for their own repute, can take pleasure in a libel directed against others, the members of this Institution may feel sure that, in vindicating the honour of the Profession, they will have the sympathy of all honourable men.

No. 1,219.—"Description of the Low Water Basin at Birkenhead." By JOHN ELLACOTT, M. Inst. C.E.[1]

DISCUSSION.

Mr. MURRAY observed that the Great Low Water Basin had been more or less prominently before the public since the year 1844. The formation of such a work on the Birkenhead side, having its bottom 12 feet under low water of spring tides, while the sill of Prince's Dock at Liverpool was 2 feet 10 inches above such low water, would be of great advantage to the trade of the Mersey, enabling vessels to enter the Low Water Basin at Birkenhead, and get out of the tideway on that side of the river.

The Basin of 1844 was to have been 37 acres in extent, with one fork extending towards Birkenhead, and another up Wallasey Pool. Both of these forks were to have had openings for the passage of vessels into and out of the Great Float, with a series of sluices on each side of them extending across and near the bottom of the Low Water Basin. It was proposed to run such a current from these sluices as to have kept the Basin free from deposits; and he was an advocate for carrying out that project. In 1853 the Birkenhead Fork was abandoned, thus reducing the Low Water Basin to 27 acres. The main fork towards Wallasey Pool was to have been 720 feet in length, and from 350 feet to 400 feet in breadth; and the bottom was to have been 20 feet 9 inches below the level of the Old Dock sill, or 12 feet under low water of spring tides. The railway interests at Birkenhead were exceedingly desirous to maintain the Great Low Water Basin, and to render it efficient by means of sluicing. The system had, indeed, been carried out, as related in the Paper; but it was not done in the manner recommended by the late Mr. Rendel. For although the levels of the sills of the sluices were not much at variance with the design of that engineer, being 2 feet 6 inches above the bottom of the Low Water Basin, yet instead of the water having a short run through the sluicing passage, so as to enable the sluices to act with efficiency, and excavate a space in front of them of 50 acres in Wallasey Pool, as recommended by Sir John Rennie and other engineers in 1848,—a different system had been adopted, the inner

[1] This Paper is printed in extenso in the last volume of the Minutes of Proceedings, vol. xxviii., pp. 518—535.

ends of the bottoms of the sluicing passages or chambers being at a level of 8 feet below the level of the Old Dock sill, and 265 feet, on an average, distant from the paddles, the sills of which had been placed at the level of 18 feet below the Old Dock sill; thus creating a fall outwardly of 10 feet, and from the sills of the paddles to the extremity of the apron another fall of 3 feet; making a total of 13 feet from the inlet sill of the sluicing passages to the bottom of the Low Water Basin.

The effect of such a fall, with the water issuing from the sluices, would tend to tear up the bottom at the extremity of the apron. Now, he was convinced, from the papers and sketches laid before him in 1844, that this was not Mr. Rendel's intention. The sluices were to have been placed at such a level that the water issuing from them would not act upon the bottom, but would pass forward, and, uniting with the currents from the contiguous sluices over the whole breadth of the basin, both in the main and the Birkenhead forks, would have produced a current of from 2 miles to 3 miles an hour throughout its entire length; whereas the 13-feet fall before alluded to had a tendency to injure the bottom; at all events, to create regurgitations in the filaments of water, and retard the velocity of the current. It had been stated in the Paper that the average duration of each sluicing was about twenty minutes, and that the effect on fifty-six occasions had been to reduce the accumulations of deposit brought in from the river to the amount of 106,100 cubic yards. In that calculation it was evident the Author of the Paper had not taken into account the large mass of material sucked out or withdrawn from Wallasey Pool. Between the dam, in which the sluices were placed, and Wallasey bridge the distance was about 2 miles, with an average breadth of water of 150 yards; and he was of opinion that, over the whole of that area, the bottom had been lowered at least 1 foot, and probably more near the sluices. If that were taken into account, 176,000 cubic yards sucked out from the Pool by the sluicings, added to the 106,100 cubic yards from the Basin would make 282,100 cubic yards discharged into the Mersey by these operations; and, therefore, he quite agreed with the Author that the sluicing was capable of maintaining the Low Water Basin at its proper depth. It was proved that the sluicing had done more; for at the time the operations commenced, a mass of clay 32 inches in depth had been carried from the bursting of the river cofferdam, and deposited over the area within it; and that at the end of ten months, when the scour had operated with more or less regularity through the twenty sluices, the deposit had been reduced to a depth of 14 inches, leading to the conclusion that, when the permanent level was reached, a less amount of scouring power would have been sufficient to maintain the required depth. Now, how had the operation of sluicing been conducted? It was not stated to what height the sluices had been drawn; but it was presumed that they were opened to their full extent. A body of water had been allowed to rush out of the sluices at the rate of from 12 miles to 20 miles an hour. In making trial of such an important work as this, it would have been judicious to have drawn the sluices about 18 inches or a little more at one time, opening some of them, keeping others closed, and interspersing the apertures in such a way as to cause the current to act in the most efficient manner throughout the Low Water Basin. He believed if these sluices had been so regulated, a current throughout the basin of about 2 miles per hour would have been found sufficient to clear it of all ordinary deposits, especially if occasional dredging had been employed to remove, or to break up, the clay that had been brought in from the river cofferdam. Drawing them in the way it was manifest they had been done, suddenly, and to their full extent, a volume of water had been discharged for the purpose of creating a great scour upon the bottom, with the probability of doing damage to the masonry connected with the sluices. He felt most strongly that had this been done in a proper manner, no such accidents would have occurred as were recorded in the Paper. He believed that, if the water had been let out judiciously from Wallasey Pool, all the required purposes would have been effected, and that the works would have been most efficient, and have done credit to the engineer who designed them.

Mr. Abernethy said, it was stated in the Paper, that, in 1856, when the Birkenhead Docks were transferred to the Liverpool Corporation, an alteration in the plans was made by Mr. Hartley, but that the Low Water Basin still remained a great feature of the plan. That was not the case. The parliamentary plan of Mr. Hartley abolished the Low Water Basin, and substituted in its place an outer dock, with locks, and a small entrance basin recessed back only 400 feet from the Mersey. Mr. Hartley was strongly of opinion, that the Low Water Basin, in connection with a great floating dock at Wallasey Pool, was inexpedient, and ought to be abandoned. The Low Water Basin was subsequently forced upon Mr. Hartley and the Liverpool Corporation, by the railway interests. The original idea in treating Wallasey Pool was that it should form a great highway, leading to docks to be ultimately formed on its margin; and the plan of 1844 showed an outer basin of 37 acres area, with single pairs of gates, and a small lock between it and Wallasey Pool. The gates were to be closed at certain times of the tide, and at low water a volume of water was to be discharged to keep the basin open, and to prevent deposit within it. But in 1858 an alteration was made. Wallasey Pool was no longer regarded as a highway, but as a great dock; and, obviously what applied in the one case could not apply in the other. The mode of sluicing proposed was inapplicable as far as the working of a dock was concerned; and this was one argument adduced against it at the time. Although the Author had given certain results, which had taken place from the effects of fifty-six sluicings, Mr. Abernethy was still of opinion that it would have been impossible to have kept the Low Water Basin open by that process. To obtain a velocity of current through the Basin equivalent to 2 miles an hour at its mouth, it was necessary to discharge the water from the level of high-water spring tides, about 18 feet 3 inches above the Old Dock sill, which gave a maximum head of 27 feet. Now it so happened that there were, on an average, three hundred and fifteen days in the year when the tide did not attain that level; moreover, in order to maintain a proper depth of water in the Float, it was specified that it should not be run down to a lower level than 13 feet on the dock sill. For one hundred and seven days the tide did not rise even to that level; therefore it was manifest that the water required to produce the necessary current to keep the Low Water Basin clear was not available. Again, it was contended, that by discharging a volume of water through sluices 2 feet above the bottom of the Basin, a current would result, equivalent to a subaqueous river, which would keep the bottom of the Basin clear. Now, the projectile force of the current would extend only to about three times the available head of water. After that it would pass to the surface, and then a certain current would flow throughout the whole Basin, but not analogous to the current of a river having an inclined bed with equivalent top and bottom velocities, because the body of water in the Basin was still, and the bed horizontal; and although there would be a current through the Basin, it would be mainly on the surface, and not proportionately at the bottom. He was struck with the remark in the Paper, relative to the experiments during spring tides, that while the velocity on the surface was $3\frac{1}{4}$ knots per hour, at 5 feet from the bottom, it was only 1 knot, and at 9 inches only $\frac{1}{2}$ a knot, a velocity which, he submitted, was altogether insufficient to remove deposit. It was to be regretted that the Author of the Paper had not produced a section showing the bottom of the Basin on the termination of the sluicing experiments. It was stated, that the average depth was 12 feet; but so far as navigation was concerned, an average depth was not the test. It appeared that, in some places, holes had been excavated to a much greater depth, and in all probability there would be proportionate shoals. He had always maintained that the varying level, due to running the water down from spring-tide level to 13 feet above the Old Dock sill—a variation of 5 feet, and the consequent creation of a current in the dock, was commercially objectionable, and ought not to be carried out. He further maintained that there was no volume of water available to produce the requisite current to keep the Basin open; and, therefore, he thought the Liverpool authorities acted wisely in determining to abandon the project, and at once to make a dock, with a small tidal basin, so far recessed from the Mersey that it could be kept open by sluicing from the gates alone.

Mr. WEBSTER, Q.C., observed that the Paper gave an account of sluicing operations of a remarkable character, and of a kind that probably never existed before. It was said that the velocity of the water through the sluices was 20 miles an hour; but whether this were the case or not, attention should be called to the fact that nothing was more diametrically opposite than the existing state of things to the principles on which these works were originally proposed by Mr. Rendel. Mr. Murray had stated, that in point of fact, there was a fall of as much as 13 feet, which led to the mischief of which he spoke. Now, although he did not conceive this was due to the fall, yet he conceived what Mr. Murray pointed out, viz., that owing to the arrangement of these sluices, and the inclined masonry channel, the water received an inclined action downwards, due to that great fall. Throughout the controversy in 1844, in which the late Sir W. Cubitt and Professor Challis took part, it was distinctly urged that it was not intended that the water should have an inclined downward action; but that it should flow from the sluices horizontally. The sluicing had failed from projecting the water downwards; which so projected, followed the same law as a solid mass; it was reflected upwards, and produced the upper current. The system proposed by Mr. Rendel had no inclined action downwards, but a mere horizontal discharge at the bottom, so as thereby to produce a subaqueous current, and a general current outwards, throughout the whole basin, which it was his great object to maintain. These were physical principles of which there could be no doubt, and he trusted they would be dealt with as such. Professor Challis, in his evidence, furnished an instance of a man of abstract science, without practical experience, having predicted results from purely mathematical deductions, which were verified in a most remarkable manner. Those who wished to see how that result was attained should refer to the recent work by Professor Challis, "on the Principles of Mathematics and Physics."[1] The principle was this:—If in the discharge of the water into a basin, it was given a downward action, a reflection upwards ensued, which was never got rid of. Such reflection had a tendency to produce a bar at the bottom; the water at the bottom was acted on by a series of waves which had less and less influence as the distance increased;

[1] *Vide* "Notes on the Principles of Pure and Applied Calculations; and applications of Mathematical Principles to Physics." By the Rev. J. Challis. 8vo., Cambridge, 1869.

but if a horizontal action at the bottom was given to a mass of water, whatever might be the distances to the mouth of the basin, having, as at Birkenhead, not a closed mouth—because that was one of the fallacies deduced from sluicing into water in a basin with a closed end, as a lock-gate—but a mouth discharging water into the stream of the Mersey, which had a velocity greater than was wanted to be produced at the outer end—a state of things existed which would produce that subaqueous current which it was the object of the system to obtain.

It was unfortunate that the experiment should not have been tried; but inasmuch as the Great Float was to have been filled to the tide of the day, and the water discharged from it, he believed, every tide, he could not agree with Mr. Abernethy's statement as following on the state of things in 1844, when the landowners' interests prevented the water being retained above a certain height. But when, in 1853, the landowners were converted into dockowners, and found the advantage of having the water retained, and its level maintained rather than depressed, then the conditions ensued to which Mr. Abernethy referred, in that the level of the water was not to be reduced below 15 feet on the Old Dock sill, whereas in 1844 it was not allowed to be raised above 13 feet on the Old Dock sill. That was the dividing line between those who advocated Mr. Rendel's plans and those referred to by Mr. Abernethy. It might be quite true that in 1853 it was difficult to get water to maintain the Low Water Basin; but the conditions of 1844 and 1853 were very different.

What was the proposition in 1844? The Float was to be filled at every tide to the level of the tide of to-day; and inasmuch as the indraft from the Mersey would be at the rate of ½ mile per hour during the six hours of flood tide, the water would only carry material due to that velocity; but the rate of discharge was to have been 2½ miles per hour, according to the period of tide at which the water was run off, a velocity amply sufficient to remove particles of mud brought in by the current at ½ mile per hour. That was the principle on which that Basin was founded; but through circumstances beyond the control of engineers, not allowed to be carried out.

Besides, the deposit discharged by the current from the float which Mr. Murray referred to, and which he had not seen noticed before, would have been removed. According to Mr. Murray's opinion, a current at the bottom of a float like that would take out the mud deposited at the upper side of the sill of the sluices. It was also part of Mr. Rendel's plan that the float should be deepened to the level of the sill of the sluices for some distance above them. That had not been done; in fact anything more opposite to Mr. Rendel's plan than what had been carried out could hardly be conceived. The area of the Low Water Basin had been reduced from 37 acres to 27 acres; he was not sure whether or not that was good in itself, but the principle was retained of filling the Basin with water at a low velocity, and discharging at a higher velocity, but not such as to prejudice the works. But what was recorded in the Paper? A velocity of 20 miles an hour through the sluices and of 8 miles an hour through the Basin. He had been told that on one occasion a vessel passed the mouth of the Basin when the sluices were open, and the current created in the Mersey was so great that the vessel would have been lost if she had carried any deck-load.

This Paper was, he observed, a valuable record of facts about the sluices; but it did not record a great number of other facts, which he trusted would be collected together.

Mr. J. A. LONGRIDGE observed, through the Secretary, that the Paper by Mr. Ellacott was interesting, as containing the actual results of a somewhat novel system of sluicing on a large scale, but it contained two statements which ought not to pass unnoticed. The first was an erroneous statement of the views of the original designer of the Low Water Basin, as regarded the operation of the sluices. The second was an inferential rather than a direct statement, that those views had in the result proved erroneous. As regarded the first, it was said in the Paper,[1] "It was strongly maintained, that although the proposed system of sluicing was entirely new, and that nothing known would in any respect bear analogy to it, still there could be no doubt whatever as to its success; the scouring water was to flow through the Basin like a subaqueous river, sweeping along the bottom with scarcely any disturbance of the surface; there would be no eddies, or foul currents, as were known to exist under the ordinary modes of sluicing; the surface of the water would not be much agitated; there would be no bubbles rising up, neither would there be any tearing away of the bottom."

No such idea as this was ever put forward by Mr. Rendel. In fact, his evidence before both the Lords and the Commons was quite at variance with such an idea. On the 7th May, 1844, before the Committee of the House of Commons, Mr. Rendel said, "The idea is to make sluices, or apertures, under the great gates, and the tide-gates, passing out near the level of the bottom of the Great Basin, and consequently under the whole of the gates . . . The sluices . . . will be gradually widened in horizontal dimensions, so as to produce a kind of sheet of water within two feet of the bottom of the Great Basin . . . . . . the effect will be to have one wide sheet of water of the width of the basin; the consequence of that is, that

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 520.

we shall be able to operate upon the bottom of the basin, not in the usual way of a large flow of water tearing up everything before it, but a sheet of water, which we can regulate to any degree of force which we like, by the sluices on the inside." [1]

He then went on to say, and this was very clear and precise: "I wish it to be distinctly understood, that we do not propose to run those sluices in the ordinary way of sluicing. I want to give the water, which is to be discharged out of this great Basin, more the effect of a river passing through with a gentle current than a great body of rushing water, and I arrange the sluices with this view."

Again, before the Committee of the House of Lords, 27th June, 1844, Mr. Rendel, speaking of the effect of the discharge from the Great Float into the Low Water Basin said, "It was not in the way of scouring, where the water was allowed to operate upon a sand-bank and surcharge itself, and deposit soil again, immediately the velocity which it had at the time is lost, but in the way of a great river putting the whole mass of water in the Basin into a gentle velocity, by some three or four times greater than the velocity with which it entered the basin, and consequently sufficient to remove any matter brought in by that velocity. . . The velocity of the water will not exceed half a mile an hour in passing into the Basin; the greatest velocity with which we shall be able to discharge that water will be from two miles and a half to three miles an hour."

In 1852, when giving evidence before the Committee of the House of Commons on the Birkenhead Docks Bill, Mr. Rendel said of the system of sluicing, "The great object of this arrangement is not to create the disturbance which is always found to arise when you sluice from large apertures, producing a torrent and eddies immediately in front of the apertures. He came to this conclusion, that we must not produce the effect upon the bottom of the Basin due to the great velocity of the stream, but we must produce the effect by suddenly admitting a large body of water in at the head of the Basin, which would make a kind of large river through the Basin." [2]

Again, "By admitting it in this way you avoid the great disturbance, and have such a current passing out as will sweep the bottom of the Basin, upon the principle that a large river keeps its bed clear. . . . What we are doing is to raise a head of water at this wall"—the great dam— . . . "if we pass from all these sluices a body of water such as they will discharge into this Low Water

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[1] *Vide* "The Port and Docks of Birkenhead." By Thomas Webster, M.A., F.R.S., p. 7 *et seq.* 8vo. London, 1848.

[2] *Vide* "Minutes of Evidence and of Proceedings on the Liverpool and Birkenhead Dock Bills." By Thomas Webster, M.A., F.R.S., p. 316 *et seq.* 8vo. London, 1853.

Basin, the effect will be, that you will raise the head of the water at the higher part of the Basin, and necessarily produce a current through the lower part of the Basin due to the difference of level between the two." Further, in reference to the idea of an under-current which had been mooted, he said, "All my experience since 1844 has tended to confirm the opinions, . . . that an under-current, if produced, would keep the bottom clear; but I rely on the general movement of the water in the Basin at a velocity not exceeding from two to three miles an hour at the outside."

Nothing could be more distinct than that Mr. Rendel at any rate did not either expect to produce or depend upon the production of "a sub-aqueous river, sweeping along the bottom with scarcely any disturbance of the surface." It was quite true that an engineer of eminence, who was examined in support of the Bill in 1844, expressed the opinion that a sub-aqueous current would be created, which would flow the full length of the Basin, 2,000 feet, at a greater velocity than the general mass of the water, but that gentleman was, Mr. Longridge thought, the only one who had such an idea. Certainly it was not held by Mr. Rendel; nor did he depend upon any such doubtful action. Mr. Longridge thought it right, therefore, to object to the statement referred to in Mr. Ellacott's Paper.

The inference to which Mr. Longridge objected was contained in two paragraphs,[1] as follows:—

"It was not, therefore, on the ground of inability to maintain it at its proper depth that the closing of the Low Water Basin, and its conversion into a Wet Dock, was determined on. The principal reasons for adopting this course may be gathered from what has been already stated; and it was not until after much consideration by the Mersey Board, and long negotiations with railway companies and other public bodies interested in the welfare of Birkenhead, that the authority of Parliament for the abandonment of this great work was sought and obtained.

"The preamble of the Act of 1866, after setting forth the section of the Act of 1858, authorizing the construction of the Low Water Basin, proceeds: 'And whereas the said works have been completed and opened for public use, but the operation of the sluices constructed in accordance with the provisions of the said Act has been found to be dangerous to the stability of the works, and practically unsuited to the proper and efficient working of the Great Float and Low Water Basin for dock purposes, and it is therefore necessary that the use of such Basin for the purposes intended by the said Act should be abandoned, and it is expedient in order to utilize as far as possible the large amount of money already

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., p. 532.

expended upon the works, that the said Low Water Basin should be converted into a Wet Dock, so as to be used in connection with the Great Float, by the construction of a sea-wall at the eastern extremity of such Basin.'"

It was here stated that the Low Water Basin was to be converted into a Wet Dock, and that "the principal reasons for adopting this course may be gathered from what has been already stated."

Mr. Longridge presumed this referred to a preceding paragraph, which said "that the running of the water was attended, not only with much inconvenience and hindrance to business, but with a considerable amount of danger." The inconvenience was said to be twofold: first, from the rapid lowering of the water in the Great Float, and secondly, from the necessity of clearing the Low Water Basin of vessels during the sluicing. The danger was to the stability of the work from the violent action of the sluicing. The inference to which Mr. Longridge objected was that the plan of the great Low Water Basin, with the sluicing arrangements proposed by Mr. Rendel, had proved a failure, and had to be abandoned. Mr. Longridge was prepared not only to maintain the contrary of this thesis, but further to argue that the failure of the present works, as described in the Paper, was attributable to the fact of the abandonment of Mr. Rendel's design, and the substitution of another widely different, and the application of the sluicing power to a purpose never intended by Mr. Rendel. First, as to the difference between Mr. Rendel's idea and the plan sanctioned by the Act of 1858. In Mr. Rendel's plan the Low Water Basin contained an area of 37 acres, and consisted of a forked basin, having at the end of one fork the great dam of 500 feet in length, and at the end of the other, the Birkenhead fork, a dam between it and the dock of 560 feet long. Thus the total length of dam through which the sluicing was to take place was 1,060 feet, and deducting one-seventh of this for the stone work at the mouth, and assuming a depth of 2 feet for the depth of the sheet of water preferred by Mr. Rendel, there would be an area of waterway of 1,820 square feet of sluicing apertures. The entrance into the Low Water Basin from the Mersey was originally designed to be about 500 feet, but was subsequently fixed at 350 feet, so that at low water the sectional area would be 4,200 square feet.

On the other hand, according to the plan authorized by the Act of 1858, after Mr. Rendel had ceased to be the Engineer, the basin was reduced to 14 acres, the Birkenhead fork was abandoned, the length of the dam between the basin and the Great Float was reduced to 400 feet, the area through the sluices was 826 feet, and the width at the entrance to the Mersey was 300 feet, having a sectional area at low water of 3,600 square feet. The sluicing apertures were not carried right across the dam, but were confined to the two sides, and consisted of a row of ten arches on each side of the central gates, each being 12 feet span, 4 feet 6 inches high at the crown, and about 3 feet 3 inches at the springing.

The difference between Mr. Rendel's plan and the plan actually carried out was therefore—

	Mr. Rendel.	Actual.
	Acres.	Acres.
Area of Basin	37	14
	Sq. Ft.	Sq. Ft.
Sectional area at entrance to river at low water .	4,200	3,600
Aperture of sluices	1,820	826
Ratios of areas of sluices to low water area of basin at entrance	$\frac{1}{2 \cdot 3}$	$\frac{1}{4 \cdot 33}$

That was to say, in order to produce a given velocity of flow through the basin into the Mersey at low water, the velocities through the sluices would by the actual plan be 1·85 times as great as those designed by Mr. Rendel; and if the action of a stream of water was as the square of the velocity, the destructive effect would be, in the actual plan, about $3\frac{1}{2}$ times greater than in Mr. Rendel's. But it must be further pointed out, that the discharge from two sets of sluices, separated by an interval of 120 feet, differed essentially from the continuous sheet advocated by Mr. Rendel; and the result of such a difference would certainly lead to eddies and foul currents, which it was Mr. Rendel's object to avoid. Mr. Longridge thought these remarks amply proved that the works, as actually executed, differed radically from those projected by Mr. Rendel. Further, the use made of the sluices, as recorded in the Paper, was quite different from the use which Mr. Rendel proposed to make of his sluices. He distinctly and repeatedly stated, that the sluicing was only to remove the daily deposits brought in by the tides. For instance, in his evidence before the Committee of the House of Lords, 28th June, 1844, he said: "There is not a single system of sluicing that I know of that at all bears any analogy to this in any respect, and the whole difference is this, that we are not endeavouring to remove banks that have accumulated, but to prevent the accumulation: to keep that daily agitation of the water in the basin which shall prevent accumulation."

The quantity of silt thus to be removed was stated by Mr. Rendel to be about $\frac{1}{10}$th of an inch in twenty-four hours, which pretty nearly agreed with the statement in the Paper, of $\frac{3}{4}$ inch per week. Now it was this $\frac{1}{10}$th inch of newly-deposited silt that Mr. Rendel contemplated removing; but instead of that, the actual sluicing operations described in the Paper were directed to the removal of not less than an average depth of 32 inches of material, part of which was carried in by the bursting of the dam on 18th June, 1863, and the remainder had accumulated from that time up to the 20th January, 1864. The quantity of material actually removed in fifty-six times of sluicing was estimated at 106,100 cubic yards, or 1,900 cubic yards each time of sluicing, which was equal to about 1 inch over the whole surface of the basin, or ten times the amount contemplated to be removed by Mr. Rendel. But even this did not put the case in its strongest light. The greatest amount of sluicing ever contemplated by Mr. Rendel was 1,600,000 cubic yards in $\frac{3}{4}$ hour, which was = 10,506 cubic feet per second. Consequently the velocity of efflux from the sluices would be $\frac{10,506}{1,820} = 5{\cdot}08$ feet per second. Now, as actually worked, take, for instance, the sluicing recorded on the Paper on 18th, 19th and 20th of August, 1864. The total time of sluicing was 81 minutes, and as the time of opening and shutting the sluices was included, and was stated to be on an average 7 minutes for each operation, it would amount to $7 \times 6 = 42$ minutes, and taking the average discharge during this period as one-half the full discharge, there must be deducted from the above 21 minutes, making the effective time of 60 minutes scouring. Now, the water run off during this time was 573,344,000 gallons, = 9,555,750 gallons per minute, or = 25,500 cubic feet per second; and as the area of discharge was 826 square feet, this gave a velocity of 30·87 feet per second. This was six times the maximum velocity ever contemplated by Mr. Rendel.

If instead of taking the three days above mentioned, the whole of the fifty-six days were taken, it would be found that the average velocity of discharge was 26·54 feet per second.

It was unnecessary to occupy more time in showing that neither in the design nor in the application of the sluices, as described in the Paper, were Mr. Rendel's views regarded; but, on the contrary, a system altogether at variance therewith was adopted. Mr. Longridge thought it was due to Mr. Rendel's memory to show that, whatever might have been the merit or demerit of that Engineer's designs, the actual results described in the Paper had no bearing thereon, and that the failure of the Low Water Basin at Birkenhead could in no degree be laid to his charge. Mr. Longridge refrained from expressing any opinion, though he had a very strong one, on the use made of the sluicing power in this instance. He would merely say, that he should have been greatly surprised if the operations carried on from 20th July, 1864, to 15th November, 1864, had not been attended with very destructive effects. This, however, he felt bound to add, that he saw no reason to abandon the Low Water Basin, even now, and although an Act of Parliament had been obtained for that purpose, he should deeply regret it being carried out. He maintained that there ought to be no difficulty in keeping the Basin clear, and that the inconveniences and dangers which were given as the reasons for abandoning the Low Water Basin were not of sufficient force. First, as regarded the danger. He would abandon the use of the present sluices. At the foot of the dam, and resting on the bottom of the Basin, and extending from side to side, he would place an iron trunk. This trunk would be constructed with a grating in front, and the water would be led down into it by large trunks placed in front of the masonry of the dam on each side of the entrance gates. These trunks would be led through the front of the dam to channels provided with proper sluices, so as to regulate the quantity of water admitted. The grating in front of the main horizontal trunk might be so arranged as to distribute the discharge uniformly from side to side, at the foot of the dam. The area of the apertures through the grating would be, in the aggregate, 1,800 square feet, which was about 9 square feet per lineal foot of trunk, and was one-half the sectional area of the entrance of the Basin at low water. By this means any required quantity of water could be admitted without disturbance to the vessels in the Basin, and a gentle current maintained from end to end. As regarded the inconvenience due to the variation of level in the Great Float, that was a matter fully discussed on various occasions before Parliamentary Committees, and Mr. Longridge need, therefore, only say, that it was not considered to weigh against the great advantages of the Low Water Basin. It might, however, be pointed out, that with a proper system of sluicing, Mr. Longridge was of opinion that a very small amount of sluicing would keep the Basin clear. The average amount of silt to be removed was $\frac{1}{10}$th of an inch per day. The average actually removed by each sluicing was 1 inch, and this was done with an expenditure of water of 8,000,000,000 gallons in fifty-six sluicings, or $\frac{8,000,000,000}{56 \times 6{\cdot}25} = 22,857,000$ cubic feet. Consequently to remove $\frac{1}{10}$th of an inch would require a daily expenditure of 2,285,700 cubic feet, which would only reduce the level of the Great Float about 5 inches. If the velocity through the basin were taken at $2\frac{1}{2}$ miles per hour, or $3\frac{2}{3}$ feet per second, the discharge would be $3,600 \times 3\frac{2}{3} = 13,200$ cubic feet per second, and the time of sluicing $\frac{2,285,700}{13,200} = 171$ seconds, or about 3 minutes. Practically, however, this result could not be obtained, and it would probably be necessary to continue the sluicing for about 6 minutes, which would reduce the level of the Great Float from 10 inches to 12 inches.

Mr. Longridge submitted, then, that neither on the score of danger nor inconvenience was the abandonment of the Great Low Water

Basin justified, and he would conclude with the words of Captain Denham before the Committee of the House of Lords, on 25th May, 1852: "Nothing short of impracticability would justify the abandonment of the Low Water Basin. It was a boon held out to the public; it was one of those points of pre-eminence in the undertaking; and I cannot conceive that the Government of the day would have allowed that shore to be enclosed, or water impound, or anything done to prevent the coaster and the river craft from going there at such times as suited their convenience but for such a public boon; anything that goes to shut up that would be a breach of faith with the public, and destroy all confidence in the undertaking."

Mr. R. Rawlinson, C.B., remarked that, judging from the tenor of the communication just read, Mr. Longridge knew little about the Low Water Basin at Birkenhead, or of the nature of the subsoil on which the walls were placed—quicksand rendering it almost impossible to build in that locality. With all due respect to the memory of the late Mr. Rendel (and the best men made mistakes), he maintained, knowing something about the Liverpool docks, the Birkenhead shore, and the low-water entrance to the Great Float, that a greater engineering mistake was never made than the attempt to place such a Low Water Basin at Birkenhead on that soil. The cross section at Wallasey Pool showed that there was rock both on the Wallasey side and on the Birkenhead side; but Mr. Rendel chose, as a site for these great works, what Mr. Rawlinson knew, from his own experience, to be a treacherous quicksand. Up to the present time, as far as he was aware, the side walls of the entrance to that Float had never been backed up, but they had become distorted though constructed of very fine masonry. He felt certain if an attempt were made to use that basin, and to fill in the ground on either side, the walls would probably fall in. With rock on both sides there had been an opportunity of making magnificent deep-water entrances, as such could have been excavated safely deep enough for vessels of any size. And if separate entrances had been constructed, one on the Wallasey side and the other on the Birkenhead side, the intervening river-wall across might have been made upon this bad ground, and the entrances to the Great Float, on rock foundations, would have remained safe and secure. With regard to the proposed method of sluicing, he gathered that the original intention was to make sluices under the apron of the dock entrance as well as beneath the walls; but he considered this impossible from the nature of the ground. He had attempted to sink a well of 7 feet diameter further in upon the shore, but the first failed on reaching the quicksand. Within the Float, numerous fresh-water springs rose to the surface; he had seen a 21-feet plank pushed down into these quicksands. The late

Mr. Jesse Hartley was so convinced of the impossibility of completing this work that he left it as a dying injunction to his son to have nothing to do with the Birkenhead low-water entrance, and Mr. Rawlinson believed that the difficulties Mr. J. B. Hartley had to contend with in attempting to combat the treacherous character of the ground there had a good deal to do with breaking his health down. If, therefore, it had now been determined to abandon these works, it was, in his opinion, the wisest, and indeed only, course that could be practically adopted.

Mr. Webster, Q.C., in reply to Mr. Rawlinson's observations on Mr. Longridge's remarks, said, there were few who knew better than he did what Mr. Rendel's opinions were on these matters, and he could confirm what Mr. Longridge had stated with regard to the views of Mr. Rendel on the Birkenhead question. Mr. Rawlinson had not informed himself of the facts of the case, as they existed at the time Mr. Rendel gave his evidence upon it; who after a most careful examination of the site of the proposed work, argued that there was a natural basis of rock, and that if that natural foundation was departed from the work would be a failure; and the result had proved the sagacity of his anticipation. After the lapse of twenty-five years it was hardly to be expected that persons, whose attention was not specially directed to the subject at the time, could know the facts of the case. The secret of the destruction of the Birkenhead system was the wealth of Liverpool against the comparative poverty of Birkenhead; therefore he could conceive that the late Mr. Hartley might well have recommended his son to have nothing to do with these works. He repeated that these works were designed to be founded upon the natural rocks as they existed; while the works carried out were in utter violation of that design; and with regard to the sluicing operations, as he had previously remarked, these, as carried out, were entirely different to those planned by Mr. Rendel.

Mr. W. Parkes looked at the fact that the intention had been to produce an equable and moderate flow in the Low Water Basin; that certain means were provided which were expected to produce that effect; and that those means failed in producing it. His impression, on reading the Paper, had been that the means were well devised, and such as he should have expected to result in success. In searching for the cause of failure, the first thing to be regarded was the work to be done, and then the means provided for doing it. The primary object was to set in motion the body of water contained in the Low Water Basin. It was 1,750 feet long, and of a width varying from 300 feet to 400 feet, and the depth, when the sluicing was begun, was 19 feet 4 inches. It was a somewhat fanciful idea that the lower stratum of the water only was to be set in motion; and although he was not prepared to say it was a false one, he was glad Mr. Longridge brought his authority to the statement, that the idea was not attributable to Mr. Rendel. The weight of the water to be set in motion, or simply to be started, was 338,275 tons; and, for this purpose, twenty sluices were provided, each of which had an area of 41 square feet, giving altogether 820 square feet, under a head of 14 feet 3 inches of water. That produced a pressure of 336 tons, which was a thousandth part of the load to be started. This was altogether disproportionate, more so than in any other instance he could recollect in which it was proposed to move a great load with a comparatively small power. The pressure upon the pistons of a locomotive bore a larger proportion to the weight of the train than this. Again, a horse weighing ½ a ton would start a canal boat weighing 30 tons, the proportion of the motive power to the weight to be moved being one-sixtieth. Theoretically if the velocity were given the necessary momentum would be obtained; but there must be some reasonable proportion between the mass of the power and the mass of the load. If a block of stone of 1,000 lbs. weight was struck with a hammer of 1 lb. weight at a high velocity, the stone would not move, although portions might be chipped off by the blow given; whereas the blow of a hammer of 100 lbs. weight, at one hundredth part of that velocity, would probably suffice to move the stone. Where there was a great disproportion between the power and the load, something equivalent to intermediate gearing was required. Without this a violent effect would be produced on a part of the load, but the load as a whole would not be moved. So in this case the 336 tons applied against the 338,000 tons at a velocity of about 17 knots per hour, did very little towards starting that great mass into slow movement. It simply had the effect of producing partial but violent disturbance; gradually the water seemed to have attained a more uniform motion; but at the end it was more like a confusion of eddies and strong currents than like a stream. It was difficult to say what kind of intermediate gearing was desirable in this case. Mr. Rendel's original plan appeared to have provided a larger area of sluices and a less velocity of issue, and was so far better than the plan carried out, but he thought that even on Mr. Rendel's plan, there would have been hardly sufficient proportion between the power and the weight to be moved. At all events it gave a lesson to engineers to be exceedingly careful how they entertained the idea of sluicing at considerable velocities.

Mr. A. Giles had been connected with Mr. Rendel in sluicing operations at Birkenhead. There were practical difficulties in the way of constructing sluices destined to produce the great effect required. The masonry of the tunnels and sluices was much injured by the excessive velocity of the water passing through, and the rebound consequent on opening and shutting the doors. He did not, however, think this or the failure of the sluicing power to keep the basin open, was the only reason for the Low Water Basin being abandoned. It appeared to him that, in such ports as Liverpool and Birkenhead, the construction of low-water basins, with a depth of 12 feet below low-water mark was a mistake. At Liverpool a vessel could not enter the river at low water, so that on her arrival at the Low Water 'Basin' she would have a greater depth than she required, and at low water she could not remain in the Basin, with only 12 feet of water under her. The Basin was therefore too deep for scouring, and not deep enough for trade; and to that alone he thought the failure of the Low Water Basin might be attributed.

Mr. J. F. Blair stated that, in the Clyde at Glasgow there was only a depth of 13 feet at low water of spring tides, the range of which was about 9 feet.

Mr. Hawksley, Vice-President, observed, that all must be pleased to find that Mr. Rendel's reputation had been entirely and completely redeemed from the imputation which might previously have existed of his having made several great mistakes in connection with this work. It was well known that, with regard to works carried on at Liverpool, between the two sides of the Mersey there had ever been such strong antagonism, that it had been almost impossible for any engineer to do justice to himself, to his employers, or to the public at large. Engineers who had been engaged on the great works in the River Mersey had encountered difficulties arising out of those antipathies and feelings of antagonism which it had not been the fate, he believed, of any engineers similarly employed to have met with in any other part of the kingdom. But with regard to this great, and, to his mind, very important, question of sluicing in water of considerable depth, he would, as a hydraulic engineer, say a few words upon the subject. Mr. Rendel evidently contemplated the removal of the deposit, not by the direct sluicing and violent action of the water rushing out of the Great Float, but by setting in motion, gradually, and at a much lower velocity, the great body of water which had been previously collected or which remained in the Low Water Basin.

Now the silt in the Mersey was of a very binding quality, and it was difficult, after it had once aggregated, to move it excepting by means of great violence. The well-known sand-banks in the River Mersey entirely resisted a velocity of from 8 feet to 12 feet per second, a velocity much more considerable than Mr. Rendel contemplated; and therefore it might naturally be expected, that if deposit of any considerable amount took place in the Low Water Basin, and remained there sufficiently long to become aggregated, the velocity contemplated by Mr. Rendel would prove to be insufficient for its removal. Such proved, indeed, to be the case; but it seemed that, even in that respect, Mr. Rendel had, to some degree, anticipated that such might be the case, for it appeared that Mr. Rendel contemplated a very frequent operation of sluicing, with a view of preventing any serious amount of deposit, and, in all probability, though it was not so stated, of preventing that effect of aggregation and agglutination from taking place. Upon the general question of sluicing, if it were intended by any engineer to effect a scour by setting a large quantity of deep water, or, at least, a substratum of water, in rapid motion, he had no hesitation in saying it would be utterly impossible to accomplish that object. No doubt, in the immediate proximity of the aperture of emission, the water would be discharged for some distance with a velocity due to the head by which it was propelled (in this case from the interior of the Great Float), but there were three causes which prevented that action from being continued to any considerable distance. The first cause was the friction between the moving water and the immovable base or bottom over which it flowed; and few persons, perhaps, but those who had studied the subject, knew or could conceive the enormous amount of that resistance; but it very soon, to use a common phrase, brought the water up. Again, water moving in water encountered an enormous friction when the velocity was very high, and even with water moving in the air it was the same, so that if it were attempted to project a jet of water into the atmosphere to the height from which it descended, it would be found it would not attain that height by a considerable amount, which was due entirely to the friction between the water and the surrounding atmosphere. If, therefore, so great an amount of friction took place between water and a fluid so subtle as air, what must the amount of friction be between a volume of water moving in a rapid current and one nearly quiescent. If the nozzle of a fire-engine were put a little below the surface of a body of water, and water was projected through it horizontally, it would be found that the velocity of the water, which might be as much as 100 feet per second at the moment of issue, would be in a short distance brought up almost to nothing; at the same time the water would be found spreading out till it assumed almost an umbrella shape in the end, when it would travel only with a very small velocity indeed. That was the form the water took when the endeavour was made to sluice the bottom of the Float at the Birkenhead Docks. The water rose up, spread, and moved the deposit away for a short distance; then, losing its velocity, the deposit again collected in banks; then, on the surface was formed a succession of waves which rolled all the way down the basin; and very little effect was, under these peculiar circumstances, produced; and the sand not only accumulated but aggregated. Nor was that all, the friction against the bottom of the Basin, of which he had been speaking, was expended upon the masonry; and the masonry not being perfectly fast—and it was difficult to make masonry, unless it was very heavy, perfectly fast under such circumstances—was torn up, and the bottom to a considerable extent destroyed. Everything had gone on naturally, and as it ought to do. He admitted that, under ordinary circumstances, it was possible to effect sluicing operations, provided a sufficient quantity of water were obtained to give a general velocity, not bottom velocity merely, necessary to move the particular material to be dealt with, but as to endeavouring to establish by means of deeply-submerged openings a powerful bottom velocity for any considerable distance (and he was glad to hear that was not Mr. Rendel's view), for the reasons he had stated it was impossible to effect that object; no such thing was known as establishing a bottom velocity of great amount for any considerable distance. The opposite was true, viz., that the velocity of water at the bottom was always less than the velocity at the top except in the immediate neighbourhood of the sluicing apertures.

Mr. Beardmore had been requested by Mr. Lyster to explain, that it was not his wish to give an opinion on the questions raised by the Paper. He had only been engaged in carrying out the works, as designed by Mr. J. B. Hartley (M. Inst. C.E.) in conformity with the requirements of Parliament. But the facts developed by the experiments were so important, that Mr. Lyster thought Mr. Ellacot quite justified in laying them before the Institution, and it was for the members to draw their own conclusions. For his own part, from old associations, he had no wish to enter into theory on the statements, or to criticize the experiments, beyond remarking that they were confirmatory of the well-known fact, that water was a dangerous weapon when used at high velocities, as it was then practically impossible to control its action. It was without precedent to sluice with such large volumes of water and with so great a head. Close-jointed ashlar granite masonry was destroyed by the pounding of the water, which descended at the rate of 30 miles an hour. A similar accident happened recently to some new weirs on a small river in South Wales. A sudden flood occurring, the water came over the partly made dam and broke up hard rock *in situ*. In that instance there must have been some stones rolling down with the flood waters to assist in the pounding effect, which was not the case in the experiments at Birkenhead.

With regard to ordinary weirs on the river Lee, when the sluices were drawn, the effective fall rarely exceeded 4 feet, producing a velocity of 12 feet per second, and this swept out the gravel bottom to a maximum depth of 21 feet. To prevent erosion, Kentish rag was used in pieces weighing from 1 cwt. to 2 cwt. each. With a greater velocity, these stones were sometimes removed, so that the weir pool was never less than 18 feet deep, gradually shoaling towards the sides, which were protected by the stones. Another instance of the power of water at high speed was shown by the honeycomb holes formed round the edge of the foot valves of pumping-engines where water passed rapidly. Few valves lasted more than two years without being honeycombed, an action no doubt promoted by oxidation.

It must be recollected that in 1844, when the Birkenhead works were proposed, no steamer in the British navy exceeded 180 feet in length. Screw propellers were not used for large vessels, and the landing stages on the Mersey had not been designed. The Cunard and other vessels now in general use, being more than double the old length, were utterly unable to enter any but large and deep docks; thus low water or tidal basins became practically of no importance in the Mersey. As soon as a vessel could get over the Liverpool Bar, she came up and transferred her mails to a tender, and then went into dock, without delay or danger. In fact, twenty-seven years had so altered the entire concomitant circumstances, that it was scarcely fair to discuss a question on scientific or engineering data that must turn upon the present requirements of the merchants of Liverpool.

Apparatus for Wedging Facing-Points.

After the meeting, Mr. Harrison, Vice-President, explained a model and two drawings, illustrating plans which had been successfully tried on the North Eastern railway, with a view to provide the means of preventing accidents at facing-points. These accidents had arisen from various causes. In some well-established cases, a blow from a wagon or carriage on the heel of the switch rail had sprung the point sufficiently to throw a carriage off the line. A piece of coke or stone getting behind the points, which would stop them from entirely closing, might not prevent the lever worked by the signalman from apparently coming home, without any defect being detected, owing to a certain amount of elasticity in the lever. Signalmen were frequently in the habit of putting up the danger signal before a train had quite passed, and, with the jerk, sometimes disturbing the facing-points. When the Queen's train passed over the North Eastern railway, it was the invariable practice to wedge up all the facing-points on the line; and it was believed a similar plan was adopted on the Brighton and South Eastern railway before express trains passed. This had led him to the adoption of the present plan. The first idea was to employ a