Paper No. 5848

"A New Method of Gauging Stream Flow with Little Afflux by Means of a Submerged Weir of Triangular Profile" †

by

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Mr Gerald Lacey observed that the Author's novel method of gauging stream flow would appear to hold out most promise when the afflux was small and the range of discharge not too great. It would lend itself, for example, to the measurement of a moderate range of discharges on a canal where every loss of head had to be reduced to the minimum. The crest of the weir could be combined with the piers of a road or railway bridge.

The Author disregarded the results for the two lower discharges of 0·577 and 0·793 cusec respectively on the grounds of "scale effect," but it was possible that that persisted, to a smaller extent, even with the larger discharges. A study of *Fig. 4* showed that the raising of the bed upstream by means of gravel had a very marked effect on the values of the coefficient C_T. The data given in Table 6 were for a limited range of the ratio P/T. Instead of drawing a smooth curve through the numerous results of Table 4, Mr Lacey had attempted a logarithmic correlation by treating Tables 3 and 4 as one collection of data. It should be noted that Table 3 was the most complete collection of observations.

In *Fig. 6*, he had plotted values of $(1 - P/T)$ against values of C_T for Tables 3 and 4. It would be seen that there were two distinct stages of flow and that two equations were necessary. For values of $(1 - P/T)$ of 0·10 and less the equation was:

$$C_T = 6{\cdot}85\,(1 - P/T)^{\frac{1}{2}} \qquad (10)$$

and for values of $(1 - P/T)$ exceeding 0·10:

$$C_T = 3{\cdot}85\,(1 - P/T)^{\frac{1}{4}} \qquad (11)$$

The fit was quite good and the equations could easily be solved using a slide-rule.

The afflux was a minimum when $(1 - P/T)$ was minimum. For that condition the discharge in unit width q was equal to:

$$6{\cdot}85\,(1 - P/T)^{\frac{1}{2}}T^{\frac{3}{2}} = 6{\cdot}85\,\sqrt{(T - P)}\,T$$

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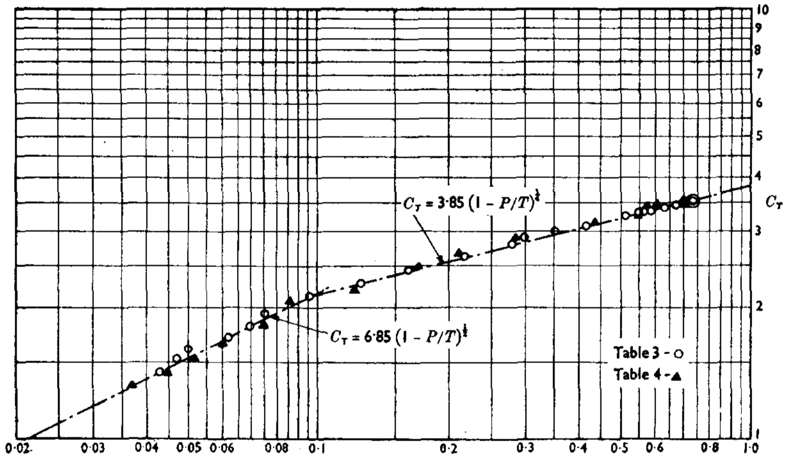
† Proc. Instn Civ. Engrs, Part I, vol. 1, p. 223 (Mar. 1952).

Fig. 6



At the limit, $(T - P)$ was equal to the velocity head, and T was equal to the depth of water. There was therefore a physical explanation for that part of the curve, $(2g)^{\frac{1}{2}}$ being replaced by 6·85.

The limit for P/T would appear to be approximately 0·25, corresponding, in terms of equation (11), to a value of C_T of 3·583.

Mr R. F. Wileman stated that his observations on the Author's valuable contribution towards the solution of the varied problem of satisfactory gauging of rivers, now a statutory duty of River Boards in Great Britain, related to certain aspects of the practical application of the suggested method of double gauging. That duty was a new one, and the advantages resulting from its performance might not at first be so apparent to some as the small inconveniences arising from its combination with the primary duty of drainage-cum-conservation of water in British rivers. It was therefore important to try to reconcile the requirements of the two duties.

Because the tendency, particularly on small rivers, was to avoid so far as possible any pier in the channel, it seemed to Mr Wileman that the Pitot-pier might arouse objection. Even if it were of small and stream-lined transverse section—as in the case in question—obstruction might be caused by the lodgement of long pieces of debris between the pier and the channel side.

The small orifices in the Pitot-pier appeared liable to blockage at low stages of flow by floating or partly submerged vegetation. Might that not interfere with the Pitot gauging until it was seen and remedied ? With regard to the piezometric holes in the crest duct, would the Author please say if the conditions of flow over the crest would be certain to prevent gradual blockage of the duct. It seemed to Mr Wileman, however, that even if solid matter did gradually accumulate in the duct, clearance might be easily effected by means of a pump at low stages.

It would be of great interest to know the opinion of instrument makers concerning the production and possible cost of an instrument which could be relied upon accurately to record the small difference between Pitot and piezometric readings, upon which the Author's method depended under non-modular conditions of flow. Such an instrument should be comparable, with regard to mechanical reliability, with a good float-operated level-recorder, which, properly installed, was remarkably free from failure.

In conclusion, Mr Wileman referred to an aspect in which the Paper seemed to offer very useful assistance in gauging only under modular conditions of flow, particularly in smaller channels. The Author had calibrated a weir of definite triangular profile, the modular discharge over which was given by formula (9). A weir of such profile was of constant coefficient and not appreciably affected by deposition of silt against its upstream face. Constructed to the proportions of the model, with metal crest, arranged in conjunction with a float-operated discharge-recorder, it should afford ample gauging accuracy under modular flow. In view of the necessity for the minimum lengths of side walls, it appeared that such a weir was not suitable for " compounding " and therefore its use had to be confined to circumstances ensuring that its width would not be excessive in relation to minimum discharge to be measured. Mr Wileman suggested that a low weir of that type, with wing walls of height just sufficient for the purpose, could in many instances be used for measuring the lower stages of discharge occurring during the greater part of a year on small rivers, the higher stages being " covered " by current-meter rating of the channel at an adjacent site. The weir structure, completely submerged at the higher stages, should offer very little obstruction to flood flow provided that its upper limit of gauging capacity was restricted to the lower limit of current-meter rating of the channel. Some extra channel protection would be required. One float-operated instrument, recording levels (only) in its upper range and discharge in the low range, would suffice.

Mr J. W. Horner found it rather disconcerting to find the well-known standing-wave flume described as a " long-throated weir," the Venturi flume as a " non-modular long-throated weir," and a recording instrument measuring the flow through a Venturi flume as a " Burkitt's headless meter."

The Author had confirmed that the standing-wave flume provided the most accurate method for measuring streams and rivers with a minimum loss of head, and that with care in design the flume should not be drowned at any rate of flow. It had frequently been found that a flume having a throat of trapezoidal section was the best for providing minimum loss of head at all flows, and quite a number of those were now in use. They were, however, rather expensive to construct, and as an alternative, where the flow could vary very widely, standing-wave flumes of a compound type were being used.

In cases where a standing-wave flume became non-modular (that was to say, a Venturi flume) it was usual to determine the flow by measuring the head in the throat as well as upstream of the flume. Mr Horner had never heard of anyone attempting to determine the flow by taking the second measurement downstream of the flume—which the Author seemed to suggest was the usual practice.

Mr Horner gathered from the Paper that the chief aim of the Author had been to produce a design of weir which would have a coefficient of discharge substantially constant under modular flow conditions, and which could be used satisfactorily for measurement purposes both in the modular and non-modular conditions. The design suggested would appear to fulfil those conditions within limits, but Mr Horner hardly thought that the Author could justify all his claims from the test figures produced.

The rates of flow used in the tests had only a small range, namely, from 0·5769 to 1·510 cusec—rather less than 3 to 1—and yet when referring to the curve in *Fig. 4* the Author had rather lightly asked that the figures obtained from the tests shown in Tables 1 and 2, when the flow represented 38 per cent and 52½ per cent of the maximum flow, should be disregarded. Surely those figures could not be disregarded on the ground that "the scale-effect to be expected with a small model is apparent." The figures actually showed the effect of "frictional" losses which reduced the coefficient of discharge on small flows.

Mr Horner also wondered why the Author had only taken figures from Tables 4 and 5 to determine $(C_H')_M$ as 3·456, and had then claimed that coefficient to be correct subject to a tolerance of 1 per cent. The values of $(C_H')_M$ taken from all the Tables seemed to show a value of 3·307 at 0·5769 cusec rising to 3·67 at 1·510 cusec—an increase of 10 per cent in a range of less than 3 to 1.

On most British rivers the range of flow between maximum and minimum was rarely less than 100 to 1, and usually nearer 1,000 to 1, and if all flows were to be measured the weir had to be of a size suitable for measuring the largest flows. On such a weir the "frictional" effect on small flows would be considerable and a coefficient of discharge which might appear to be constant on large flows would be very far from constant on small flows. The same effect was evident on standing-wave flumes when the coefficient 3·09 on a rectangular flume fell considerably on flows which were only a small percentage of the maximum. It seemed to Mr Horner that the same effect was evident in the figures presented by the Author, even though the range of flow was only 3 to 1.

With regard to the practical aspects of the weir, Mr Horner was of the opinion that the cost of maintenance would be heavy on many rivers.

All designs of weirs and standing-wave flumes should be such that the effect of sand, boulders, leaves, and debris was reduced to the minimum, but even so it was no uncommon thing for large connecting pipes and float wells to be choked with sand and debris, and for boulders and stones to be piled up against a weir. He felt therefore that in the Author's weir the small holes leading to the ducts, and the ducts themselves, would very rapidly become choked with silt or leaves and become ineffective. The Pitot orifice in the piers too would become choked, and debris would cling to the piers themselves. No doubt the Author had given that matter some consideration and would have his remedy.

Mr E. Gresty observed that the Author had attempted to develop a new measuring device by a study of known results and a careful selection of features from various devices not normally associated together. The Paper gave a clear account of the successive steps of the reasoning, though the reader had first to master a terminology which saddled well-known appliances with unfamiliar and unattractive names.

An engineer considering a measuring installation would naturally wish to compare the old and new methods. Table 7 was an attempt to compare the new weir with the "standing-wave flume" for a particular case.

The standing-wave flume gave a very high accuracy of measurement over a wide range of flow, provided that a loss of head of 6 or 7 inches could be maintained.

The new form of weir assumed a value of $(C_H')_M$ which remained constant at all rates of flow, and although the Author had stated that the value was 3·456 within 1 per cent, his justification was not very convincing. In addition, for the non-modular range the rate of flow could only be deduced from the *difference* of two gauge readings.

If, at the maximum rate of flow, the difference between upstream and downstream water level was less than about 6 inches, the standing-wave flume became drowned, and the Crump weir offered the advantage of measurement under otherwise almost impossible conditions. The width of weir had, however, to be increased to pass the required flow; for example, a width of 33 feet would be required for a 3-foot loss of head; that would probably lead to non-modular conditions at comparatively low flows. It also involved expensive constructional work and a large number of the special crest sections.

Measurement Officers would feel indebted to the Author for a new approach to the principle of weir flow, and for justifying the popularity of the standing-wave flume, rather than for the introduction of a new method of measurement for widespread application.

Mr A. B. Tiffen agreed that the triangular weir could be a very useful instrument for gauging the flow of streams, and considered the fact that an accumulation of gravel on the upstream side did not affect the measurement of the discharge to be a valuable property, but he thought that there were points that required consideration.

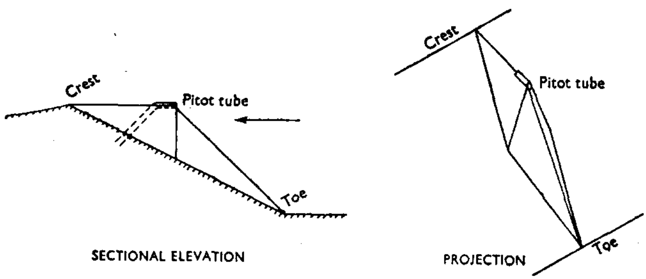
TABLE 7.—COMPARISON OF "STANDING-WAVE FLUME" AND CRUMP WEIR

Maximum rate of flow: 1,000 cusecs. Depth of channel: 10′-0″

	Standing-wave flume. Side contractions	Standing-wave flume. Hump only	Crump weir. (Modular)	Crump weir. (Non-modular)
Height of sill above bed	—	2′ 0″	2′ 6″	28′ 6″
Head above sill	10′ 0″	8′ 0″	7′ 6″	7′ 6″
Width	10′ 0″	14′ 0″	14′ 0″	16′ 6″ / 33′ 0″
Width of channel	about 20′ 0″	14′ 0″	14′ 0″	16′ 6″ / 33′ 0″
Minimum loss of head between upstream and downstream	6% = $7\frac{1}{4}$″	6% = $5\frac{3}{4}$″	30% = 27″	6″ / 3″
Accuracy	Very high providing minimum head loss is available			Assumes constant value of $(C_H')_M$. Also depends on difference between two readings
Flooding	Flooding caused upstream if head loss does not exceed the minimum value stated			
Stream velocity	Can be controlled by suitable design		Height of sill causes low velocity at low flows, probably leading to silting	
Lowest flow measurable	Very small—about 3 cusecs with compound instrument, or 50 cusecs with simple instrument		?	?
Type of instrument	Normal type of flow recorder (single float) giving continuous records in rates of flow. Integration if desired		Independent level recorders. "Spot" values of rate of flow can be obtained by reference to curves or tables	
Cost of construction	Rather more extensive concrete work than for weir, but only one float chamber, and normal standard of workmanship satisfactory		In addition to construction of weir, accurate gun-metal crest pieces required, and these must be laid to correct angle. Two float chambers and centre piers	

The Author had not explained why he considered Pitot-piers more practical than tubes. In many streams it was probable that pieces of cloth, clumps of grass, or other trash would be carried along near the bottom and would wrap round the nose of the piers and interfere with the operation of the Pitot-tubes in the piers; and at low flows floating or partly submerged trash would do likewise. To overcome that, tubes could be used without piers but with sloping fins in front which would tend to cause submerged trash to rise and run past the mouths of the tubes. Such an arrangement was illustrated in *Figs 7*. The edges of the fins would, of course, be rounded.

Figs 7



There was no indication of the minimum head at which the weir would function, and since in many cases it was necessary to measure both minimum and maximum discharges, the value of the weir would be limited unless it could be used to measure the former. It appeared that the minimum head might be about 3 inches.

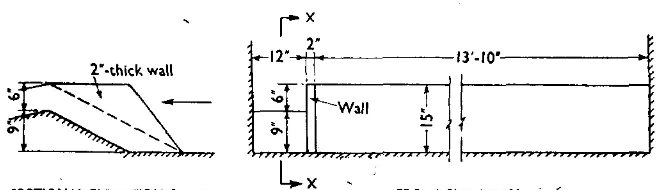
Mr Tiffen considered the problem of an earth channel of 15 feet bottom width which had a maximum flow of about 600 cusecs when running 5 feet deep and a minimum flow of about $\frac{1}{2}$ cusec. A weir 15 feet long with a level crest and with 3 inches head would discharge about $6\frac{1}{2}$ cusecs when modular, and with less head the discharge would be very uncertain, so to solve that difficulty the following method could be used for a practical solution of the problem.

The desirable height of a weir for a depth of water of 5 feet would be 15 inches.

If a 12-inch length at one end of the weir were made 9 inches high, as in *Figs 8*, then with a depth of $3\frac{1}{3}$ inches over the crest of that reduced weir the flow would be about $\frac{1}{2}$ cusec, and low flow could be measured between depths of $3\frac{1}{3}$ inches and 6 inches, corresponding to discharges of $\frac{1}{2}$ and $1\frac{1}{4}$ cusec.

At maximum flow with a 5-foot depth of water, the weir would function much as a 15-inch-high weir right across the full 15-foot width, and the error arising from the dip at one end would probably not exceed 1 per

Figs 8



SECTIONAL ELEVATION ON XX

FRONT ELEVATION

cent. The discharge would thus be within 1 per cent of that indicated by applying readings obtained from the weir 15 inches high by 13 feet 10 inches long to a weir 15 feet long, whether in the modular or in the non-modular range.

Separate recording apparatus would be required for the separate lengths, but that would not increase the cost of the installation unduly, since at low discharge the flow over the weir would be modular and only the " *T* " reading would need to be recorded.

At intermediate flows, particularly with a small head over the crest of the longer length, the discharge would be somewhat indeterminate, but with those flows great accuracy in measurement would not be necessary and a reasonable estimate could easily be made and a discharge curve plotted.

Mr Tiffen did not quite understand the Author's remark about the scale effect at the two lower discharges in the experiments, and would like that matter further elucidated. Since the velocity over the crest would have been considerably higher than 1 foot per second at modular flow in both cases, Mr Tiffen would have expected no modification of the flow pattern.

Dr M. M. Kansoh, of Cairo, observed that the Author had laid stress upon the " complexities and liability to error " of double-gauging. In that case it was necessary to try to improve single-gauge flow meters by:—

(1) Improving the accuracy by basing the functioning of the device on a sound mathematical foundation.
(2) Widening the modular range.
(3) Reducing the head loss in the device, that was to say, the afflux and dissipation in standing waves.
(4) Reducing the cost by using short inexpensive devices.

On p. 227 of the Paper, Q was considered to be a function of the radius of curvature of the underside of the nappe. In fact, Q was a function of the actual pressure at the section under consideration. The pressure was affected by the upward acceleration due to curvature. The acceleration (or more precisely, the effective acceleration) was dependent not only upon the radius of the underside of the nappe, but also upon some other mean effective radius.

It was stated on p. 229 that, since H' and h' involved Q, the latter could only be calculated by means of a tedious trial-and-error procedure. That could easily be avoided and the discharge calculated directly by applying the formula :

$$Q = C \,.\, a\sqrt{2g(H-h)+V^2} = C \,.\, a\sqrt{2g(H-h)\times\frac{1}{1-\left(\dfrac{a}{A}\right)^2}}$$

Dr Kansoh did not see any need, from the point of view of measuring the discharge—especially in the modular range—for the downstream gauge, at which the depth sometimes attained different values for the same discharge and same upstream depth.

A downstream gauge was needed only if it was required to know the submergence or recovery or the total loss in the meter. It was better, therefore, to follow the advice of the Author (p. 232) by constructing a gauge well, especially in the long-throated measuring weirs, at the " control section " at mid-point of the throat, to take the place of the usual downstream gauging station, and thus render the latter unnecessary.

The decision that " in a long-throated measuring weir, the position of the control section is approximately half-way down the throat " was a trifle optimistic. The control section was supposed to be the section where the depth, in the modular range, was critical—that was to say, equal to $\frac{2}{3}H'$ or $\frac{2}{3}T$. Within and beyond the modular range, the value of the depth at the control section was always added to the value of the velocity head at the same section and equated to the total head H' or T. That was equivalent to saying that the depth was equal to the potential head, or to the pressure head plus the position head with the crest level as datum. That was never precisely true except when the flow at the control section was uniform or parallel, with no curvature, convergence, or divergence.

In the hope of finding one definite fixed section fulfilling those two conditions at different rates of flow, Dr Kansoh had experimented on a number of Venturi flumes with throats of different length-to-width ratios and different cross-sectional forms, at different rates of flow, both in the modular and drowned ranges.

As could be observed from the results recorded in *Figs 9* to *14*, no such definite control section could be fixed.

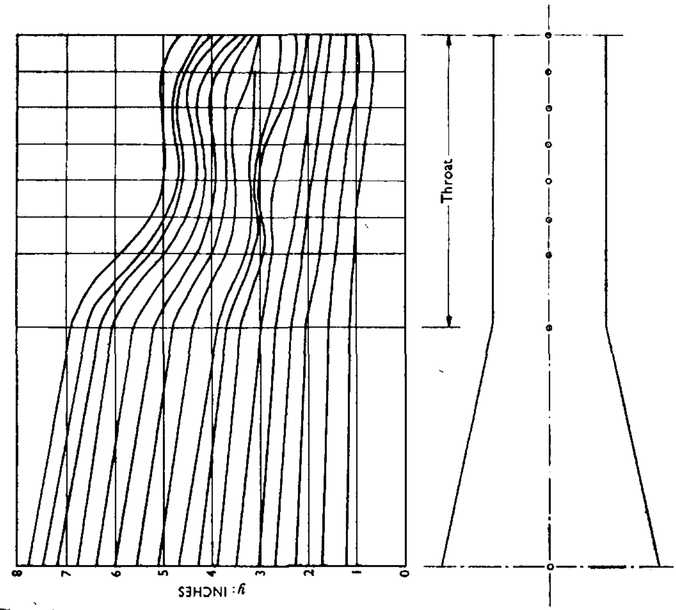
That agreed with Woodburn's [1] and Webb's [2] experiments on weirs of different profiles, as was shown by *Figs 15* and *16*. The small circles denoted what they had believed to be the critical depths.

Those who were especially interested in that point could refer to the work of Bakhmeteff,[3] Rouse,[4] Hinds,[5] and Stevens.[6]

Dr Kansoh also wished to know on what basis, if any, had the Author

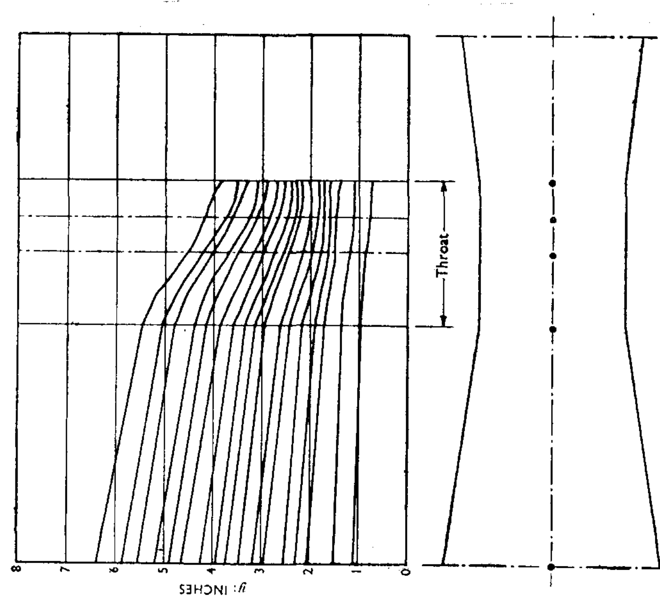
[1] The references are given on p. 767.

Figs 10



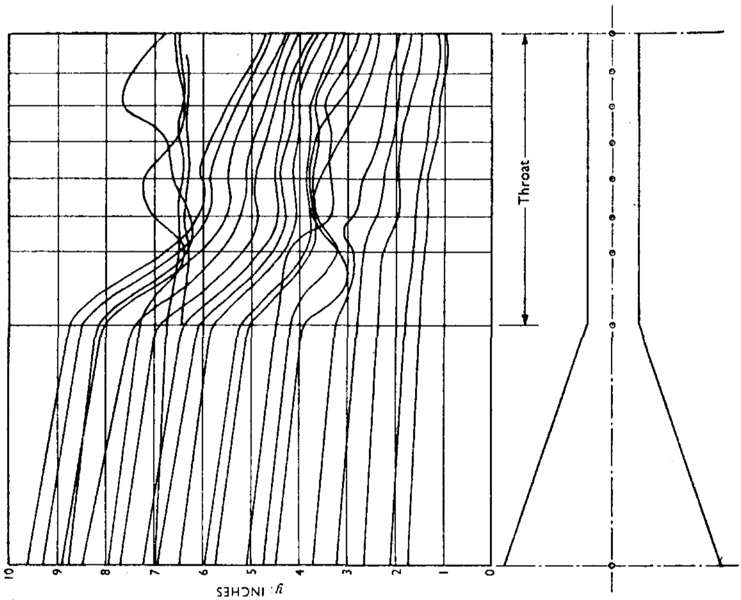
Water Profiles in a Rectangular Throat, 9 inches by 24 inches

Figs 9



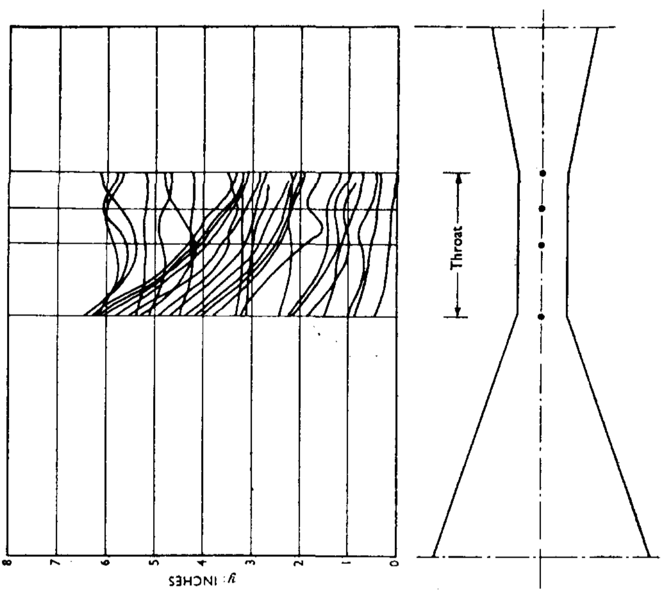
Water Profiles in a Rectangular Throat, 12 inches by 12 inches

Figs 12



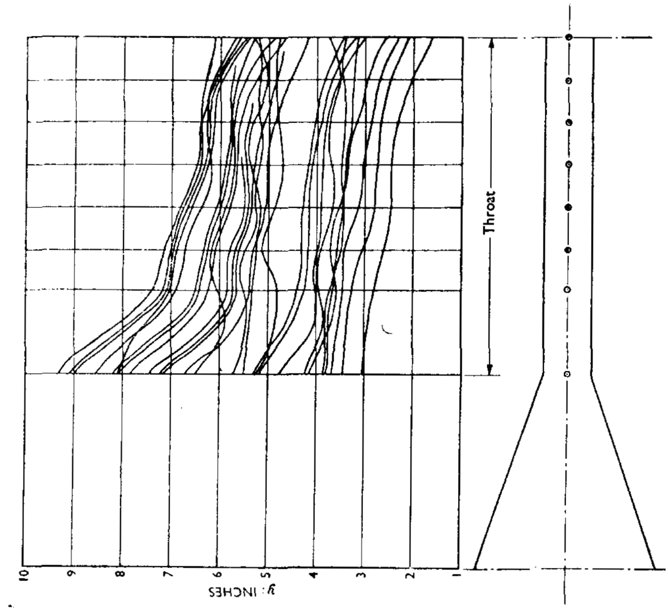
WATER PROFILES IN A RECTANGULAR THROAT, 4·53 INCHES BY 24 INCHES

Figs 11



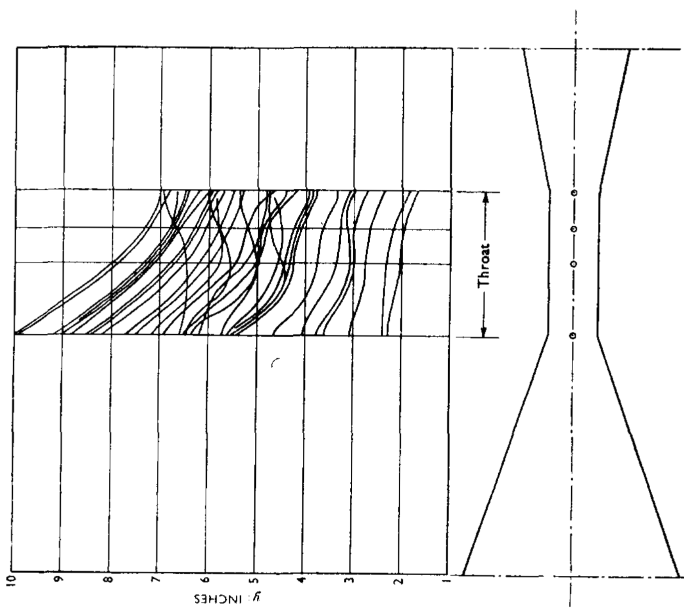
WATER PROFILES IN A RECTANGULAR THROAT, 4·53 INCHES BY 12 INCHES

Figs 14



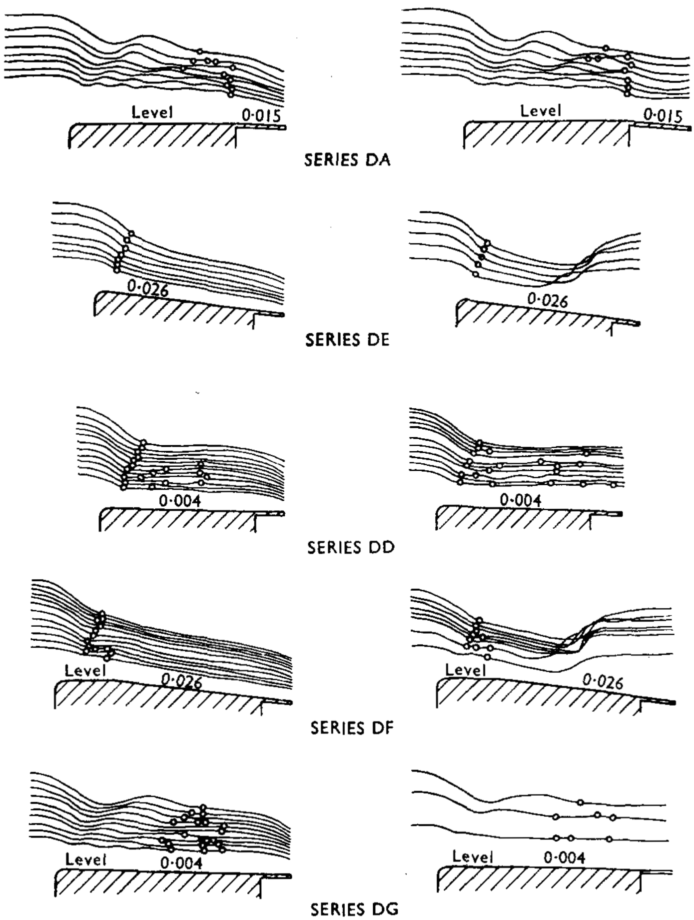
WATER PROFILES IN A PARABOLIC THROAT ($f = 0{\cdot}15$ INCH; $L = 28$ INCHES)

Figs 13



WATER PROFILES IN A PARABOLIC THROAT ($f = 0{\cdot}15$ INCH; $L = 12$ INCHES) chosen the position of the downstream gauge, or control section. Furthermore, in view of Woodburn's and Webb's experiments, why had the Author selected the particular upstream and downstream slopes of his triangular weir? Was it certain that there would always be a low-pressure

Figs 15

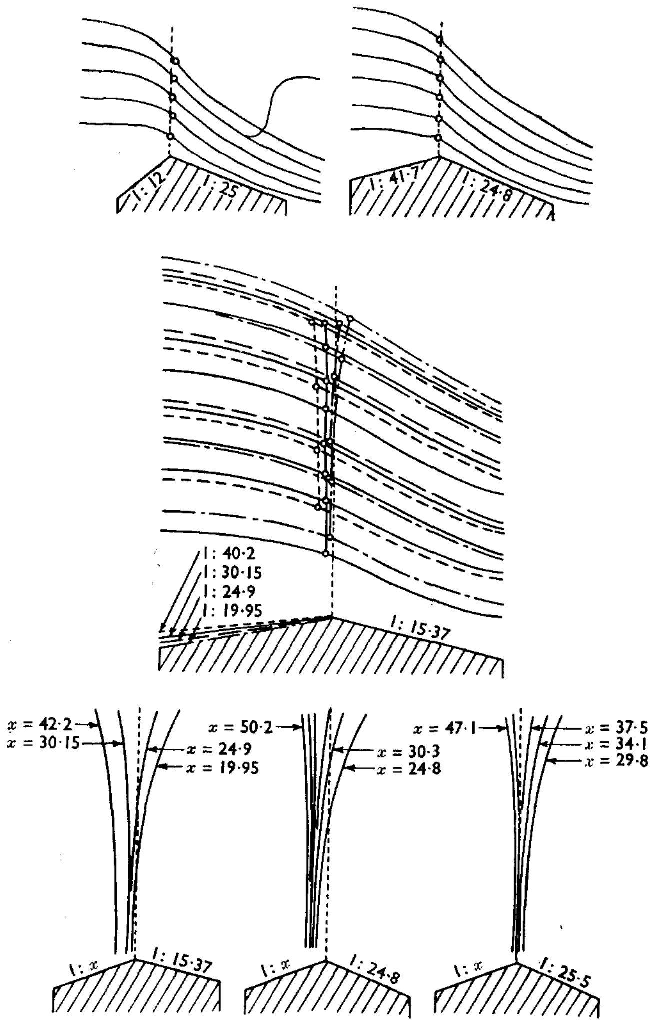


WOODBURN'S EXPERIMENTS ON BROAD-CRESTED WEIRS

pocket of eddying water with its highest point at the same position or control section, even at low rates of flow?

In carrying out the experiments, four manometers having their zero at crest level had been used in recording the values of h, P, T, and H.

Figs 16



CRITICAL DEPTH LOCI (WEBB'S EXPERIMENTS)

The technique employed by some investigators for determining the zero of the manometers had been to empty the channel until the water surface was apparently at crest level of the weir, ignoring surface tension of the water. Dr Kansoh hoped that the Author had taken that into consideration and had used some instrument similar to that used for determining the zero of a notch.

The Author had provided in each of two piers a single Pitot orifice which "should be at crest level." For what reason was a single orifice to be made at crest level in both piers ? Was such an orifice going to give a representation of the average or mean value of H' under all conditions ?

In Dr Kansoh's opinion, such an orifice should be placed opposite the locality of the average or mean velocity of the stream—for example, at a certain depth below the water surface down to the centre line of the channel ; or alternatively, a series of orifices should be used.

Therefore, it was not to be expected that the corresponding values of T and H' in the Author's experiments would agree with one another. Excluding the value $H' = 2{\cdot}667$ of the sixth run in Table 1 (which was due to a printer's error), it was to be observed that the values of H' were greater than the corresponding values of T in the first four Tables (pp. 235 to 237), except in the third and fourth runs of Table 1, the runs Nos 25, 26, and 27 of Table 3, and the first run of Table 4, while the values of H' were less than the corresponding values of T in Table 5, with the exception of runs Nos 7 and 8, and in Table 6, except in the sixth run.

It was true that the difference between H' and T was small, but it was equally true that in not one of the 81 experiments did H' have the same value as T. It seemed that, after all, the proposed weir was but another of the double-gauge methods with most of the "complexities and liability to error."

The Author, in reply, observed that Messrs Lacey, Horner, and Tiffen had criticized his disregard of the results obtained with the two lower discharges of Tables 1 and 2. Comparing results obtained in the modular range with the proposed standard values of 3·580 for C_T and 3·456 for $C_{H'}$ Tables 1, 2, and 3 gave the results shown in Table 8.

TABLE 8

Table	Q	T: inches	C_T	Difference: per cent	H'	$C_{H'}$	Difference: per cent	No. of observation
1	0·577	2·644	3·347	−6·5	2·665	3·307	−4·3	(1)
2	0·793	3·238	3·433	−4·1	3·276	3·335	−3·5	(1)
3	1·172	4·077	3·551	−0·8	4·111	3·507	+1·4	(6)

The Author had assumed that practical engineers would seldom be interested in values of T or H' less than 4 inches, and had considered that the results obtained for the three higher discharges justified the simplification of adopting for general use the constant value for C_T proposed by him. In cases where discharges fell to give T a value less than 4 inches and where it was important that those low discharges should be accurately measured, the necessity for adopting smaller-than-standard values for C_T or $C_{H'}$ was manifest.

Under modular conditions in the Author's tests, T had not exceeded a value of 0·4 foot, and a more important question arose as to what extent the Author's standard coefficients would hold good in cases where T might be as much as 10 feet, or even more. In that connexion the Author would invite attention to results obtained in 1899 at the Cornell University hydraulic laboratory on a very large model, the profile of which differed only very slightly from that used by the Author. The faces of the Cornell model (Series 9) had the same slopes as the Author's model, but the crest instead of being sharp had a relatively narrow flat 0·33 foot wide; the height F above bed was 4·94 feet and the highest value of H' was more than 5 feet. Values of the coefficient as recomputed by Robert E. Horton[7] were directly comparable with the Author's $C_{H'}$. Horton's values (after correcting an arithmetical error in No. 3) were as shown in Table 9, and indicated that the error arising from using the proposed standard values of C_T and $C_{H'}$ for large weirs would not be excessive.

TABLE 9

No.	H': feet	$C_{H'}$	Percentage in excess of 3·456
1	5·0992	3·575	+3·3
2	4·2116	3·525	+2·0
3	3·3747	3·465	+0·3
4	2·5573	3·482	+0·8
5	1·6950	3·557	+2·9
	Average	3·521	+1·9

In *Fig. 6* Mr Lacey had presented an interesting analysis of the nature of the standard curve of *Fig. 4*. For $P/T = 0{\cdot}90$, equations (10) and (11) gave C_T the same value. Compared with the tabular values of *Fig. 4*, salient discrepancies were given in Table 10.

In high floods with P/T approaching unity, the effective jet after crest-contraction would flow in a surface-stream without curvature. In those circumstances the velocity at the *vena contracta* would be $\sqrt{2g(T-P)}$ and equation (10), which gave the discharge intensity as:

$$q = C_T \, . \, T^{\frac{3}{2}} = 6{\cdot}85\,\sqrt{(T-P)}T = (0{\cdot}854T)\,\sqrt{2g(T-P)}$$

indicated a contraction of the jet to a depth of 85·4 per cent of T.

In reply to Mr Wileman, the Author had had no experience of British rivers, but on Punjab canals, where measuring weirs were usually attended and recorded daily, he had frequently used Pitot-piers without experiencing the troubles envisaged by Mr Wileman. On British rivers, the Author considered that it would be safe to use Pitot-piers at sites where debris could be cleared by a daily attendant. Pending experience so gained,

TABLE 10

P/T	C_T Tabular	C_T Calculated	Difference: per cent	Equation No.
0·26	3·580	3·571	−0·2	(11)
0·37	3·458	3·430	−0·8	
0·47	3·300	3·285	−0·4	
0·75	2·776	2·722	−1·9	
0·90	2·124	2·165	+1·9	
0·90	2·124	2·166	+2·0	(10)
0·91	2·052	2·055	+0·1	
0·92	1·960	1·937	−1·2	
0·97	1·156	1·186	+2·6	

general adoption of Pitot-piers appeared inadvisable. Regarding the piezometer holes, the Author considered that, while there would be little risk of them failing to operate by collecting leaves or submerged vegetation, gradual choking of the duct by small solid particles was inevitable, so that occasional flushing of the duct by pouring water into the float-chamber would be necessary. For this to be effective, provision would have to be made for a removable watertight plug of adequate diameter screwed into the metal of the duct and flush with its surface.

Whilst it was possible to devise a mechanism which, actuated by the two floats, would directly record the discharge, that would be costly and liable to unavoidable error owing to friction and backlash. For that reason the Author had contemplated the use of two separate instruments of the usual simpler type for recording P and T respectively, leaving it to the engineer to calculate the discharge by means of the Tables in *Fig. 4*.

As Mr Wileman had suggested, by raising the level of its crest a weir having the standard profile of the Author's model could be rendered modular up to any stage of discharge that the designer chose. A single recorder would then give the discharge over the modular range of operation, leaving the engineer to assess by current meter the discharge value of readings recorded in the non-modular range of operation. For accurate measurement of low discharges, Mr Wileman had also suggested a depressed weir of suitable width flanked by submersible side-walls. Those side-walls would have to be carried, with some rounding, into the concrete-covered side-slopes of the main channel; they would thus form the crests of the two side-weirs which might be designed to spill on to a concrete floor at channel-bed level.

In reply to Mr Horner, the Author had used the term " long-throated " to emphasize the need for a long prismatic throat required to obtain a high modular limit, and to include throats of any cross-section.

Provided the throat were long the second reading would, as Mr Horner had stated, always be taken in the throat. If, however, there were no throat—for example, in the case of a sharp-edged weir—the only alternative would be to take the second reading in the tail-water, which the Author had suggested as being the usual practice.

Mr Horner's next point had already been dealt with.

In presenting *Fig. 3* and selecting Tables 4 and 5 for the purpose, the Author's object had been to ascertain the modular range of his model and the effect on the coefficient $C_{H'}$ of a raised bed. His intention had been, not to claim constancy of the modular coefficient for different discharges, but to verify its constancy—within 1 per cent up to 80 per cent submergence—as indicated by the last seven results of Table 4.

For very small flows, with T less than about 4 inches, the Author realized the necessity of adopting a modular coefficient smaller than the standard value.

He had recognized the need for occasional flushing to remove silt from the piezometer ducts. The same precaution applied to the Pitot-duct, and for that he suggested placing a removable flushing-plug in the nose of the pier a few inches above the Pitot-hole.

In compiling Table 7 Mr Cresty had credited standing-wave flumes with a modular limit of 94 per cent, and a Crump weir with only 70 per cent. The Author claimed that his *Fig. 3* fully justified raising the latter limit to 80 per cent—thereby reducing the minimum working-head from 27 to 18 inches. For a standing-wave flume he considered that a limit of 94 per cent would call for an extremely elaborate and costly design and could only be adopted with safety if the outfall channel were stable and its stage-discharge relationship known with precision. For a normally good design, a limit of 90 per cent would be a more reasonable figure, and even that figure would require slow divergence in bed and sides to ensure recovery of pressure-head. A modular limit of 90 per cent gave a working head of 12 inches for the 10-foot flume, and of 9½ inches for the 14-foot flume. The Author would never dream of putting a 33-foot weir into a 20-foot channel and would be quite content with the 16½-foot alternative of Table 7. At maximum discharge that would operate with a working-head considerably smaller than could be safely allowed for either of the two flumes and, being very much shorter in axial length, would certainly require much less concrete work.

Replying to Dr Kansoh the Author observed that single-gauging required the meter to be modular and that, in that case, suggestions (2) (widening the modular range) and (3) (reducing the limiting modular afflux) had the same meaning. The Author was of the opinion that the standing-wave flume or weir was a device upon which it would be difficult to improve in regard to features (1), (2), and (3). For that device to have a high modular range, of 90 per cent or more, the Author considered that a long throat was essential and that suggestion (4) (reduction of cost by shortening the throat) could only be attained at the price of a reduced modular range. In other words : improvements (4) and (2)–(3) suggested by Dr Kansoh were mutually incompatible.

On p. 227 of the Paper, equation (1) expressed the fact that Q depended upon both pressure and curvature. For the hypothetical variation dQ of equation (2), if r was constant p was variable, and vice versa. The Author was at a loss to understand what Dr Kansoh meant by " some other mean effective radius."

The Author was also unable to grasp the significance of the expression for Q given by Dr Kansoh.

In *Figs 9* to *14* the position judged to be the control-section had not been indicated. In *Figs 15*, only the weir of Series DA had a long crest, and in that weir the sharp upstream corner would cause " separation," giving a coefficient less than the 3·09 of a gently curved approach. All the weirs of *Figs 16* were angular and would behave like the Author's model, where the true control section was not at the crest, but downstream of it, so that conditions of flow were complicated by curvature and contraction of the effective jet.

The Author had assumed that the pressure of the eddy, as measured by his P-gauge, would be much the same at different points in the eddy, and that assumption appeared to be confirmed by the fact that modular values of P/T were sensibly the same for different values of T. He had chosen the two slopes with the dual object of obtaining a low value of the modular ratio P/T and of attaining a moderately wide modular range.

Dr Kansoh could rest assured that due care was taken to ensure correct " zero readings " on the four manometers.

The Author had deemed it advisable to use a single Pitot orifice in a standard position that could be reproduced in prototypes. To cover low discharges the orifice had to be no higher than the crest. In that position the value of T recorded was admittedly less than the average kinetic head of all filaments and therefore less than H', except in the case of Table 5 where the raised bed had a larger effect on T than on H'.

References

1. J. G. Woodburn, " Tests on Broad-Crested Weirs." Trans. Amer. Soc. Civ. Engrs, vol. 96 (1932), p. 387.
2. See ref. 1. Appendix by A. R. Webb, " Supplemental Tests—Weirs with aprons inclined up stream and down stream," (p. 408).
3. See ref. 1. *Discussion* by B. A. Bakhmeteff, p. 423.
4. H. K. Palmer, " Adaptation of Venturi Flumes to Flow Measurements in Conduits." Trans. Amer. Soc. Civ. Engrs, vol. 101 (1936), p. 1195. *Discussion* by Hunter Rouse, p. 1218.
5. R. L. Parshall, " The Improved Venturi Flume." Trans. Amer. Soc. Civ. Engrs, vol. 89 (1926), p. 841. *Discussion* by J. Hinds, p. 859.
6. See ref. 5. *Discussion* by J. C. Stevens, p. 872.
7. " Weir Experiments, Coefficients and Formulas." Paper No. 200, Dept of the Interior, U.S. Geological Survey. Washington Govt Printing Office, 1907.