Correspondence.

Mr. Balfour. Mr. J. A. BALFOUR remarked that the Paper was of immediate practical value to the hydraulic engineer. The sections in *Fig. 1* and in Fig. 7, Plate 1, of Vol. CXC of the Proceedings, invited attention to the increase in discharge over a spillway obtainable by rounding, to a fairly large radius, both the upstream and downstream edges of the crest. In the case of a reservoir constructed by Mr. Balfour some little time back it was calculated that the discharge of the spillway per linear foot would be 7·45 cusecs with the ordinary flat-top design when H was 2 feet. With the value 3·009 for C given in Table III (p. 108) the Nant-y-Gro discharge would be 8·5 cusecs per linear foot, while with the first-mentioned spillway, if both the upstream and downstream edges were rounded, the calculated discharge would be 10·5 cusecs per linear foot. With 4 feet of water above the crest level of the spillway the calculated discharge of a flat-topped weir would be 21·9 cusecs, and with the weir rounded both upstream and downstream 30·6 cusecs, per linear foot. As the value of C for the Nant-y-Gro wall was not given for values of H greater than 2 feet, it could not be compared with the other types for the 4 feet depth over the crest. For $H = 2$ feet the Nant-y-Gro type of crest thus had a discharge 14 per cent. greater than that of a flat-topped weir, and the weir rounded both upstream and downstream had a discharge 41 per cent. greater than the flat-topped weir; while for $H = 4$ feet the gain was only slightly less. The coefficients for the flat-topped weir and for the weir rounded upstream and downstream were based on Tables given in a publication by the United States Geological Survey,[1] in which the bases of the coefficients used were fully discussed. The spillway referred to was accordingly built with a rounded upstream crest merging into a parabolic downstream curve designed to correspond nearly with the underside profile of the overfall. Writing from memory, the upstream curve had a radius of about 4 feet. The saving in length of spill-wall required to deal with the flood-discharge was 100 feet, which resulted in very considerable economy. A further advantage of rounding the upstream edge was that damage from large floating logs was less likely to occur. He had seen large blocks of stone removed from weir-crests by such floating logs.

Mr. Gourley. Mr. H. J. F. GOURLEY congratulated the Authors, not only on having accomplished a most useful piece of research, but also on having been able so to convince a municipal authority of the value

[1] R. E. Horton, "Weir Experiments, Coefficients and Formulas." (U.S. Geological Survey, Water-Supply and Irrigation Paper No. 200.) Washington, 1907.

Mr. Gourley.

of the investigation, that the cost of carrying it out had been met out of public funds. It was to be hoped that in course of time other engineers would be equally successful, for there was no doubt that there was great scope for field—as distinct from laboratory—experimental work, and he felt that, in the past, many opportunities had been missed. The results of the experiments were expressed by a formula, in which the index of H was 1·48 ; and the logarithmic plotting indicated clearly that that figure accurately represented the whole range of the experiments. It was interesting that, as long ago as 1851, Francis arrived at the value of 1·47 for sharp-edged weirs, though he reverted in 1852 to 1·50. Since then, various experimenters had found that a value less than 1·50 more accurately represented the results of their work. In 1914, experimenting with Mr. B. Santo Crimp, Assoc. M. Inst. C.E., on the flow over sharp-edged notches, Mr. Gourley found[1] that the discharge over a considerable range of angles varied as $H^{2\cdot47}$, and for sharp-edged weirs with ends sloping at various angles the discharge over the sill was proportional to $H^{1\cdot47}$, being augmented by ends at other than the vertical by a quantity varying as $H^{2\cdot47}$. It might be argued that the difference between 1·47 or 1·48 and 1·50 was slight, and that for practical purposes the more easily manipulated 1·50 was quite near enough. In most cases this argument carried weight, but as the practice of using small-scale models to determine the discharging-capacity and behaviour of a large structure was becoming more general, it was essential to use the real law of discharge when determining the flow-ratio between the model and its prototype. In experiments on the flow of water over sharp-edged circular weirs[2] up to 26 inches in diameter, he found that the index of H was 1·42. Experiments had been carried out recently on a $\frac{1}{36}$-scale model of a circular spillway or overflow with the object of determining the adequacy of the spillway of the Davis bridge dam then under construction.[3] The diameter of this model spillway was about 53 inches ; it had a rounded outer edge, and a top inclined slightly towards the shaft, followed by a curve which reduced the diameter to that of the shaft, namely, 7·5 inches at a depth of 26 inches below the sill of the weir. His examination of the experimental results showed that the flow over the model up to the limit of 2·33 inches (corresponding to 7 feet in the actual spillway) was given by $Q = 2\cdot14\ LH^{1\cdot34}$. The coefficient in the actual spillway would probably approach that given by the Authors, but it was difficult to see how the index could alter materially. If 1·34 applied to the

[1] Minutes of Proceedings Inst. C.E., vol. cc, p. 388.

[2] *Ibid.*, vol. clxxxiv, p. 297.

[3] Trans. Am. Soc. C.E., vol. lxxxviii, p. 1.

Mr. Gourley. actual spillway, then the flow-ratio would be of the order $\frac{1}{36} \cdot \frac{1}{(36)^{1 \cdot 34}}$, or $\frac{1}{4380}$, instead of $\frac{1}{36} \cdot \frac{1}{(36)^{1 \cdot 5}}$, or $\frac{1}{7776}$, if the "1·5" law were held to apply, notwithstanding the experimental results. This case was mentioned to emphasize the importance first of obtaining the true index and then of applying it.

Mr. Justin. Mr. Joel D. Justin considered that the experiments undoubtedly gave results of sufficient accuracy for calibrating the discharge of the Caban dam itself within the range of the heads experimented on. The consistency of the results attained indicated the great care with which the experiments had been conducted. Reliable experiments on the discharge of broad-crested weirs were rather rare. Among the best-known experiments along this line were those[1] of the late Mr. T. E. Blackwell, M. Inst. C.E., and the United States Deep Waterways Board.[2] Mr. R. R. Lyman[3] had also presented valuable data, and had shown the influence of the depth of water upstream, and of the width of the weir, on the discharge. The real value to the engineering profession of such experiments as those made by the Authors lay in the possibility of applying the coefficients determined to other dams with similar crests which had not been calibrated. He felt that more precise information as to the exact form of the crest, the degree of roughness, and the depth of water upstream from the dam—all of which might affect the value of the coefficient—would greatly increase the utility of the experiments to engineers who might have a similar dam, the discharge over which they might wish to compute. The height of the Caban dam was stated as 35 feet, so the depth of water above the dam was probably so great that it did not influence the experiments. The roughness of the surface could well be shown by a diagram indicating the departure from an enveloping cross section at various points. At least the size of stones on and just below the crest could be stated, and the depression depths in and between them could be given. *Fig. 1* left some doubt in his mind whether the long curved face just downstream from the crest was a reproduction of the face of the Caban dam, but he would assume that it was, as under some conditions it would affect the discharge. At some critical head, somewhat above the maximum experimented on, there would probably be a kink in the discharge curve, due to the formation of a partial vacuum at the point where

[1] Minutes of Proceedings Inst. C.E., vol. x, p. 331.

[2] R. E. Horton, *loc. cit.*

[3] Trans. Am. Soc. C.E., vol. lxxvii, p. 1189.

the water left the crest and dropped to the long curved downstream face. Friction on the sides of the flume doubtless had some effect on the value of the coefficient; that was to say, for a long crest the discharge for a given head would be greater than that indicated by the experiments: but he was of the opinion that such difference would be insignificant for the range of heads experimented on. If the experiments had been carried to greater heads that factor would have been worthy of consideration. Mr. Justin.

Mr. F. C. TEMPLE observed that study of this interesting Paper gave rise to a desire for further information. Now that the yield of the Elan Valley works could be determined very accurately, how closely did the actual yield agree with the calculated yield? That information should be a valuable check on the Tables for calculating discharge from a catchment. How far would the discharge be influenced by the shape of the sill and the curve of the crest? When so much apparatus was already available in the place, it was to be hoped that the Authors would continue their experiments for different shapes of sills and different curves of crest. Mr. Temple.

Mr. S. M. WOODWARD considered that the results were of decided value, but would have additional value if the exact form and dimensions of the crest were stated. Of a different, but somewhat similar, nature were some experiments which he and others had carried out within the last year on the Keokuk dam across the Mississippi river. That dam had a rounded crest, and the gate-openings were calibrated under a head of 11 feet. The coefficient obtained for the ordinary weir formula was, of course, much higher than that obtained for the flat crest of the Caban dam. The report of the results had not yet been completed, but the coefficient approached 4·0. It was hoped that the report would be published soon. Mr. Woodward.

The AUTHORS, in reply to the Correspondence, stated that the majority of the contributors had referred to the appreciable increase in the discharge which occurred when the edges of a weir were rounded. The chief reason for making these experiments in the first instance had been inability—in the light of any previous results—to translate this effect into quantities which would be accurate for the somewhat peculiar profile of the sill of the Caban dam. Both upstream and downstream edges were rounded in this case, and, in addition, there was a slight slope on the broad-crested weir itself. On this account the Authors made no claim that their measurements had resulted in a formula capable of general application. The Authors.

With regard to Mr. Balfour's remarks, there was no object, had it been practicable, in measuring flows 4 feet in depth over the weir. It had been estimated that the greatest flow off the gathering-

The Authors. ground would not give a greater depth than 3 feet over the Caban dam, whilst the greatest flood experienced in the Elan valley since the construction of the reservoirs had not exceeded 2 feet 4½ inches over the Caban dam. Assuming that the formula held good, however, for heads greater than those of the experiments, it was possible to calculate the coefficient C in the formula $Q = CLH^{1.5}$ for any desired head. The U.S. Deep Waterways Survey[1] using a weir 2 feet 8 inches wide, and with the upstream edge rounded to a radius of 4 inches, obtained for a head of 2 feet a value of 3·00 for the coefficient C, as compared with 3·009 in the present series.

In reply to Mr. Gourley, it certainly seemed from the results of the best experiments that the power of H to which the discharge of a weir was proportional probably lay between the original value of 1·47, as first found by Francis, and 1·49. It was certainly less than 1·50, and the value of 1·48 found in the present experiments was a very satisfactory mean. In regard to the circular spillway of the Davis Bridge dam it would appear that the weir as such was very inefficient, judging by the model. A discharge of 2·14 cusecs per linear foot with a head of 1 foot was very low, for even the crudest form of straight broad-crested weir would give 2·63 cusecs per linear foot with that head.

A more detailed drawing of the profile of the weir-crest had been added (p. **123**). No correction was necessary for the depth of water in front of the weir, either at the experimental dam, where the depth was 35 feet, or at the Caban dam, where the depth exceeded 120 feet. The surface of the side walls which determined the length of the weir undoubtedly must have introduced an element of friction, and this was probably the only flaw in the value of the experiments. It was hoped, however, that with the small heads available the influence of this was practically negligible, though a greater volume of water could have been wished for, which would have permitted of a longer experimental weir, to eliminate this effect almost entirely.

The relation between the rainfall and the yield was being worked out month by month for the whole 44,000 acres, as desired by Mr. Temple. In addition, a valuable record had been commenced recently by the erection of a sharp-edged weir 150 feet long where the flow of the Claerwen valley only was being measured continuously. This weir controlled the yield of 22,760 acres out of the 44,000 acres, and the results would form a very convenient check.

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[1] H. W. King. "Handbook of Hydraulics," p. 144. London, 1918.