Discussion.

Mr. Vernon-Harcourt.

Mr. Vernon-Harcourt said, that since he presented his Paper to the Institution he had visited France, with the express purpose of inspecting some of the most recent of the different kinds of weirs in that country, and also to find out what modifications or improvements had been made, and in order to converse with some French engineers who had had most experience in that particular branch of river engineering. The first weir to which he would call attention was the bear trap. The diagram (Plate 2, Fig. 1) showed a section of the weir in France at Laneuville-au-Pont. That was one of the earliest movable weirs introduced, being of an American type, called the bear trap. But it had been found, that though the intention was, as he had explained in his Paper, that the gates should be raised by the pressure of the upper pool acting through the sluice, that pressure was not generally sufficient until the water was lowered to too great an extent in the lower pool to allow of proper navigation. It had, therefore, in practice been found necessary to raise the upper gate by ropes or chains; because in order to get a sufficient water-pressure in the sluice it would be necessary to have an accumulator on the banks, or a large reservoir. This weir, therefore, possessed rather an historical than a practical interest. No more weirs of that type had been made in France, and it might be regarded as rather a clumsy weir. The needle weir was a very different type. It was first used by MM. Poirée and Chanoine. The novelty of the weir was not the needle, which had been used in French stanches before any of these movable weirs were introduced. The stanches which they then used were very similar to those which might be seen at the present time in some parts of the Thames above Oxford, and which used to exist on the river Severn, a description of which had been given by Mr. Cubitt in 1845.[1] Those on the Severn were closed by planks, and those on the Thames generally by rimers and paddles. The peculiarity of M. Poirée's system was the movable frame that could bend right down; but he preferred calling it the needle weir to distinguish it from other systems in which similar frames were employed. The weir shown on Plate 2, Fig. 3, was not the largest type of needle weir that had been erected in France. It was the type generally used on the Meuse, and also on the Moselle. The largest type of weirs used in France were those at Suresnes, Bezons, and Martot,

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 111.

Mr. Vernon-Harcourt.

the latter being the weir that separated the tidal from the non-tidal portion of the Seine. He had visited the weir at Suresnes. This weir was higher than Teddington weir, being able to hold up 10 feet of water, whereas the height of the Teddington gate was only 6 feet. If the weights were compared, it would be found that at Teddington each frame weighed about 1 ton, whereas at Suresnes each frame only weighed about 4 cwt., showing that there was a great difference between the weight of the frames put up in France and those put up at Teddington. It ought, however, in justice to be said, that the frames at Teddington were about double the distance apart of those at Suresnes, and at Suresnes the foot-bridge was not raised to such a high level as at Teddington. It appeared to him that one objection to the Suresnes weir was that the foot-bridge that went on the top was about level with the water in the upper pool, and therefore it might be difficult, and in one instance was proved to be impossible, to remove the needles in time when a flood came suddenly down. He thought, however, there would be less difficulty now than there was in 1873, when the weir was regularly submerged, as M. Belgrand had now established such a good system of warnings that all the weir-keepers could be warned when a flood was coming down. In fact, on one occasion in 1876, M. Belgrand was able to predict the greatest flood height in Paris to within ½ inch three days before it occurred. A plan was adopted at Suresnes of regulating the discharge of the weirs without removing the needles at all, by just pushing forward the needle at the top, and then putting a small block of wood to keep it in place. When the water had to be raised it was only necessary to remove the block and the needle returned to its place. That obviated the difficulty of removing the needle. When he was at Suresnes, several of the needles were blocked up. There were no mechanical arrangements for removing the needles. He asked the weir-keeper about it, and was told that all he did was to push each needle away with his foot at the top, and the needle fell out of its place. There was a rope attached to it, and by that means it was brought up on to the bank. But on the Meuse, where there were needle-weirs of about the same size, there was a bar, near the top of each frame, supporting the needles that turned on a vertical pivot. There was also an arrangement for releasing it from its point of support on the adjoining frame, when the bar would turn round its pivot and release the needles. The Suresnes weir was built in 1866, and was the most recent needle weir on the lower Seine. It maintained the level of water through Paris up to Port-à-l'Anglais

Mr. Vernon-Harcourt.

weir, a little above the confluence of the Seine and the Marne. No doubt some of the members had noticed the weir at La Monnaie, which was in the centre of Paris. That had been erected some years previously to the weir at Suresnes, and was practically not used now, except sometimes in the winter in order to prevent an undue rush of water during flood passing under some old bridges in Paris. The weir could be raised 3 feet 3 inches. It was generally under water, and was under water when he saw it. The movable shutter weir as adopted at Port-à-l'Anglais, was shown on Plate 3, Fig. 1. It was the largest of the shutter weirs in France. There was another shutter weir, without the foot-bridge, at the same place, and when he went to see it, it was shut. One of the gates, however, was not in position; but was somewhat down. He asked the weir-keeper the reason of that, and was told that there was something wrong either with the tripping-bar or the shoe, and he was told that it would be necessary for a diver to go down to put it to rights. Apparently one of the defects of this system was, that those weirs were rather costly to maintain. The weir-keeper informed him of that fact, and M. Boulé confirmed it. It took about fifteen minutes to open Port-à-l'Anglais weir, and about half a day to close all the shutters. Originally at the overfall portion of that weir there used to be a kind of movable counterpoise, in order to adjust the shutter, so that it should adapt itself exactly to the amount of water that was to be brought over, but it had been found that the small weight which was put on was not sufficient to counteract the effect of the rush of water over the weir. Apparently the same kind of weirs as those shown in Plate 3, Figs. 1 and 2, were being put up now in the United States. He had seen the drawings of the Kanawha river weirs, and they appeared to be very similar. The one kind was put over navigable passes, and the other, with a foot-bridge, over overfalls. The next type of weir he would refer to was the drum weir. He went to see the largest, and, he believed, one of the most recent specimens of that type at Joinville, one of the weirs on the Marne, not far from Paris. When he went to see it, some of the paddles were up, some were a little bit inclined, and some were at an angle of 45°. He got the weir-keeper to shut the weir, and he did so by simply opening the sluice-gate in one of the abutments—just turning round a handle, as in the case of an ordinary sluice-gate. He was able, without the slightest difficulty, to close the whole of the weir in a very short time. Then he asked him to open it, and he did that with equal ease, and restored it to the position in which it was at first. He should

Mr. Vernon-Harcourt.

say that the opening and the closing of the weir could be done by the weir-keeper in about five minutes. The man seemed to have entire control over the whole weir. Some of the paddles might be standing upright, others a little bit inclined, and he could regulate the discharge over the weir by just a turn, or half a turn, of the handle for turning the sluice-gate. The man seemed to take great pride in working the weir, and certainly it was most satisfactory. He asked him about repairs, and was told that all that was required was to tar the weir once every three or four years, and that no other repairs had been needed since the weir was erected in 1866. One very good plan, which prevailed in France, was to have full-sized models of the parts of each weir on the banks in many cases. They had one at this weir, so that any person who was not acquainted with the working of the weir could see the full-sized model close by. At Port-à-l'Anglais there was a model of the large navigable pass shutter; also a model of the overfall shutter, and of a shutter of the ordinary navigable pass that had been put up some time before, so that, if it was necessary to put in a new piece, it could be made according to the full-sized model on the bank, and was certain to fit exactly. In addition to this, there were at the École des Ponts et Chaussées models of almost all the movable weirs in existence. There was one large room, not quite so large as the hall of that Institution, filled with all sorts of engineering models, and it had occurred to him that it was a pity there was not such a model-room in connection with the Institution of Civil Engineers in this country. He next came to the Port-Villez weir. The history of that weir was curious. Until he went over to Port-Villez, he could not find out what was being done there. It was proposed to erect a weir larger than any other that had ever been erected in France, as it had been decided to increase the navigable depth on the Seine from 6 feet 6 inches to 9 feet 9 inches. It was, therefore, necessary to erect some new weirs on the Seine, and Port-Villez was one of the places chosen. The French engineers had never made the ordinary frame-weir nearly as large as the height proposed, and so they began to think what other weir they could adopt. M. Krantz was ready with his pontoon weir, saying that it was capable of being used for much greater heights than had ever been used before. It was therefore determined to try it. In France the Government paid for the erection of weirs on the rivers, and therefore naturally enough it was not very difficult to get experiments tried, as, if successful, the experience gained might be utilised throughout the country. The weir was commenced at

Mr. Vernon-Harcourt.

Port-Villez; but, as it was a new system, it was thought better to experiment upon it first, as he had mentioned in the Paper, at Bougival. It did not, however, prove a great success; it did not work with that nicety that was desirable, and seemed to require a greater pressure of water than would be got by the mere difference of level between the upper and lower water. At last it was decided to abandon that system, and, having no other system particularly to recommend in its place, the French resolved to go back to the old frame weir. But they wanted a very much larger frame than at Suresnes, Martot, or Bezons. The height of the Martot weir was about 11 feet, but the Port-Villez weir had a total height, from the top to the bottom, of 18 feet. That, of course, necessitated a considerable increase in the size of the needles, but as they were not quite certain whether they would use needles or other means of shutting the weir, they determined to strengthen the frames so that they might be suitable for needles or any other form of barrier. In using needles it was only necessary to make the frames capable of resisting the pressure on the top bar, because the needles abutted against the sill and against the top bar, and did not touch the other part of the frame; but in the case of a hinged shutter, such as was put up at Port-Villez, it was necessary to have the frame strengthened, so as to be able to bear the pressure of the water all down the front. In consequence of their having not settled what sort of barrier they would employ, they made it stronger than it otherwise would have been—strong at the top, and strong all the way down. Not having settled whether they would use large needles or other arrangements, they made provision for needles on the sill. It might be imagined that it was rather a bold notion, to think of putting up needles for such a height. The size of the Suresnes needles was 3 inches square; but the needle that was considered to be necessary for the Port-Villez weir was 8 inches square. Provision was made for needles there, without any arrangement having been devised for putting down the needles or raising them; and when it was remembered that the needles at Suresnes were about the greatest weight a man could carry, it would be imagined that a needle of that scantling, and much greater length, would be impossible to manage. Naturally enough, the French engineers began to consider by what other method they could close this weir. M. Boulé had designed an arrangement which he tried at Port-à-l'Anglais. He put some panels along the Port-à-l'Anglais foot-bridge, of which a description was given in the Paper, and by this means he was able to use a much smaller scantling of timber

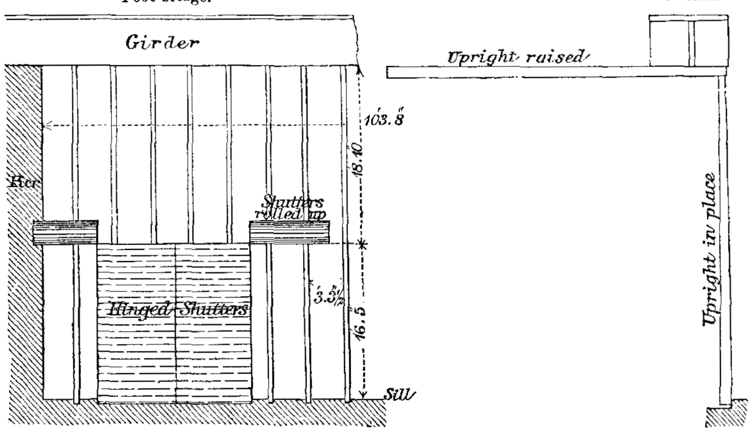
Mr. Vernon-Harcourt.

than if he had used needles. M. Boulé found this quite successful, and proposed it for the Port-Villez weir, but it was thought that another system would be better. In the meantime, the Russians were putting up a somewhat similar weir on the Moskva, at Moscow, and they were rather in a difficulty. They proposed to have needles 7 inches square, but they did not know how to manage with such large needles. They heard of M. Boulé's panels, but the arrangement they adopted was somewhat different. The frames were very light, and calculated only to resist the strain at the level of the top bar against which the needles were to rest, and were not suited to support the pressure that a series of panels would bring upon them. The arrangements they adopted were these. They put a needle down opposite each frame, and they formed grooves in front of each needle; and they slipped planks of timber down the grooves with little projecting pegs, by which they could lift them up. They were able by that means to keep the strains on the place where the frames were designed to support them, and they were able to do away with the trouble of using these very large needles. He ought to mention that the frames and hinged shutter adopted at Port-Villez were as shown on Plate 4, which he had made from a drawing kindly given him by M. Caméré, and that was the weir as he had seen it. He was fortunate enough to see one of the series of frames in place before the cofferdams were removed. He was therefore able to see the whole set of frames from top to bottom. The other bays had been finished, and this set of frames was just finished, the water was shortly to be let in, and the cofferdams to be removed. There was one other matter he would like to mention, and that was that another weir was going to be erected at Poses, below Vernon. It was to be of greater height than any of the weirs hitherto erected on the Seine. In the case of the Poses weir it was arranged that, instead of having movable frames all the way along, as at Port-Villez, there should be piers 100 feet apart. There were to be seven openings altogether; and over these girders were to be placed which would carry the foot-bridge. Uprights were to be hinged to the girders, and against these uprights the hinged shutters were to be placed. These uprights hung down, when in place, as shown on Fig. 1 (see next page). They rested against the sill at the bottom, and they were hinged to the girder, so that when desirable they could be lifted up, and rest in a horizontal position. Therefore the whole of the framework of the weir could be placed entirely out of the water. The drawings had been completed for this weir at Poses, and the work had been commenced. It was 3 feet 3 inches higher than that

Mr. Vernon-Harcourt.

at Port-Villez, but it was a question whether its cost would not hinder its adoption in other weirs on the same river. This type of weir appeared to have been thought of by the late M. Tavernier, engineer-in-chief on the Rhone, where the boulders brought down by that river rendered the raising of frames difficult, and where consequently it was very desirable to be able to lift all the fragile portions of a weir out of the river in flood time; but the employment of movable frame weirs on the Seine were not open to these objections, and hitherto had fully answered their purpose. The cost of different weirs as given him by M. Boulé was as follows, for a height of weir of 13 feet above the sill: the needle weir, £61 per lineal foot; the shutter weir, £73; the pontoon weir,

Fig. 1.



£147 to £158; and it was estimated that this new weir of M. Caméré would cost about the same as the pontoon weir.

Mr. Buckley.

Mr. R. B. Buckley did not wish to add anything to his own Paper, but to make a few remarks on Mr. Vernon-Harcourt's. That Paper was one of great interest to all engineers connected with hydraulic works, and especially interesting to himself, since his experience in India had been mostly in connection with weirs and other works dealing with water. Last summer he had an opportunity of visiting all the weirs that Mr. Vernon-Harcourt had described, except the Krantz weir (which he believed had been removed, wherever it was erected), and the bear trap, which, as Mr. Vernon-Harcourt had said, had almost become obsolete. The first part of the Paper described the general construction of weirs,

Mr. Buckley.

and opened out considerations on which he should like to make some remarks; but as the real discussion before the meeting was in regard to movable weirs, he would only make one observation upon the first part of the Paper; that would be with reference to the oblique weirs. Mr. Vernon-Harcourt stated; "The tendency of oblique weirs, like those referred to, is to divert the strongest stream, and consequently the deepest channel, towards the bank on which the upper end of the oblique weir is situated." It was no doubt quite true that, in rivers where a good foundation could be obtained, there would be very little objection to oblique weirs; but in rivers such as those which had to be dealt with in India, with sandy beds, and difficult foundations, they were very objectionable, for three reasons. First of all, they induced currents parallel to the weir; secondly, they caused a deepening of the channel above the weir, near the up-stream end, which was often dangerous; and, thirdly, they raised the level of the water in the river at the lower end of the weir. There was a remarkable instance of this in a weir constructed by General Rundall. There happened to be, near the site where that weir was to be erected, an old stone causeway built diagonally across the river, used, when the river was low, as a crossing for bullock carts. General Rundall thought it would be an advantage to use that roadway for the toe of the slope of the weir, and consequently he put the weir at a considerable angle to the stream. The weir was undermined more than once in consequence of the parallel channels induced, and General Rundall said, "The water piled up against the left wing so much, that, in full flood, there was a plunge of 2 feet over it, while in the other flank no sign of any obstruction was visible." It was hardly necessary to point out what great danger there was with a depth of 2 feet of water over the top of the wing of a weir across a river with a volume of 700,000 cubic feet of water per second. This weir was across the river Katjoree in Orissa; it was 1,200 yards long, the crest was 12 feet above the river bed, the rise of the river in flood was 30 feet, that was 18 feet above the crest of the weir. The work was ultimately made safe against the action of the parallel currents by throwing in large quantities of rubble stone in front of the weir. Oblique weirs had been advantageously made in India in rivers with boulder beds.

At the head of the Jumna canal the river had a declivity of 15 feet per mile, and the bed consisted of large boulders, which in the flood season came down with immense velocity, and were very dangerous things to have to deal with. In this river in the dry season the water meandered among the boulders in such

Mr. Buckley. a way that it was most difficult to draw it into canals. For this reason the weir was made oblique to the stream, by which during floods a heavy stream was brought to the lower side where sluices were placed, so that a deep channel was formed which led the water to the canal.

A list had been given by Mr. Vernon-Harcourt of five different kinds of weirs in France. Mr. Buckley was sorry to see that one of the most modern, and in some respects, he thought, the best, had been omitted from the list. It was casually referred to as M. Girard's system, and it was mentioned that "this contrivance was tried at the overfall of Brûlée Island weir." That would lead persons to suppose that only an experiment had been made with it, whereas the fact was that it had been permanently constructed and was extremely successful. On one bank there was a lock which, during high floods, might be entirely submerged; next the lock there was the "Navigable Pass," which in this weir was 98 feet long, and beyond that was the "Déversoir," or regulating weir, 82 feet long. During floods the water-line would be above the top of the lock walls, all the shutters of the weir would be open, and boats would pass freely over the weir. The floor of the "Navigable Pass" was level with the sill of the lock, the crest of the regulating weir being 3 feet 4 inches higher. Where the weir was entirely open, and the discharge of the river was such that it gave a sufficient depth of water over the "Navigable Pass" to enable boats to pass, the lock was not used, and the navigation was worked through the pass. When the river was low it would be necessary to impound the water, the shutters of the weir would be up, and the lock would be used for passing the boats. The shutters of the "Navigable Pass" were of the ordinary Chanoine type, as described by Mr. Vernon-Harcourt. The regulating weir was of stone, the face being ashlar and the heart rubble. The down-stream face of the weir was sloped at an angle of 30° with the floor. The shutters of this weir were of wood, 11 feet $6\frac{1}{2}$ inches long by 6 feet $1\frac{1}{2}$ inch high; they were hinged on a horizontal axis to cast-iron bearing blocks, which were firmly embedded in the crest of the weir. On the sloping face of the weir hydraulic cylinders were fixed. A small copper pipe 1 inch in diameter led from the bottom of each of these cylinders, through a trough, which was cut in the masonry of the weir, to an accumulator in an engine-house on the abutment of the weir. There were seven shutters on the weir; each shutter was fitted with a hydraulic press. The plunger of each of these presses had, at its head, a cast-iron cross-head, about 4 feet long, which worked in three cast-iron guideplates fastened to the slope of the weir. This cross-head was connected by three connecting rods to a horizontal axis on the back of the shutter at about half its height. That weir had been at work, he thought, for six or seven years most successfully, and he saw it at work the other day in France. Each shutter when down was horizontal: at the point where each shutter met its neighbour there was a stone pier built out into the river below; grooves were cut in the piers so that baulks of timber could be dropped into the grooves, if necessary, and the bay being pumped out, the hydraulic presses could be examined and repaired. Mr. Buckley.

The weir was worked in this way. On the bank at the side a small house was fitted with a turbine, which was driven by the head of water of the weir. This turbine worked a double-action water-pump and a single-action air-pump. In that house there was a cast-iron accumulator, 24 inches internal diameter, 2 inches thick, and 11 feet high. The turbine was put to work, and the air-pump first of all pumped the air in until there was a pressure of 170 lbs. on the inch. Then water was pumped into the accumulator until a pressure was obtained of 350 lbs. on the inch. There was then accumulated sufficient force to lift up all the shutters on the weir in about five minutes. From the accumulator a separate copper pipe led to each hydraulic press. Each of those pipes was fitted, in the engine-room on the bank of the river, with a small cock, so that at any time any one of the seven shutters could be placed in communication with the accumulator, or with the waste water tank, which was in the same house. The man in charge of the weir could, therefore, when his accumulator was charged, either lower all the shutters at once, by simply putting the pipes into communication with the tank in the engine-room, or let any one down, or lift one up, or raise one and lower one at the same time. It was very interesting to see the man with a small spanner, which could be put in a waistcoat pocket, raise or lower any of the shutters against a head of 6 feet 1½ inch of water.

The shutters were kept in position by the hydraulic pressure on the piston. It struck him that there must be some leakage, and he enquired from the keeper whether that was not so, and whether he had not constantly to keep pressure on the accumulator in order to replenish any press that might leak. The lock-keeper said that was not so at all—that practically there was not the slightest leakage—that they had feared there would be, but that there was not. It also seemed to him, when he was there, that there would be considerable danger from frosts—that if severe frosts were to occur, probably the hydraulic cylinders would burst, or the pipes

Mr. Buckley. would burst, or the water get frozen up. He had received a letter from an engineer resident on the spot, which, with the permission of the meeting, he would read presently. He would mention, first, that the presses were purposely below the level of the weir, and were always kept under water, so that the frost did not have an opportunity of exerting its whole force upon them. He should certainly have supposed that in the late frost some accident might have been anticipated, but that was not the case. In a letter from an engineer close to where the weir was erected, it was stated that the frost was – 25° Centigrade, or 13° below zero, Fahrenheit.

The engineer to whom he had referred, M. Lavoinne, wrote, "No accident whatever occurred out of the engine house; viz., in the cylinder connected with the shutters, or in the conduits bringing the water-pressure to them, during the very hard frosts we had here (– 25° Celsius). In the engine room only, on account of insufficient heating, two feed pumps, which should have been emptied, and a pipe connecting the reservoir with the hydraulic presses, were broken by the frost because of the neglect of the engineman. The opinion of the superintendent is that with more care and better efficiency of the heating apparatus, no damage should have occurred. The cost of the repairs, consisting of the replacement of the broken cylinders and pipe, was not over 500 francs; the whole system was again in order within two weeks." He believed that the weir at the Isle Brûlée was the only one in the world constructed on that system.

The bear-trap system had, he thought, been given over. Some improvements were proposed upon it, but perhaps it was hardly worth while referring to them, as they were never put into practice. M. Poirée's weir had these great advantages. It was, he believed, the cheapest of all the systems which had been invented. It was very much used in France, and was the simplest of all the systems, the most easily repaired, and did not bring such a heavy strain on one part of the apron when it was removed as M. Chanoine's system. In the latter system one shutter must be let down first, and the shock with a head of 10 feet of water brought a heavy strain on the apron, which sometimes yielded. M. Poirée's system let the water through gradually, but it had this disadvantage, which had not been alluded to in the Paper—that the frames, when they were lowered down on to the floor, as they were when the weir was entirely open, were liable to get caught by anchors or boats, and to damage from those causes. The system at Port-Villez was no doubt an excellent one, but he was not aware

Mr. Buckley.

that it had been adopted. It had always surprised him that something of the same kind had not been used on those weirs after the fashion of Venetian blinds. He thought it would be easy to make a rolling shutter to go down the frames, with bars some few inches wide, which might at first be kept horizontal so that there would be no pressure on them; these bars might be hinged on horizontal axes, and gradually turned with their flat faces to the stream, as it was required to diminish the discharge. M. Chanoine's system had been used in various parts of the world, and in one instance in India. It had the great advantage over M. Poirée's system that, when it was down, all the moving parts were hidden by the shutters, so that there was no danger of their being caught by anchors or boats, or anything else that might pass.

All the systems of weirs that had been described in Mr. Vernon-Harcourt's Paper had this disadvantage—that they could only be erected against comparatively small heads of water. He had a list of the maximum heads against which the Chanoine weirs had been erected, and he believed that on the average the greatest head against which the last shutter had been lifted was 3 feet 6 inches. These systems were not applicable to cases such as occurred in India, where a shutter had to be lifted against a head of 10 feet of water. The drum weir was no doubt an extremely ingenious and beautiful appliance. He had seen it at work in France, as Mr. Vernon-Harcourt had described, with one shutter erect, another down, and the others at different angles, but he did not understand how that arrangement was obtained. One point in connection with this form of weir had not been prominently brought forward in the Paper, namely, that each of the paddles was divided from its neighbour below the surface of the weir by a diaphragm. The aperture marked there was the hole which was cut in the diaphragm, so that each of the lower paddles when it turned fitted almost watertight against the diaphragms. The apertures which were cut through the diaphragms, one above and one below the paddle, were connected in the abutment or pier with culverts worked with sluices. The construction of those culverts was somewhat complicated, and he did not think it necessary to explain it. It was quite easy to understand that when the water in the upper portion of the trunk was in communication with the higher level, and when the water in the lower portion of the trunk was in communication with the lower level, considerably below the crest of the weir, and when the shutter was in a horizontal position, it would assume an upright position. It was

Mr. Buckley. equally easy to understand that when the lower aperture was put in connection with the greater head, and the upper one in connection with the lesser head, the pressure would turn the paddle round and bring the shutter down into a horizontal position; but he did not think it was easy to understand how, when there were six or eight of these shutters in one line, there could be any arrangement for admitting the water into this or that tube, so that one shutter would fall, the next would be at an intermediate angle, and the third perhaps right down. Surely, whatever the condition of affairs might be, the pressure must be uniform throughout the whole length of the shutters connected with the same sluice. Why, then, should one shutter stand upright, the next one fall down flat, the third be at an angle, and the fourth upright again? He knew it was so, because he had seen it himself, but he did not understand it, and he should be glad if Mr. Vernon-Harcourt would explain it. In the Noisiel weir, to which Mr. Buckley particularly referred, it was not the case that there was any communication from the abutment to the pier, but it was worked entirely from the pier, from one end only of the weir.

The system of pontoon weirs of M. Krantz was tried, he believed, in France, but when he was over there he was told that it had been removed, not having been found applicable. The most general systems of French weirs were Poirée's and Chanoine's, which were used in 60 per cent. of the weirs in France. The next was that of Desfontaines, the drum weir, which was also considerably used, but that system was only suitable for overfalls, as the portion below the crest had to be about one half as deep again as the head of water on the weir. M. Girard's system appeared to him not only applicable to the regulating weir but also to a navigable pass. There was no reason why the hydraulic presses should be inclined at an angle. They might be laid horizontally on the floor: it was only necessary to lay them sufficiently below the water to keep them from frost. The system was excellent, and for large discharges in Indian weirs would certainly be a good one.

With reference to the cost of the different systems of weirs on French rivers he wished to give the following Table, which he had prepared from the French works on these weirs. He thought that the method of comparison by superficial foot of shutter was in some respects more likely to be useful than by lineal foot of weir.

Mr. Buckley.

System.	Height of Shutters.	Approximate Cost per Lineal Foot of Weir.		Approximate Cost per Superficial Foot of Shutter.	
		Including Foundations.	Movable Part only.	Including Foundations.	Movable Part only.
	Feet. Inches.	£. s.	£. s.	£. s. d.	£. s. d.
Poirée or Boulé	13 1½	46 7	..	3 10 7	..
Chanoine	10 0	39 0	10 0	3 18 0	1 0 0
Girard	6 5½	38 2	25 8	5 18 0	3 18 8
Krantz	9 10	82 10	..	8 7 10	..
Desfontaines, or Drum weir	2 10	29 0	10 0	10 4 2	3 10 5
American, or Bear trap	8 10	101 0	..	11 8 8	..
Vanne of M. Poirée	..	..	21 16	..	..

He agreed with Mr. Vernon-Harcourt that while embanking rivers might be a good plan, dredging their beds was better.

Mr. L. B. Wells said the navigation of which he was engineer was so small, compared with the large rivers to which reference had been made in the Papers, that he felt reluctant to trespass upon the time of the members by referring to it; but, as the trade carried on it was an important one, and the trustees of the river Weaver had, during the last few years, spent a considerable sum of money in improving their navigation, he had therefore thought it his duty, as a Member of the Institution, to endeavour to be present at the discussion. The level of the pond on the Weaver, communicating with the tidal waters of the Mersey, was 16 feet 6 inches below Northwich pond, on which a great deal of salt was made, and that difference of 16 feet 6 inches was pretty evenly divided between four weirs and four locks. Some years ago it was determined to build more capacious locks to facilitate towing in train as now largely practised on the Weaver, and also to accommodate coasters; and at the same time it was decided to build two sets of locks, one set to take the place of two sets of the older ones. In the first instance the water was raised readily by placing a fixed weir across the flood course at a short distance below the weir holding up the water for the Northwich pond, the pond raised being almost entirely a canal, and consequently no drains were interfered with, nor was the flood discharge of the river affected. This was suggested by Mr. E. Leader Williams, M. Inst. C.E., when engineer for the Weaver, the work being carried out and the locks commenced by his successor, Mr. J. W. Sandeman, M. Inst. C.E. But in the second instance the locks were placed at the lower end, Mr. Wells.

Mr. Wells. near the fourth weir from Northwich; and had that weir been raised, as it was a fixed weir with small side sluices, a dam of 4 feet 3 inches would have been thrown across the river $1\frac{3}{4}$ mile below the present discharge at the same level. He considered that would be impolitic, as rendering the trustees liable to litigation; moreover the foundations of the old weir were not sufficient to warrant the rise; he therefore recommended the trustees, as it was absolutely necessary to raise the water, to do so by means of sluices which could be lifted clear of the river in flood time, and so leave the waterway unobstructed. The proposal was submitted to their consulting engineer, Sir John Hawkshaw, Past-President, who expressed his approval of it. The sluices, eight in number, 15 feet wide and 13 feet deep, were now in course of construction; they would be fixed in the valley a short distance above the Dutton viaduct of the London and North Western railway. He thought that if the bed of the river was cleared of all obstructions at that point, and the two existing weirs were removed, no land or property owner on the navigation could have any cause of complaint. While greatly admiring the ingenuity displayed by engineers in France and India in dealing with the rivers in the methods described, still he felt bound to state that he should not feel satisfied to trust the trade of the Weaver to works of so light a character. During the past twelve months he had raised the water in five of the ponds of the Weaver navigation by means of movable caps. In May last the chief carriers on the Weaver, who were also makers of salt, and owners of the craft (locally flats) that conveyed it to Liverpool, had a conference with the trustees, and made a very strong representation that the navigable depth should be increased from 8 feet to 10 feet, and that this should be done for the trade of the coming summer. It was also decided that the river should be run off in the middle of July to enable the midfeather of one of the old locks to be removed, and for other purposes. He demurred at the haste with which the work was required to be done, but his objection was overruled. He at once set to work, and, with the help of Mr. W. H. Hunter, who aided him very materially, in a fortnight plans were prepared and the work was ordered to be proceeded with. It was necessary to raise the water on the sills of five locks. One of the locks would be removed when the large sluices at Dutton, to which he had referred, came into operation, and the weirs in that case were only partially capped; in the others the whole width of the weir, about 75 feet, was covered by three movable caps of equal length. The weirs, with one exception, had fixed

Mr. Wells.

wooden caps varying from 6 inches to 16 inches in depth; these were incorporated with the movable caps, and as the stone crest of the weir was lowered 5 inches, a very considerable improvement in the flow of water was obtained. Owing to the difference in depth required over the several lock sills, the height of the caps varied from 1 foot 11 inches, to 3 feet 2 inches. They were formed of iron beams properly braced and green-heart planking—a number of short lengths from the old lockgates being available. The sills were of green-heart, and the cap was of pitch-pine. There was a light overhead bridge, formed of rolled iron beams, resting upon masonry, on the banks, and on cast-iron columns on the weir-head; this also supported two semicircular brackets, through which the lifting screws worked. The lifting screws, two to each cap, were $2\frac{1}{2}$ inches in diameter, and, to lessen friction, four cast-iron rollers on turned wrought-iron axles were bolted to each corner of the caps. The caps were spaced 4 inches apart, and the joint made by a wooden stop water hinged at the bottom, closed by the water-pressure and opened from the bridge. At the top of the bracket attached to the screw-nut were wrought-iron arms, supporting light cast-iron rims: over these a pitch chain was carried, so that the two screws worked simultaneously. The caps, which had been in operation about six months, had worked remarkably well. They were made in the shops of the trustees, and were fixed on the weirs, and workable at the end of the stoppage, July 31st, two months after date of order. Their cost was about £3 per lineal foot. No doubt it would have been considerably less but for the haste with which the materials were bought, and the work was done. The caps enabled the water to be let off in flood time, and maintained an increased depth under ordinary circumstances, and, as the Weaver craft carried about 3 tons to the inch, this was of considerable importance to the owners. A large barge had already been built to carry from 360 tons to 400 tons, whereas 250 tons previously constituted an exceptionally large cargo.

The question of sluices being, in his opinion, so much akin to that of movable weirs, especially in rivers where the traffic could not be navigated along the flood course, he thought this a proper occasion to mention an experimental sluice which he had constructed twelve months ago, to try the effect of rollers as a means of lessening friction, and also to see if the joint between sluice and post could not be made by water-pressure in front as readily as at the back of the sluice. The sluice in question had a clear width of 9 feet 4 inches, and the ordinary head of water was 4 feet 6 inches; the sill being uncovered every opportunity was afforded

Mr. Wells. for examination. No special trouble was taken. Four rollers 7 inches in diameter and 3 inches wide were found in the yard, the axles were not turned and the rollers were fixed in brackets bolted to the side uprights of the sluice. When in place, a Duckham's weighing machine was attached to the sluice, and to a block and fall, the end of the fall being taken to a crab. The sluice weighed 1 ton 15 cwt. Water was then let in through the cofferdam and rose to 4 feet 6 inches above the sill. This gave an area of pressure of 42 square feet.

Mean pressure . . .	2·25 feet ×	62·4 lbs.	= 140·4 lbs.	
Total pressure . . .	42 „ ×	140·4 „	= 5,846 „	= 2·63 tons.

The sluice was started when a pressure of 1 ton 19 cwt. was registered by the weighing machine, or 5 cwt. more than the dead weight of the sluice. The coefficient of friction was therefore ·095. To close the vertical joints, a stopwater of oak, 5 inches square, loaded to the specific gravity of water, truly planed on two adjacent sides, was attached by a bolt, on which the stopwater hung loosely, to the front edge of the sluice; a width of 5 inches of the edge of the sluice was planed and also of the side in way of the stopwater, so that there were four contiguous smooth surfaces; the pressure of water kept these in contact, and an excellent watertight joint was made. There existed in his office a correspondence between Mr. Sandeman and Mr. F. G. M. Stoney, and the latter gentleman had prepared plans for the Dutton sluices. Mr. Stoney proposed longer spans, and to work the sluices on a system of free rollers, of which he was the patentee, and which was a very ingenious invention; but for reasons which need not be entered upon his plans were not adopted. Having been in the habit of using wheels for heavy doors on land, and in general seeing rollers employed to lessen friction, Mr. Wells had taken an early opportunity of testing their use for sluices, up to the present time with undoubted success; and he saw less reason to apprehend difficulty in working rollers than in working the screws with which so many sluices were lifted.

Mr. Parkes. Mr. W. PARKES said his object in rising was to take exception to a small portion of Mr. Vernon-Harcourt's Paper. He hoped in doing so that it would not be thought that he did not appreciate the great care and industry which that gentleman had displayed in collecting so much interesting information, which he believed would be of great use to those engineers whose duty led them to adopt a system of movable weirs in rivers. But when, some weeks ago, he saw the notice of Mr. Vernon-Harcourt's Paper on "Fixed

Mr. Parkes.

and Movable Weirs," he had hoped to have a valuable contribution to a question which had never yet been properly solved, namely, the theory of fixed weirs in rivers. When the Paper came into his hands he was disappointed to find that that question, which he regarded as one of great importance, was treated in a very cursory manner. Indeed, he thought that to treat a question in that way was really doing a mischief to the practice of the profession. If any engineer who was several years younger than himself were to take up Mr. Vernon-Harcourt's Paper as an authority, and a very high authority it would be as coming from that gentleman, as to how rivers should be treated, he would come to the conclusion that the system of fixed weirs had been by general consent regarded with indifference, if not condemned. He could not admit that that was the case. The Paper alluded to the case of the Severn. That matter had been discussed a great deal many years ago, but so many years ago that many gentlemen present could remember nothing about it; and therefore he thought he might profitably occupy a little time in giving a short sketch of what really did occur. He believed he should succeed in showing that the question was of much more importance than any person would be led to suppose from the way in which Mr. Vernon-Harcourt had treated it.

In the year 1841 the River Severn Commissioners applied to Parliament for power to improve about 42 miles of the river for the purposes of navigation. The engineer whom they employed was the late Mr. (afterwards Sir William) Cubitt, then a Vice-President of the Institution and a man of the highest eminence. The plan which he proposed was to put in the river five solid weirs, which would be placed obliquely to the stream, and alongside each weir a lock in a side cut to accommodate the navigation. That was to give about 6 feet navigable depth throughout that length of river. Mr. Cubitt contended that the placing of those weirs in the river would not interfere with the discharge of flood-waters, and he stated that the great virtue of his weirs was their length, which enabled the water to pass in a thin film over a considerably greater length than the ordinary breadth of the river. He made it from two and a half to three times the breadth of the river, and he obtained that length by putting the weirs obliquely in the stream. But he asserted there was another advantage in the obliquity of the weirs. When the water rose to such a height that at the lower side of the weir its level was nearly equal to the level at the upper side, the current then pursued its course downwards parallel to the general line of the stream, and did not fall over the weir.

Mr. Parkes. In that case, Mr. Cubitt contended that the obstruction caused by the weir was simply the cross-section of the weir itself in a line at right angles with the stream. If a cross-section of the river about the middle of the weir was taken there would be first a dip down to the natural bed of the river; then the weir and rise over that, and then the natural bed again. Thus there would be the natural section of the river with an erection in the middle, which Mr. Cubitt said was the only obstruction, and this obstruction he contended could be compensated for by giving some extra width to the river at that spot. This theory was very much contested. It was not altogether the essence of Mr. Cubitt's scheme, because he said that his main point was the great length of the weir. That was the evidence which Mr. Cubitt gave to the Parliamentary Committee.

The Gloucester and Berkeley Canal Company employed another engineer of equal eminence—the late Mr. James Walker—and many then present might know that he, Mr. Parkes, was a faithful though unworthy disciple of that eminent engineer, and all his personal sympathies were with the cause which that gentleman espoused. He should now, however, show that in this particular case he thought Mr. Walker was mistaken. Mr. Walker objected altogether to the lowest of Mr. Cubitt's five weirs, and proposed an alternative plan of improvement, preferring that for the lower 10 miles the river should be treated as a free stream, merely equalising the section throughout, so as to give uniform slope and depth. Then for the upper 12 miles, he agreed that they should be treated by means of locks and weirs. But he wished to put into the stream a system of movable weirs, which were designed in very great detail, and no doubt if carried out would have furnished material for another chapter in Mr. Vernon-Harcourt's Paper. But it was not carried out. Mr. Walker objected most strongly to Mr. Cubitt's theory of the weir being only an obstruction to the extent of its cross-section at right angles to the stream. He maintained that the weir offered an obstruction to the flood waters equal to the breadth of the river multiplied by the height of the weir, whether the weir were placed directly or obliquely to the stream. If he might be permitted to do so, he would read Mr. Walker's own description of his views on the matter. In a Report which he addressed to the Gloucester and Berkeley Canal Company in 1841 he stated, "There is, I think, no doubt that placing solid dams at intervals across the stream, whether directly or obliquely, and from 5 to 11 feet above the present bottom of the river, will diminish the velocity of that portion of the water which is below the level of the weirs, and near them, and of the whole descending column for a very considerable way up the river; and that in this length so interfered with, particularly near the weirs, first the water will be kept back, then a deposit will take place, which will diminish the depth, and therefore raise the surface of the water and increase the floods." That was Mr. Walker's opinion with regard to these solid weirs, whether direct or oblique. In the evidence that he gave before the Committee in the same year he was asked whether, supposing Mr. Cubitt's plans were followed, and it was found that they did not answer, would the damage be anything more than the expense of building them and taking them down again? His reply was, "The river would have found itself a new regimen; the river would be in steps in place of being in an inclined plane. Every weir you put in makes a step in the river, and if you were to go back again, and make it an open river, you would have to remove all the shoals formed at the back of the weirs. I think the expense of doing that would be immense." That showed that Mr. Walker's opinion was very strongly opposed to solid weirs in the Severn, upon two grounds, First, that they would interfere with the free passage of the flood-water; and secondly, that they would form deposits up stream. He failed to persuade the Committee of this with regard to four out of the five weirs. Those were sanctioned to be carried out on Mr. Cubitt's plan; but with regard to the fifth and the 10 miles of river dependent upon it, Mr. Walker's plan was ordered to be carried out—that of regulating the river, and reducing it to a uniform section. These works were shortly afterwards commenced, under Mr. Cubitt's superintendence, by Mr. Leader Williams, the engineer of the Severn Commission. In the year 1845 Mr. Williams presented the Paper to the Institution of Civil Engineers, which was alluded to in Mr. Vernon-Harcourt's Paper, giving a description of the works. He there stated that the locks and weirs were completed and in successful action; but the 10 miles to be dealt with by Mr. Walker's plan had not been completed, and he promised a further communication with regard to it. He would now read what Mr. Williams stated with regard to the effect of those weirs: "At Holt, an old barge, which had been laid up as useless by the contractors, got adrift and sunk in 10 feet water, 20 yards above the weir. It continued undisturbed during the short-water season; but the first heavy fresh raised it from the bottom, and laid it upon the upper sill, there not being sufficient water to carry it over. Another proof of the uninterrupted action of the under-current is, that the bottom of the channel, immediately above the Mr. Parkes.

Mr. Parkes. weirs, not only maintained its original depth, but has been scoured out; in some instances, to a depth of 2 feet." It was therefore evident that two or three years after the works had been completed there was nothing of the evil which Mr. Walker had anticipated. In place of the accumulation which he expected to find there was actually a deepening, and this barge was brought up by the flood and carried away to the weir.

Shortly after, the Severn Commissioners found that, according to their judgment, the works which they were carrying on, on the system recommended by Mr. Walker, were likely to turn out a complete failure. They therefore applied to Parliament again for power to make another lock and weir, not in the spot formerly chosen, but 4 miles further down the river, at Tewkesbury. In the year 1851, Mr. Walker was employed by the Admiralty to report upon that, and Mr. Parkes was associated with him in that Report. They went over the river and examined it very minutely. The result of Mr. Walker's investigation was that he was of opinion that his plan for equalising the river had not been so far fairly treated. He therefore recommended that it should be persevered with, and he showed wherein it had not been fairly dealt with. This was simply incidental, but the portion of Mr. Walker's conclusion important for the present discussion was this. It was contained in his report to the Admiralty, dated the 1st of September, 1851: "I think it right to say of the locks and weirs and other improvements in the river between Worcester and Stourport, that they appear to give general satisfaction as respects the passage of the trade, without prejudicing the drainage of the country that is within their scope." Now, considering the opinion that Mr. Walker had given ten years previously, that was a very remarkable admission. It was as much as to say that he had changed his mind about the action of these weirs, and that they were, after all, a success, and Mr. Parkes felt bound to confess for his own part that he also considered they were a very great success.

The Admiralty were not persuaded by Mr. Walker to carry on their opposition to the lock and weir at Tewkesbury any further, and the Commissioners were allowed to carry out the works. There was some little delay about doing it, and not until 1860 did Mr. Leader Williams present another Paper to the Institution. In that Paper Mr. Williams gave a fresh description of the effect of the locks and weirs, which, if the meeting would permit, he would read. This was in 1860. "On comparing the original section of the river, made in 1842, before the weirs were erected, with a series of transverse soundings taken at

Mr. Parkes.

16 feet from the head of the weir, it was found, that the depth of the channel had been actually increased 3 feet to 5 feet. On taking longitudinal soundings $1\frac{1}{2}$ mile up the river, it was again found, that the depth had been increased the whole distance 3 feet to 5 feet. The same effect had been produced in the whole of the pools between the weirs; the channel, indeed, was deepened to such an extent, that the banks which had stood for many years previously, had, in some places, fallen in, from the increased energy of the current having scoured out the bottom." This was some fifteen or sixteen years after the weirs were erected, and surely there was plenty of time during that interval for the anticipated deposit to have taken place, if there had been any tendency towards it. But the tendency was evidently in quite an opposite direction—namely, to scour out the river. To what could that scouring be attributed except to the erection of the weirs, which were the only artificial works made in the Severn? That, however, did not seem to have been the opinion of some engineers at that time, for on the very same evening Mr. Bidder, who was then in the chair, made these remarks: "He could not believe, that all the facts connected with the works of the Severn had been detailed, because, so far as he understood the results, they had been produced without adequate causes." That rather reminded him of the man who said: "If your facts do not agree with my theory, so much the worse for your facts." Mr. Parkes preferred to think that the facts spoke for themselves, and if theories did not account for those facts, engineers must try and improve their theories. For his own part, he confessed he was not able to satisfy himself entirely how such a remarkable result was attained, but he could not fail the less to admit that it was attained, and that in some way which must be attributed to the weirs, and to some extent, he thought, to the oblique position of the weirs. Now it really appeared to him that Mr. Vernon-Harcourt had something of the same notion as Mr. Bidder, for he said, "The merit claimed for these weirs, of actually increasing the rate of discharge, and diminishing damage from floods, is inadmissible." He submitted most respectfully that that statement required proof. In a Paper on fixed weirs, it was hardly fair to make such an assertion as that, and leave the proof to the imagination. The facts were undoubted, and to what but the increased capacity of the river could they be due? If so, the floods must have a freer discharge than previously. Mr. Cubitt made no claim for an improved flood discharge. He only contended that it would not be lessened. The claim for improve-

Mr. Parkes. ment was a subsequent one, based on actual experience of the results obtained. Now, what were the grounds on which this claim was based? Mr. Parkes gave only a negative value to the evidence of landowners that the flooding of lands was reduced. There was no good standard of comparison except in a long series of years, and he would only assume that it was proved the floods were not aggravated. The one important and definite fact established was the deepening and enlargement of the river channel itself. He conceived this could be accounted for only by an increased scouring power. As a rule the scouring power of a river channel was the land floods, but a given volume of flood water would be more or less effective as a scouring agent according to circumstances. If it were thrown into the river with such rapidity that the channel was unable to carry it off, it would overflow on to the adjoining lands, and there, by evaporation, absorption, escape by by-channels, and retardation of escape into the river channel, much of the scouring power would be wasted. Hence, anything that facilitated the immediate passage of the flood waters by the river channel increased the proportion of those which were effective for scour. This was what was done by the pounded river. The disturbance caused by the sudden accession of water at any spot would be transferred down the course of the channel with a velocity depending on the square root of the depth of water in the channel, and therefore far more rapidly in the pounded than in the unpounded channel. Thus the escape of the flood by the channel was facilitated, and the rise above the banks was retarded, in some cases it might be even altogether prevented, and thus the water was kept flowing in the defined channel for a longer period under conditions favourable for scour. Of course it was an essential condition that the weir itself should have a capacity of discharge at least equal to that of the channel above and below; but this was assumed to be provided for by length of weir while it acted as an overfall, and by width of channel above the top of the weir when it was "drowned." He considered that these two conditions of the weir were not distinguished with sufficient clearness in former discussions on the subject.

The utilisation of scouring power seemed to have been a result attained, in the case of the Severn, to an extent perhaps beyond the anticipations or intentions of the authors of the scheme, but not the less instructive to their successors. He thought that what he had mentioned would show that the question of solid weirs in a river was a most important one, and one which ought to occupy the attention of any engineer who was going to improve a river bed. The system of solid weirs claimed to do what the systems illustrated in the diagrams did not claim to do, namely, to give a really better discharge for the floods than the unimproved river itself gave. He thought, therefore, Mr. Vernon-Harcourt should either withdraw that portion of his Paper which professed to deal with solid weirs, so that he might not influence the case by treating them in the way he had done, or that he should amplify the portion of his Paper relating to fixed weirs. Mr. Parkes.

The cost of various kinds of movable weirs had been given by Mr. Vernon-Harcourt as from £40 to £70 per lineal foot. He did not know what the actual cost of the Severn weirs was, but they were originally estimated at £7 per lineal foot; and as, to cross the river, three times the length was required, that made them £21 per lineal foot of breadth of the river, or one half the cost of the cheapest weir Mr. Vernon-Harcourt had quoted.

Mr. R. RAWLINSON, C.B., had not intended to speak on the question of movable weirs, but there was one point with regard to the action of solid weirs in a river which had not been referred to, and he could very simply state it. Diagrams of one of the weirs on the Severn were given in one of the Rivers Pollution Reports, and the action was this. The river rising in flood, say a mile above the weir, rose a foot; upon the fixed weir it only rose an inch. As the river went on rising beyond the influence of the weir foot by foot it added inch by inch on the weir, so that, when there was a depth of 10 feet in the river, there would be only one of 10 inches on the weir. Now, he held that those who cried out against weirs being such fearful obstructions to a river, could not know what the real action of a fixed weir was. If the river went on rising the weir was lost entirely to view, and the flood flowed on as if the weir did not exist. Rivers with fixed weirs might have relief from by-washes, having movable plank stops in 10 or 12 feet lengths. A foot-bridge placed over the by-wash would enable the stop-planks to be placed or removed by hand as required. By-washes were common on canals, impounding reservoirs, and on some rivers where there were mills. Mr. Rawlinson.

The Rev. Dr. PEARSON said, somewhat like M. Girard,[1] whom Mr. Buckley had complimented so highly, he was not a member of the Dr. Pearson.

[1] M. Girard was a civil engineer in private practice; and it was said, in the "Annales des Ponts et Chaussées," that his invention had been adopted by the Administration with the view of encouraging voluntary efforts. He was accidentally shot by a Prussian sentry in February 1871.

Dr. Pearson. profession, but as he had ventured in a scientific society to which he belonged to bring forward this subject, he hoped he might be allowed to make one or two remarks upon it. In bringing it before his own society at Cambridge, he said that the subject had not come before this Institution, and he believed he was right in saying so. He did not wish to make any remark in regard to fixed weirs; and in saying what he had said, he only referred to the movable weirs such as those that are used in France. He thought that there need not necessarily be a contest on the present occasion between fixed and movable weirs, as M. Chanoine, who, he considered, was the most inventive, if not the most successful engineer concerned in these matters, had simply improved upon the system of M. Poirée, which again was only intended to be an improvement on the old system of stanches: such as also existed in England, but which all would allow were now antiquated. He admitted that the system of needles, such as was used on the river Meuse, was also an extremely suitable invention; anyhow, he thought that a weir which was capable of being lowered absolutely into the bed of the stream must cause a smaller obstacle to the discharge of the flood water than a solid weir, although he fully admitted that the results must be tested by what had actually taken place, and not only by theoretical views on the subject. One large river, the Shannon, had not been referred to, but the floods on that river had seriously been complained of. He had been unable to find the Report referred to in Mr. Vernon-Harcourt's Paper by Mr. Forsyth and Mr. Manning, on the subject of that river, but it had occurred to him, from a theoretical point of view, that the self-acting shutters or valves on M. Chanoine's system might possibly relieve the pressure of water considerably, especially as the navigation on the Shannon was not of that primary importance which it was on the Seine, where it had been found necessary to modify their mode of action in practice. He had seen the weir at Port-à-l'Anglais, and had conversed a good deal with the lock-keeper, and he was led to think that the objections to the working were not so great as Mr. Vernon-Harcourt seemed to represent. It must be remembered that M. Chanoine was not now alive to defend his own system. He had nothing more to say, except that he spoke merely as an outsider. He thought it very probable that for the large depths which it was now thought desirable to obtain on the river Seine, a system such as that of M. Chanoine's would not be really practicable, and that it was necessary to introduce some new device, such as the rolling shutters described by Mr. Vernon-Harcourt. There was one very important point affecting the manipulation of the needle system which had not been referred to, which must not be neglected by those who were inclined to employ it, viz., the great difference in the weight of the needles when dry and wet; the difference would be found stated in the "Annales des Ponts et Chaussées," but he could not give the reference at once. He thanked the meeting for permitting him to address them on the subject. Dr. Pearson.

Sir CHARLES HARTLEY remarked that in addition to the valuable Papers that had been read on the subject of movable and fixed weirs, those who were present on the last occasion had the pleasure of listening to some further very interesting particulars from the lips of the Authors concerning the present type of movable dams in France. In considering the broad question of improving rivers by damming them back at times of low water for purposes of navigation and irrigation, and allowing them to run freely by well-directed channels at times of high water, it was hardly possible to avoid speaking of weirs and dams in the same breath. The Authors of the Papers had, however, dealt almost exclusively with the subject of movable dams. That was, no doubt, due to the fact that the subject was a novel one in the annals of the Institution. He thought it might therefore be well in continuing the discussion to confine it principally to movable dams as distinguished from fixed weirs. He intended to confine his observations to a few remarks on M. Boulé's new movable dam closed by vertical sliding doors and trestles—an arrangement which Mr. Vernon-Harcourt had mentioned in his Paper, but in very few words. Mr Buckley had said that in France rather over 60 per cent. of the movable dams that had been erected were either after the type of the Poirée needle dam, or after what might be called the semi-automatic system of M. Chanoine. Looking at the drawings, it would be seen that the principal feature in the construction of both of those dams was the iron trestles hinged to the apron. In one case they sustained the strain brought on them by the chains of the movable shutters in front, and in the other the trestles themselves directly supported the head of water against the needles from behind. Some years ago, when M. Boulé, Ingénieur des Ponts et Chaussées, was engaged in preparing designs for movable dams for high lifts, he considered that it would be more desirable to improve on the system of Poirée than on that of Chanoine, inasmuch as it appeared to him that the trestle of the Chanoine system and the backstay of the movable shutter seemed to be doing the same thing twice. It was obvious that the trestles must be sufficiently strong in themselves and close Sir C. Hartley.

Sir C. Hartley. enough to each other to hold up the shutters, unaided by their backstays, against any head of water that could be brought against them. On the other hand, M. Boulé considered that the Poirée system was one which should be limited to lifts not exceeding 7 feet, and that the needle should not be longer than could be readily manœuvred by one man. Therefore the height of the frame in such a case would be limited by the length of the needles. These views led M. Boulé to devise a plan for converting the frames at Port-à-l'Anglais (a place which Sir Charles Hartley visited two years ago) into buttresses for the support of ordinary sliding doors, like mill sluices, directly against the frames (which were 15 feet 6 inches high and 3 feet 6 inches apart), thus altogether suppressing the movable shutters with their complicated accessories. This new system of gates was tried at Port à-l'Anglais in 1875, and the pool, which up to that time had been maintained by the Chanoine system, was temporarily held up, through the medium of the gates of the new model, to a height of 12 feet 9 inches above the sill. The draw-doors, which were fitted with angle-irons to keep them in place when being lowered or lifted, were in three tiers or rows, and three oak gates, 3 feet 6 inches wide, 4 feet 3 inches high, and 3 inches thick, were worked vertically against the two adjacent trestles. Thus there were eighty-one gates for the twenty-seven bays of the dam, which had a waterway of 94 feet. To prepare for floods, the gates were lifted with sufficient expedition by means of a travelling crane, which went across the surface bridge from end to end. This crane lifted first the upper row; then, when the waters had fallen, the next row, and occasionally the third row. The gates were at once conveyed, by a wagon running on the same rails as the crane, to stores close at hand. The operation of re-fixing the gates was done by the same simple machinery. The trial was so successful that a ministerial order was given to construct the Port-Villez dam on the same system. Perhaps Mr. Vernon-Harcourt would be able to say whether M. Boulé's system was likely to be permanently used at Port-Villez in connection with the very substantial trestles or iron frames which were there already, and which Mr. Vernon-Harcourt had explained in detail. He also said that there was once an idea of applying needles to that frame, and he explained that the scantling would have to be very great to resist the pressure of the water. Compared with the vertical rolling shutter plan, which it had also been proposed to apply directly against the trestles at Port-Villez, the lifting machinery must evidently be much more powerful than that required for the Boulé sluices; and, besides, as each bay would be opened by a single lift, and not gradually as the level of

Sir C. Hartley.

the floods subsided, the water would not be spread uniformly over the whole width of the dam as on M. Boulé's system. M. Boulé claimed as the advantages of his plan that his gates were very much closer than the Chanoine shutters, that the cost of construction and maintenance was less, that there was no submerged mechanism, and that the dam could be readily raised much higher, and even to the level of the banks of the river, if desirable; but there might be one disadvantage, namely, the slowness of manœuvring in times of sudden flood. That, however, was an objection which could be removed by having an automatic arrangement in some of the doors, or by perfecting the power for lifting the gates with any required celerity. It was evident that French engineers were still far from unanimous on the question of the best kind of movable dams for high lifts. As he had not visited the sites of the movable dams in Indian weirs described so lucidly by Mr. Buckley, he would not attempt to criticise them, but he would ask to be allowed to describe the regulation dam across the Ganges canal at Myapore, which he inspected six years ago, and which was then being successfully worked on the same principle as the plan brought into use for a short time at Port-à-l'Anglais. At Myapore, where the Ganges canal left a branch of the Ganges, there was a regulation bridge. That bridge had ten openings of 20 feet each between piers of solid masonry. Those piers on the upward end had their cut-waters arranged for slides, or grooves, in which were worked three sets of shutters, immediately in rear of one another. As each shutter rested on its own sill, they worked independently of each other. When the two lower shutters were down, a depth of 6 feet of water was constantly maintained in the canal, and when the third shutter, or a portion of it, was brought into operation, a depth was maintained varying from 6 to 10 feet. The upper shutter merely consisted of planks or sleepers dropped down one on top of the other. The two lower shutters were worked with great ease by native workmen by means of two fixed windlasses to each 20 feet bay. The upper shutter required no machinery to work it. The system seemed to answer admirably, and, as he had said before, was similar to that advocated by M. Boulé. In discussing the various types of movable dams and weirs used in India and France, it should not be forgotten that the physical characteristics of the rivers in those two countries were very dissimilar, and that there was a vast difference in the volume of water discharged. For instance, whilst the Seine at Paris only discharged during high floods 60,000 cubic feet of water per second, the two great tributaries of the Ganges, the Jumna and the

Sir C. Hartley. Sone, discharged at times of flood as much as 1,000,000 cubic feet per second. Therefore, before deciding definitely on a type of weir or dam to be adopted in a new country, great care should be taken to ascertain whether a system which appeared to be the best for a comparatively small river would be equally advantageous when applied to a large river, and *vice versâ.*

Mr. Redman. Mr. J. B. REDMAN said an exceptional interest attached to the Papers that had been read, from the fact that there was an avowed necessity for some means of more quickly and expeditiously delivering the flood waters of the Thames. Mr. Vernon-Harcourt's Paper contained an historical review of the various types of movable weirs. The draw-door, or primitive sluice-door of timber which was formerly common on the Thames, and which in succeeding years had been stereotyped in metal, had obviously many drawbacks, and those were intensified by the application of that system to great heads of water. Instead of the head of water becoming a servant and assisting in opening the weirs, it affected a larger area of sluice-gate, which consequently had to be made heavier, involving an additional friction, necessitating a larger amount of expenditure on over-head machinery, and the use of planed brass surfaces to reduce the friction. Types of those gates were constructed half a century ago. There was one on the river Lee, but it had been disused and taken up since the improvements had been carried out. There was another on the river Stour, the "Stonar" sluice, near Sandwich in Kent. Both those were manufactured by Hunter and English. They were of simple form moved by toothed racks, and one man could readily run up the gates. But when this old-fashioned principle was applied to great heads of water, it was certainly most objectionable. There was one type of gate which he was surprised that the Author had ignored altogether in his review, namely, the type of sluice-gates which had been applied for the purposes of weirs, in the low countries more extensively than elsewhere, but of which there had been an example in the Metropolitan area within a very few years. He referred to the vertical balance pivot gates upon a vertical shaft. An example of that type existed, though it was now mudded up, on the tidal portion of the river Lee. Under one of the Acts, certain compensation reservoirs were constructed for storing water at high tide for the benefit of millers. A few years ago he was employed by some of the largest mill interests to look into the question of the water supply, and he examined those gates. They did in fact form a weir, 125 feet in length. There were brick and stone abutments at each end, and two intermediate piers 5 feet 6 inches of brick and stone, so that there were three spans of 38 feet, with a head of water 7 feet. There were two gates to each of these openings. The platform was flush, the gates upon a vertical shaft revolving upon a plane platform. One half the sill abutted against the upper part of the gate, and one half against the lower part of the gate; and the meeting posts or quoins being in the same relative position, each pair of gates abutted against each other. The gates were turned by a cast-iron toothed quadrant on the top of the gates, and there was a small pinion from the overhead bridge, but the head of water running through the inclined surface of the gates of course did the major part of the work. The same principle had been applied in the Low Countries. One practical objection to those gates was the fact that they traversed upon a level platform, and were more likely to be impeded by passing obstructions. But assuming that the sill projected 12 inches above the platform, and the gate had a lip of 3 inches and 9 inches clearance under ordinary circumstances, that objection would be obviated. In some of these gates the pivot was out of the centre, and as soon as they were unlocked, the head of water, acting on the larger area, opened the gate, and they were in fact automatic. In recent times there had been three simultaneous inquiries with regard to tidal and up-country floods in rivers. Mr. Grant Duff's committee, a committee under Mr. Octavius E. Coope with reference to the floods in the valley of the upper Thames, and another under the presidency of the Duke of Richmond respecting the conservancy of rivers. An esteemed member of the Institution, the engineer of the Thames and Severn canal, Mr. Taunton, gave evidence before two of those committees, and referred directly to the position taken by Mr. Parkes.[1] He thought Mr. Parkes was justified in commenting upon what appeared to be an *ex cathedrâ* setting on one side of the opinion that he had advanced, and in asking that that particular passage of the Paper should be expunged, seeing that it was a mere assertion backed by no argument or proof. Mr. Redman.

Mr. F. G. M. Stoney observed that for the last ten or twelve years he had devoted himself almost exclusively to the designing and working out of suitable appliances for controlling water in rivers for the purposes of irrigation and navigation. Mr. Stoney.

Before attempting to describe any of those appliances, he wished to lay before the meeting a short outline of the principles by

[1] *Vide* Report from the Select Committee on Thames Floods Prevention, 27 July, 1877. Minutes of Evidence, p. 204.

Mr. Stoney. which he was guided. He started with the principle that the first great requirement of every river was that it should be so deep and straight as to be able to discharge extreme floods without overflowing its banks and flooding the bordering lands. His next principle was, that the drainage capacity of a river could not be improved by putting any work into the river, but by taking something out of it.

Starting on such principles, he arrived at a law that standing obstructions, such as fixed weir mounds, could not increase the capacity of a river for discharging floods; he made this statement with all due deference to the experience of some gentlemen who advocated fixed weirs. It seemed to him incorrect reasoning to infer that because fixed weirs caused a deepening of the river bed in their immediate vicinity (the effect being purely local), they therefore increased the drainage capacity of the river. Such deepening might favourably affect the weir, but it did not prevent the flood waters $1\frac{1}{2}$ mile up-stream from being piled up to gain new head for velocity of approach to the vicinity of the weir. Reference had been made to the case of a certain weir, where, when 1 inch depth of water flowed over the weir, the flood rose 1 foot $1\frac{1}{2}$ mile up-stream, and with 10 inches depth of water flowing over the weir, the floods rose 10 feet at the same place up-stream. This would show that the weir was fairly able to deal with such water as could come to it; but it also seemed clearly to point out that the fixed weir must have robbed the river bed of a considerable amount of its natural fall; it would be interesting to know how many feet less in height the floods would have risen at that place had the weir not existed. He considered fixed weirs at best but a compromise; they were required to retain as much water as possible, but had to be kept low enough to allow the floods to pass over them. He felt convinced that much better control of rivers could be obtained by movable weirs than by fixed ones. If, in a river capable of discharging floods, it was required to retain water in dry seasons for navigation or irrigation, that object could best be gained by such appliance as would, when moved, cause least obstruction on the river bed, and occupy the smallest amount of the transverse sectional area of the river; and because such a structure was movable it might safely be made to full height to retain the full head of water for all purposes. He considered fixed weirs might possibly be used with economy in rivers having naturally an abundant fall, but for such rivers as the Shannon, having very little fall, any fixed obstruction must be directly detrimental.

Mr. Stoney.

About twelve years ago, while engaged on irrigation works in India, he had an opportunity of seeing some rather crude pieces of mechanism in the way of sluices, several of them were ordinary wooden doors under considerable pressure, which had never been opened. He had examined similar doors of smaller size, and had but little doubt that the wooden door pressed against very indifferently finished masonry faces, and got embedded thereon. He had also seen some of the revolving balanced shutters on vertical axes, which mechanical engineers would recognise as of the throttle-valve type; they were about 10 feet high by 6 feet wide. In places the axles had got cut by sand and grit, and it would require great force to move them. He considered sliding friction on a large sluice should be avoided, even though the surfaces could be large to resist cutting up; but to concentrate a heavy load on the necessarily small surface of axle pivots, where they might be cut up by grit, seemed but short-sighted policy. These things, and the necessity for good appliances, directed his attention to the construction of large sluices which could yet be easily actuated under heavy water-pressure by manual power. He had for eight years been familiar with the plans of the various movable weirs adopted by the French engineers, but before acquiring this knowledge he had worked out the principles of his own system of large sluices for rivers; and it happened that he had worked in the opposite direction to the French engineers; while they made everything shut down to the river bed, he made his sluices to be lifted, and leave neither work nor obstruction in the river bed (Plate 6).

He thought the French systems were open to some serious objections, inasmuch as they required a very large proportion of the materials and workmanship to be buried in the river bed, at increased cost of construction and maintenance, while they entailed more or less permanent obstruction in the river, and were troublesome to work, and the moving parts were numerous and liable to fracture and loss. One serious objection struck him as to all but the needle system; so far as he understood, there was but little power of regulating the flow of water by degrees as the floods increased. The first opportunity he had of trying one of his sluices arose soon after he came from India ten years ago. He had an engagement with Messrs. Bell and Miller, of Glasgow; that firm were carrying out some large waterworks in Brazil, and they had designed for the Pelotas works a sluice of 20 feet span and 9 feet deep. The duty of the sluice was to dam up the river, whence the water was drawn off into reservoirs, settling tanks, &c.

Mr. Stoney. The river was subject to heavy floods, which carried down mud and floating débris, and at such times the sluice should be entirely open, and no water allowed to enter the reservoirs. In considering the difficulty of working an ordinary sluice of 20 feet span, with about 20 tons pressure on sliding friction, he saw that, in a country so far away from skilled labour, it would be difficult to apply sufficient power economically, and troublesome to work. He had previously designed sluices in which the pressure should be carried on free rollers instead of sliding friction. He suggested his plan to Messrs. Bell and Miller; they adopted his arrangement, and permitted him to patent it for his own benefit. The principle of this large sluice was extremely simple. Most engineers were familiar with the working of rolling bridges across large spans. The idea occurred to him that sluices might be worked similarly on free rollers if he could only devise a simple means of suspending the rollers so that they would work against a vertical rail, and be free to follow their natural relative motion with the gate rolling on them. He soon found that a simple chain loop, passing round a small pulley suspending a frame with rollers, one end of the chain fixed to the upper end of a rail on the back of the gate, and the other end of the chain attached to a fixed point, such as the upper end of the stationary vertical rail, met all the requirements of the case. The rollers moved half the distance travelled by the gate, and the length of the chain loop always accorded with the position of the rollers, while they were moved by the motion of the gate pressing against them.

In the Pelotas sluice (Plate 6), instead of allowing the gate to slide in the usual way against planed faces on the down-stream side, he made the face on the up-stream side, so that the tendency of the water-pressure would be to separate the gate from the fixed faces, and the entire pressure was carried on free rollers at the back, on the ends of the gate. To facilitate the adjustment the front faces on the ends of the gate were in this case made wedge-shaped, so as to touch fairly water-tight at the same time that the bottom of the gate touched the sill in the floor, which was on a level with the river bed. The gate was lifted by a pair of strong screws, one at each end, simultaneously actuated by simple bevel gear, worked by a pair of pinions on a horizontal shaft having a handle at each end. This sluice, with a clear waterway of 20 feet and a pressure of about 20 tons, was worked by two Spaniards. It could be raised about 10 feet, and had been in continual service for the last seven years without costing anything for repairs, or getting out of order. It had answered well, and had given every satisfaction to its

Mr. Stoney.

proprietors, while the cost, including all fittings and gearing, amounted to only £245.

A few years ago he had made, for a place near Welshpool, four sluices of a like kind; they were 12 feet clear span, and opened 7 feet; one pair might be subject to a pressure due to 14 feet head of water. In these gates the entire front faces were inclined planes. In 1876 four small sluices on free rollers were made, and put into the new Jaoli locks on the Ganges canal, by Mr. Richard Foley of the D. P. W.; they had neither screws nor racks, but were easily actuated by a pair of common close link chains passing over sprocket wheels, carrying a counterweight at one end and the sluice at the other. The wheels were carried on a horizontal axle above, and were turned directly by a simple hand-wheel without any multiplying gearing.

A fair example of such sluices might be seen in those proposed for the under-sluices of the Okhla weir in the same irrigation works. These sluices had an area of about 65 square feet, and worked under a pressure of about 16 feet head of water. They were compound doors, and were so arranged that the water-pressure made the inner door tight just as in a common sluice, but that door was relieved of pressure before the sluice was opened.

To accomplish this there was as at first a sluice door on free rollers; on the down-stream face of this door was a recess, into which the back of another door neatly fitted; when both doors, always moving together, were shut down, water leaked in between them, put all the pressure on the inner door, and pressed it home against the sluice frame, while it relieved the original door and rollers of all pressure. In the bottom of the inner door was a sliding valve of such size as to be easily worked, and capable of letting the water out from between the doors faster than the leakage let it in. The first operation in opening the sluice was to open this valve, when the inner door was quickly relieved of pressure, which was then transferred to the original door, and on to the rollers, when the sluice was ready to be lifted as before. This kind of compound sluice was very suitable for canal locks and graving docks, &c., when hydraulic power was not at hand. Mr. Buckley had referred to the Okhla weir, and Mr. Stoney wished to say he had, after some correspondence with Mr. Clinton Anderson and Mr. J. C. Beresford, sent out plans and proposals for sixteen of these double-door sluices in addition, to form a cap for the Okhla weir. The weir cap was intended to be 2,500 feet long, composed of sluices on rollers, in eighty spans of

Mr. Stoney. 31 feet 3 inches from centre to centre of the iron piers, which were but 9 inches thick, leaving clear spans of 30 feet 6 inches. The gates when shut would add 3 feet to the depth of water on the crest of the weir, and were designed to be lifted 10 feet. The cost of all the ironwork and fittings was estimated at under £6 per lineal foot, and the cost of the sixteen compound under-sluices was estimated at £220 each; single-door sluices would be cheaper.

He wished now to call attention to a more recent design for some large sluices for a special case. The clear span was 40 feet, and the depth of water 12 feet. The gates were designed to be lifted 12 feet. In this case the up-stream face was vertical, and the gate simply fitted at its ends against planed guides in the pier faces, the contact being kept close by self-adjusting slips, and the gate was free to press down fairly on a level sill. He considered this much better, more easily made, and cheaper than the wedge system. The gate was simple; it was composed of two main girders, placed equally at each side of the centre of pressure; cross vertical beams connected these girders, and carried the sheeting and top of the gate. For the information of those who wished it, he would mention that the static water-pressure was 81 tons. Each girder was calculated to carry 60 tons, with a strain of 4 tons on the net section of the iron, making a total strength of 120 tons, with a factor of safety of 5 to carry 81 tons. The weight of the gate was 18½ tons, and the moving weight, including rollers, was roughly 20 tons. The whole was arranged to be lifted by a pair of strong right and left screws (like a railway carriage coupling), pulling out of each other so as to eliminate all friction of fixed collars. These screws were placed horizontally on a foot-bridge, and acted on large nuts travelling in guides; each nut pulled chains which passed over large pulleys down to the gate, where they were symmetrically grouped round its centre of gravity. At the foot of the gate some displacement was arranged to produce an initial upward force of about 5 tons, so that the maximum work to be done was at the top of the lift—a point to which the gate might seldom have to be lifted; and at the lower portions of the lift, which would be in more frequent action, the work to be done would be least, the contrary being the case to an inconvenient degree in all sliding sluices. Mr. Vernon-Harcourt had given the cost of some of the French systems as reaching £140 per lineal foot. This seemed extreme, but much material and workmanship so very indirectly applied in those cases no doubt augmented the cost greatly in proportion to the effective weir. He had full confidence that his system of large

Mr. Stoney.

span sluices in a single moving part, that could be actuated at all times to any required degree, would compare favourably as to cost with any system at present in use.

Engineers might, from the figures above given, judge of the strength provided for in the foregoing 40-feet span sluice, and with the following figures might form a fair notion of the comparative cost. The weight of this large sluice-gate, with the rollers, &c., moving with it, was 19 tons; the fixed castings, such as roller rails and guide beams, 3 tons; foot-bridge and lifting gear, 5 tons; in all 27 tons. Putting this even at £30 per ton would only amount to £20 per lineal foot—not much considering that the depth of water was 12 feet. In addition to this, piers and floors had of course to be provided.

It might be objected that this system of large lifting sluices could not be applied to the navigable channel of a river, but he had much pleasure in stating that it could easily be so arranged as to allow ships to pass through between the piers, the spans being made large enough, and this with a small increased cost as compared with the same spans in the ordinary application of his system.

Prof. Unwin.

Professor W. C. Unwin said he became acquainted some two or three years ago with the sluice, a model of which Mr. Stoney had exhibited on the table. Certainly it was one of the most ingenious he had ever seen, and it worked in a most admirable manner. He did not think anything better could be adopted in cases where a large pressure of water had to be resisted. Mr. Vernon-Harcourt's Paper had given him very great pleasure, although he had become acquainted with the weirs there described from reading the rather copious French literature on the subject. Four years ago, Mr. Fouracres, when in England, was good enough to talk with him about the weirs in India, which no doubt were suggested by the French weirs. As Mr. Vernon-Harcourt seemed to have found hardly any English reference to those French weirs, he wished to mention that they were pretty fully described in some Papers in the "Engineer" ten or twelve years ago. It was only fair that that should be mentioned, as he believed it was the first adequate reference in English to the subject. He had not much additional information to give about those weirs, because Mr. Vernon-Harcourt had visited them, and had consulted all the sources of information upon them; but in regard to the size to which they could be extended, it might be useful to mention that in Heusinger von Waldegg there was a reference to a needle weir in

Prof. Unwin. Norway, almost identical in size with the Port-Villez weir. The reference was only a short one, but he alluded to it because apparently, in that case, a needle weir was adopted nearly as large as that at Port-Villez. At the last meeting it was stated that at the Desfontaines drum weir, shown in the diagram, it had been noticed that some of the paddles stood up, others lay down, and others were inclined, and the reason of this had not been discovered. He might possibly throw a little light upon that peculiar action. It appeared that when Desfontaines first designed that weir he was very much afraid of the action which would occur if, on opening the sluices at the end, the whole of the paddles suddenly went down. A great flood of water would then be liberated over the weir, and he contrived very much to avoid the simultaneous opening of all those paddles. In his first designs he employed behind the free or upright paddle an inclined strut very much like that in the Chanoine weir, which slid in a groove, and he had across the whole length of the weir certain angle-irons or locking bars, which could be pushed out before the sluice was opened, so that as the strut came up against the bar it was stopped. Those locking bars were so arranged that any number of paddles could be liberated to one-half of their extent or more, as was required. In that way the paddles could be gradually opened, and the sudden release of the water, by opening them all at once, was prevented. It was accidentally discovered that nearly the same result could be achieved in a much more simple way. In the Desfontaines weir, sluices had been contrived at both ends. When the sluices went one way they admitted the head of water to the upper side of the lower paddle, and *vice versâ*. It was found that having two sets of sluices, one at each end of the weir, if they worked those two sets in opposite ways they obtained the peculiar effect of some paddles standing up and some lying down. If they worked the sluice at one end of the weir so that the paddles ought to go down, and worked the sluice at the other end so that the paddles ought to go up, and had the sluices not exactly equally open, then some paddles would be standing up and some lying down. He believed that that was the origin of the action referred to. At the last meeting Mr. Parkes raised a kind of small flame in the embers of what seemed to have been at one time a rather burning controversy. He especially raised the question whether experience was not a great deal better than theory in reference to questions of this sort. He would be a very bold man indeed who would question Mr. Parkes' facts, or would think that any hydraulic theory was perfect enough to enable him to upset them. He, therefore, had no idea of rebutting the facts or conclusions, but he wished to understand exactly what were the questions raised in regard to these fixed weirs. When he turned back to the original Papers, as Mr. Parkes had recommended, he did not find in them very much with which he could find fault. Mr. Cubitt alleged that if there was a river of very varying slope, some parts of it torrential, and some nearly stagnant, weirs should be built in that river in such a way that the land floods would be less deleterious than before. He saw no reason to quarrel with that statement; but with regard to practical experience on the Severn, he just wished to make one remark. According to Mr. Cubitt's statement there were originally on the Severn fourteen natural weirs or shoals, over which there was only 18 inches of water; that those shoals were removed, and in their places four masonry weirs were built. Now under those circumstances, he saw no difficulty in believing that the floods on the Severn might be considerably diminished. It appeared to him that no theoretical question arose in that case, but he found that this experience on the Severn was now being quoted in a way which seemed to him to make it almost a paradox. It was sometimes urged in such a manner that it would be imagined any number of weirs could be built across a river, and the floods would go down more easily than before. That was carrying a perfectly sound and practical doctrine to an extreme conclusion. Mr. Parkes raised three separate questions. The first was as to the action of oblique weirs, the second whether when a weir was built across a river the bed of the river above the weir was or was not deepened by the action of the weir, and the third question was whether or not the discharging capacity of the river was increased by weirs. With regard to the question of oblique weirs, he would like to say, that, in his opinion, there was no doubt that in such cases a greater discharge was obtained than from a normal weir; but the question was, whether that advantage was a large or small one. No doubt if the river was flowing with a very small velocity, the oblique weir acted almost like a normal weir of extra length; but as in flood the river was flowing with great velocity, it seemed to him that the advantage of the oblique weir was at once diminished. In the latest French treatise on navigation, M. de Lagrené stated that there were no sound experimental results which gave any information about oblique weirs. Why he was inclined to doubt the efficacy of the oblique weir was, that observations showed that the particles of water going over the oblique weir followed directions which, to the eye, were apparently parallel Prof. Unwin.

Prof. Unwin. to the axis of the stream, and then it was very difficult to see how the advantage of the oblique weir could be great. In any kind of orifice the discharging area must be measured normally to the direction of flow. He had referred to the Papers in the Transactions of the Institution with regard to the oblique weirs, and he would wish to refer to one point about the Severn weirs. In the theoretical discussion of the question, Mr. Cubitt said, that if a river was widened out to three times its original width at the weir there would be much less backwater. He also said that all the advantage of that widening of the river might equally be obtained by putting a weir obliquely in the straight course of the river; but when he came to examine the drawings of the Severn weirs he did not find that that was at all the kind of weir actually adopted, especially in the case at Tewkesbury. The stream was widened very much, and the obliquity of the weir to the axis of the widened stream was much less than 3 to 1. The river had been so widened where the weir was, that nearly all the advantage of extra length in the weir was due to the widening and not to the obliquity of the weir. No doubt that widening of the river tended very much to diminish the backwater produced by the weir. With regard to that curious fact which Mr. Parkes mentioned of an old barge being lifted up and placed on the crest of the weir during flood, there was a great deal of other data of the same kind available. In some cases it appeared that a wedge-shaped bank was formed by silting which came almost up to the crest of the weir, but in many other cases there had been considerable deepening of the bed of the river above the weir. In the old treatise of Minard several instances were quoted, where gravel was thrown in above the weir, and was scoured out at the first flood. He was therefore inclined to agree with Mr. Parkes that there might be some deepening of the river above the weir. The other question as to whether not only an equal but a freer discharge of floods could be secured in a river impounded than in a river not impounded, was too complicated for him to enter upon at that time, but it seemed to him that it depended upon the fall of the river which was available.

Mr. Bruce Bell. Mr. BRUCE BELL, said that as his colleague, Mr. Miller, and himself were the engineers of the works in Brazil alluded to by Mr. Stoney, he wished to make a few remarks in regard to the weir referred to. The river mentioned by Mr. Stoney was selected as the source from which to supply the town of Pelotas, in Rio Grande do Sul (Brazil), with water by gravitation. And as any fixed weir, erected at the point chosen for the source of supply, would have subjected the country during the rainy season to severe floods, which no doors or sluices could have possibly prevented, Messrs. Bell and Miller decided to abandon all idea of a fixed weir, and to form a chamber of masonry in the river, and construct within it a movable vertical gate or weir, filling the entire space, which in time of floods could be lifted entirely out of the water, and thus leave the floods full scope to descend. The point chosen for this work was a gorge in the river having a good rocky bed suitable for foundation. The interior width of the chamber was 20 feet, the height of the door 9 feet 6 inches, the floods rising at times to 12 feet, presenting a solid body of 240 square feet of area. Mr. Bruce Bell.

They found, however, that the machinery necessary to overcome the friction upon an ordinary sluice face of such a body of water, would be too cumbrous and slow for two men to work. Mr. Stoney suggested the idea of reversing the face of the door, and making it face against the direction of the stream, and obtain the pressure necessary to keep the dam watertight by making the groove in which the door had to slide wedge-shaped, so that when shoved down to its position, it would be forced by the inclination against the face of the wedge-shaped groove, and so make it perfectly water-tight. The pressure of the weir under the action of the stream, in place of bearing against a flat surface, was conveyed to the bearing surface of the groove in the chamber facing the stream by rollers upon the back of the gate, which materially lessened the friction. This arrangement was shown in the plan prepared by Mr. Stoney from their working drawings.

The work was carried out under this arrangement, and proved a complete success; and as Mr. Stoney had stated, the weir was acting now as well as when first erected, and it could be raised at full flood by two men by the action of a simple wheel and pinion. It is a question whether a gate of such a size had ever been erected which needed so little power to lift it. He considered that Mr. Stoney was a very ingenious man, and his designs were well worthy of the consideration of dock and hydraulic engineers, particularly his arrangements for sluices for docks and locks. Mr. Bruce Bell some years ago advised Mr. Sandeman, who was at that time engineer for the Weaver navigation, to adopt them upon the large locks he was erecting upon that river, and there were now no less than twenty-eight sluices at work, which had been very successful in action.

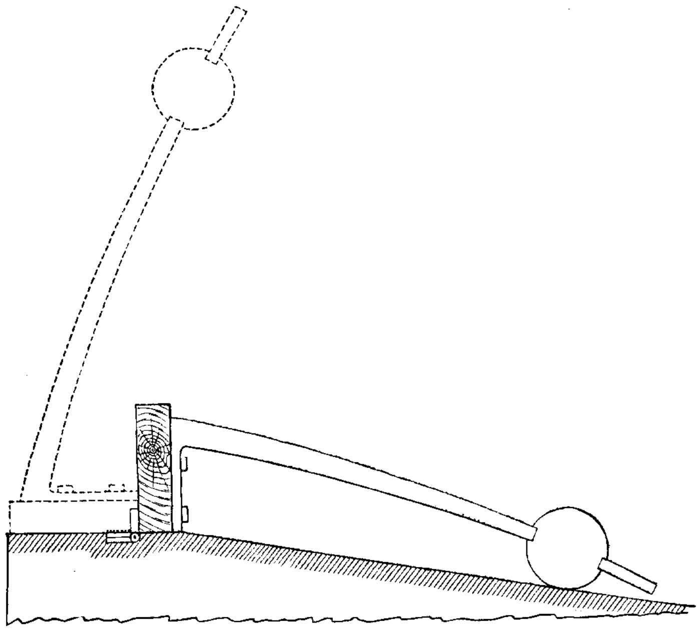
Mr. Baldwin Latham.

Mr. BALDWIN LATHAM said he would describe a very simple self-acting weir on the River Weaver, at Nantwich. The apparatus

Mr. Baldwin Latham.

consisted of a movable plank, hinged at the bottom, and fixed on the crest of a stone weir (Fig. 2). The plank was 18 inches in

Fig. 2.

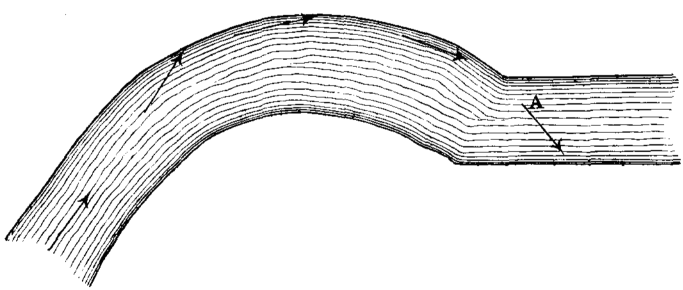


depth, and the weir was 29 feet in width. On the up-stream side of the weir, four curved iron levers were fixed to the plank, each lever being 5 feet 6 inches long, and on the levers iron weights were placed, the weights and length of lever being so adjusted as to keep the plank in a vertical position under a given head of water. When, however, this head of water was exceeded, the extra pressure caused the plank to tip over, and with the first movement, the leverage of the counterbalance was shortened. The result was that the dam suddenly fell down, bringing the levers into a nearly vertical position, as shown by the dotted lines in Fig. 2. The weights on the levers still overhung the hinge of the plank, so that when the water had flowed off to such an extent that the pressure was removed from the plank, and the weight on the levers could overcome the resistance, the plank again assumed the vertical position. The action was accelerated by reason that, in moving back the leverage the counterbalance increased, so that when once started the plank quickly took the vertical posi-

Mr. Baldwin Latham.

tion. He was unaware who was the inventor of this ingenious device, but he had been informed that it had been in operation for more than fifty years. As he had given some attention to the movements of water in rivers, he would endeavour to demonstrate why in some cases a fixed weir on a river led to a scour immediately above the weir, and not to a silting up, as was at one time supposed must be the consequence of the erection of such an obstruction in the channel of a river. Hitherto, with few exceptions, works on hydraulics treated only on the movement of water in the horizontal plane of a river; but D'Aubisson showed in his treatise on "Hydraulics" that water moved both round the horizontal bends and over the curved bottom of a river by a series of reflexions. Three years ago Professor James Thomson, of Glasgow, endeavoured to demonstrate that the movement of water round the bend in the horizontal plane of a river generated centrifugal force. But the force at work in a river was one that caused the bend, and was therefore anterior to the generation of centrifugal force, which Mr. Latham did not believe had anything to do with the direction of the currents in the bend of a river. For example, Fig. 3 represented a horizontal bend in a river. On

FIG. 3.

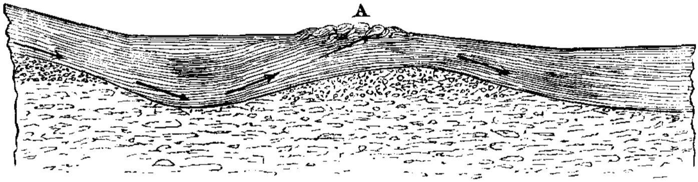


examination it would be found that, as the water moved round the curve, the concave bank was eroded by its action, while a silting up took place on the convex side. It must not be forgotten that the most rapid moving vein of water in a river had some elevation above the veins of water moving with less velocity. So, in a straight channel of uniform section, the surface of the water was convex, highest in the centre where there was the greatest velocity of flow, and lowest at the sides, where there was the least velocity of flow. In a curve of a river, the greatest velocity of flow was on the outer or concave bank; there the surface of the water was the highest, the point of maximum velocity having been

Mr. Baldwin Latham.

shifted from the centre of the stream to the concave bank; as a consequence, on the opposite or convex bank, the surface was abnormally lowered, so that by gravity, movements of water were set up from the raised water on the concave bank towards the low water on the convex bank, and so silt was deposited on the convex side of the stream. The movement of water in the bend of a river was simply due to what might be called the lineal movement of water, or the tendency of water always to move in straight lines, and its subsequent reflexion round the bend. By reference to an experiment with a channel like Fig. 3, it would be found that the movement of the water followed the direction indicated by the arrows. After the water had run round the concave bank of the stream, it would not have a tendency to flow off along the outer bank at A, which should be the case if centrifugal force was in operation, but the current of water crossed over to the opposite side of the stream, and there tended to form a similar curve to the one it had previously left. In the vertical plane of a natural river, it would always be found that the river consisted of a series of deep and shallow places following one another in pretty regular succession, and what were known as holes in rivers always remained as such. The existence of these holes was a sort of standing protest against some of the ordinarily received notions on hydraulics, in which it was held that scour in a river or channel depended upon velocity, and that velocity was inversely as the section, so that with a given volume of water, a large section gave a small velocity of water and little scour, and a small section a large velocity and great scour; consequently, if this doctrine were complete in itself, and the results were only considered in reference to velocity, all these holes or deep places in a river, where the velocity was the smallest, should silt up, and the shallows should be scoured out; but as a matter of fact the reverse was the case. The cause of this anomaly was to be attributed to the varying angles at which water moved in the vertical plane of a river. Where there was a shallow, the fall or inclination of the surface of the stream was the greatest; when the water was deep the fall was the least. A rapid inclination preceding a comparatively flat fall caused the water to move downwards in the direction of the arrows in Fig. 4 and to strike the bottom, by which it was again reflected upwards towards the surface, and might be seen in the lower side of these holes to be gushing up just as if there were a spring at the bottom of the river. This welling up of the water often caused an eddy, as the atmosphere was unable to sustain the column of water thrown up, and consequently it flowed off in all directions, and partly towards the head. The general flow of water down the stream, and the partial flow up the stream, gave a rotating movement to the water, causing the eddy so often observed in these holes in a river. That the currents in a river moved in the way described he had observed when a boy fishing; for, when fishing with a vertical float, having little power of flotation, if the line were dropped into the upper end of one of these holes, the tendency of the stream was to draw the line and float under the water; but when the line was dropped in the lower side of the holes, the upward current carried the line upward, and the float lay on the surface of the water. Venturi observed that the movements of water in the vertical plane of a river were affected by the bed of the stream, and he showed that, in a section such as that illustrated in Fig. 4 the water would flow to the surface at the point A. These movements of water were all due to its tendency to travel in straight lines. The movements of water in the vertical plane of a river acted in a similar manner to those in the Mr. Baldwin Latham.

FIG. 4.



horizontal plane, and the concave bed was always eroded, and a deposit occurred on the convex part of the bed of the stream. Applying the observation already made to the case of a fixed weir in a river, such as those in the River Severn; it will be observed that at the points where all these weirs had been placed, the channel of the river was either naturally wider or had been widened; so that, compared with the channel a short distance higher up, the section immediately in front of the weir was greater than higher up the river; in fact, a condition of things similar to those referred to in the case of the deep part of a river had been artificially produced, and the water under ordinary circumstances was deflected towards the bottom of the stream immediately in front of the dam, and was reflected upwards by the dam, which, as would have been observed, was a movement favourable to the removal of deposit. The effect of the great elevation of water by a weir tended to intensify this action of moving water, so that below a weir a deep hole was generally made by the down-

Mr. Baldwin Latham.

ward movement of the water, which in its turn was followed by a shoal created by the uprising of the water, just in the same way that the deeps and shallows were produced in a natural river. The obliquity of the weirs in the River Severn also favoured the clearance above the weir, as the water had a tendency to flow in lines parallel to the weir. Fixed weirs might be used in some rivers without detriment, provided the banks of the stream were high, and the water was impounded at a level well below the surface of the adjacent land. In flat districts liable to floods, a fixed weir might raise the height of the floods, and in such cases movable weirs had a decided advantage over a fixed weir; and it was to be hoped that they would be brought into general use in this country, as in many places they could be adopted with advantage.

Mr. Longridge.

Mr. J. A. Longridge said he joined in the regret which Mr. Parkes and another speaker had expressed, that the question of fixed weirs had not formed a greater portion of the discussion. He thought it was unfortunate that so much time had been spent upon things which, however interesting they were in themselves, yet from a professional point of view were not of equal importance to fixed weirs. He remembered the discussion which took place a great many years ago; and he had refreshed his memory by referring to Vol. V. of the "Minutes of Proceedings." Sir William Cubitt then seemed to think, that provided the length of the weir was three times the breadth of the river, and the area of section along the line of the weir was equal to the cross section of the area of the river, there would be no obstruction. He laid down that as a general proposition, but in those terms it was not true, though there were circumstances in which it became true. A good deal of vagueness in the discussion arose from the fact that no distinction was made between an overfall weir and a submerged weir. It was, he considered, incontrovertible that in overfall weirs there must be a backing up of water behind.

Take the case of a channel with a uniform slope running with a uniform depth of water. The water in any given length of that channel, say a mile, had a certain amount of *vis viva*. If now a weir were interposed, so as to make an overfall, there must be a loss of *vis viva*; and if at the lower end of the channel it was to deliver the same volume of water as at the top, it must, running the same depth and the same velocity, have the same *vis viva*. The loss, therefore, at the overfall must be compensated by an increase of head above the weir, so that the flood-level must be raised. This must apply to all overfall weirs, whether normal or oblique to the current. The case, however, was different with submerged weirs. It was quite possible to erect such weirs without any disturbance of the flood-level. This might be shown as follows:— For the sake of simplicity, take the case of a rectangular channel whose breadth was b, depth of water d, inclination I, and velocity of flow v. Mr. Longridge.

The discharge was $v\,b\,d$,

$$\text{or } \mathrm{D} = \mathrm{C}\sqrt{\frac{b\,d}{b + 2\,d}\,\mathrm{I}}\;b\,d,$$

$$\text{or } \mathrm{D} = v\,b\,d \quad \ldots\ldots\ldots\ldots \quad (1)$$

If this channel was crossed by a weir, of which the upper crest was at a distance δ from the bottom of the channel,

l the length of the weir,
Δ the height of the upper pound above the crest,
d_1 = difference of level between upper and lower pounds,
d_2 = depth of weir below lower pound,
h = height due to velocity of approach v,

the discharge from the weir would be—

$$\mathrm{C}_1\,l\sqrt{2g}\,\{d_2\sqrt{d_1 + h} + \tfrac{2}{3}(d_1 + h)^{\frac{3}{2}} - h^{\frac{3}{2}}\},$$

which, when $d_1 = o$, and $d_2 = \Delta$, becomes—

$$\mathrm{C}_1\,l\sqrt{2\,g\,h}\left\{\Delta - \frac{h}{3}\right\};$$

but $\sqrt{2\,g\,h} = v$; therefore

$$\text{discharge} = \mathrm{C}_1\,l\,v\left\{\Delta - \frac{h}{3}\right\} \quad \ldots\ldots\ldots\ldots \quad (2)$$

and equating (1) and (2), and writing $d - \delta$ for Δ,

$$l = \frac{b\,d}{\mathrm{C}_1\left\{d - \delta - \frac{h}{3}\right\}}, \quad \ldots\ldots\ldots\ldots \quad (3)$$

and since $h = \dfrac{v^2}{2\,g}$,

$$\frac{h}{3} = \frac{\mathrm{C}^2\,b\,d\,\mathrm{I}}{6\,g\,(b + 2\,d)}, \text{ and substituting this in (3)}$$

$$l = \frac{b\,d}{\mathrm{C}_1\left\{d - \delta - \dfrac{\mathrm{C}^2 . b . d . \mathrm{I}}{6\,g\,(b + 2\,d)}\right\}},$$

Mr. Longridge. from which it was evident that l varied when d varied, the other elements remaining constant.

The length of the weir therefore depended upon the height of the flood, and it would be seen that a weir which would pass a high flood without disturbance of surface level, would produce an overfall, and consequently a backing up of the head water in a lower flood. For instance, in the case of a rectangular channel of the following dimensions: breadth, 100 feet; inclination, 1 in 3,000; weir 6 feet above bed of channel. The following Table gave the necessary length of weir and sectional area along its crest for these floods, viz., 12 feet, 16 feet, and 22 feet respectively:—

Height of Flood.	Depth on Weir.	Length of Weir required.	Sectional Area of Water in Channel.	Sectional Area of Water along Line of Weir.
Feet.	Feet.	Feet.	Square feet.	Square feet.
12	6	225	1,200	1,350
16	10	201	1,600	2,010
22	16	172	2,200	2,752

It appeared, therefore, 1st. That the necessary length of weir decreased as the length of flood increased, and, 2nd. That the sectional area along the line of the weir must always exceed that of the river channel, and not simply be equal to it, as was supposed by Sir William Cubitt. It mattered not whether the weir was placed normally or obliquely to the stream, provided it had the requisite length. In the former case the river would have to be widened out, and thus would have the disadvantage of decreasing the velocity of approach, and consequently would tend to silt up the channel at the back of the weir and decrease the discharge. On the other hand, the diagonal weir had the disadvantage of tending to scour behind the back of the weir, and to cause an erosion of the bank below the weir, near the up-stream extremity, where the bank would consequently, if of soft material, require some protection. As regarded the increase of depth which had been stated to have taken place in the Severn since the weirs were built, he thought that could easily be accounted for by the fact that previous to the erection of the five weirs, that portion of the river was crossed by no less than fourteen natural dams of sandstone, marl, or gravel, dividing the river into a series of deep pools, separated by a series of rapids, with a minimum depth, in the low-water season, of 18 inches. The removal of these fourteen dams, which took place when the weirs were built, no doubt considerably increased the mean hydraulic depth of the river, and consequently its scouring power; but such improvement was rather in spite of than in consequence of the creation of the weirs. Mr. Longridge.

Mr. G. Higgin remarked that one point of great interest, as regarded the construction of fixed weirs, was, as to the best form or profile, with a view to give the greatest facility of discharge, and to prevent erosive action on the bed of the river below the weir. It was well known how troublesome and vexatious was the labour entailed by the proper protection of the apron or tail of the weir. The action produced at this portion of the weir was due almost directly to the form or profile of the down-stream side of it. Hence the great importance of deciding on the proper form that should be given to the slope. Mr. Higgin.

In many of the Indian weirs or "anicuts," such, for instance, as the Kistnah, the crest of the weir was horizontal for a distance of 19 or 20 feet, and the down slope was concave, with the intention doubtless of delivering the water at the point where it finally left the stonework in lines parallel to the river-bed. It would be desirable to know how far these results had been obtained. Other Indian weirs, such as the Coleroon, had a vertical drop. In Spain there were many examples of old weirs, some of them six hundred or eight hundred years old, the generality of which had their down-stream side made in a series of gentle slopes, almost indeed horizontal, broken by small steps. The result of this might be seen in such weirs as those of the rivers Turia and Jucar. In these weirs it had been necessary to protect the river-bed for a considerable distance below the tail by heavy paving held in place by a system of piling with horizontal walings. This protection piling extended in some places 200 feet beyond the termination of the weir proper; but a deep hole was always found at the termination of the paving, and there was a continual tendency to an enlargement of this, and erosion of the bed backwards, which was only prevented by constant care and attention. In some few instances in Spain the weirs were made with a vertical drop, notably in all the small mountainous rivers of the north, and in other places, such as in Alicante, where there was a weir with a vertical drop of about 24 feet. Perhaps the most extraordinary instance of a vertical drop was that of the dam across the River Lozoya, for supplying Madrid with water. This dam was 105 feet in height, and during floods the river poured over it in an unbroken sheet. The dam was built of ashlar founded on rock.

About sixteen years ago he had occasion to construct a large

Mr. Higgin. weir across a river in Spain, for an irrigation canal, of which Mr. Bateman, Past President, and he were the engineers. This weir was founded on a soft rock; the crest was 20 feet above low water of the river, and the profile of the weir was of the ogee form; the tail of the weir was benched into the rock. In spite of this, the floods exerted an erosive action on the bed, a large hole having been scooped out of the rock at the tail, where the apron ended.

The fall on the line of this canal was about 6 feet to the mile; it became necessary therefore to introduce a number of falls. The first of these, which had a total drop of about 17 feet, was made with a ramp or paved slope of $1\frac{1}{2}$ to 1. The disturbance created in the lower part of the canal below the fall was very great, and was propagated for a long distance, destroying the banks of the canal. In the remainder of the falls, therefore, the form of construction was varied, and they were built in steps, each step being $6\frac{1}{2}$ feet wide and $3\frac{1}{4}$ feet high. The water fell into a pool 13 feet long, and $3\frac{1}{4}$ feet deeper than the bed of the canal. This system answered perfectly; the water leaped down from step to step, and fell entirely deadened into the pool, from whence it flowed away with a gentle easy current. One of these falls was 40 feet deep, and the descending water was a beautiful sight.

The system of vertical drops, where practicable, would seem, therefore, to be the best for destroying the erosive action of the water; and this was in accordance with what might have been expected from the laws which governed the fall of water and other bodies.

As regarded the silting up behind the weir, he understood Mr. Parkes to say, that in the Severn the effect of the weirs had been to deepen the bed of the river above them. This was, he believed, opposed to the general experience of engineers. In the Indian rivers the silting up of the river-bed appeared to be the invariable result of the construction of a weir. Colonel Baird Smith in his work on the "Madras Irrigation Canals," gave it as his opinion that such an effect must be accepted as a natural consequence of a weir. In the weir above referred to, in Spain, although the crest of the weir was 20 feet above low-water level, the first winter's floods, after the closing in of the breach, sufficed to fill the whole bed of the river up to the level of the crest; and so it had remained to this day. In fact it would appear to be the tendency of all weirs placed across rivers subject to heavy floods, and carrying consequently large amounts of detritus, to elevate the river-bed. When closely examined, it would be seen that such an effect was merely a natural consequence of the laws that governed the flow of water in open channels. Mr. Higgin.

The oblique position of the weir appeared to be entirely a question of circumstances. In cases where a river-bed had a considerable fall, and the weir was consequently never likely to be submerged, and where the banks were sufficiently high, there could be no objection to placing the weir at right angles to the course of the stream. Where the banks were low, and the natural fall of the river-bed small, so that in times of flood the weir might be submerged, obliquity should be given to the weir. There was no mystery about the oblique position; the effect of thus placing the weir was merely that of increasing its discharging capacity; so that, other things being equal, an oblique weir did increase the discharge on account of the extra length thus obtained. A simple calculation would explain this. Take the case of a river 100 feet wide and 10 feet deep, flowing with a mean velocity of 2 feet per second; the discharge would be 2,000 cubic feet per second. Now, if the fall below the weir was sufficiently great to prevent the backwater from rising to the level of the crest, and the banks were high, the weir might be placed directly across the stream. With the ordinary form of weir, a depth of 4 feet on the crest would discharge the whole 2,000 cubic feet in a second; if, however, the banks were low, and it was desired to keep down the height of the water, the weir must be placed obliquely. If it was placed so obliquely as to double the length, the depth need then, roughly speaking, only be 2 feet on the crest to discharge the same 2,000 cubic feet of water per second. This was not exactly correct, because the best experiments showed that an oblique weir discharged per foot of length rather a less quantity than one placed directly across the stream. The old Moors and Spaniards well understood this; in cases where the fall was great and the banks high, their weirs were generally placed directly across the river; in opposite cases the weirs were placed more or less obliquely. The question as to the desirability of oblique weirs appeared, therefore, to be entirely one of circumstances. There was one other point of great interest as regarded weirs, and that was the laws governing their discharge. About this most important point there appeared to be great want of information. The various experiments that had been made—the Lowell experiments, those of Castel, Mr. Blackwell, M. Bazin, and others—were all conducted on weirs of a short length, seldom exceeding 10 feet, and under exceptional conditions as regarded the form of the weir, and the materials of which it was composed. The results obtained were more suitable for gauge

Mr. Higgin. boards than for large weirs. These latter were ordinarily composed of ashlar or of rough paving. The form or profile rarely approximated to the form of the gauge boards used in the various experiments, and there was reason to believe that the coefficients obtained were not applicable to the cases of large weirs. It was only comparatively of late years that the experiments of Messrs. Darcy and Bazin had shown how all-important was the question of the materials of which the sides of channels were made. These experiments had revolutionised the old formulæ for the discharge of water in open channels; the same laws applied to the discharge over weirs, and no doubt the material of which the crest was composed had a large influence over the discharge. In the case of the Henares weir, he found that with low depths of water on the crest, the calculated discharge, using the ordinary coefficient, was much larger than the actual discharge. For a form of crest, such as that of the Henares weir, a coefficient of 0·40 was given in most treatises on the subject; but in practice, with depths of only a few inches on the crest, the coefficient was not more than 0·28 in the formula $v = c\sqrt{2gh}$. The effect of this laxity of the formula might, he thought, be seen in some of the calculations made of the discharge of rivers; for instance, Mr. Law, M. Inst. C.E., in his evidence given recently before the Thames Enquiry Commission, stated the mean daily flow of the Thames at Teddington weir to be more than 133,000,000 cubic feet. Mr. Leach, who made a long series of measurements at the same weir, estimated it at 50,000,000 cubic feet. Mr. Haywood estimated it at from 70,000,000 to 90,000,000 cubic feet. This great divergence of opinion pointed, in his opinion, to a great difference in the various coefficients used, as it was not likely that the mean daily flow of the same river at the same point could vary so much as from 50,000,000 to 133,000,000 cubic feet in the course of a few years.

It was much to be desired that some better rules could be fixed for calculating river discharges. The subject was one of vital importance for all riparian proprietors, who, like the dwellers in the Thames valley, had to suffer from the periodical inundations of their property. With the existing knowledge of the rainfall, and of the quantities that might reasonably be expected to flow off the ground, there was no reason why the dwellers in the Thames valley should not be secured from inundations.

In the case of such a river as the Thames, where, in most cases, the banks were low, it would probably be necessary to adapt, to many of the weirs, a self-acting movable crest, such as that which it was intended to apply to the Sone weir; but whether this were necessary or not, it was within the bounds of engineering science to arrange the Thames weirs in such a manner as to prevent the excessive flooding to which the valley was now subjected, without interfering with the navigation. Mr. Higgin.

Mr. G. J. SYMONS thought it was a misfortune that the title of the Paper was "Fixed and Movable Weirs." It would have been better to have simply taken movable weirs, and treated of fixed weirs at another time. A statement in the *Hereford Times* of last week curiously illustrated what Mr. Parkes said about the Severn weirs. That paper contained an account of a meeting in which the Earl of Coventry and others took part, with a view to memorialise the Severn Commissioners, because of the floods that existed at present, and which were attributed to the weirs on that river. With respect to the bibliography at the commencement of Mr. Vernon-Harcourt's Paper, that gentleman had, unfortunately, overlooked a very interesting paper which had been read by Mr. J. Neville, "On fixed and movable weirs," before the British Association at Dublin in 1878. That paper had been reprinted by Mr. Edward Easton in the form of a pamphlet, and he would strongly recommend it to the consideration of all the members of the Institution. At the end of Mr. Vernon-Harcourt's Paper, there was a reference to the application of these movable weirs to the Shannon. He considered it a great pity that the advisers of the Irish Board of Works seemed to have adopted the foregone conclusion that the French movable weirs, for which he himself had a great respect, were of no use. He was glad to notice that in the discussion which took place at the Dublin meeting, and which also had been printed, Mr. Price, who was formerly engineer to one of the principal Irish railways, expressed the following strong opinion. "If the system advised by Mr. Neville is adopted, that is, the use of sluices and movable weirs, a great improvement will be effected. It is quite plain that, with fixed weirs only, it is impossible to regulate a river such as the Shannon." He need hardly say how desirable it was under those circumstances that the application of some system of movable weirs to the Shannon should be duly considered by the authorities responsible for that river. With respect to the plan of the hydraulic brake shutters, one point probably occurred to everybody, namely, that those small outlets would be very awkward if they became plugged up by silt. But perhaps that difficulty could be explained away. The only other remark he wished to make was to express the pleasure with which he had listened to Mr. Vernon-Harcourt's Mr. Symons.

Mr. Symons. observations as to the desirability of having in connection with the Institution something analogous to the model room of the École des Ponts et Chaussées. He, himself, in a paper respecting the floods of 1875,[1] most earnestly appealed for the establishment of something like the École des Ponts et Chaussées, or, as he described it, an Institute for Experimental Instruction in the Laws of Hydrology. He was, therefore very much gratified to hear the present appeal for a model room.

Mr. Harris. Mr. H. G. HARRIS said that Mr. Bramwell had asked him to bring to the attention of the Institution, a model, which bore slightly on the subject under discussion. It was a model of a fish pass invented by an American gentleman, named McDonald, of Lexington, Virginia. The Board of Public Works in Virginia, had rendered it obligatory upon all authorities, over rivers in that State, to use the fish pass, of which this was a model, wherever there were any dams or weirs. A description and engraving of this pass would be found in the "Scientific American" for the 1st November 1879.

*** The replies of Mr. Vernon-Harcourt and of Mr. Buckley will be found at the end of the Correspondence.

Correspondence.

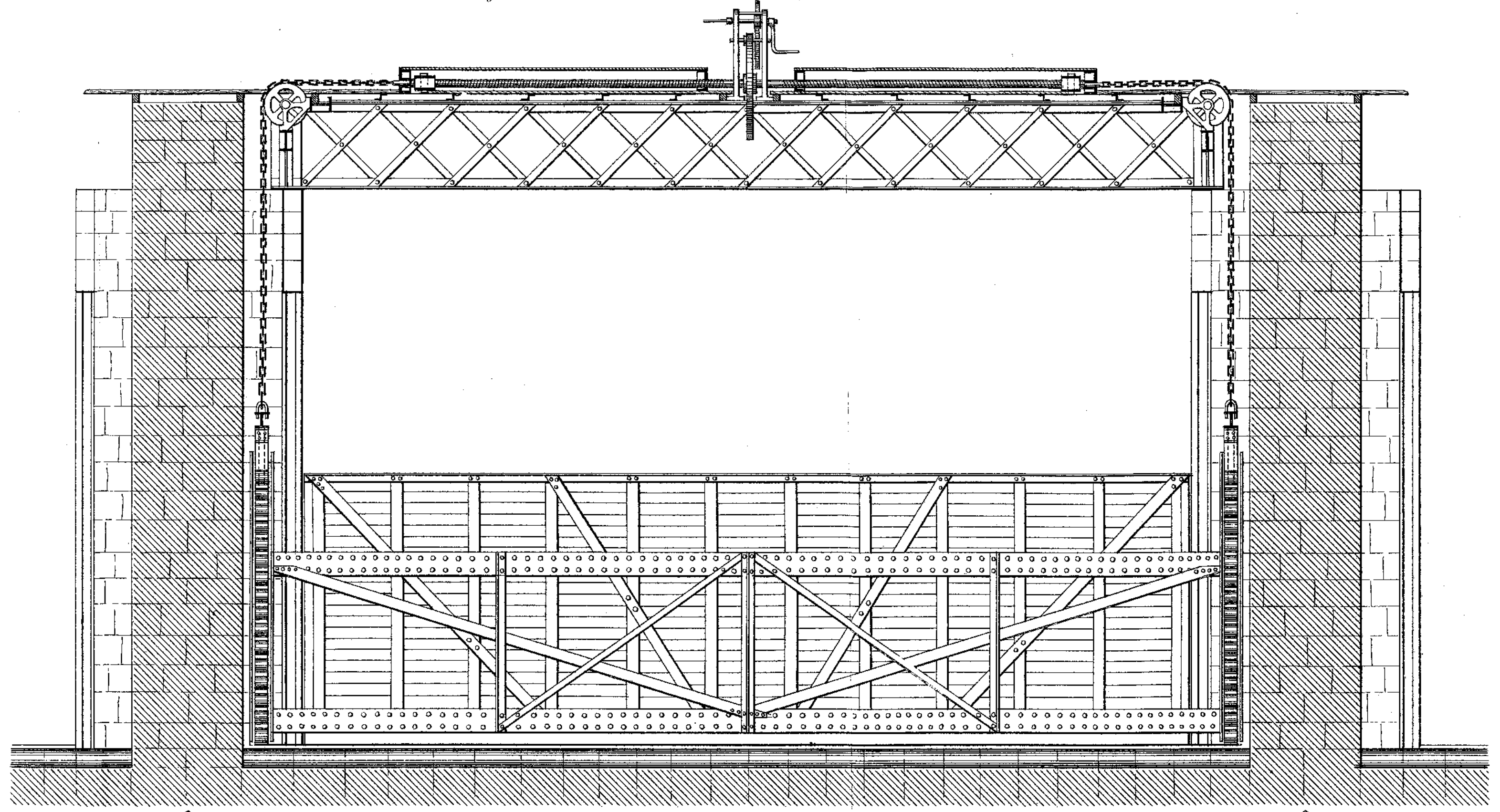
Mr. Apjohn. Mr. J. H. APJOHN observed, that during the time that the shutters of the Midnapore weir were fitted with the old gear, similar to that in use on the Mahanuddee weir, their working was most unsatisfactory. In the first place, great difficulty was experienced in the dropping of the down-stream row of shutters, in consequence of the double struts with which each shutter was fitted; as soon as one strut was knocked out of its notch the shutter got twisted, and the second strut was disengaged with the utmost difficulty. He had more than once spent all the daylight hours endeavouring, with the aid of a large gang of men, to drop the shutters, and by nightfall had only succeeded in opening half of one 50-feet-wide bay. Since the shutters were, in 1875, fitted with single struts, disengaged by efficient gear, no difficulty had been experienced in opening the sluices at any time of the day or night when the necessity had arisen, and, as at Midnapore, this might be as often as a dozen times in the season, it was essential that the shutters should work easily. At the same time that the down-stream shutters were fitted with single struts, jointed bars were

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

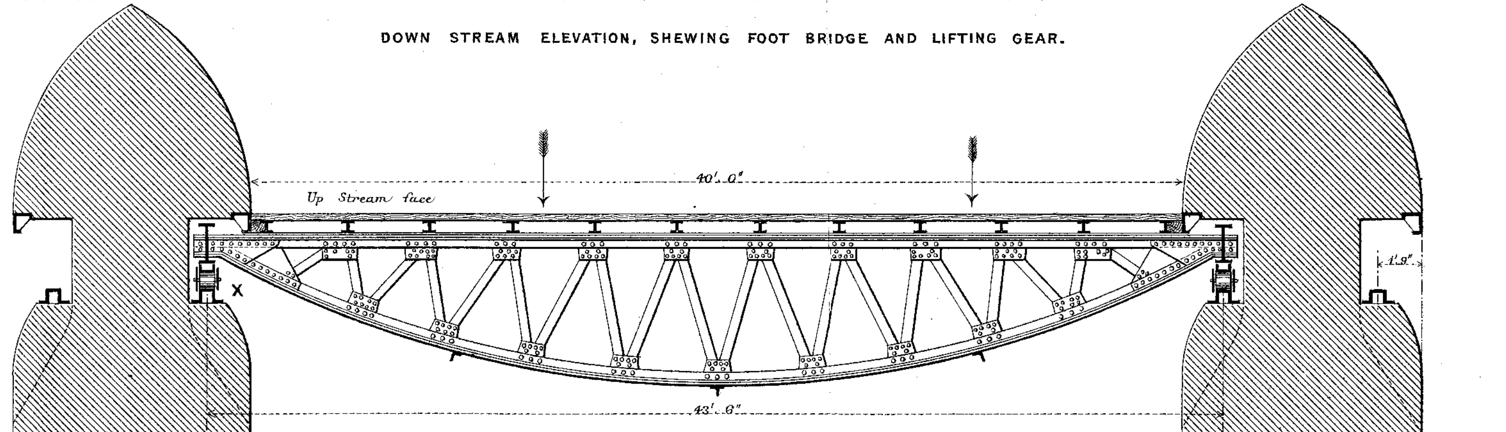
FIXED AND MOVABLE WEIRS.

PLATE 6.

Lifting Sluice Gate on Free Rollers; Clear Span 40 feet; Depth of Water 32 feet.

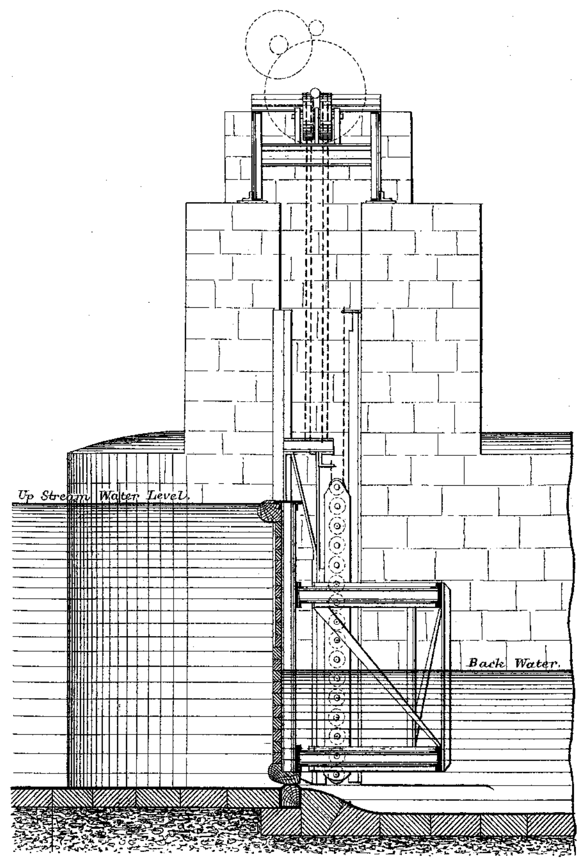


DOWN STREAM ELEVATION, SHEWING FOOT BRIDGE AND LIFTING GEAR.

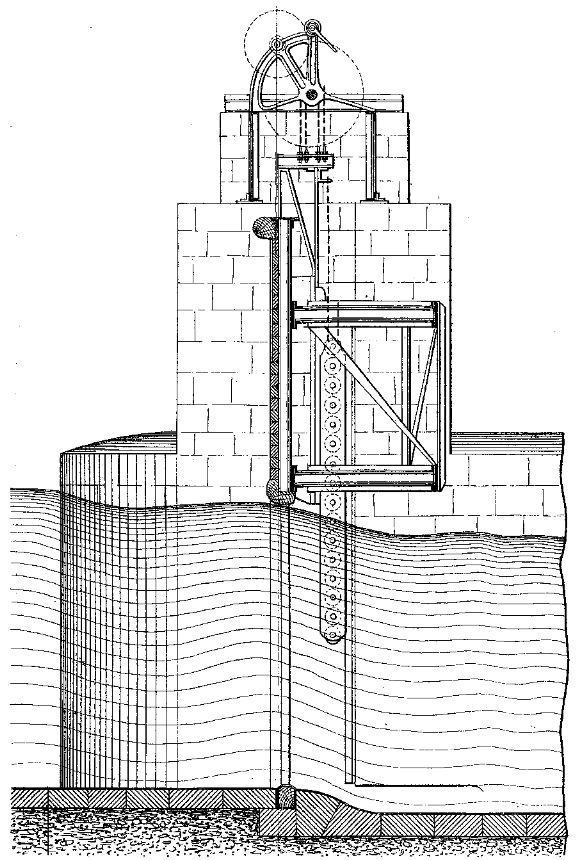


PLAN OF SLUICE GATE.

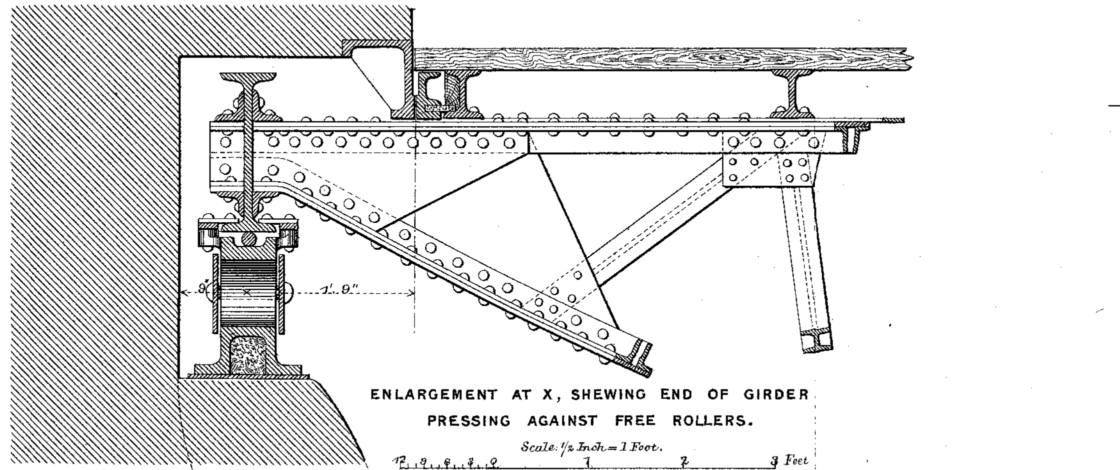
Scale, 1/8 Inch = 1 Foot.



TRANSVERSE SECTION SHEWING SLUICE SHUT.



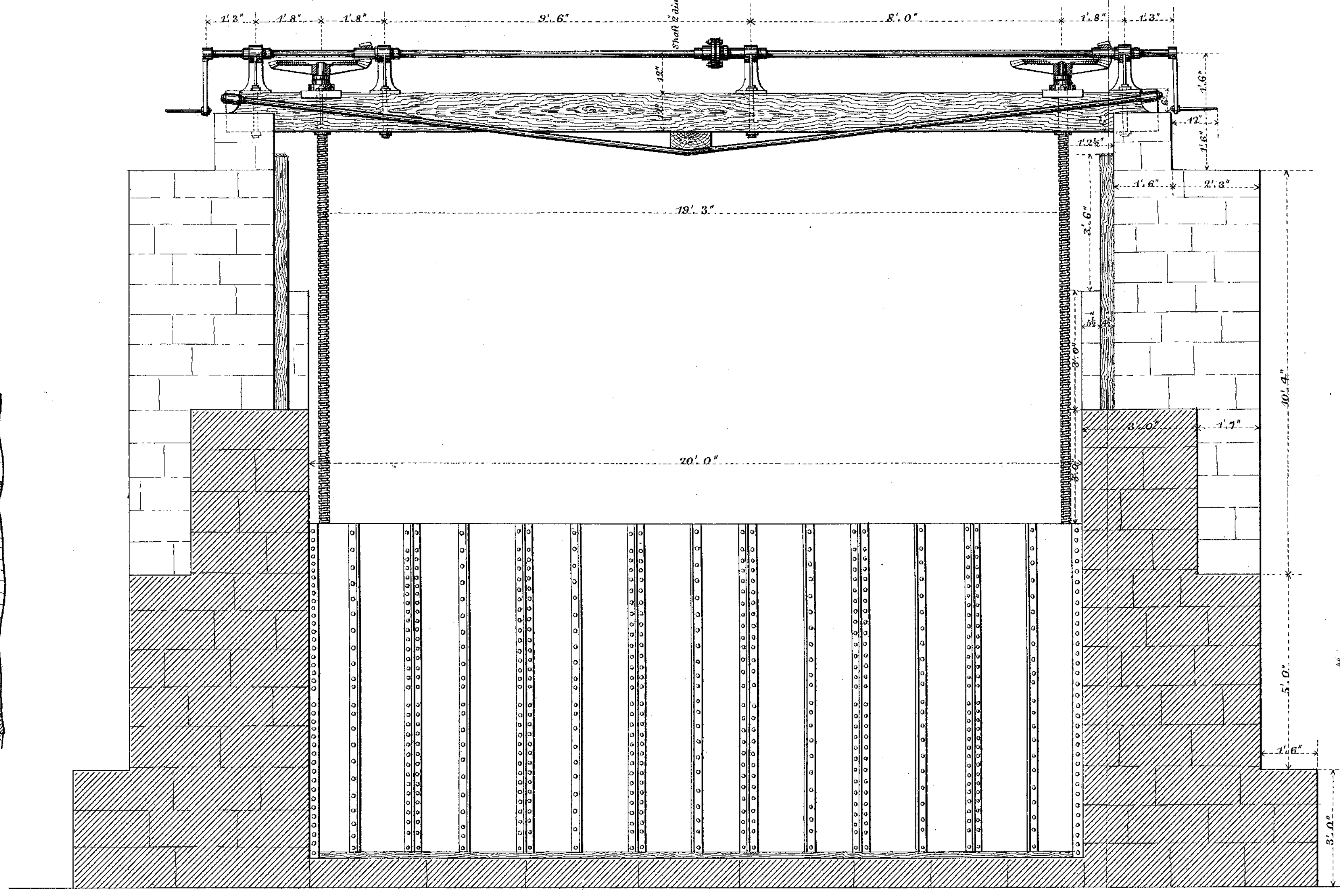
TRANSVERSE SECTION SHEWING SLUICE OPEN.



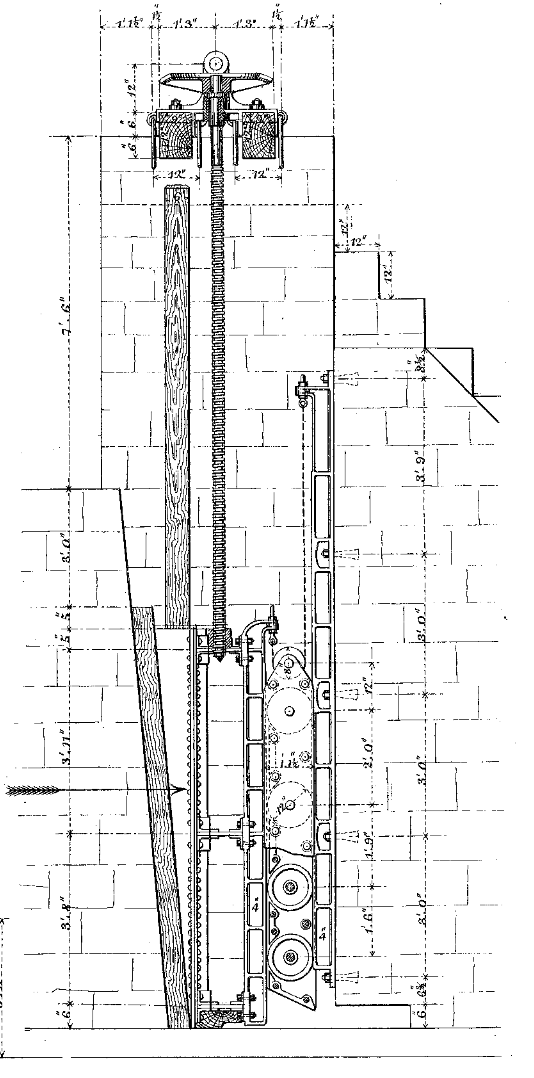
ENLARGEMENT AT X, SHEWING END OF GIRDER PRESSING AGAINST FREE ROLLERS.

Scale, 1/2 Inch = 1 Foot.

PELOTAS SLUICE.

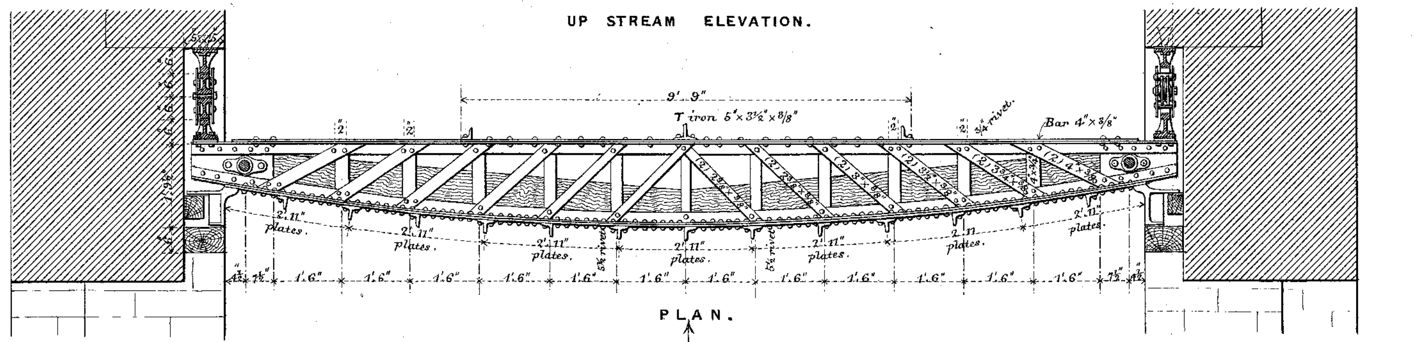


UP STREAM ELEVATION.



TRANSVERSE SECTION.

Scale, 1/4 Inch = 1 Foot.



PLAN.

Up Stream.

E. G. M. STONEY, DELT.

THOS. KELL & SON, LITH. 40, KING ST. COVENT GARDEN.