April 21, 1863.

JOHN HAWKSHAW, President,
in the Chair.

No. 1,092.—“Account of the Cofferdam, the Syphons, and other works, constructed in consequence of the failure of the St. Germain's Sluice of the Middle Level Drainage.” By JOHN HAWKSHAW, F.R.S., President Inst. C.E.

AT one of the meetings of the Institution last year, the Author was requested to give some account of the works proposed to be constructed, consequent upon the failure of the Outfall or St. Germain's Sluice, of the Middle Level Drainage. The disaster having then so recently occurred, the Author, for obvious reasons, refrained from complying with that request; but he stated that at some subsequent time, he would bring the subject before the Institution, in a Paper descriptive of the works. This he proposes now to do.

The original St. Germain's Sluice was situated at the confluence of the Middle Level main outfall drain with the River Ouse, near the upper end of the Eau Brink Cut. This drain was made in 1847, from the designs and under the direction of Messrs. Walker, Burges, and Cooper; but it was not until 1857, that it was deepened to the full extent originally contemplated by them. The success of that work, in improving the drainage of the Middle Level was, as is well known, most satisfactory. The drain, as thus deepened in 1857, has at its lower end a bottom width of 48 feet, the side slopes being 2 to 1. The level of the bottom is 7 feet under low water of spring tides in the River Ouse, at the point where the drain enters that river. The rise of the tide in the Ouse at that point is about 19 feet at spring tides, and the level of the cill of the St. Germain's Sluice is 6 feet below low water of spring tides. The section of the drain near its lower

Fig. 1.

Section of Middle Level Drain near its lower end.

end is shown in Fig. 1. The bed of the drain is there of soft
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blue clay, and the sides, from the bottom of the drain to the surface of the ground, consist of variable thicknesses of soft blue clay, peat, yellow clay, and surface-soil. Of these materials the side banks above the level of the ground are composed.

On the 4th of May, 1862, the St. Germain's Sluice gave way, thereby admitting the tidal waters from the River Ouse into the drain, which rushed up, and again poured out of the drain with great velocity, and throughout a distance of upwards of 20 miles they ebbed and flowed. This state of things lasted for a few days, during which time much attention was devoted to the banks, and several minor breaches were successfully stopped; but at length the western bank of the Middle Level Drain burst, at a point about 4 miles from the St. Germain's Sluice, inundating upwards of 9 square miles, or about 6,000 acres of land. (Plate 14.)

Immediately on the failure of the sluice the late Mr. Walker, (Past-President Inst. C.E.) was consulted by the Middle Level Drainage Commissioners; but as that gentleman was unable, from advanced age and failing health, to undertake the operations that were urgently needed, he advised the Commissioners to request the Author to act in the matter; and full instructions were given to do whatever was considered necessary to shut out the tidal waters, regardless of expense. In order to expedite the organisation of a staff of men, and to obtain immediate possession of the plant and materials necessary for carrying on the operations, the Author secured the services of Mr. J. T. Leather (Assoc. Inst. C.E.) as contractor. That gentleman was fitted, from his extensive experience, to carry out the Author's plans, which he did with much vigour and judgment. In this he was ably aided by his assistant, Mr. E. P. Smith. Mr. Alexander G. Linn, (Assoc. Inst. C.E.) was, at the Author's request, appointed Resident Engineer, a position he was well qualified, from his previous career and experience, to undertake, and the duties of which he performed in a highly creditable manner.

Previous to the Author's assuming the direction of the works, and directly after the failure of the sluice, an earthwork dam was commenced, which was attempted to be thrown across the drain at a spot about 500 yards from the fallen sluice. This dam was not immediately relinquished, but its construction was pursued by sinking horizontal cradles of fascines weighted with clunch (a hard chalk stone, procured in Suffolk and Cambridgeshire), and by the use of bags filled with clay, the Author not wishing to abandon an experiment, which he did not originate, without having fairly tried it. It is clear, moreover, that if the dam had been carried up even to a moderate height, which was the utmost the Author ever expected, or desired to accomplish, it would have had the effect of shutting out a certain quantity of tidal

water, which would to that extent have relieved the banks of the drain, and have assisted the construction of the permanent cofferdam. On the other hand, by continuing this dam, the introduction of successive layers would pen up an increased quantity of water in the drain; and the more it was raised, the greater would be the scour from the water flowing over it at ebb tide, which scour was considerable when the dam was only raised a few feet. Numerous barges also were required in its construction, any one of which would, if it had broken loose when the tide was running up the drain, have ruined the permanent cofferdam. Great caution was therefore necessary in pursuing its construction; and not long after the permanent cofferdam was commenced, the Author determined to relinquish altogether proceeding with the earthwork and cradle dam, tidal observations having shown that it was unnecessary, when the construction of the permanent cofferdam had advanced to a certain stage. There is no doubt, that the system of raising such a dam by cradles of fascines might be introduced with advantage, in many situations, and under certain circumstances. The Author intrusted the superintendence of sinking the cradles to Mr. Müller, who had considerable experience in raising banks in this manner, and who described the process in a Paper read before the Institution during the last session.¹

COFFERDAM.

Immediately on receiving instructions from the Commissioners to do whatever might be considered necessary to shut out the tidal waters, the Author determined to construct a permanent cofferdam of pile-work across the drain, as the only plan that was likely effectually to answer the desired end. His original intention was to use the road-bridge spanning the drain about 1,000 yards from the fallen sluice, as a staging from which to drive the piles; but the work was scarcely commenced before the bridge, which was a timber structure, was destroyed by a barge breaking loose and running against it. The site finally fixed upon was about 120 yards to the north of the bridge, and that distance nearer the fallen sluice. Figs. 1, 2, 3, and 4, Plate 15, show the dam as constructed.

It will be desirable, however, before proceeding to describe the dam, to give some particulars relative to the levels of the water in the River Ouse and in the drain. The level of high water of spring tides in the river is, as before mentioned, about 19 feet above low water, but it was not more than 9 feet in the inundated fen, where, owing to the large area of the inundation, the rise and fall of the tide did not exceed 6 inches. The only in-

¹ *Vide Minutes of Proceedings Inst. C.E., vol. xxi., p. 466.*

erval of repose, therefore, was when the water in the Ouse was at the level of the water in the fen. Fig. 5, Plate 15, is a diagram explanatory of the tidal action. This interval of repose was of very short duration. A few minutes scarcely elapsed before an inward or outward current (according to the state of the tide in the Ouse) became perceptible, which current rapidly increased in intensity. The velocity of the tide up the drain, and again out of the drain, amounted to about 6 miles per hour at spring tides, and 4 miles per hour at neap tides. The depth of water in the drain below low water spring tides was 7 feet; but the bottom of the drain, in the neighbourhood of the dam, having been scoured away about 2 feet, the depth there, at slack water, was about $17\frac{1}{2}$ feet. The material composing the drain and the banks being of so soft a nature, and the velocity of the current being so great, it was clear that much caution would have to be exercised, throughout any operations that might have to be undertaken, to guard as much as possible against the effects of the scour.

The cofferdam, which was commenced on the 16th May, may be thus described:—Temporary piles were screwed into the ground in the first instance, and a platform was erected thereon, to form a staging for the pile-driving engines. When this was done, the permanent pile-work was commenced, by driving two rows of sheet-piling, 25 feet apart, transversely down the slope of the drain on each side. This sheet-piling extended from the centres of the banks to within about 20 feet of the bottom of the drain, leaving a space of 20 feet on each slope and of 48 feet (the bottom horizontal width of the drain), together equal to a central space of 88 feet of cofferdam to be completed. This portion of the dam was thus constructed (Fig. 2.):—Piles of whole

Fig. 2.

Plan showing the Construction of the Central part of the Cofferdam.

timbers were driven on each side, so that when in place they would be in pairs, 7 feet 6 inches apart, from centre to centre. The piles in each pair were placed back to back, a space being left between them of 7 inches, this distance being preserved by a central piece 7 inches by 3 inches. These piles were driven separately, one of the piles, with the distance-piece attached, being first driven, and afterwards the second pile. The grooves thus left

were for the reception of sliding panels, to be used in order to fill up the spaces between these several twin piles. These piles could only be pitched during the few minutes of slack water. Waling pieces of whole timbers were fixed to the inside and the outside, both at the top, and also as near to the low water level as possible. As the piles were driven, proper struts and ties were inserted to stiffen and strengthen the dam, and strongly framed raking struts were fixed, abutting against the dam and against abutments, composed of piles backed with concrete, on the land. The struts, ties, and raking struts will be clearly understood by reference to the drawings of the dam. (Plate 15, Figs. 1, 2, 3, and 4.) The panels are composed of a series of timbers (7 inches thick, and of the length necessary to enable them to slide into the grooves), fastened together by bolts $1\frac{1}{4}$ inch diameter, and further strengthened and weighted by flat wrought-iron plates on one side, each plate being 6 inches wide by 1 inch thick. In order to put these panels in place, a frame (Plate 15, Figs. 1, 3, and 4) was erected, from which they were suspended, and from which they could be lowered, and raised again if necessary, by pulleys.

The rush of water through the dam, which was considerable before the piles for the panels and the walings were erected, was materially increased when they were in place,—so much so, that there was at times a difference of level of 4 feet, or 5 feet between the water on the two sides of the dam. Already the precaution had been taken of throwing in sacks of clay, with gravel, puddle, and stone (kept in place by footings of clunch) on the upper and lower sides, forming aprons extending the whole width of the drain, and for some distance up the slopes. It now became of the utmost importance carefully to watch these aprons, and also the centre of the dam between the two rows of piles, where, from the necessity which existed of depositing in that space nothing but material impervious to water, there was an increased difficulty in maintaining the bottom from being scoured away. In order to ascertain the state of the aprons and of the centre of the dam, soundings were made, and, for the purpose of throwing in materials, stages were erected. The drain throughout had also to be carefully watched, as the soundings revealed the existence of large holes in the bottom, as well as of considerable scour. In one place the drain had been scoured to a depth of 15 feet from its original bed, maintaining this depth for a length of not less than $\frac{1}{4}$ mile; and at other places it was discovered that the cast-iron culverts, some of which were of large size, passing originally several feet under the bottom of the drain, had been laid bare. Only a limited quantity of stone was thrown into the centre of the dam, lest it should prevent the clay being afterwards made perfectly water-tight,

and should increase the difficulty of driving the piles that yet remained to be put in place, at the back of the panels on the lower side. Great quantities of puddle, however, were cast into the dam at slack water; but most of this was washed away by the rush of water through it, which acquired a velocity of 8 to 9 miles an hour; and it was only with the utmost difficulty, and by incessantly persevering with this operation, that the level of the bottom of the inside of the dam could be maintained at the same level as the bottom of the drain; all attempts to accumulate material within the dam above that level proving ineffectual. At this period it became very difficult to maintain the aprons on the outside, and with the utmost exertion they could only be raised about a foot above the bottom of the drain at their junction with the dam, and for some length from it, gradually increasing in height from this latter point to the end of the apron, where the footings of clunch were made.

The panels in the first, or lower tier were each 7 feet deep. They were pointed at the lower end, so that they could be driven down some depth into the mud; and when all those of the first set were driven, another set was put in. These latter were of variable depths, inasmuch as the first series could not all be driven to the same level, and the lengths of the second set were so arranged as to raise the panelling uniformly to the level of about low water of spring tides. Whilst the panels were being driven, and after they were down, the operation of throwing in sacks of clay and gravel, both on the inside and the outside of the dam, was persevered in; and although the aprons on the upper and on the lower sides were by this means extended, and raised to the height of the panels, nothing remained in the inside of the dam excepting a few sacks of gravel, which were thrown in close to the panels to prevent any 'blowing' from taking place.

It now became clear, that the only practicable mode of excluding the water was to shut in the remainder of the dam at one operation, and to rely on its strength for resisting the pressure that would come upon it, before it could be finally completed. As before observed, it had been previously well strutted both on the inside and on the outside. It was necessary to do this at still water, when there would be a small differential head for the dam to sustain; and, in order to accomplish the object, the panelling, which was required to be 12 feet deep, was suspended from the scaffolding (Plate 15, Fig. 3) on each side of the dam, so as to be dropped into place at slack water.

The first attempt to close the dam, made on the 10th June, 1862, resulted in failure, from the fracture of three of the twin piles (marked X, Plate 15, Fig. 4) on the lower side of the dam, owing probably to their having been injured in driving, and in giving way

they released some of the bottom panels. These failed after the tide had receded 3 inches, and when there was a head of 8 feet of water. The other panels were readily lifted up and removed; but a delay was occasioned, as the damage had to be made good, which was done by driving sheet-piling (marked Z, Plate 15, Fig. 4) up to the level of the lower waling, thereby filling in the spaces between and adjoining the broken piles. The tendency of this was, of course, still further to contract the waterway; but it was considered the most desirable course to adopt, as, upon a diver being sent down, it was found that the ground had been much disturbed, by the tearing out of the panels between the broken piles. The second attempt was therefore postponed until the succeeding neap tides; but in addition to the work that had to be performed, the interval was taken advantage of to meet and provide against every contingency that might arise. The first attempt was made at still water of flood tide, as the dam would have to sustain a somewhat smaller differential head at high water than at low water, and by the time the tide had ebbed to its lowest point, the dam would have been filled in to a considerable extent. The second attempt (made on the 19th June) proved a complete success. The panels were again slung ready to be dropped at slack water, but this time the operation was attempted at low water of ebb tide as being more convenient, the difference of the head at high water and at low water not being considered of sufficient importance to counterbalance other advantages. The process of lowering the panels lasted about twenty minutes, and immediately this was effected, the inside was filled with clay, and with sacks of gravel, clunch being thrown into the centre. The aprons on the upper and the lower sides were at the same time raised and extended. About 3,000 yards of clay with several hundred sacks of gravel and clunch were prepared for the operation, and 800 men were in readiness to put these materials in place, from several barrow-roads and waggon-roads; and so perfect were the arrangements, that the raising of the dam inside was kept in advance of the rise of the tide, and before high water the operation was completed. The contrast between the rush of water before, and the calm after, the operation, was remarkable. The tide rose quietly, and the dam, as thus far constructed, did not exhibit the slightest indication of failure, or weakness.

After these panels were placed, sheet-piling was driven behind them on the lower side of the dam, thereby filling in all the spaces between the twin piles, and converting the lower side into one continuous row of sheet-piling, and the dam was further completed without any trouble, or anxiety. In addition to the piles before referred to, extra piles were driven at the sides of some of the twin piles, where it was imagined the panels might not have a sufficient

hold. With these exceptions, and one, or two minor alterations, which suggested themselves as the work progressed, the dam was constructed in every respect in the manner, in the order, and to the extent, originally intended by the Author. The cofferdam was commenced on the 16th May, and the tidal waters were shut out on the 19th June, 1862. Appendix A (page 509) contains the quantities of the several kinds of material used in the construction of the cofferdam and in the syphons.

SYPHONS.

During the time the cofferdam was being constructed, serious attention was given to the means to be adopted for the future drainage of the Middle Level. After a careful consideration of this question, the Author came to the conclusion that, in addition to such drainage as could be obtained through Salter's Lode Sluice, the old outlet into the Ouse, — the drain leading to which had to be widened, cleared out, and re-opened by the removal of a bank existing across it,—syphon pipes should be laid over the cofferdam, and that nothing should be done as to the erection of a new sluice, until these latter had been fairly tried. The Author had occasion, in 1839, to enlarge the capacity of the reservoir for supplying the Manchester, Bolton, and Bury Canal with water, which was effected by increasing the height of the reservoir embankment. The old outlet, which passed under the embankment, being of insufficient capacity, he adopted a syphon passing over it, for an additional outlet; so that the experiment of discharging water by the action of the syphon was not to him a novel one. It must here be mentioned that, immediately after the cofferdam was closed, feeling it would be impossible to continue to devote as much time to the works as he had hitherto done, the Commissioners, at the Author's request, associated with him Mr. Thomas E. Harrison, (M. Inst. C.E.) who has since continued to act with him.

The syphons are shown in Plate 16. They differ in no respect from the original design and intention of the Author, excepting in the arrangement of the valves. In the first design, a single valve was placed in a box at the top of the syphon, and in the design as executed, a valve was placed at each end, for reasons which will presently appear. The number of syphons at present erected is sixteen. These are laid across the dam at an inclination of 2 to 1 on either side, and horizontally over the top; each end being terminated by a horizontal length containing the upper and the lower valves. The upper surface of these bottom horizontal lengths is laid at a level of 1 foot 6 inches under low water of spring tides,—so that the ends of the syphons are always under water,—and the top of the syphon is 20 feet above the same level.

The total length of each syphon is about 150 feet. The syphons are of cast iron, 3 feet 6 inches internal diameter, put together in lengths (exclusive of the irregular pieces) of 12 feet, and have spigot and socket ends and lead joints. Four bosses, or lugs are cast on the ends of the several lengths, for the purpose of bolting them together with $1\frac{1}{2}$ -inch bolts. The thickness of the metal in the syphons (excepting at the socket ends, where it is thicker) is $1\frac{1}{8}$ inch. The syphons rest on the top of the dam and on inclined framework, supported on piles on either side. The piles, which are 14 inches square, are driven so as to be underneath each of the joints of the pipes composing the syphons. These piles are connected together by a horizontal transverse cill, and each syphon rests on whole timbers 1 foot 9 inches apart in the clear, and bolted to the cill. Underneath the extreme ends of the syphons, a row of sheet-piling of whole timbers is driven across the drain, the sheet-piling being properly hollowed out to receive and support the terminal lengths.

The space occupied by the inclined framework between this sheet-piling on each side and the dam, is filled in above the apron that was formed to resist the scour, and up to the underside of the syphons, with clunch, clay, and gravel, thus forming a solid and impervious embankment. The bottom of the dam, at the inlet and outlet of the syphons, is protected by substantial permanent aprons extending across the drain. These aprons are shown in Plate 16, Figs. 1 and 2. The lower parts of the syphons and the aprons were laid by means of dams, consisting of close sheet-piling surmounted by slackers, or sluices. These dams were about 90 feet long, and were thrown across the drain 30 feet from the ends of the syphons. From near their extremities, two parallel rows of sheet-piling, (Plate 16, Figs. 1 and 2,) were driven towards the dam, to within 25 feet of it on the lower side and 35 feet on the upper side. The lower apron extends from the sheet-piling at the termination of the syphons to the sheet-piling of the half-tide dam, and is 30 feet long. It consists, for the first 20 feet of its length nearer the syphons, of piles, 5 feet apart, driven into the ground, and surmounted by cills. The ground, from the top of the cills, is excavated to a depth of 2 feet 6 inches, and the space is filled in with concrete, to the underside of a layer of close planking 4 inches thick, which is spiked to the cills. The remaining 10 feet of this apron, to the sheet-piling of the half-tide dam, is of concrete 2 feet 6 inches deep. The sheet piling of the lower half-tide dam was cut off at the top of the concrete, so as to protect the ends of the aprons from injury and scour. The upper apron is 10 feet long, and consists of piles 5 feet apart, driven into the ground, and surmounted by cills to which close planking,

4 inches thick, is spiked; the toe of this apron being pitched, (Plate 16, Figs. 1 and 2).

Both at the inlet and the outlet of the syphons, a row of sheet piles is driven on each side, inclining towards each other, and contracting the channel to a width of 60 feet. This is for the purpose of keeping the 'wash' off the slopes of the drain.

The upper, or inlet valve (Plate 16, Figs. 4, 5, and 6) consists simply of a flap of teak wood working inwards, and the lower valve (Plate 16, Figs. 7 and 8) is of cast iron, working outwards, and is fitted with a balance-weight. The syphons are put into action by exhausting the air from the inside, by means of an air-pump worked by a steam-engine. This is placed on the western side of the drain, and near to the dam. A horizontal flanged pipe, 10 inches diameter, runs transversely across the dam, over its centre, at a height of 6 feet from the top of the syphons; and vertical pipes, provided with slide cocks, connect each syphon with this horizontal pipe, and with the air-pump. By means of the slide cocks, each syphon can be shut off at pleasure, or be brought into operation when required. Some of the syphons are provided with glass gauges attached to the centre of the sides, and to the vertical pipes at a point above the slide cocks. It can thus be seen when the syphons are full of water. Three brass taps, $1\frac{3}{4}$ inch diameter, are fitted into the horizontal flanged pipe at the extreme end, for the purpose of admitting air when required, and thus readily stopping, or regulating the working of the syphons. The air-pump has three cylinders, worked together by a three-throw cranked shaft. Each cylinder is 15 inches diameter, and the length of the stroke is 18 inches. The engine is of 10-horse power, and high pressure; the diameter of the cylinder being 12 inches, and the length of the stroke 20 inches. The syphons were cast by Messrs. Cochrane and Co., of Woodside Ironworks, near Dudley; and the steam-engine and air-pump were manufactured by Messrs. Easton, Amos, and Sons, of Southwark.

The reason for adopting two valves in the syphons instead of one, as the Author originally intended, was for the purpose of enabling them to be put into operation, either by exhausting the air, or by filling them with water should there be any necessity for it. The inlet valve, being a loose hanging flap of wood, opens inwards as soon as the outward is the preponderating pressure. The outlet valve turns on a hinge at the top, and is balanced; it is rendered capable of resisting an interior pressure, by means of a bridle which holds it fast, but which can readily be released, when the valve is converted into a flap opening outwards. In filling the syphons with water, the same machinery would be employed as is used for exhausting the air, and the water would be pumped up into a reservoir, where it would be in store, ready to be turned

into the syphons when needed. For the purpose of controlling the operations connected with the raising and lowering of the outlet valves, a chain is attached to each, worked by a small crab, placed on the top of the dam. At present, the only method that has been tried to work the syphons has been to exhaust the air. The inlet and outlet valves are so arranged, that they can readily be drawn out should it be necessary.

On the lower side the syphons, up to the level of high water neap tides, are protected by a rubble deposit of clunch, extending from the centre to 15 inches above the top of the syphons; the surface of the clunch is pitched with Wansford rubble, 9 inches deep, the pitching being continued to the end of the inclined pilework, (Plate 16, Figs. 1 and 2). The lower part of the syphons, on the upper side, is covered with puddle to a depth of 15 inches above the syphons, this puddle being similarly pitched with Wansford rubble, also 9 inches deep. The upper part of the syphons on both sides is covered with puddle to a depth of 18 inches, on which grass sods are laid, and on the top of the dam a hut is erected, into which steam heating-pipes, 4 inches inside diameter, communicating with the boiler, are placed. By these means the water in the syphons and pipes can be protected from frost. A grating and an ice breaker are placed across the drain in front of the syphons, at the upper end. In Appendix B (page 509) some examples of the results of the working of the syphons are given.

STOPPING THE BREACH, AND CONCLUDING REMARKS.

After the breach occurred, it soon became evident, that all attempts to stop it should be abandoned. The area flooded was surrounded by banks, which confined the mischief within limits, as long as those banks held good. Any attempt to stop the breach, until the tidal waters could be excluded, would only have increased the evil, by causing breaches in other places when still greater damage would have resulted, by the flooding of other lands. The large area flooded, operated as a safety valve, preventing the tidal waters from rising to the height in the drain they otherwise would have done, and actually did rise before the bank burst, and to that extent relieving the banks and preventing breaches at other points.

It was not, therefore, until the cofferdam was closed in, and the tidal waters were excluded, that the breach was stopped, and, still water being obtained, this was easily effected. The first operation consisted of tipping stone, so as to form a footing on each side, at the toe of the embankment that had to be raised. This embankment consisted of clay, to the level of the bottom of the drain,

so as to make good the material that had been scoured away. The rest of the bank was of clay mixed with a small quantity of clunch, (about half a dozen barge-loads to every 4 feet of depth,) to stiffen and weight it. The total quantity of material used to restore the bank was about 25,000 cubic yards. The bottom of the drain, where the scour had taken place, was also repaired, and the banks generally were put into good order. After the work connected with securing the breach was completed, the water on the inundated land was let off, through the Marshland Smeeth and Fen Drain, and the adjoining Marshland sewer. Since the dam has been closed, much attention has been devoted to thoroughly securing and making good the banks of the drain between the dam and the River Ouse, which had been much damaged by the scour, and they had, from time to time, to be secured and repaired. They are now put into good order by clay and fascine work, so as to admit the efflux and reflux of the tidal waters without suffering deterioration.

The Author has only, in conclusion, to remark, that he believes siphons will be found to answer all the purposes of a permanent sluice. The results obtained have hitherto been of a most satisfactory character. They possess moreover the advantage of not rendering the safety of a district dependent on single pairs of gates; for it is clear that, from their independent action, any one, or more of the siphons may be damaged, or destroyed, without injuring the operation of the others, or endangering the district. A good deal of consideration was at one time bestowed on the advisability of making a sluice in the dam, in addition to the erection of siphons. It was thought that in this way an outlet could be established for the land water, in the readiest and most rapid manner, in anticipation of a land flood occurring in the interim, and before the siphons could be brought into operation. The desirability, however, of not interfering with the dam after it had been erected, led to the abandonment of the notion.

The Paper is illustrated by a series of drawings and diagrams from which Plates 14, 15, and 16 and Figs. 1 and 2 have been compiled.

Fig. 1.

SECTION ON LINE C D.

Fig. 2.

North or lower Side. PLAN.

Fig. 3.

SECTION ON LINE A B, SHOWING PANELS SUSPENDED, READY TO BE DROPPED IN PLACE.

Fig. 4.

ELEVATION OF COMPLETED DAM. (NORTH SIDE.)

Scale 20 Feet to the Inch.
0 10 20 30 40 Feet.

Minutes of Proceedings, Institution of Civil Engineers, Vol. XXII Session 1862-63.

Fig. 5.

DIAGRAM ILLUSTRATIVE OF THE FLOW OF THE TIDE IN THE DRAIN AFTER THE BREACH HAD OCCURED.

When the tidal observations were taken the lower panels were in the Dam up to Datum level, and the sheet piles, (driven to the level of the lower waling in the spaces Z Fig. 4) were in place.

KELL BRO'S LITHO CASTLE ST HOLBORN.

COFFERDAM AND SYPHONS, MIDDLE LEVEL.
Fig:4.

APPENDIX (A).

TOTAL QUANTITIES OF THE SEVERAL KINDS OF MATERIAL
USED IN THE CONSTRUCTION OF THE COFFERDAM AND THE
SYPHONS.

COFFERDAM.

Timber	.	.	.	.	.	.	90,693 cubic feet.
Iron	.	.	.	.	.	.	75½ tons.
Cement	.	.	.	.	.	.	432 casks.
Clunch	.	.	.	.	.	.	2,444 tons.
Sacks	.	.	.	.	.	.	36,524 in number.

SYPHONS.

The total weight of metal-work in one syphon, exclusive of the pipes and the connections, is 36 tons; and the total weight of metal-work in the sixteen syphons, including the communication and air-pipes, and connections, complete in every respect, is 610 tons.

APPENDIX (B).

WORKING OF SYPHONS.—6th March, 1863.

Time.	Gauge above Dam.	Gauge below Dam.	Vacuum.
12.50	5' 9" above datum.	1' 5" above datum.	11 inches Mercury.
1.0	5.6 "	1.5 "	13 "
1.5	5.3 "	1.5 "	
1.10	4.10 "	1.8 "	
1.15	4.8 "	1.10 "	
1.20	4.6 "	1.10 "	
1.25	4.6 "	1.10 "	
1.30	4.5 "	1.9 "	16 "
1.45	4.3 "	1.6 "	
2.0	4.2 "	1.5 "	16 "
2.15	4.0 "	1.3 "	
2.30	3.8 "	1.2 "	16 "
2.45	3.2 "	1.0 "	
3.0	2.10 "	0.10 "	15 "
3.15	2.6 "	0.8 "	
3.30	2.4 "	0.7 "	14 "
3.45	2.1 "	0.6 "	
4.0	1.10 "	0.5 "	14 "
4.15	1.10 "	0.11 "	
4.30	2.0 "	1.11 "	14 "
4.35	2.2 "	2.2 "	

7th March, 1863.

Time.	Gauge above Dam.	Gauge below Dam.	Vacuum.
12.50	1' 11" above datum.	1' 10" above datum.	14 inches Mercury.
1.0	1.10 "	1.6 "	14 "
1.15	1.8 "	1.3 "	
1.30	1.5 "	1.0 "	18 "
1.45	1.4 "	0.9 "	
2.0	1.2 "	0.7 "	18 "
2.15	1.0 "	0.6 "	
2.30	0.10 "	0.4 "	17 "
2.45	0.8 "	0.2 "	
3.0	0.6 "	0.0 "	16 "
3.15	0.4 "	0.1 below datum.	
3.30	0.2 "	0.3 "	17 "
3.45	0.1 "	0.4 "	
4.0	0.0 "	0.6 "	17 "
4.15	0.1 below datum.	0.7 "	
4.30	0.1 "	0.8 "	17 "
4.45	0.2 "	0.9 "	
5.0	0.2 "	0.2 "	15 "

8th March, 1863.

12.30	4' 11"	4' 10"	12 inches Mercury.
12.45	4.8	4.4	
1.0	4.6	3.10	14 "
1.15	4.4	3.5	
1.30	4.2	3.0	15 "
1.45	4.0	2.7	
2.0	3.10	2.3	16 "
2.15	3.6	1.10	
2.30	3.4	1.6	16 "
2.45	3.0	1.3	
3.0	2.9	1.2	16 "
3.15	2.6	1.0	
3.30	2.3	0.11	16 "
3.45	2.1	0.8	
4.0	1.10	0.7	16 "
4.15	1.7	0.6	
4.30	1.4	0.4	16 "
4.45	1.2	0.2	
5.0	1.1	0.2	16 "
5.15	0.11	0.6	
5.30	1.3	1.3	16 "

[NOTE.]

NOTE.—During the time the syphons were working, the doors at the Outwell Sluice were closed. The following is the capacity per foot in height above datum, of the drain between the syphons and the Outwell Sluice :—

Between datum and	1 foot above	.	3 008,003 cubic feet
„ 1 foot and	2 feet above datum	.	3,165,865 „
„ 2 feet and	3 feet	„	3,411,652 „
„ 3 feet and	4 feet	„	3,681,918 „
„ 4 feet and	5 feet	„	4,005,962 „
„ 5 feet and	6 feet	„	4,253,012 „
„ 6 feet and	7 feet	„	4,567,515 „
„ 7 feet and	8 feet	„	4,886,176 „
„ 8 feet and	9 feet	„	5,047,941 „
„ 9 feet and	10 feet	„	5,273,587 „

It having been represented that it might be inconvenient, while the matters relating to the Middle Level Drainage were under litigation, to discuss the questions raised in the Paper by the President, it was resolved—

That the discussion upon Mr. Hawkshaw's Paper, "On the Cofferdam and Syphons, Middle Level," should be abandoned.