Discussion.

Professor Dixon.

Professor S. M. Dixon remarked that, like most persons who lived in this country, he had never seen siphons such as were described in the Paper. He was therefore interested to learn not only that the siphons were working satisfactorily, but that they were some of the largest which had been constructed. Ever since 1921, when, in that room, he heard Professor Luigi Luiggi, M. Inst. C.E., describe, in a lecture, the siphons which he had constructed and used in Italy, he had been interested in the matter, because he then learned how much was required in the way of research in order to determine the losses of head in the various parts of the siphon so as to improve the discharge. It was noteworthy that the discharge-coefficient of the Maramsilli siphons was very poor for such a simple piece of plant. The use of siphons would appeal to all hydraulic engineers, in view of their low cost of construction, as compared with an ordinary spillway, and their compact design. The siphon was not only automatic, it was also very sensitive in the adjustment of the discharge. While he congratulated the Author on the design and construction of the siphons, the calculations of the losses of head did not appeal to him, as so many constants were involved and such a wide choice was left to the calculator. As the Author stated (p. 53), "It is difficult to determine where one source of loss ends and the other begins." The care taken by the Author in the analysis was shown by the close agreement between the total calculated loss and the total measured loss of head. Further details of the working of the siphons would be of value to engineers who were thinking of constructing siphon spillways. At what level did the main siphon begin to work, and at what level did it cease action? Probably the discharge-measurements could be made more accurate if some modifications were made in the measuring-weir. He had not been able to visualize the arrangement of that weir until he had seen it in the photograph thrown on the screen. He found it difficult to follow the piezometer readings in the Appendix. A diagram showing the positions of the piezometer pipes would be of great assistance in a study of the actual measured losses of head in the various parts of the conduit. Why was such a large mass of concrete required in the construction of the type B

Professor Dixon.

siphon? Had the siphons been subject to vibration when discharging, or had any ill effects of vibration been detected? It seemed that on a channel 8 feet by 8 feet with walls of only 10 inches of reinforced concrete the vibration effects were likely to be serious. The experiments on models particularly appealed to him, because at the present time Mr. K. C. Wu was carrying out experiments on an automatic siphon at the Imperial College. The material used was soft pine impregnated with paraffin wax. The first siphon used was similar in design to one on the Glens Falls feeder which supplied water to the Champlain Canal in the United States of America. The model was one-twelfth of full size, the inlet being 2 inches by 6 inches wide, the throat 1 inch by 6 inches wide, and the outlet 2 inches by 3 inches wide. Piezometer tubes were fitted in the usual way, and modifications had been made in the model by means of which a glass plate could be introduced on one side so that the flow of the water through the various passages could be seen. Experiments on the principle of similarity would be carried out, and then modifications in the conduit would be made to see if it was possible to improve the coefficient of discharge. Details of the original siphon and its performance had been given[1] by Mr. G. F. Stickney, the efficiency being 61 per cent. That research was necessary, he thought, would be seen at once when the low efficiency was considered. The Author stated that the efficiency at which he was aiming in most of the experiments was about 50 per cent. The efficiency of the siphon which Professor Dixon had just described was, as he had stated, 61 per cent. Mr. Stickney had said that the efficiency ought to exceed 70 per cent., but he did not explain how that result could be achieved. Mr. Weirich reported[2] that an efficiency of 97 per cent. had been obtained in a model tested at the Karlsruhe technical school, which showed what might be aimed at. The efficiency got on a small model was generally less than that obtained in practice, so it was quite evident, he thought, that research on the subject of spillways would enable engineers in the future to increase the efficiency of siphons from 60 to 70, or even 80, per cent.

Mr. Gourley.

Mr. H. J. F. Gourley observed that the lantern-slides had shown that there was a very unusual concentration of flow coming out of the spillways, passing over an apron, and then falling 20 feet on to the river-bed. The discharge of the type B siphon gave a

[1] Trans. Am. Soc. C.E., vol. 85 (1922) p. 1105.

[2] *Deutsche Bauzeitung*, 30 May, 6 June, 1917. An abstract of this article is given in *Annales du Ministère de l'agriculture, Direction générale des eaux et forêts*, 1917–18, p. 570.

Mr. Gourley. head over an ordinary weir of about 12 feet, and the erosive effect of that volume of water on the bed of the river could easily be imagined. At the Wilson dam on the Tennessee river in the United States of America there was an apron 250 feet wide, and water had been discharged in a similar concentrated form through sluices during some 16 months; the result had been erosion of the river-bed extending several hundred feet downstream. He feared that the same might happen in the Maramsilli spillway, unless the rock was very hard and sound. The erosion which had taken place at the Wilson dam had been attributed to suction and erosion underneath the toe of the apron caused by the formation of the hydraulic jump at the downstream edge of the apron, and also to the progressive lifting of large slabs of limestone downstream of the toe. The remedial measures had comprised the construction of a stout concrete wall at the end of the toe and the grouting of the rock which had been weakened and eroded underneath the toe. As the conditions which had brought about the erosion were not likely to recur, these measures were considered satisfactory. Had any special provision been made in facing the concrete inside the siphons? Some years ago he read in an American periodical that serious erosion had taken place in a concrete-lined tunnel, owing to the formation of a vacuum. That had been overcome in that case by the insertion of the necessary air-vent pipes. In the case of a siphon that could not be done, as it would destroy the siphonic action; but the vacuum was there. The Author recorded 14 inches of mercury as the vacuum at the head of the siphon; and, in view of Professor Dixon's question as to the possible effect of vibration, Mr. Gourley would be interested to know whether any ill effects had been discovered in the surface of the siphons. If there was both vibration and suction, it seemed that those somewhat frail siphons could not have a long life. At the Arrowrock dam, in America, water travelled at about 60 feet per second through a tunnel, and it had been found there that, by drying the concrete and applying two coats of hot tar, which closed the pores and filled small irregularities, it had been possible to eliminate all erosion due to suction effects on the minute projections which otherwise would have appeared on the surface of the concrete as exposed after the removal of the shuttering. On the Alwen dam, which his firm had constructed for the water-supply of Birkenhead, erosion had been observed on the face of the concrete facing-blocks on the down-stream side of the dam. Those blocks had been made so as to simulate rock-faced masonry, and it had been found that in many cases small portions of aggregate had been plucked out of the under side of the projections. It had been difficult to account for this, but, after various possible causes had been considered, it was concluded that the erosion was attributable to the formation of a partial vacuum, set up locally by the water travelling at high velocity over the projecting portion of the face during periods of reservoir overflow. The same thing might possibly happen in the siphons of the spillway under discussion. Mr. Stickney's Paper,[1] which Professor Dixon had mentioned, was well worth referring to. Many examples were given of different types of siphons, and in one or two cases during the discussion on that Paper attempts were made to work out the losses taking place at the various points throughout a siphon. The Maramsilli siphons were unprecedented, he thought, as regarded their height. In the Sweetwater dam in America the siphons were 12 feet wide and 6 feet high, and each unit had an estimated discharging-capacity of 2,000 cusecs. Those siphons had an efficiency of only 60 per cent. He agreed with Professor Dixon that, in the absence of a graphical record, it was difficult to follow the results of the Author's pressure observations. Mr. Gourley.

Mr. JAMES WILLIAMSON remarked that the question of the automatic spillway would become of increasing interest as hydro-electric projects extended. With regard to the action of a siphon spillway and the conditions which made its use desirable, the essential difference was that for an ordinary spillway, with water flowing over a weir, a great depth of flow was required in order to pass the flood volume, whereas with a siphon spillway atmospheric pressure forced water out under a high head. A comparison between an ordinary spillway with 9 feet depth of water flowing over and an automatic spillway with a depth at the throat of 9 feet would be interesting. If the automatic spillway had a total depth between the water-level in the reservoir and the tail water-level of 22 feet (which was about the maximum that could be used owing to the vacuum conditions) the effective head in an efficient type would be about 16 feet. The velocity of discharge, therefore, would be $8\sqrt{16}$, or, say, in round figures, 30 feet per second; and for every foot of effective length of the siphon spillway there would be a discharge of $9 \times 30 = 270$ cusecs. In the case of water flowing over the ordinary spillway 9 feet deep, the flow per linear foot would be about $3{\cdot}33 \times 9^{1{\cdot}5} = 90$ cusecs; that was, the siphon spillway would discharge, for every linear foot of effective length, three times as much as the ordinary spillway. There was a further important difference. The siphon spillway would prime and come into operation as a result of a Mr. Williamson.

[1] *Loc. cit.*

Mr. Williamson. difference in water-level of a foot or two in the reservoir. Taking 2 feet as a maximum, the siphon system gave an effective difference of 7 feet depth in the storage-capacity as compared with the ordinary spillway. On a large reservoir that might be an enormous volume, and the value of that storage so saved might be far in excess of any extra cost of the siphon spillway. There was a further point that, on the basis of the rough comparison which he had made, the ordinary spillway, even if a maximum overflow of 9 feet depth were allowed, would require to be three times the length of the equivalent siphon spillway; and it was not always practicable to make an ordinary spillway of such length. There were other automatic means than the siphon spillway of passing flood waters and limiting the useless depth at the top of the reservoir. Several different designs of automatic gates served the same purpose, but the question of using such gates for a reservoir required careful consideration. Automatic gates were more commonly used in passing flood waters, say, on a river which was impounded for hydro-electric purposes; and in such use they came into operation frequently and over considerable periods of time. If they were applied to a reservoir, there was a possibility that under normal conditions it would not spill very often. There might be intervals of 2 or 3 years in dry-weather periods when the water-level did not reach the top of the reservoir, and automatic gates involving mechanism were not so desirable, because they might be neglected, and when they were required to operate they might fail. The question of the loss of head through the siphon spillway was not perhaps of very great importance compared with the actual difference between a siphon spillway and an ordinary spillway, but it was still of considerable importance; and when it was considered that in passing water through turbines where the head was comparable with that of a siphon spillway—through a vertical draught-tube and a right-angle bend—the efficiency of the whole operation might be between 80 and 90 per cent., it certainly seemed that it ought to be possible with an apparatus in which there was no rotating or moving mechanism at all to get something better than 50 or 60 per cent. efficiency. It ought to be only a matter of research into the arrangement of proper entrances, diverging outlets, and gradual curves, to attain a better efficiency. Siphon spillways would always be required to be reliable when the flood was greatest, and at such times the severest storms were likely to occur. In the case of reservoirs with large surface-area—he had in mind particularly a reservoir where the floods might amount to 40,000 cusecs—the wave-formation in a storm might be appreciable. In that case, he thought, there was some doubt as to when the priming would take place, owing to undulatory motion of the water at the mouth; and it would be prudent to allow on siphons for important reservoirs a considerable margin beyond that which would be used when it was certain that the water on the upstream side would always be still. Mr. Williamson.

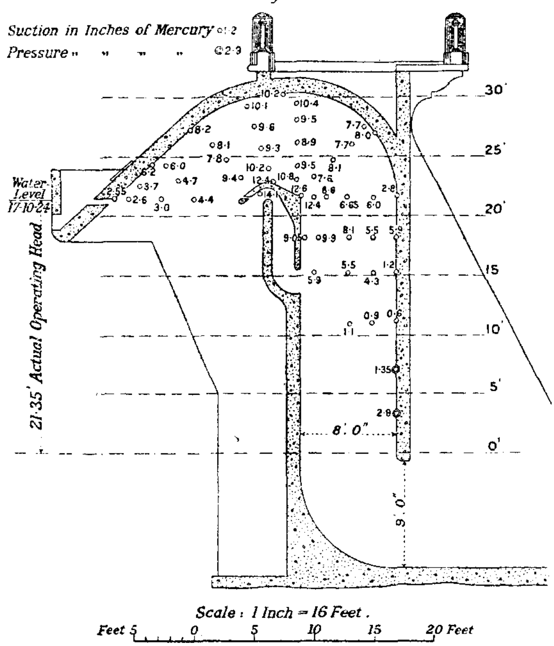
The PRESIDENT remarked that the Author stated that the adoption of a siphon spillway in place of the ordinary overflow type had enabled a substantial reduction to be made in the height of the dam for the same capacity. His mind was not quite clear as to that statement, and he would be glad if Mr. Williamson would refer to it. The President.

Mr. WILLIAMSON agreed with the Author's statement. Taking the case which he had already explained, of the siphon spillway as compared with an ordinary spillway three times as long, with the former the flood height required to operate a siphon might be only 1 foot. With the ordinary spillway, under the conditions he had assumed, a spill height of 9 feet would be required. When the flood had passed, that extra 8 feet by which it was necessary to raise the embankment was all lost so far as the permanent storage-capacity of the reservoir was concerned. In the case of the siphon spillway the siphon was put at the same level as the ordinary spillway, and the water never rose more than a foot above it; whereas with the ordinary spillway the rise would be something like 9 feet. Mr. Williamson.

Mr. ERIC CREWDSON observed that the first point that had struck him in reading the Paper had been that referred to by Professor Dixon and Mr. Gourley, namely, that it would have been a great convenience if a diagram had been given showing the piezometer readings. For that reason he had prepared two diagrams, *Figs. 5* and *6* (based on *Figs. 1* and *2*), on which he had put the piezometer readings. He did not feel that a correct use had been made in the Paper of the term "efficiency," and that "coefficient of discharge," used by Professor Dixon, would be a more suitable term. A siphon spillway might be very efficient in the sense of having a high coefficient of discharge, but at the same time it might be uneconomical in construction. For instance, if it were imagined that the downstream floor of the siphon shown in *Figs. 1* were raised from the level there shown—which was 9 feet below the bottom edge of the downstream wall—by, say, 7 feet, the discharge-area, upon which the efficiency was calculated in the Paper, would become 2 feet by 8 feet. The result of that would be to reduce the loss in the upper bend and all the friction losses, so that practically the whole head would be available for producing velocity in that narrow outlet, and as high an efficiency as 90 per cent. might easily be obtained on that basis of calculation. That example showed that Mr. Crewdson.

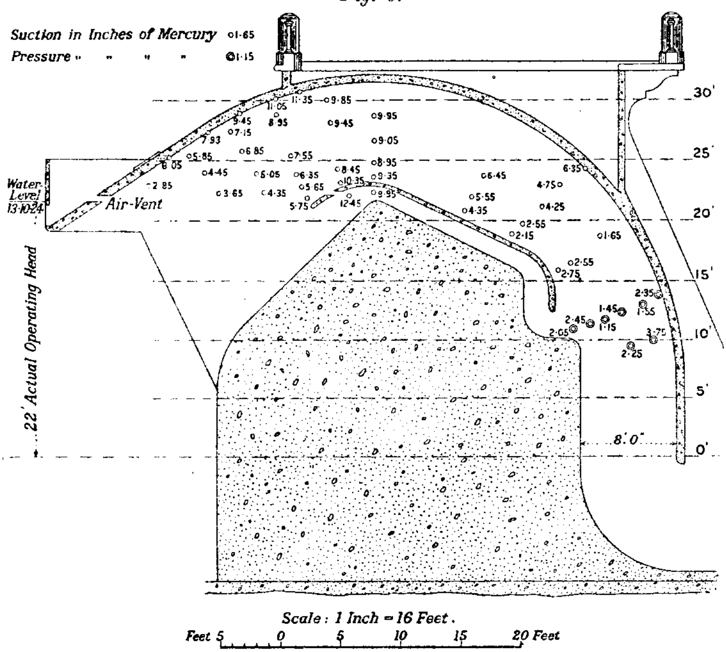
Mr. Crewdson. the question of efficiency was not by any means the most important. The most important question seemed to him to be the cost per cusec of discharge, and that might be reduced to a lower figure with a relatively inefficient siphon than with a very efficient one. The Author's proposition that the motion of the water round the bends approximated to that in a free vortex (p. 47) was fairly well borne out by the piezometer readings so far as the pressures went; but the Author went on to say that the curve of velocities in a section

Fig. 5.



taken normal to the direction of flow was hyperbolic. Nowhere in the Paper did the Author give justification for that statement. It could only be justified by Pitot-tube or other measurements in the actual current. The second proposition (p. 47) did not appear to be generally true. It might be true in the type of siphon used by the Author, but even that Mr. Crewdson doubted, for the following reason. In the analysis of the losses in the type A siphon (p. 51) the Author gave the loss in the lower bend (No. 9) as 9·2 feet, and he deduced that that was the loss on the basis of his second proposition, in the following manner. The point of change from pressure to suction readings was 9·3 feet above the discharge-level; deducting from that an assumed friction loss of 0·1 foot, the Author arrived at the loss of 9·2 feet. He took the loss in kinetic energy at the outlet as a loss to be reckoned above that point of change from pressure to suction, and not below it. In the analysis of losses in the type B siphon, the Author gave (No. 14, p. 52) 11·18 feet[1] as the loss in the lower bend. It was reasonable to assume that that figure had been obtained in the same way as the corresponding figure for the type A siphon, but it was obvious from the diagram that the change from Mr. Crewdson.

Fig. 6.



pressure to suction took place at a point between 15 and 16 feet above the discharge-level. If, then, the proposition which the Author put forward was true for that siphon, he should surely have allowed at least that amount for the loss in the lower bend. Was the loss in kinetic energy at the outlet really a loss? It was necessary to have some velocity to carry the water away below the siphon, and if, for instance, the discharge-passage below the siphon was designed for a velocity of 16 or 20 feet per second, there was no loss chargeable to the siphon at all due to the head necessary to produce a similar velocity in the siphon itself. The Author stated that the loss by friction in the lower part of the outlet leg (No. 7, p. 51) was

[1] See footnote to p. 53.—Sec. Inst. C.E.

Mr. Crewdson. 0·16 foot. That presumably was a calculated loss, because from the Author's readings the observed loss would appear to be very much more than that. Reference to Table I, piezometer readings Nos. 44 and 45, and to piezometer reading No. 9 in Table II, showed that those readings were all taken at approximately the same reduced level, namely, about 1224·3, and they gave a suction reading on the average of about 0·86 inch of mercury—or, say, 1 foot of water. Now, piezometer reading No. 12 in Table II at 1216·56 feet was 2·9 inches of mercury, or, say, 3·3 feet of water-pressure. There was a difference of elevation, between the first set of readings and the second, of 7·7 feet. The area of the passage was not changed—it was a perfectly straight piece of the siphon—and therefore presumably the mean velocity had not changed. He would therefore expect that the lower reading would be much higher, corresponding to a difference of about 7·7 feet. Actually the difference of pressure worked out at 3·76 inches of mercury, or 4·3 feet of water. The observed loss, therefore, was 3·4 feet. He did not understand where that loss occurred. Probably the explanation was that the velocity was very unsteady in that part of the tube. But there did not seem to be any justification for estimating that friction loss as only 0·16 foot. He would be glad if the Author would state how soon, after the water-level fell below the air-inlet, the siphon ceased to discharge? Also, was the air-inlet carried right across the face of the siphon? There was an anomaly between Tables I and II, in that, if piezometer reading No. 32 in Table I was compared with piezometer reading No. 6 in Table II, it would be seen that they were at almost identically the same point, and one of them read 4·7 and the other 2·8. It seemed that the 2·8 was definitely an error if one followed the figures on either side of it in the Table.

Mr. Silcock. Mr. E. J. Silcock, remarking that he did not think the point raised by the President had yet been made quite clear, pointed out that a siphon spillway was a device for increasing the velocity of discharge over a weir to such an extent as would secure a material reduction in the head required to carry off flood water. In the case under discussion the reservoir had an earth embankment, and it was stated that with an ordinary spillway or bywash it would be necessary to allow for a discharge of 9 feet in depth to provide for floods. The top of the embankment would therefore be not less than 9 feet plus a freeboard of 6 or 7 feet, say a total of 15 feet, above the crest of the bywash. By adopting a siphonic discharge the head could be reduced from 9 feet to 2 feet, and hence the embankment could be reduced by 7 feet whilst still retaining the same storage-capacity and margin of freeboard. This might not seem a

Mr. Silcock.

matter of much importance, but it must be borne in mind that the effect would be to cut off 7 feet of the embankment at its base, which would effect a substantial saving in cost. Another way of expressing the effect of the use of the siphon would be that if the height of the embankment was constant, in one case the crest of the spillway would be 7 feet higher than in the other without reducing the margin of freeboard. This would enable a layer of water 7 feet deep to be added to the top of the reservoir where it would most effectively increase the storage-capacity without submerging any additional land.

Mr. Sangster.

Mr. W. P. SANGSTER drew attention to the fact that the siphon spillway under discussion was not the only example of siphon spillways in India. The Author mentioned (p. 41) that automatic siphons were now being frequently adopted wherever close regulation of water-levels was required, as, for example, at the forebay of hydro-electric works. It had been desired to utilize for hydro-electric power a fall on the Lower Bari Doab irrigation-canal. The supply varied at different seasons from about 1,000 to about 7,000 cusecs; and the problem had been to utilize the fall, which was only 7 feet, to the best advantage. The solution had been an automatic siphon, because, whether 1,000 or 7,000 cusecs was flowing, the discharge would pass the crest of the siphon with very little variation in mean level—no more than 1 to 1½ foot. That was a case where an automatic siphon had been of great advantage. It had been very simply made, of reinforced brickwork. Timber was very expensive and scarce in the Punjab, and the form-work for reinforced-concrete construction would have been complicated and difficult to make. The use of reinforced brickwork had enabled timber form-work to be almost entirely dispensed with, and the work had been easily constructed by means of the native labour available. He thought that work was almost the first example of siphon spillways in India; and, although it was on a smaller scale than the spillway described by the Author, it was an interesting example.

*** The Authors reply will be found at p. 80.