide.	Accumulated Head.	Velocity.	Mean Discharge.
Feet.	Feet.	Feet per Minute.	Cubic Feet per Minute.
·50	·32	272	43,928
1·42	1·00	482	116,470
1·75	1·60	610	155,500
1·75	2·00	681	164,684
2·25	3·30	875	177,970
2·66	4·80	1,056	194,986
2·67	6·25	1,205	190,918
2·25	7·10	1,282	168,461
1·25	3·75	933	122,929
Tide left	2·35	723	69,425
gate cill	1·60	610	32,535
			9,760
Total . . .			1,447,562

Then  $1,447,562 \times 30$  minutes = 43,426,860 cubic feet; being the total discharge through the opening during the tide; the actual volume which passed through, is estimated from other sources at 42,000,000 cubic feet, or 0·96 of the theoretical amount.

Fig. 1.  
GENERAL PLAN

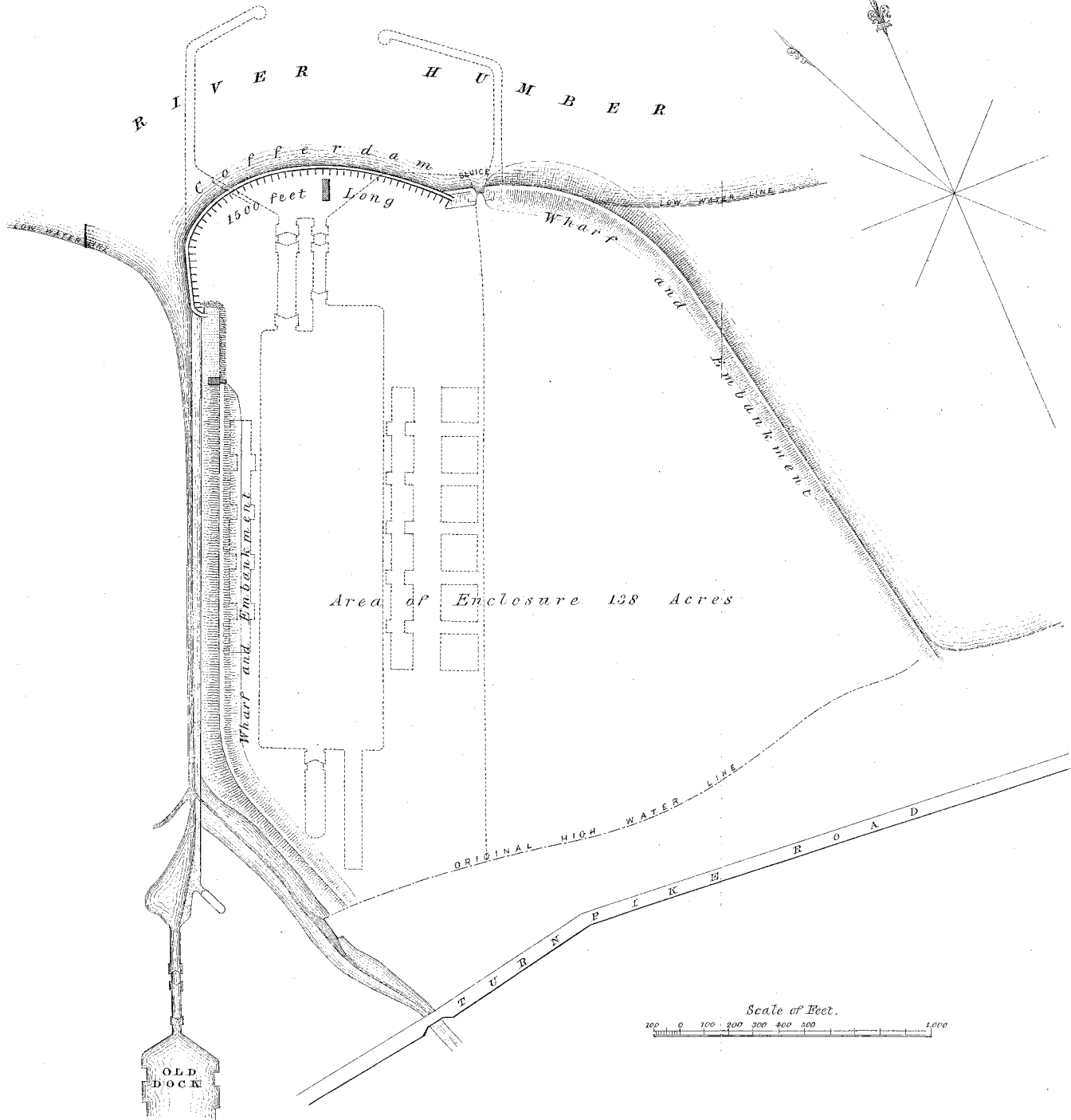
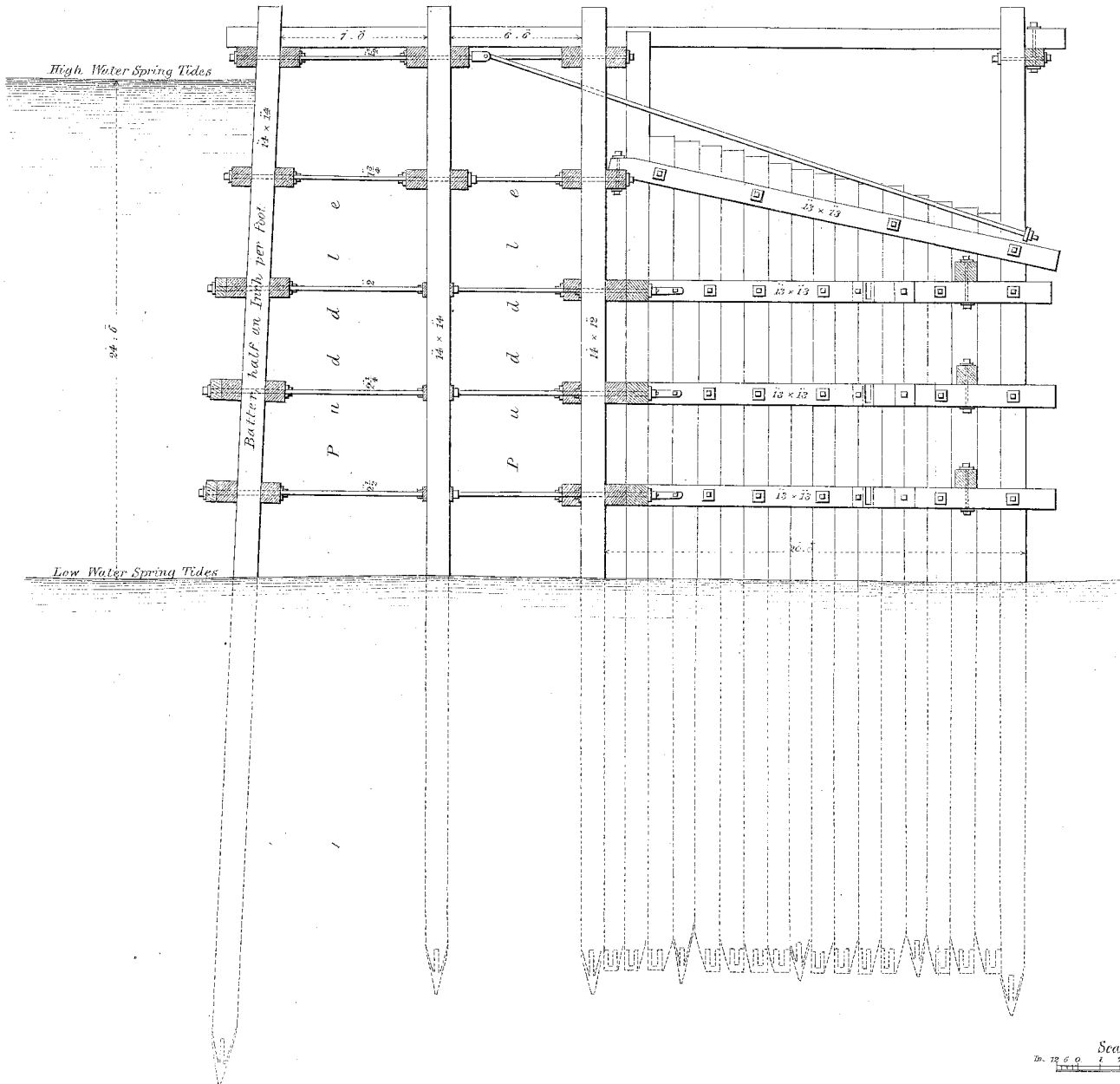


Fig. 2  
TRANSVERSE SECTION.



COFFER DAM

Fig. 3.  
PLAN

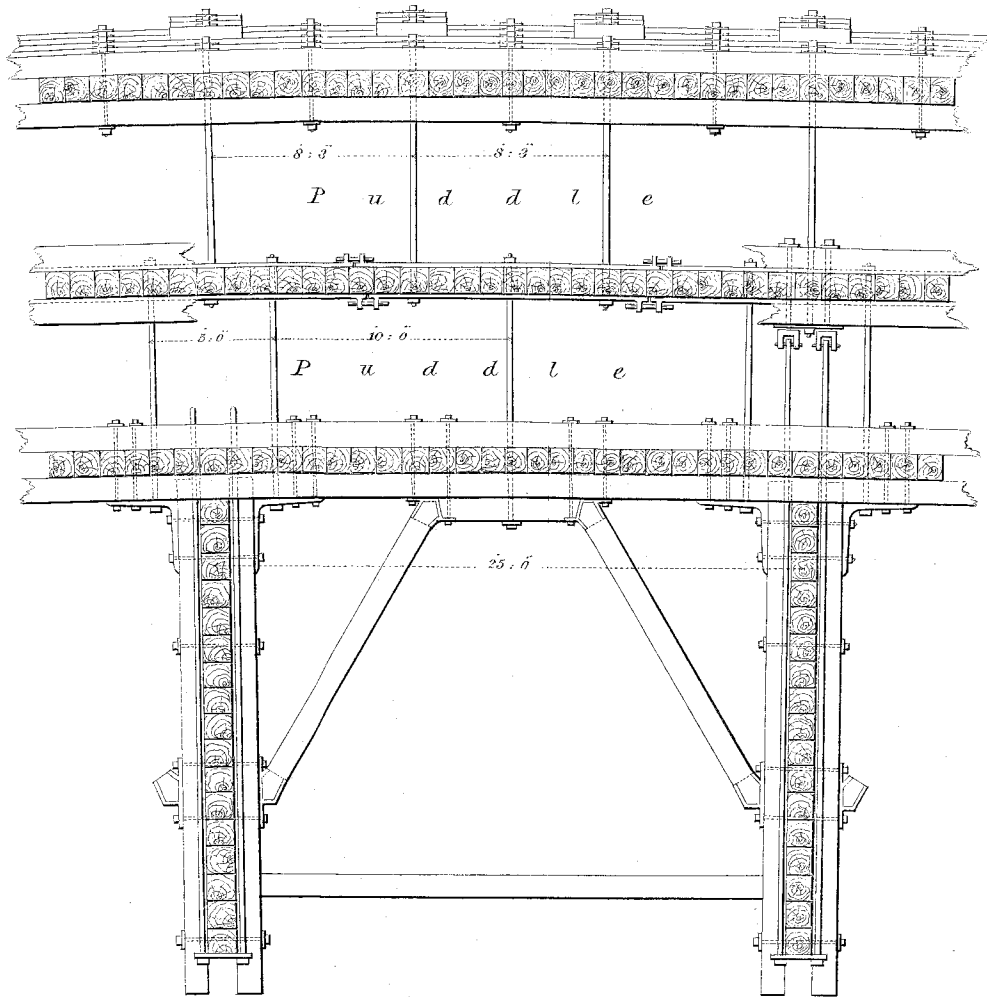
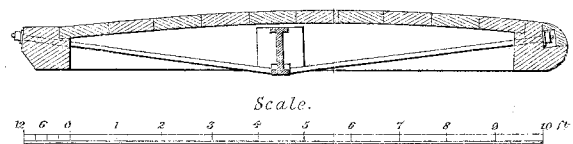


Fig. 4.  
HORIZONTAL SECTION OF TRUSSED SLUICE-GATE.



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quarters of a mile of quays, with graving docks and slips opening into the float, and warehouses lining the quays, and fronted by the railway, of which Grimsby has been aptly defined as the "Water Terminus." Of the two entrance locks to this float, one will measure 70 feet in width, and 300 feet in length of the pen, the other 45 feet in width, and 200 feet in length of the pen; their depth of water has been before described. These works, of which the first stone was laid by H.R.H. Prince Albert in the month of April, 1849, are now actively progressing, and the subject of the Grimsby Dock will probably be again presented to the notice of this Institution, when the remaining portions of the undertaking pass from the hands of the engineer, to take their place among the many noble works of their class, which so properly adorn this maritime and commercial country.

The communication is illustrated by three drawings, Nos. 4458 to 4460 (from which Plate I. is compiled), showing the general plan of the works, the details of the construction of the coffer-dam, and the mode of trussing the flood-gates.

Mr. CUBITT, *V.P.*, said, that after the complete description given in the paper, he could offer nothing, except a general expression of admiration of the extent of the works, and of the skill exhibited in their execution. These monuments of engineering skill must be seen to be appreciated, and no description could give a just idea of their merits. He believed the coffer-dam exceeded in extent any similar construction in the kingdom; and, as a dam, it was the longest, the strongest, the deepest, and the soundest work of the kind he had ever seen. He hoped soon to see the object of the dam fulfilled, and the great works, so ably projected by Mr. Rendel, successfully completed, and filled with shipping; when it was to be expected, that Mr. Neate would record that success, by another paper, as interesting as the one just read.

Mr. RENDEL, *V.P.*, said, in answer to questions from Members, that although the general design of the coffer-dam was of the ordinary description, there were some novelties involved in its construction, and these he would allude to somewhat more fully than had been done in the paper. All engineers who had constructed coffer-dams, to resist a great pressure of water, knew how difficult it was to prevent leaks, which could only be accomplished, by getting the puddle to set so closely against the piles, as to arrest any percolations at the outset. This common defect had been, in the present case, obviated by two simple contrivances; the first of which was, the substitution of the continuous iron plate-bands, for