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Discussion of “Multivariable 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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This paper is about the discussion of “Multivariable 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 B₁ 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 (E₁ − Δ) is minimum (i.e. Eₘᵢₙ = Eₖ) for a given flow (Q) and the depth (y₁) 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 (E₁) and the flow is choked resulting in critical flow depth (y₁) at the control section.

For a given flow (Q), if the height of obstruction (Δ) is more than the critical height (Δₑ) 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 (Bₑ), flow will be completely choked resulting in high afflux. Critical heights (Δₑ) of weirs/notches are to be fixed for the maximum discharge (Qₘₐₓ) so that it will continue to develop critical flow at the minimum discharge (Qₘᵢₙ) also. On the contrary, the critical width at throat (Bₑ) of flumes is to be fixed for Qₘᵢₙ so that it will develop critical flow at Qₘₐₓ also. Here, Qₘₐₓ and Qₘᵢₙ 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 > Bₑ) and corresponding crest height (Δ < Δₑ) 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 Qₘₐₓ and Qₘᵢₙ passing through the channel for which the flow meter will be just choked and act as a modular one within the design flow range.

\[
B = \left[0.7\left(Qₘₓ² - Qₘᵢₙ²\right)/\left(E₁ₘₐₓ - E₁ₘᵢₙ\right)\right]^{1/2}
\]

(1)

\[
Δ = E₁ₘₐₓ - \frac{3}{2}\left(\frac{Qₘₓ}{B₀}\right)^{2}/g\right]^{1/3}
\]

(2)

where Qₘₐₓ and Qₘᵢₙ are the maximum and minimum flow through the canal; E₁ₘₐₓ and E₁ₘᵢₙ are the corresponding maximum and minimum specific energy of approach flow with depths Y₁ₘₐₓ and Y₁ₘᵢₙ respectively, and given by Equation (3) below.

\[
E₁ₘₐₓ = Y₁ₘₐₓ + \frac{V₁ₘₐₓ²}{2g} \text{ and } E₁ₘᵢₙ = Y₁ₘᵢₙ + \frac{V₁ₘᵢₙ²}{2g}
\]

(3)

Here, Y₁ₘₐₓ and Y₁ₘᵢₙ are the normal flow depths and V₁ₘₐₓ and V₁ₘᵢₙ are the mean velocities of flow in the channel upstream of the meter corresponding to Qₘₐₓ and Qₘᵢₙ, 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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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:

\[ Q = C_d \cdot B \cdot H^{3/2} \]  

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. \( h_{L1} = 0 \) 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/s\(^2\) and \( Z = 0 \), Equation (1) in the paper reduces to:

\[ Q = 1.705 C_d \cdot C_r \cdot B h_1^{3/2} \text{ m}^3/\text{s} \]  

(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

\[ Q = 1.705 C_d \cdot C_r \cdot b h_1^{3/2} \text{ m}^3/\text{s} \]  

(6)

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

\[ H_1 = h_1 + \alpha_1 V_1^2 / 2g \]  

(7)

where \( V_1 \) is the approaching mean flow velocity and \( \alpha_1 \) is Coriolis’ coefficient or kinetic energy correction factor given by the expression:

\[ \alpha_1 = \left(1/A_1 V_1^2\right) \left(\int u^3 dA\right) \]  

(8)

In Equation (8), \( u \) is the velocity through an elementary area \( dA \) and \( A_1 \) is the cross-sectional area of approach flow. \( \alpha_1 \)-value for prismatic channel usually varies from 1.10 to 1.50 (Chow 1959). In non-uniform and distorted flow, however,
Table 1. Performance of proportional flow meter with adversely sloping expansion floor.

<table>
<thead>
<tr>
<th>Expt. no. (1)</th>
<th>$Q$ (LPS)</th>
<th>Side splay expn. (3)</th>
<th>$\beta$ (4)</th>
<th>$C_d$ (Equation (4))</th>
<th>$C_v$ (Equation (5))</th>
<th>Modular limit (Scr)</th>
<th>$\eta_1$</th>
<th>$\eta_0$</th>
<th>$a_2$</th>
<th>Remarks (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>1:1</td>
<td>16.6</td>
<td>1.67</td>
<td>0.92</td>
<td>87</td>
<td>90</td>
<td>1.30</td>
<td></td>
<td>Two symmetric small eddies confined within floor, uniform flow in tail channel</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>1:1</td>
<td>16.6</td>
<td>1.69</td>
<td>0.92</td>
<td>89</td>
<td>91</td>
<td></td>
<td>-Do-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>1:1</td>
<td>16.6</td>
<td>1.69</td>
<td>0.92</td>
<td>93</td>
<td>99</td>
<td>1.23</td>
<td>-Do-</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>2:1</td>
<td>8.48</td>
<td>1.70</td>
<td>0.96</td>
<td>88</td>
<td>91</td>
<td>1.23</td>
<td>-Do-</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>2:1</td>
<td>8.48</td>
<td>1.70</td>
<td>0.96</td>
<td>92</td>
<td>93</td>
<td>1.23</td>
<td>-Do-</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>2:1</td>
<td>8.48</td>
<td>1.73</td>
<td>0.96</td>
<td>98</td>
<td>99</td>
<td></td>
<td>-Do-</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>3:1</td>
<td>5.67</td>
<td>1.67</td>
<td>0.98</td>
<td>90</td>
<td>93</td>
<td>1.17</td>
<td>-Do-</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>10</td>
<td>3:1</td>
<td>5.67</td>
<td>1.69</td>
<td>0.98</td>
<td>95</td>
<td>94</td>
<td></td>
<td>-Do-</td>
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<tr>
<td>9</td>
<td>10</td>
<td>3:1</td>
<td>5.67</td>
<td>1.73</td>
<td>0.98</td>
<td>99</td>
<td>99</td>
<td></td>
<td>-Do-</td>
<td></td>
</tr>
</tbody>
</table>

1. Modular limit is given by $y_2/g_1$ where $y_2$ is d/s depth of flow up to which flow is free.
2. Inlet transition efficiency, $\eta_1 = 1 + C_i$ where $C_i = h_i/(a_1V_i^2/2g - a_1V_i^2/2g)$.
3. Outlet transition efficiency, $\eta_0 = 1 - C_o$ where $C_o = h_o/(a_0V_o^2/2g - a_0V_o^2/2g)$.

$\alpha_1$-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 ($a_1V_i^2/2g$) 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 $h_1/L_{ax}$ and $y_h/h_1$, 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 $y_p$, are found to vary from 1.15 to 1.70 in the different models.

Except $B_1Z_3$ model, all other models belong to case-2 in the paper. In $B_1Z_3$ 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

$$Q = C_d \cdot C_v \cdot 1.705 \cdot bh_1^{3/2} = 6.3 \times 10^{-3} \text{m}^3/\text{s}$$

The above predicted discharge could not be verified with actual observed discharge since the actual discharge measured by the authors in $B_1Z_3$ and other experiments are not given in the paper. Taking $C_d = 0.97$, $Q$-value is found to be $7.15 \times 10^{-3} \text{m}^3/\text{s}$ from Equation (4) by the method of successive approximation of approach velocity head $a_1V_i^2/2g$ 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 $a_2$-value. Discusser (Mazumder & Roy 1999) developed straight expansions (Figure 1) and derived expression for adverse slope of floor ($\beta$ 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.

References


