DISCUSSION

TECHNICAL NOTE 52

The rounding of the upstream edge of a broad-crested weir

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The Authors clearly demonstrate that the degree of curvature of the upstream edge of a broad-crested weir will markedly influence the accuracy of discharge measurement by this device. That weir roughness is an additional factor is also made clear, so much so that measurement errors in excess of 10% could be incurred without knowledge of the Authors' findings. However, even with this knowledge it seems possible that a not insignificant inaccuracy could in time occur for initially sharp-edged ($R<P/20$) and smooth, well calibrated structures. Although this type of weir is currently one of the less well favoured devices, is it not also possible that, to a lesser degree at least, other types may also in time experience some loss of efficiency for similar reasons? Seen from a water abstraction viewpoint, the economic implications of this might not be trivial.

11. The Authors extend their studies of rounding to the limit when the radius equals the weir height. Presumably, normal designs fall well below this limit, and often in the region $R<P/8$? Fig. 2 might give the impression that the great majority of structures operate in the constant C region, away from the troublesome region below $R=P/8$.

12. The significant effect of small upstream curvature is also observed in the flow about isolated bluff cylinders, both the drag coefficient and the Strouhal number for vortex shedding rate change by proportions resembling those noted by the Authors for similar ratios of R/P[5].

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Notation

- B width of weir across flow
- C_d dimensionless discharge coefficient
- h upstream head over weir crest
- h/p ratio describing flow geometry
- q unit discharge
- Q discharge
- V velocity of flow
- y depth of flow over the weir crest
- α, β kinetic energy correction factors

14. The experimental investigation into the effect of rounding the upstream edge of a broad-crested weir on the discharge coefficient is a welcome addition to this topic. However, the presentation of the results in a dimensionless form as done by Hay and Markland[6] and Kandaswamy and Rouse[7,8] for sharp-edged weirs, and by Tracy[9] for broad-crested weirs, would have made it easier to appreciate the influence of edge-rounding alone on the coefficient of discharge as distinct from the influence of other variables, e.g. weir geometry and absolute size of the weir, roughness of the weir surface, rounding of the upstream edge of the weir crest, fluid properties and the pattern of velocity upstream of the weir. Differences of the order of more than 10–15% in the discharge coefficient may result from changes in the velocity distribution upstream of the weir. As so many factors influence weir flow all data obtained on

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weirs should be presented on a uniform and comparable basis. This has also been stressed by Engel and Stainsby.[10–14]

15. Experiments have been done on a broad-crested weir with square edge in reference 15. The size of the weir and the channel used are shown in Table 2, which also includes the sizes of weir models tested by Woodburn[1], Bazin,[16–18] Doeringsfield and Barker,[19] and the Authors' present experiments. The values of the coefficient of discharge C_d as defined by equation (1) have been computed and plotted as a function of the ratio h/p in Fig. 3.

$$Q = \tfrac{2}{3}C_d\sqrt{2g}Bh^{3/2} \qquad (1)$$

16. On the basis of the assumption of parallel flow at critical depth over the broad-crested weir the theoretical expression for discharge is usually given by

$$Q = \frac{2}{3\sqrt{3}}\sqrt{2g}\,B\left(h+\frac{V^2}{2g}\right)^{\frac{3}{2}} \qquad (2)$$

Table 2. Various tests done on weirs

	1. Bazin	2. Woodburn	3. Doeringsfield and Barker	4. Wakhlu	5. Francis and Salih
Year	1886	1930	1939	1963	1971
Variable L	6·56 ft	10 ft	1·12 ft 2·25 ft	1·0 ft	60 cm
P	2·46 ft	1·75 ft	0·262 ft 0·471 ft 0·53 ft	2 in.	10 cm
B	6·55 ft	2·00 ft	?	8 in.	10 cm
h, max. value	1·50 ft	1·50 ft	0·60 ft	3·28 in.	14 cm
L/p	2·67	6·0	4·25	6·0	6·0
h/p, max.	0·60	0·85	0·23	1·64	1·40
h/L, max.	0·225	0·150	0·535	0·277	0·233
Edge shapes	Square Rounded, $R=0·033$ ft	Square Rounded	Square	Square	Square Rounded, $R=0·5$–10 cm
Material of model	Concrete	Timber	Brass plate	Timber	Perspex sheet
Velocity profile				$\alpha\simeq 1·0$ $\beta\simeq 1·0$	
Model scale	Prototype				
L P B	1:1 1:1 1:1	1·5:1 0·72:1 0·305:1	0·17:1	0·15:1 0·068:1 0·102:1	0·30:1 0·136:1 0·051:1

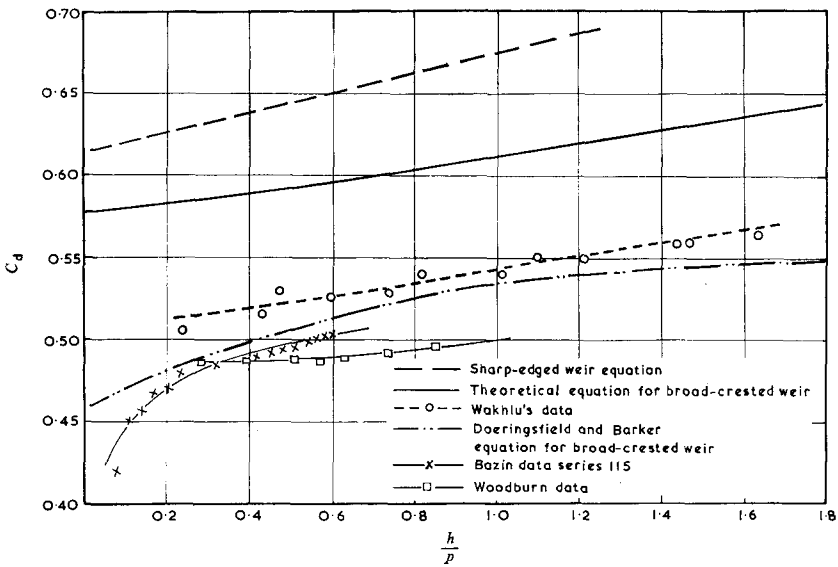

Fig. 3. Discharge coefficient of broad-crested weir

17. Comparing equations (1) and (2) the theoretical value of C_d would be given by the expression

$$C_{\mathrm{d}} = \frac{1}{\sqrt{3}}\left[1+\frac{4}{9}\left\{\frac{h/p}{(1+h/p)}\right\}^2 C_{\mathrm{d}}{}^2\right]^{\frac{3}{2}} \quad . \quad . \quad . \quad . \quad (3)$$

18. This equation has been plotted in Fig. 3 with the results obtained in various experimental studies. It would be interesting to plot the Authors' results with the rounded upstream edges similarly to appreciate better the influence of the edge-rounding. Doeringsfield and Barker[19] have obtained an expression for the discharge coefficient which reduces to the form

$$C_{\mathrm{d}} = 0{\cdot}65\left\{h+\frac{p}{h}+2p\right\}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

assuming the ratio of the head upstream of the weir to the depth of flow at mid-section of the crest is equal to 2·00. The results in reference 15 are different from this equation because the value of the ratio h/y is less than 2·0, proposed by Doeringsfeld and Barker for the equation in reference 19.

19. *Actually h/y is a function dependent on the ratios h/p and L/p.* In reference 15 the values obtained for the weir with $L/p=6{\cdot}0$ are shown in Table 3. It would be

Table 3. Values obtained for weir with $L/p=6{\cdot}0$ for same tests as in Table 2

Test	1	2	3	4	5
h/p	0·43	0·74	1·21	1·44	1·64
h/y	1·295	1·79	1·812	1·77	1·53

worthwhile to examine this aspect of the flow pattern in the case of the broad-crested weirs with rounded edges reported by the Authors.

20. Tracy[9] reported a constant value of discharge coefficient for the range $0<h/L<0{\cdot}40$. In reference 15 the value of h/L is less than 0·30 but C_d varies with h/p as shown in Fig. 3. The constant coefficient reported by Tracy[9] as well as by the Authors is computed on the basis of total head, a procedure which often obscures the true nature of the discharge coefficient. The Authors also remarked on this in §§ 3 and 7 and perhaps their experimental results might be analysed afresh in the light of the above remarks.

21. The Authors have compared their results obtained with rounded crests with those obtained by Woodburn.[1] Although there is some consistency of ratios in the two tests, it would be observed from Table 2 that the maximum value of h/L in Woodburn's tests is about half of that in the Authors' tests. This needs further examination. As the Authors' model and the model of reference 15 are comparable with regard to absolute size and dynamic similarity, it might be better to compare the results of the rounded-edge experiments with those of the writer.

22. In Fig. 3 the plot of the equation for the rectangular sharp-edged weir is also shown. Equation (5) has been proposed by Hay and Markland.[6]

$$C_d = \left(0{\cdot}615 + 0{\cdot}06\frac{h}{p}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

23. A coherent study of all shapes of weirs is surely possible now and should always be attempted.

Mr Salih and Professor Francis

The Authors agree with **Dr Shaw** that the roughness of the weir surface may make as much difference on C as that of the edge rounding. However, it is common to find weirs made with high quality, well-finished concrete or masonry which covered with slime and so on does not change its roughness much with time.

25. **Dr Wakhlu** comments on the way in which the Authors did not plot their results by using the ratio $h/(h+P)$. The omission is deliberate; although it is generally agreed that this ratio is appropriate for correlating results of sharp-edged weirs, it is by no means so obvious that it is appropriate for round edges. In the former case the size of the separation zone is likely to depend on $h/(h+P)$ and so control the development downstream of a boundary layer. In the latter case the beginning of the boundary layer is fixed by the geometry of the rounding which $h/(h+P)$ is unlikely to affect. Recent work by Wilson[20] is appropriate in this respect. When comparing the results of sharp-edged, insufficiently rounded, and fully rounded weirs, the Authors consider that $h/(h+P)$ is not appropriate over the whole range of experiment.

26. The Authors also point out that Dr Wakhlu's tests in Table 3, which apparently use y as a parameter, fall into a number of regions where C changes very differently. Test 1 is in the region* where C is nearly constant; and test 5 is where C commences to rise again by the effect of $h/(h+P)$. These regions are not necessarily the same as those for a rounded-edge weir, and should not be used for comparison.

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* Where the water surface over the weir is wavy so that the y measurement is unreliable; tests 2, 3 and 4 are in the region.

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Conversion factor

Imperial units	*SI units*
1 ft	0·3048 m