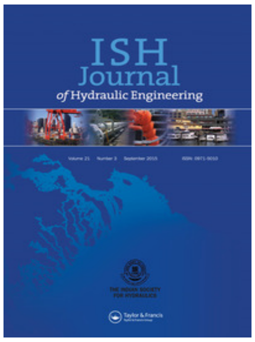

ISH Journal of Hydraulic Engineering

ISSN: 0971-5010 (Print) 2164-3040 (Online) Journal homepage: http://www.tandfonline.com/loi/tish20

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ISH Journal of Hydraulic Engineering, 2015
Vol. 21, No. 3, 287–289, http://dx.doi.org/10.1080/09715010.2015.1017748

Discussion of "Multivarible regression models for prediction of discharge and approach velocity coefficients in flow measurement flumes with compound cross-section" by Issam Al-Khatib and Khaled A. Abaza (2015)

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(*Received 24 December 2014; accepted 3 February 2015*)

This paper is about the discussion of "Multivarible regression models for prediction of discharge and approach velocity coefficients in flow measurement flumes with compound cross-section"; I. Al-Khatib & K.A. Abaza (ISH Journal of Hydraulic Engineering, 19th Jan 2015, vol. 21, no. 1, pp. 65–84).

Weirs, notches, and flumes are used for flow measurement in open channels. Parshall-type (1950) and Cut-throat-type (Skogerboe and Hyatt 1967) flumes are very popular devices for measurement of discharge in irrigation canals. In uncontracted weirs, the flow is choked by raising the bed vertically by an amount (Δ), whereas in case of flumes, the channel is contracted laterally from B_1 to B (Figure 1) such that a control section develops and flow is critical at the control section. In the first case (uncontracted weirs and notches), flow is choked when the available specific energy at the control section ($E_1 - \Delta$) is minimum (i.e. $E_{\min} = E_c$) for a given flow (Q) and the depth (y_c) at the control section is critical. In the second case (flumes), studied by the authors in this paper, flow intensity ($q = Q/B$) at the control section becomes maximum for a given specific energy (E_1) and the flow is choked resulting in critical flow depth (y_c) at the control section.

For a given flow (Q), if the height of obstruction (Δ) is more than the critical height (Δ_{cr}) at just choked condition, the flow is completely choked resulting in high afflux. Similarly, if the width (B) at the flumed section is less than that at just choked condition (B_{cr}), flow will be completely choked resulting in high afflux. Critical heights (Δ_{cr}) of weirs/notches are to be fixed for the maximum discharge ($Q_{\max}$) so that it will continue to develop critical flow at the minimum discharge ($Q_{\min}$) also. On the contrary, the critical width at throat (B_{cr}) of flumes is to be fixed for $Q_{\min}$ so that it will develop critical flow at $Q_{\max}$ also. Here, $Q_{\max}$ and $Q_{\min}$ are the working range of flow for which the flow meter is to be designed with free flow condition.

There is yet another kind of critical flow meter (also called standing wave flume), where critical flow can be developed at the control section by simultaneously raising the bed and contracting the channel laterally as shown in Figure 1. In this type of flow meter, the optimum width of throat ($B > B_{cr}$) and corresponding crest height ($\Delta < \Delta_{cr}$) of the flow meter can be determined theoretically (Mazumder and Roy 1999) such that the flow is just choked with critical depth at the control section. Depth–discharge relation can be maintained upstream of such flow meter with negligible afflux within the given flow range for which the flow meter works as modular one. Equation (1) gives the optimum width at throat (B) and Equation (2) gives the corresponding optimum crest height (Δ) for maintaining critical flow for all discharges within the range $Q_{\max}$ and $Q_{\min}$ passing through the channel for which the flow meter will be just choked and act as a modular one within the design flow range.

$$B = \left[0.7\left(Q_{\max}^2 - Q_{\min}^2\right)/\left(E_{1\max} - E_{1\min}\right)\right]^{3/2} \tag{1}$$

$$\Delta = E_{1\max} - 3/2\left[\left(Q_{\max}/B_0\right)^2/g\right]^{1/3} \tag{2}$$

where $Q_{\max}$ and $Q_{\min}$ are the maximum and minimum flow through the canal; $E_{1\max}$ and $E_{1\min}$ are the corresponding maximum and minimum specific energy of approach flow with depths $Y_{1\max}$ and $Y_{1\min}$, respectively, and given by Equation (3) below.

$$E_{1\max} = Y_{1\max} + V_{1\max}^2/2g \text{ and } E_{1\min} = Y_{1\min} + V_{1\min}^2/2g \tag{3}$$

Here, $Y_{1\max}$ and $Y_{1\min}$ are the normal flow depths and $V_{1\max}$ and $V_{1\min}$ are the mean velocities of flow in the channel upstream of the meter corresponding to $Q_{\max}$ and $Q_{\min}$, respectively. The various symbols used in the equations, the flumed section, the inlet and outlet transition structures, etc. are illustrated in Figure 1.

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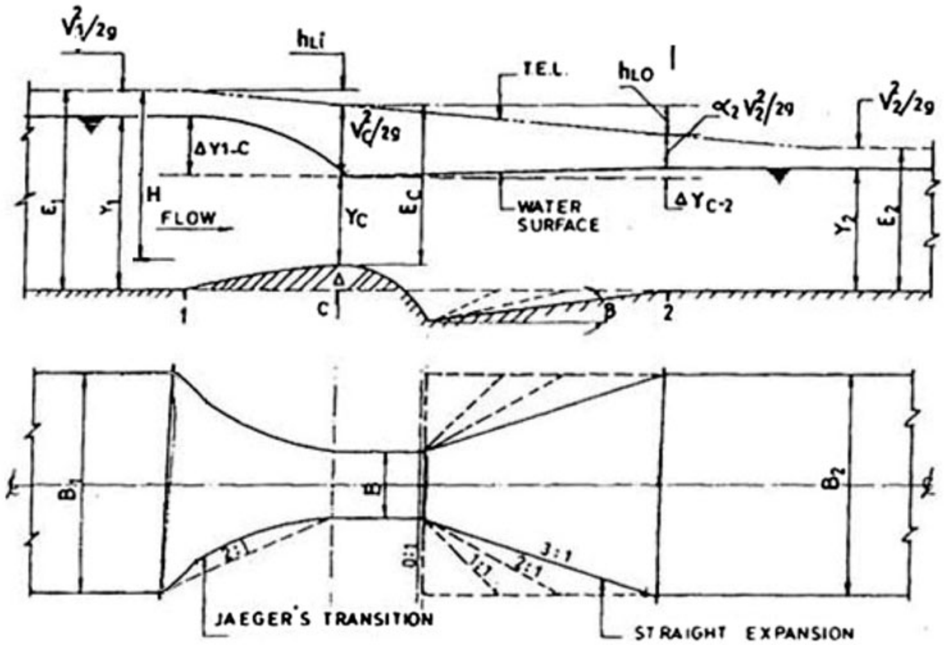

Figure 1. Plan and section of critical flow meter developed by Mazumder & Roy (1999).

Unlike authors' compound section at the control section, most of the flow meters including the one developed by the discusser (Figure 1) have a rectangular cross-section for ease in computing flow. The discharge equation can be expressed in a simple form as:

$$Q = C_d \cdot B \cdot H^{3/2} \tag{4}$$

where Q is discharge in cumec, C_d is the coefficient of discharge in $m^{1/2}/s$, B is the width of the flume in m at the control section, and $H(=H_1)$ is the energy head in m above crest i.e. the difference between upstream energy level and crest level as shown in Figure 1. Assuming no loss in energy between the upstream gauging section and the control section (i.e. $h_{Li} = 0$ in Figure 1), it can be proved that $C_d = 1.705\ m^{1/2}/s$ for free flow. The total energy head above crest i.e.

$$H = H_1 = h_1 + \alpha_1 V_1^2/2g$$

Equation (5) used by the authors for flow measurement in a compound section reduces to expression similar to Equation (4). With $g = 9.8\ m^2/s$ and $Z = 0$, Equation (1) in the paper reduces to:

$$Q = 1.705\, C_d \cdot C_v \cdot B_0 h_1^{3/2}\ \mathrm{m}^3/\mathrm{s} \quad \text{(as per Figure 1 of of the paper)} \tag{5}$$

When $h_1 < Z$ and $y_c < Z$ i.e. as in case-1 of the paper, Equation (5) of the authors can be expressed as

$$Q = 1.705\, C_d \cdot C_v \cdot b h_1^{3/2}\ \mathrm{m}^3/\mathrm{s} \tag{6}$$

h_1 values in Equations (5) and (6) above are the water head above crest corresponding to energy head

$$H_1 = h_1 + \alpha_1 V_1^2/2g \tag{7}$$

where V_1 is the approaching mean flow velocity and α_1 is Corrioli's coefficient or kinetic energy correction factor given by the expression:

$$\alpha_1 = \left(1/A_1 V_1^3\right)\left(\int u^3 dA\right) \tag{8}$$

In Equation (8), u is the velocity through an elementary area dA and A_1 is the cross-sectional area of approach flow. α_1-value for prismatic channel usually varies from 1.10 to1.50 (Chow 1959). In non-uniform and distorted flow, however,

Table 1. Performance of proportional flow meter with adversely sloping expansion floor.

Expt. no. (1)	Q (LPS) (2)	Side splay expn. (3)	β^0 (4)	C_d (Equation (4)) ($m^{1/2}/s$) (5)	Modular limit (Scr) (6)	% η_I (7)	% η_o (8)	α_2 (9)	Remarks (10)
1	20	1:1	16.6	1.67	0.92	87	90	1.30	Two symmetric small eddies confined within floor, uniform flow in tail channel
2	10	1:1	16.6	1.69	0.92	89	91	–	-Do-
3	5	1:1	16.6	1.69	0.92	93	99	–	-Do-
4	20	2:1	8.48	1.70	0.96	88	91	1.23	No separation and eddies, uniform flow in tail channel
5	10	2:1	8.48	1.70	0.96	92	93	–	-Do-
6	5	2:1	8.48	1.73	0.96	98	99	–	-Do-
7	20	3:1	5.67	1.67	0.98	90	93	1.17	-Do-
8	10	3:1	5.67	1.69	0.98	95	94	–	-Do-
9	5	3:1	5.67	1.73	0.98	99	99	–	-Do-

1. Modular limit is given by y_2/y_1 where y_2 is d/s depth of flow up to which flow is free.
2. Inlet transition efficiency, $\eta_I = 1/1 + C_i$ where $C_i = h_{Li}/(\alpha_c V_c^2/2g - \alpha_1 V_1^2/2g)$.
3. Outlet transition efficiency, $\eta_o = 1 - C_o$ where $C_o = h_{Lo}/(\alpha_c V_c^2/2g - \alpha_2 V_2^2/2g)$.

α_1-value may be very high (Mazumder 1971). Authors have not measured any velocity distribution in the approach compound section, but assumed a value of $\alpha_1 = 1.04$ in Equation (8) in their paper. C_d and C_v used by the authors in their Equations (1) and (5) are dimensionless. Whereas, C_d takes care of loss in energy between the approach and control section, and velocity head ($\alpha_1 V_1^2/2g$) is considered using C_v. Discharge equations are expressed in terms of water head, h_1 which is measured at the gauging point. Figures 9 and 16 in the paper show the variations of C_d with h_1/L_{thr} and y_f/h_1, respectively, for the nine models listed in Table 1 in the paper. Parameter C_d is found to vary from 0.86 to 1.06. Similarly, C_v-values, plotted in Figure 24 (of the paper) against y_f, are found to vary from 1.15 to 1.70 in the different models.

Except B_3Z_3 model, all other models belong to case-2 in the paper. In B_3Z_3 model, $C_d = 0.97$ (Figure 15 in the paper) and $C_v = 1.3$ (Figure 22 in the paper) corresponding to the geometry given in Table 1 in the paper. With authors' Equation (1) which can be also expressed as

$$Q = C_d \cdot C_v \cdot 1.705\, b h_1^{3/2} = 6.3 \times 10^{-3} \mathrm{m}^3/\mathrm{s}$$

The above predicted discharge could not be verified with actual observed discharge since the actual discharge measured by the authors in B_3Z_3 and other experiments are not given in the paper. Taking $C_d = 0.97$, Q-value is found to be 7.15×10^{-3} m^3/s from Equation (4) by the method of successive approximation of approach velocity head $\alpha_1 V_1^2/2g$ with $\alpha_1 = 1.04$. There is an error of 13.5% between the two discharges.

Authors used a drop at the exit end for developing modular flow with hydraulic jump at exit. Such drops may not be available all the time. Authors have not furnished any information regarding performance of their flume at the outlet end. When the Froude's number of approaching flow [$F_1 = V_1/\sqrt{(gy_1)}$] is low in a purely venture-type flume ($\Delta = 0$), extent of lateral fluming (Mazumder and Ahuja 1978) for developing critical flow is very high. As a result, the outlet expanding transition has to be designed very carefully to avoid separation of flow from the boundary and formation of skew-type hydraulic jump which results in highly non-uniform flow at exit with very high α_2-value. Discusser (Mazumder & Roy 1999) developed straight expansions (Figure 1) and derived expression for adverse slope of floor (β shown in Figure 1) corresponding to different rates of expansion such that the basin act simultaneously as an energy dissipater and a transition structure. Table 1 gives the excellent performance of the flow meter developed by the discusser.

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