Discussion.

The President.

The PRESIDENT, in moving the vote of thanks to the Authors, remarked that he had read the Paper with great interest. It had been, indeed, his own insistence on the value of aprons that caused Sir Arthur Webb, who was Under-Secretary of State at that time in Egypt, to allow him to put down the aprons below the Assuan dam. As many of the members would be aware, a considerable pounding action took place through the discharge of the water on to those aprons. At Assuan, owing to the sills of the various sluices being at different levels and the rock downstream being very irregular, the slopes of the aprons were not everywhere the same. One particular apron had a considerable slope—about 1 in 7, if he remembered rightly. It extended for about 200 feet downstream; but at the foot, notwithstanding that long length of protection, the rock was eroded away. "Erode" might not be a good word to use, though it was difficult to know what would be the correct one in a case like that. It was not abrasion of the rock that took place; what happened was that the natural joints in the rock itself were cleaned out, the material in each joint, whether sand or clay, was removed, and the water thus got in and forced each loosened block out. A year or two later another apron was built with a slope of 1 in 13. The end of that slope was so arranged that the last little piece was flat, or indeed, if he remembered correctly, slightly inclined upwards. The result was that the water rushing down that slope shot up into the air, and no destructive effect on the rock downstream was apparent. That arrangement produced somewhat the same effect as the Authors mentioned as being produced by the small wall shown in *Fig. 29* (p. 220). The Authors, after making experiments, had introduced into some barrages in Egypt that small wall at the end of each apron, and it had the effect of preventing the erosion which normally would take place downstream. That was undoubtedly a very great improvement. As they rightly pointed out, it was not a new idea, because it had been done previously in certain other cases; but there could be no question that, if it had been adopted in the case of the Asyût barrage, it would probably have lessened the work undertaken by Dr. Lowe-Brown and the late Sir Arthur Webb when that structure was turned temporarily into a flood-regulating work. It would be noticed that the Authors did not say that blocks were a perfect substitute for aprons, but they had done admirable work in settling what the size of block should be

The President. in specific cases and also in pointing out at what distance downstream the action of the stream was reversed. He had noticed recently that model tests had been carried out some years ago in connection with erosion below the Conowingo dam in the United States.[1] There could be no doubt that the Authors had gone a great deal farther than had been done in that case in the States, and had advanced very considerably knowledge in regard to erosion and the effects of the flow from sluices in dams and in barrages; and they were indeed deserving of the thanks of The Institution.

Mr. Binnie. Mr. W. J. E. BINNIE remarked that he had had the privilege of visiting the Delta barrage while the experiments described in the Paper were being carried out. A great deal of very useful work had been undertaken at the Authors' laboratory, but it had been published only by the Public Works Department in Cairo, and was in the hands of very few engineers. He hoped one day to persuade the Authors to write a book dealing with all the experimental work they had carried out in Egypt. The book by Mr. John R. Freeman, referred to on p. 176, described much of the work that had been carried out up to 1929 in laboratories on the Continent, but a great deal of it had been done without knowledge of the work done in Egypt, and of the fact that there was therefore no necessity to continue that particular line of research. Mr. Freeman had visited and described about nine laboratories in Germany and Scandinavia, and his book was entitled "Hydraulic Laboratory Practice"; but he made no mention in it of any hydraulic laboratory in this country, and, although he did refer to some of the work carried out by Professor A. H. Gibson, M. Inst. C.E., any one reading that book would conclude that English engineers were very much behind the times or took no interest in experimental work of the kind in question. There was no doubt that it was very difficult to predict what would happen in the case of structures controlling the flow of water, and it was fortunate that the laws of similarity applied with extraordinary accuracy in that case. The actual discharges of a sluice at the Esna barrage were given at the bottom of p. 178, and plotted in *Fig. 3*. By the laws of similarity it would be necessary to multiply litres per second by no less than 17,700 in order to get the cubic metres per second expressed in the last column of the table at the top of p. 179. The remarkable accuracy with which the experiments had been carried out would be seen from *Fig. 3*, for any small error would be multiplied 17,700 times; and the results were a great tribute to the Authors' work. That accuracy was also

[1] *Engineering News-Record*, vol. 108, p. 127. ["Engineering Abstracts," No. 51, p. 55.]

comforting because it showed that it was possible to obtain such reliable results with a model which was only one-fiftieth of full size. One of the most interesting points with regard to the experiments was the fact that the Authors had introduced into the water above the sluice, or whatever it was they were testing, very small filaments of coloured silk, which distributed themselves through the water where there was any turbulence so that the vortices could be seen and photographed. Turning to the question of aprons, to which reference had been made by the President, Dr. Rehbock had carried out at the laboratory of the Karlsruhe Technical University a number of experiments on the same lines as those indicated in the Paper and had evolved a sill which was similar in sectional area and shape to that shown in *Fig. 29* (p. 220); but he called it a dentated sill, because it was not continuous right across the full width of the apron, gaps being left. Dr. Rehbock claimed that that was an improvement. Had the Authors ever tested such a sill? He had visited the laboratory with Dr. H. E. Gruner, M. Inst. C.E., who had expressed the opinion that there was really no advantage to be gained by adopting the dentated sill as compared with an ordinary plain wall such as was shown in *Fig. 29.* At all events Dr. Rehbock had thought it sufficiently good to patent it. He would like to refer in conclusion to the very interesting discussion of the effects of lack of symmetry at the Esna lock, illustrated by *Fig. 23* (p. 211). He had been present while that vortex was forming. It had been very dangerous to bring a boat up to that lock, which was at the west end of the Esna barrage, and the model experiments described had really been the means of saving heavy annual expenditure on maintenance of works. He thought, therefore, that before any large works were undertaken introducing novel features for dealing with large quantities of water, it was essential to have model experiments carried out. Mr. Binnie.

Dr. W. L. Lowe-Brown observed that the Authors had shown how experiments with models could be used for the design of such works as they referred to, and not only for the works themselves but also for the secondary works required to protect the bed from the erosive action of the water in the disturbed zone between the point where it emerged from the gates and that at which normal flow became re-established some distance downstream. They had also advanced the technique of model experiments considerably by analysing the various forms of eddy currents set up. The general form of the eddies must be common to all works of the kind, but he was sure the Authors would be the first to say that their results could not be used quantitatively for any other structure. In fact, they actually stated that the use of a model for every major structure during the period of design was strongly advocated, which meant Dr. Lowe-Brown.

Dr. Lowe-Brown.

that their results must not be applied to any other work without specific investigation. The description of the two kinds of horizontal vortices was, he thought, the most important part of the Paper. Any one who had had to do with the maintenance of works of the kind in question knew quite well what the Authors called the negative vortex. He remembered having had to take soundings downstream of the Asyût barrage when there was quite a strong negative vortex, and the difficulty there was in keeping the launch from being carried upstream under the fall: but, as soon as the water rose a little more and there was a submerged weir, the negative vortex disappeared, and—though he was not aware of it at the time—what was called a positive vortex formed underneath. He did not think any one had really suspected the presence of that vortex underneath, but it obviously increased the velocity, and, instead of its being difficult to keep the boat from being carried upstream on to the barrage, the vortex made it difficult to get near enough to take soundings. He did not propose to deal with the theoretical side of the question further, but he desired to discuss the practical implications. Although the Sennar and Assuan dams were similar in many respects, the conditions with regard to scour were widely different; for, whereas at Assuan when the maximum effect was taking place there was practically no water downstream, at Sennar under similar conditions of discharge there was a good water cushion. No one who had undergone the experiences which Sir Murdoch MacDonald underwent at Assuan during the first few years after the dam had been put into service would ever have dreamed of building another pierced dam without substantial aprons downstream. He himself had been there, and he knew the worries Sir Murdoch had gone through and the sleepless nights he had passed, and it was small wonder, therefore, that when he came to design the Sennar dam he provided aprons. When that work was in progress and the aprons would in the ordinary course have been built, Sir Murdoch was no longer responsible for it, and the aprons were omitted for financial reasons and also, Dr. Lowe-Brown believed, because it was thought that the water cushion would render them unnecessary; but it had been pointed out by himself and others in the discussion on Mr. O. L. Prowde's Paper [1] that aprons would be required, and very soon it had been shown that that was the case. The experiments described in the Paper gave a much clearer idea of how the aprons should be designed, and no doubt those at Sennar would be altered and improved, but the general system suggested by Sir Murdoch MacDonald when he designed that work would have to be followed. The most interesting part of the Paper,

[1] "The Gezira Irrigation Scheme, including the Sennar Dam on the Blue Nile." Minutes of Proceedings Inst. C.E., vol. 222 (1926), p. 81.

Dr. Lowe-Brown.

he thought, was that which referred to barrages. It was of much more general application. It was necessary to divide the barrages on the Nile into two categories. The older barrages, at the Delta, Zifta, and Asyût, were all designed for low-Nile regulation, and the later ones at Esna and Nag Hammadi were designed for flood-regulation. The Asyût barrage, it was true, had been used for flood-regulation, even in its first year, but it had not been designed for that purpose. He had previously explained the reasons which induced Mr. (afterwards Sir Arthur) Webb to undertake what was considered a very dangerous experiment.[1] He was subjected to bitter adverse criticism, but in spite of that, and with his eyes wide open, he undertook the risk. He ordered the gates to be let down against the flood, which was equivalent to opposing a barrier 5 metres high for the whole width of the river against the Nile in flood. He did not do it without taking precautions in the way of providing stone, etc., to be thrown in, in case serious erosion took place. Soundings were taken daily downstream to watch the scour, and at first no damage was done, but, as the flood increased, erosion somewhat of the nature shown by the Authors, but greater in extent, took place, and when a depth of 5 metres had been scoured out, an attempt was made to throw in stone from boats, as had been arranged. It was found, however, that that was impossible on account of the strong current, and it was therefore necessary to rig up a gantry on the barrage, from which to throw the stone. While the gantry was being put together, the hole increased to a depth of 11 metres, very much more than occurred at Esna, perhaps because the flood regulated in that year (1902) was 50 per cent. greater than the flood dealt with at Esna in 1913. The dotted line in *Fig. 31* (p. 228) showed the erosion described by the Authors, and the full line the erosion which took place at Asyût before it was possible to throw in the stone. The gantry which was rigged up for throwing in the stone was designed in about half an hour on the floor of the foundry and built as quickly as possible. It was arranged so that it could be traversed longitudinally on two trolleys, one at the rear end and one in the middle, so that it could be moved along the barrage from point to point where deep holes were found. Mr. Webb returned to Asyût just about the time that this gantry was ready to work, and when he heard the result of the soundings he ordered the gates to be opened, but his object had been attained, as the fields had already received their proper quota of water. Lord Cromer said in his report for 1902 that in that one year Egypt benefited to the extent of £600,000 by that action on the part of Mr. Webb, and the whole Asyût barrage only cost £720,000. He would like to show

[1] Minutes of Proceedings Inst. C.E., vol. 232 (1931), p. 376.

Dr. Lowe-Brown.

the changes that had taken place in the design of protective aprons

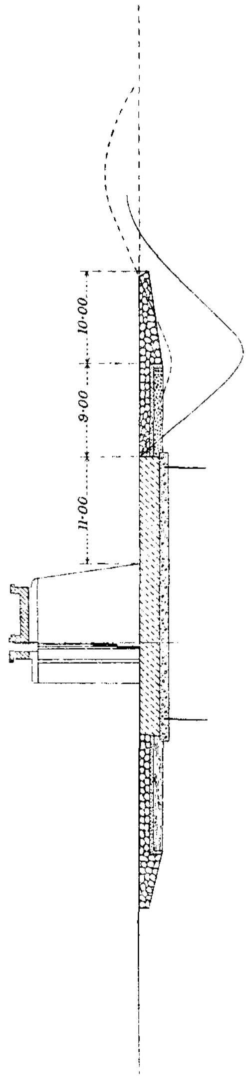


Fig. 31.

(Dimensions in metres.)

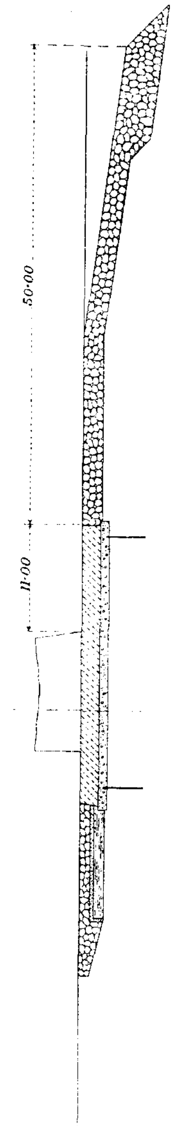


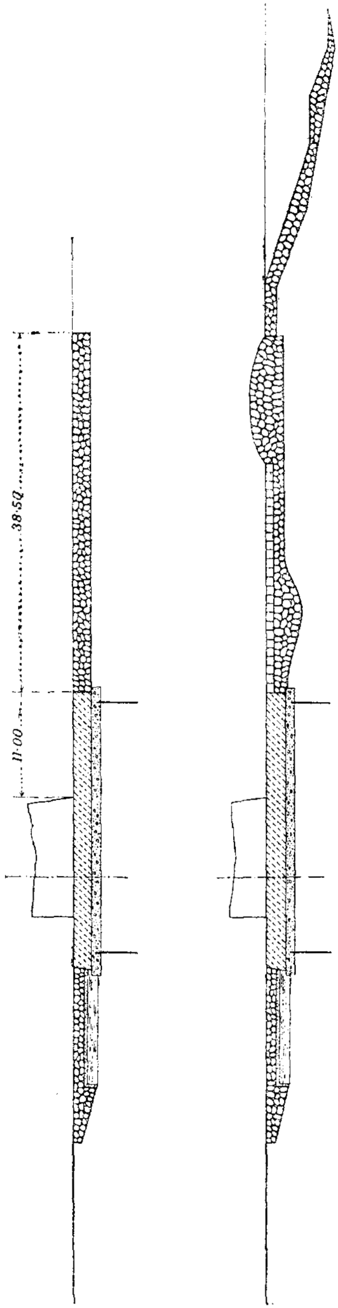
Fig. 32.

as a result of the experience of flood-regulation in Egypt. *Fig. 31* showed the aprons at Asyût as originally built. The main structure stood upon a masonry raft 3 metres thick protected by two rows of cast-iron piles to assist in resisting percolation. This raft extended 11 metres downstream of the piers. The next 9 metres consisted of an inverted filter of graded pebbles and gravel covered by 1 metre of pitching. Downstream of that again there was a further 10-metre strip of pitching averaging about 1·50 metre in thickness. When the aprons at Asyût were damaged during the first experience of flood-regulation it was thought that the erosion started in the soft bed of the river downstream of the pitching. It was supposed that a hole was first scoured out in the mud; then, after it had reached a certain depth, the lower end of the pitching became undermined and fell into the hole; and then another hole was formed farther upstream. It was thought the hole gradually advanced upstream in that way. As would be seen from the various remedies proposed, no one had imagined that the current attacked the upper surface of the pitching directly, as the Authors had shown it might. His suggestion for repairing and strengthening the apron at Asyût was shown in *Fig. 32*. He had been under the impression that this sketch had never been shown to any one but Sir Arthur Webb, but he had forgotten Sir William Willcocks, and when looking up some reference in Sir William's book that day he had seen, for the first time, that his proposal was approved by Sir William, who stated that he had used it in the design of the Euphrates barrage.[1] It would appear, therefore, that Sir William Willcocks held the same view of the way in which the damage took place. Sir Arthur Webb's ideas of the best form of apron were embodied in the design of the Esna barrage, which was prepared by him after the experience at Asyût. That design was shown in the upper section in *Figs. 33* (p. 230). Pitching was still used, but it was made twice the width of that at Asyût. When the work was severely tested by the flood of 1913 it was badly damaged. At one point an area 24 metres by 25 metres was eroded to a considerable depth. That was repaired by filling the hole with broken stone and covering the stone with concrete blocks 1·50 metre by 1·00 metre by 0·70 metre, weighing about 2·4 tons each, while the pitching was extended downstream as shown in the lower section in *Figs. 33*. Subsequent experience proved that those concrete blocks were a great improvement, although not quite heavy enough to resist the scour unmoved. The next design was the Nag Hammadi barrage (*Fig. 34*). The masonry was extended 28 metres downstream of the piers, instead of 11 metres, and that was followed by a width of 32·50 metres of concrete blocks weighing 4·3 tons each, or nearly twice as heavy as those used at

Dr. Lowe-Brown.

[1] Sir W. Willcocks and J. I. Craig, "Egyptian Irrigation," 3rd ed., vol. ii, p. 663. London, 1913.

Dr. Lowe-Brown.



Figs. 33.

(Dimensions in metres.)

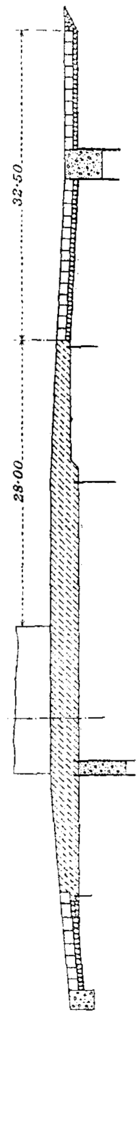


Fig. 34.

Esna. There was, however, another reason for making the floor of the Nag Hammadi barrage stronger than the older ones, namely, that it was placed 3 metres higher, i.e. 2 metres above the average level of the river-bed instead of 1 metre below it as at Asyût. The latest advance in the design of aprons was the addition of the lip described by the Authors at the end of the masonry floor. Another feature in the design of barrages which had been undergoing change was the arrangement of the gates. In the three barrages designed for regulation at low Nile, namely, the Delta, Asyût, and Zifta barrages, the upper gate was placed downstream of the lower gates, so that when regulation took place between the gates the stream of water was directed downwards towards the floor. At Esna and Nag Hammadi the arrangement had been reversed, so that under similar conditions the direction of the current would be upwards. He believed that the grooves at Asyût had been modified subsequently by extending the downstream groove down to floor-level, but whether the gates had been reversed at the same time he did not know. Perhaps the Authors, who had evidently studied that point very carefully, would say exactly what had been done. Dr. Lowe-Brown.

Mr. H. A. Reed remarked that the subject interested all engineers who were concerned with rivers. A great deal of time was taken up in looking after sluices, the question of maintenance being of great importance. Many sluices had had to have stone put down below them because the floors had been designed in such a way that scour was taking place. It was very interesting to find that the Authors had begun to discover methods of directing the flow of the water in such a way that the scour on the bottom of the channel would become less. The lip wall to which they referred was a thing which he would certainly try at some of his sluices, to find out whether it would reduce maintenance-costs. The slope below the sluices which the Authors described as the "ideal surface," and which really followed the neutral line of the water and the reversed vortex, was also very interesting and instructive. At the Latchford locks on the Manchester Ship Canal there were two locks and three sluices. There were only three sluices, because a great deal of the water passing down went through the old river-channel, and the sluices only had to pass the excess of water in times of flood. The gates were 30 feet wide (*Fig. 35*, p. 232), and lifted from the bottom, so that the water ran underneath them; the head was 16 feet, and there was a concrete apron. The bed of the canal was of New Red Sandstone. That was not a very hard rock, and the scour which had occurred was shown between the dotted line which represented the original surface below the sluice and the irregular line at the bottom. From time to time the depression had been filled with stone, much Mr. Reed.

Mr. Reed.

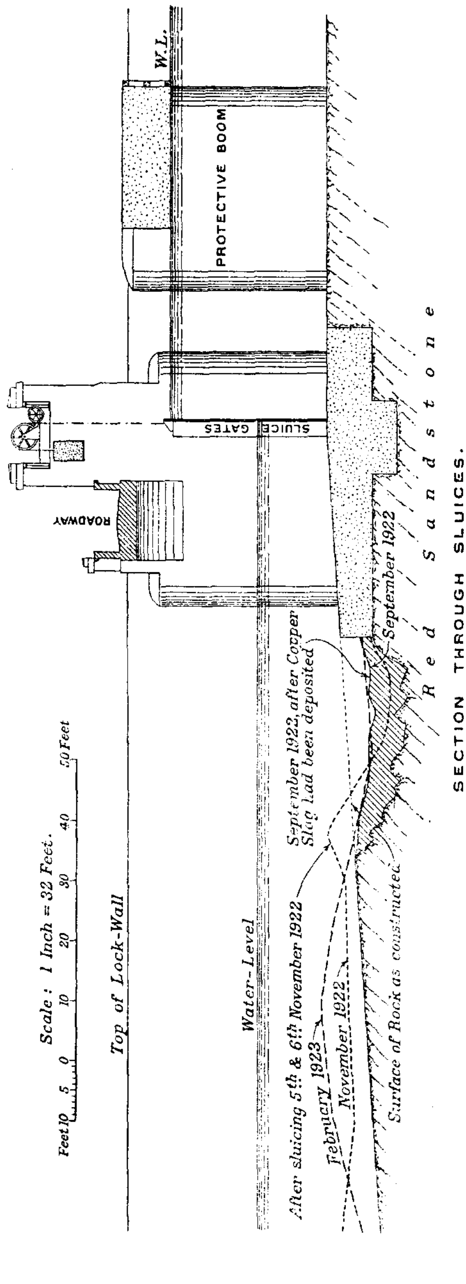
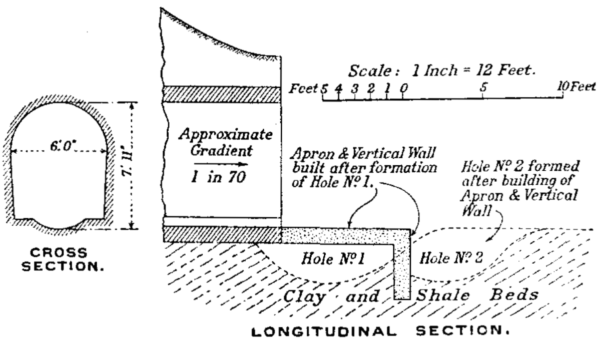


Fig. 35.

Mr. Reed.

of which was slag, at first of the size of a man's head or smaller. A great deal of it had been scoured out, as would be seen from the dark line, and had gone a little way downstream. The hole was subsequently filled with blocks weighing 1 to 2 tons, with the result that scour had ceased and the level had been practically restored to the dotted line which marked the original level. The stone had had to be put there because if nothing had been done the main concrete apron above would have been gradually undermined. *Fig. 36* showed a small culvert which illustrated what was described in the Paper. It was on a slope of 1 in 70. The ground in front of the culvert, consisting of clay with shale beds, had not been protected, and the water scoured it out in front of the culvert, the hole gradually extending upstream underneath the mouth of the culvert. The hole had been

Fig. 36.

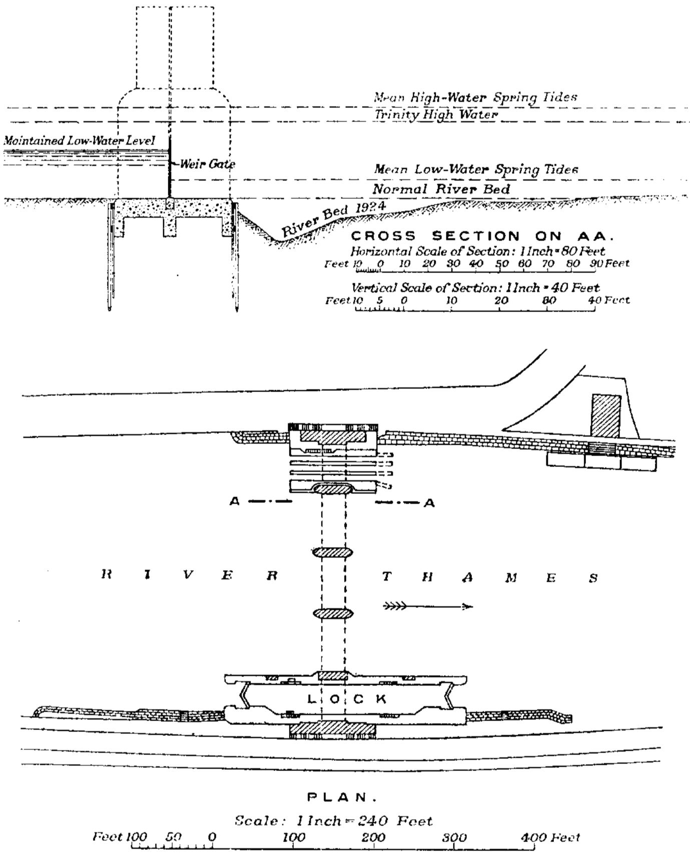


filled during dry periods (the water being run through a trough in the meantime) and concrete had been put in, as shown in the Figure. It had been taken deep enough on the downstream side to be below any likely hole. Under flood discharges a second hole had been scoured at the end of the concrete, but that did not matter very much, as it did not affect the culvert, and it had been left in that state. Those holes were practically the same as were shown in certain cases in the Paper. *Fig. 20* (p. 205) showed very much what happened at Latchford after the slag had been put in and then scoured out and thrown into a heap in front, although he supposed that in the case shown in that Figure the water probably ran over the top of the gate, whereas at Latchford it ran underneath, along the floor, when the gate was lifted. In *Figs. 6* (p. 182) the middle diagram with the negative vortex was similar to what had happened at the culvert face. Those similarities showed that, if such questions were considered and models were made before works were carried out, it was likely that the works

Mr. Reed. would be designed and built in such a way that a great deal of subsequent maintenance would be saved. He quite agreed with what Mr. Binnie had said about the technical publications issued in Cairo, which were very useful; they included very interesting Papers on weir-discharge by Mr. Butcher. He himself had managed to obtain them, but many engineers did not know of their existence.

Mr. Binns. Mr. ASA BINNS remarked that engineers had been accustomed to dealing with scale models in the sense of the simple model illustrating a new project, but not introducing any dimensional ratio except that of length. The scale models under discussion, however, introduced ratios of length, mass, and time, and there, of course, the difficulties of arriving at reasonable deductions were very much increased. The Authors laid down explicitly (p. 176) the problems which they had attacked; they had suited their apparatus to those problems; and he thought their conclusions were of great value. Obviously, apparatus of the kind described in the Paper, which was not at all costly, could be applied to problems of erosion such as occurred in every phase of hydraulic engineering. The practical results of the Paper were, he thought, threefold. First there was the means of deducing the profile of the apron on the downstream side of a sluice from a determination of the neutral points in the currents. That might be exceedingly useful in all kinds of hydraulic work. Then there was the suggested deflector plate in order to make, as he understood it, a cushion of water. Though it might be effective, a deflector plate would, as the Authors themselves pointed out, be exceedingly difficult to maintain. Most situations in which it would be employed were permanently drowned, and underwater work was very expensive. The last suggestion was the provision of a lip wall at the end of the apron, which unfortunately in dock and river engineering would not usually be admissible, for navigational reasons. Many illustrations might be given of the causes and prevention of bed erosion, and he wished to refer shortly to two historic cases in the Port of London. The first was the Dagenham breach of the River Thames in 1707, which resulted in 1,000 acres of marsh being flooded and the formation of shoals in the river which made navigation difficult. Dagenham lake remained to this day an example of the destructive effect of erosion under such circumstances. Old London Bridge was another very interesting example. It was a stone bridge with eighteen arches, and its wide piers reduced the actual waterway from 900 feet to about 300 feet, so that the bridge acted as a weir. When that bridge was removed, a hundred years ago, the erosion was so pronounced for miles upstream that measures had to be taken to safeguard the foundations of Blackfriars Bridge and Westminster Bridge. The weir on the Thames at Richmond was constructed in 1894, and erosion, as shown in *Figs. 37*, had taken place by 1924, although the flow was tidal. The cavity was about 6 feet deep. It threatened the masonry, and it had been necessary to throw in several hundred tons of old granite coping-stones, mooring-blocks, etc. He thought that with those remedial measures taken it would last for another 30 years. At the Victoria Dock there was an entrance-lock 80 feet **Mr. Binns.**

Figs. 37.

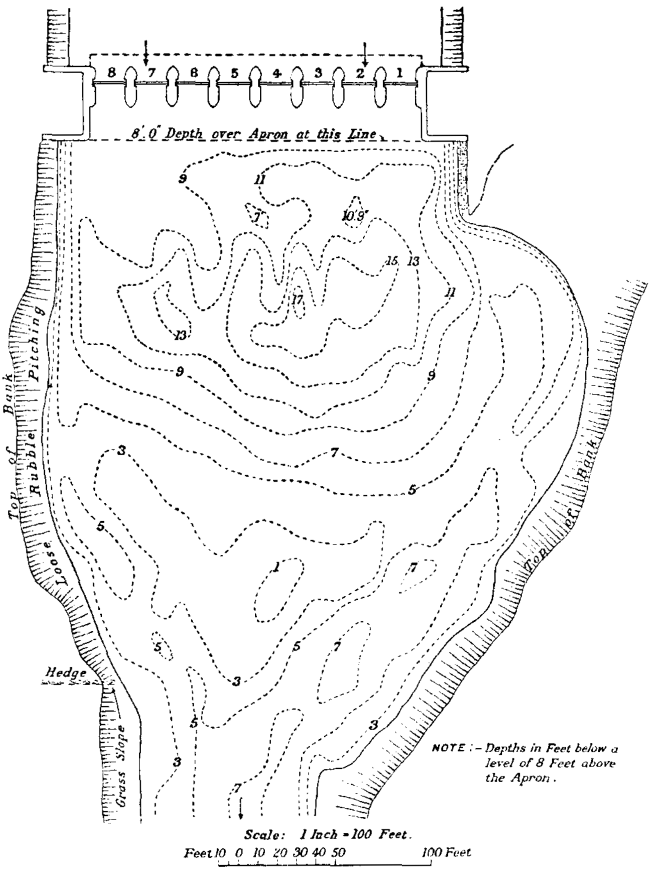


wide built in 1855, the lock-chamber being constructed in brickwork and having a curved cast-iron clapping-sill bolted to the brickwork. For many years trouble had been caused by water getting under the plate and boiling up on the river side, and ultimately it was decided to dry the sills and repair them. [The speaker exhibited two lantern-slides showing the condition of the masonry after the water had been

Mr. Binns. pumped out.] It would evidently have been futile to attempt to stop such erosion by getting divers to plug the leaks with concrete bags. At the Royal Albert Dock there were three impounding pumps, each of which delivered 15,000 cubic feet of water per minute into the Albert basin. They discharged through 6-foot culverts at such an angle that a straight line from the culverts would impinge on the dock bottom 70 feet from the wall. Actually scouring took place at twice that distance from the wall, and, though those pumps brought annually thousands of cubic yards of silt in the water, which it was necessary to dredge from the basin, there was a hole 6 feet deep at 140 feet from the wall.

Mr. Saner. Mr. J. A. SANER remarked that it was always difficult to view the actual vortices and direction of the currents in a large weir, because of the turmoil of the water, and the Authors' models could be studied without any danger of being engulfed in the river. It might be of interest to refer to some of the experiences on the river Weaver, although, of course, there were not such large sluices there as those on the Nile. At Dutton, in 1888 to 1891, the Trustees were altering the river—raising some of the pounds and lowering others—and it was necessary to deal with the flood water which at times came down very rapidly. In 1888, therefore, they built eight sluices at Dutton. The sluice-gates were 15 feet wide and 14 feet deep, and the maximum discharge was about 1,000,000 cubic yards per hour. The result of soundings taken a few days ago (*Fig. 38*) showed that the contours below the weir were very much in accord with what would be expected from the description given by the Authors. The doors could only be lifted one at a time, because there was a single travelling crab which lifted them. When the crab was over No. 4 or No. 3 gate the attendant did not always run it on to the next sluice, and therefore gates Nos. 3 and 4 were used more frequently than the others; that was shown by the deeper hole opposite those gates. The sluices themselves, so far as their construction was concerned, were very much like those to which Mr. Reed had referred; in fact, they might almost be said to be the forerunners of those on the Manchester Ship Canal, having been built before the canal was made. They had an apron 30 feet long in front of the sluices and about 13 feet long on the upstream side. From time to time since he had been in charge of them it had been necessary to deposit a large quantity of stone and heavy debris of different kinds, and also to dredge away a barrier formed about 40 yards below the deep water. From *Fig. 38* it would be seen that about 260 feet below the sluice there was only 1 foot 3 inches of water, whereas at the sluices there was 8 feet, and at the deepest point 17 feet. It had never been contemplated that it would be necessary to dredge away the barrier formed by the action of the water, yet that had had to be done 2 or 3 years ago. The head was 9 feet and the total length of the weir was 120 feet. At Dutton the discharge of water took place under the gates, but in another case, farther up the river, instead of building an entirely new set of sluices, the water had been raised by means of small gates on Mr. Saner.

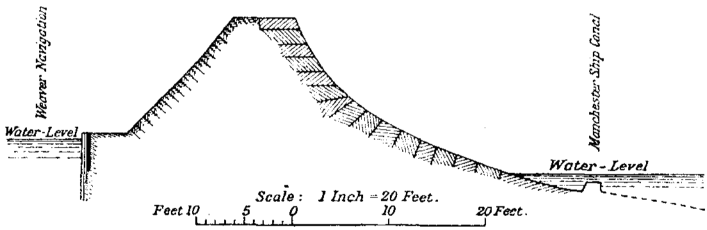
Fig. 38.



the top of the old weir. There were four doors there, 15 feet by 4 feet 6 inches, and the water fell on to the apron, but, of course, from a height. It was more like the case of the Assuan dam, shown in *Figs. 1* (p. 177); and the same action took place there. Fortunately the apron was built of solid masonry; but there was deep water immediately below it, and there was a considerable shoaling effect

Mr. Saner. about 150 yards farther down. The Authors suggested that the form of apron could be improved, and it at once struck him that the old weir or causeway across the river Dee at Chester had an apron which was prolonged at an angle of probably about 1 in 5 or 1 in 6, or possibly a little less. That old weir, which was subject to tidal action, had a pool below it and also a pool above it which was caused by the tide coming up. He believed it was built about the time of Edward I. It was washed away, or part of it was washed away, in the year 1601, and it was then repaired, but it had not been touched since, so that it was evidently a form which was fairly stable. It was, of course, not an ordinary weir. It had originally been a causeway, and the top of it was of considerable width. The Authors' suggestion that there should be a raised toe at the foot of the apron reminded him that the sea-wall on the Mersey, about 1 mile long, which was built by Telford about 1810, was of that form. That wall

Fig. 39.



had never moved, but it had now been protected by the Manchester Ship Canal. Within his recollection, previous to the construction of the canal the wall had been subject to severe action from waves, which would find a cushion of water just by the toe, as shown in *Fig. 39.*

Mr Lindley. Mr. E. S. Lindley observed that the Paper was of great value in definitely demonstrating the reliability of model tests in one of the directions in which their trustworthiness was not obvious. At the same time it must be remembered that eddying flow might not be reproduced in full detail, and so some important elements of erosive action might be missed. Viscosity was not to scale in the model, nor was rugosity, and accidental departures from the true form of the work were not copied: the smaller eddies that were not reproduced would produce local but intense variations of pressure, and it was not unknown for blocks to be sucked or blown out from their places in an unmortared apron. A further valuable suggestion was that of blocks to scale in weight and size, to measure erosive currents; and that he believed to be novel. Some references in the Paper and the discussion revealed the existence of an obsession for horizontal aprons in some minds. That measure was open to the *reductio ad absurdum:* if the apron were extended every time scour took place at its toe, it would have to be extended to the mouth of the river (or farther), but considerably above sea-level. The investigation arrived at a reasonable form of apron, dipping so as to provide a pool in which energy could be dissipated; the only difficulty, in some cases, was to lay this deep enough under water: but, on sandy beds at least, it was feasible to lay a flexible apron, and gradually to scour it into position by means of action of increasing severity. He had on occasion thus placed an apron consisting of no more than two courses of bricks breaking bond in both directions. The curve of "natural slope" was shown to rise after reaching a maximum depth; the rise would depend on the ratio of width of sluices to stream-width, and in an extreme case a bar would form across the river not very much below water-level. It seemed worth while calling attention to the fact that the length of the vortex in the open-regulator type was identical ($0{\cdot}25V^2$) in the two cases in which a single vortex occurred. But, while the Paper dealt principally with vortices about horizontal axes, he considered these to be the least dangerous of the actions that originated at such works. Another form of action that was also not very dangerous but was insidious was a surface pulsation which produced a broad gently-shelving beach at water-level, and acted even through pitching. He had observed some points of interest in connection with those pulsations; but as the Paper dealt with bed-erosion he would only remark that they were described in the discussion on a Paper published by the American Society of Civil Engineers.[1] The most dangerous form of action was an eddy with a vertical axis: a small eddy in a corner of a work could grind bad pot-holes in the floor with the pebbles that it entrained, so that it was advisable to avoid corners in which such eddies would be stationary. While he was in charge of the Rasul headworks of the Lower Jhelum canal the weir was once nearly wrecked by such a large eddy or whirlpool. An island had formed upstream of the weir near the right flank; at the time, that island largely masked the last bay but one of the weir (bay 7), and the channel between it and the bank was being developed by the set of currents above its head. Though bay 8 was kept fully open, it could not pass the flow of this channel, and a whirlpool formed behind the nose of the upstream groyne, in bay 7. Standing orders for regulation naturally prescribed that the whole weir must be opened to pass floods exceeding certain limits, and it fell to him to represent that under the circumstances it would be fatal to open bay 7. For one thing, while the bay was closed it ponded up water- Mr. Lindley

[1] Transactions, vol. 94 (1930), p. 1142.

Mr. Lindley. levels and forced a maximum of the flow of the right-bank channel to pass through bay 8; if the bay were opened, the flow causing the whirlpool would be very considerably increased: for another thing, the opening of the bay would alter the set of the currents in a manner that would bring the whirlpool much nearer to the work. Those representations were not accepted. When the next flood occurred, all but a few of the shutters in bay 7 jammed; to have tried to drop them would have involved risk of life. After the flood subsided, a section of the upstream apron collapsed, and it was found that scour had reached to the bottom of the main line of wells, that was, about 30 feet below water-level at a distance of more than 50 feet from the centre of the eddy. Regarding the lip wall described in the concluding portion of the Paper, similar devices had been developed by Mr. C. A. Colyer,[1] Assoc. M. Inst. C.E., in the Punjab, and by Mr. C. C. Inglis, M. Inst. C.E., in Bombay. Both these experimenters regarded it as essential to make the height of the lip wall sufficient for it to act as a broad-crested weir, so that the converging flow to it drew out or straightened the eddies; naturally, turbulence was again created in the flow from it, but not enough to cause excessive action. This brief reference should not be regarded as a summary of the Papers referred to.

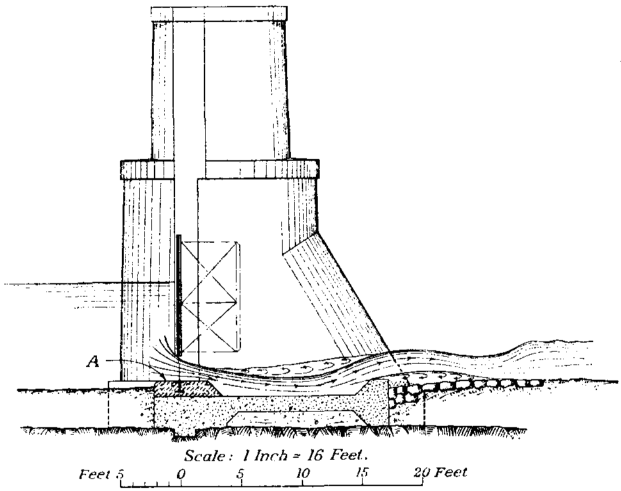
Mr. Griffiths. Mr. G. J. Griffiths stated he was controlling fifty-six weirs and had daily experience of scour. He wished to say that the Paper had enlightened him very much and had given him valuable information which he intended to apply in practice.

Mr. Williamson. Mr. James Williamson stated that there had recently been completed in Scotland what was probably the only river barrage in this country comparable, though on a small scale, with those in Egypt and elsewhere; and before completing the design of the sills, model experiments had been made. Those responsible had not been aware at that time of the experiments on the lip, but in the result they had arrived at a lip and something in addition which he would like to explain, as probably being of interest. The sill of the barrage (*Fig. 40*) went down to rock. The maximum head was about 8 feet, and there was a steel-plate gate with a steel sill embedded in concrete. In making the experiments a depression was arranged downstream of the sill, and very satisfactory results were obtained. On making another test next day, quite a different and less favourable result was obtained, and it was not until it was noticed that the sill projection (*Fig. 40*), which was a removable piece (A) in the model, had been omitted that the cause of the difference was ascertained. It was evidently better to put in a downward slope at the gate sill and repeat it in a reverse direction by a lip at the end of the floor than

[1] Punjab Engineering Congress, 1925, p. 103a, and 1927, p. 61.

to carry on a flat floor with a downstream lip only; and recently, in observing the action of the discharge it had been noticed that, with the gate partly open, the main stream took a downward tendency and finished up with a rising curve over the lip and a standing wave beyond. The Authors had put very clearly the difficulties in preventing erosion with discharge through sluices under a consider- Mr. Williamson.

Fig. 40.



able head. Another method which would obviate entirely the provision of expensive sills in cases where the head was high was to maintain the passage from the back of the sluice as an enclosed passage finishing up with a tapered pipe, and to put in what was known as a disperser, which was really a fixed metal part with vanes rather like a screw propeller. The effect was to form at the outlet a vortex with the water spinning more rapidly at the centre of the pipe than at the outside, so that the central stream, with its greater centrifugal force, burst outwards, and the result was discharge in the form of spray and rain over a large area. That device was also being adopted in a number of cases in Galloway for the discharge of water under high heads. In one case a single outlet would be capable of dispersing the energy of 30,000 or 40,000 HP.

*** The Authors' reply will be found at p. 274.—Sec. Inst. C.E.