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Discussion on paper "Flow through a sluice gate over a broad crested weir under free and submerged-flow conditions"

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ABSTRACT
Please insert a Abstract as per journal style:This discussion paper is regarding the values of coefficient of discharge (Cd) and submergence (S) of a vertical type of sluice gate mounted on a broad casted weir. Discusser has used open channel specific energy principles justifying the values of Cd found by the author theoretically. Discusser has furnished the experimental values of Cd for a vertical type and tainter type gates. Discusser has also added the experimental values of Cd under free and submerged flow conditions in a model study for Salal dam spillway. An innovative proportional type flow meter developed by the discusser has been furnished for flow measurement within a given flow range.

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KEYWORDS
Coefficient of discharge; submergence; critical submergence; vertical sluice gate; tainter gate; proportional flow meter

Using momentum and energy principles, authors derived 39 equations for theoretical determination of C_c, ε, C_d and S values for a vertical sluice gate over a broad crested (B.C.) weir under free and submerged flow conditions. Since the downstream bed level is below the upstream bed level, Figure 1 in the paper under discussion resembles a typical canal drop/regulator which is used for flow regulation and flow measurement. Conventional methods of flow measurement in a canal/stream by use of floats, current meter, ADCP, etc. are costly and time consuming. Hydraulic structures like spillways, weirs, flumes can be conveniently used for measurement of flow by simply gauging the upstream water level in case of free flow. For submerged flow, however, both upstream and downstream water levels have to be gauged for flow measurement. Coefficient of discharge (C_d) for orifice flow is defined as(a) Sluice Gate, (b) Tainter Gate, (c) C_d-values for Vertical Sluice Gate, (d) C_d-values for Tainter Gate under free and submerged flow conditions ($K = C_d$).(Source: Engg. Fluid Mechanics by Garde and Mirajgaonker 1977).

$$C_d = q/[W\sqrt{[2g(Y_0-P_u)]} = Q/[WB_c\sqrt{[2g(Y_0-P_u)]} \quad (1)$$

or

$$q = C_d.W\sqrt{[2g(Y_0-P_u)]} \quad (2)$$

same as Eqs. 1 and 2 in the paper under discussion.

The different symbols explained in the paper under discussion are shown in Figure 1 of the paper under discussion. Term (Y_o-P_u) is the same as H, i.e. Head above crest of the B. C. weir. The value of C_d for a free flowing weir with gate fully raised is usually taken as 1.705 $m^{1/2}$/sec when q is the discharge in m^3/sec per meter width of the weir which may be explained as follows:

Under free flow, there must be a control section where the specific energy (E_c) is minimum. From specific energy principles, it can be proved that

$$Y_c = 2/3E_c = \left[q^2/g\right]^{1/3} \quad (3a)$$

or

$$q = \sqrt{(8g/27)E_c{}^3} = 1.705E_c{}^{3/2} \quad (3b)$$

When there is no loss in head between sec-1 (in Figure 1 of the paper under discussion) and the control section above crest of the B.C. weir, E_c is the same as H, i.e. (Y_0-P_u). Hence Eq. 3(b) may be written as

$$q = 1.705H^{3/2} \quad (3c)$$

If the full effective width of the B.C.weir is B_c in m, then the total flow passing over the weir (Q) in m^3/sec is given by Eq. 4

$$Q = C_dB_cH^{3/2} = 1.705B_cH^{3/2} \text{in m unit} \quad (4)$$

In Figs. 2a–d of the paper under discussion, experimental values of Cd- have been plotted in the ordinate for four different gate openings (W = 3,5,6 and 7 cm) against (Y_0-P_u) in the abscissa. From all these figures, it is seen that the non-dimensional values of C_d = Q/[W.Bc. √ (2gH)] approaches 0.45 when (Y-P_u)/W = 1.0, i.e. free surface flow with gate fully opened. It is verified for one case (Figure 2a) as follows:

With Q = 100 LPS = 0.1 m^3/s, B_c = 97 cm = 0.97 m, W=H = 3 cm = 0.03 m and g = 9.81 m/sec^2

$$C_d = Q/[W.Bc.\sqrt{(2gH)}]$$
$$= 0.1/\left[0.03 * 0.97 * (19.62 * 0.03)0.5)^{0.5}\right] = 0.45$$

Thus, C_d-values in Fig.8 of the paper under discussion are identical to Eqs. 1 and 2 given above under free flow. However, it is seen that whereas in Figs. 4 and 5, C_c and ε-values are plotted in ordinate against (Y_o-P_u) in the abscissa, C_d-values in Fig. 8 of the paper under discussion are plotted against Y-P_u in the abscissa. Authors have defined Y as effective head but they have not explained what is Y and how did they find Y-values from their experiments. An illustrative table showing the different values of C_d computed from the observed data could have been added.

Figure 1(a–b) show the vertical and tainter type sluice gates, both mounted on a level bed, respectively. C_d-values

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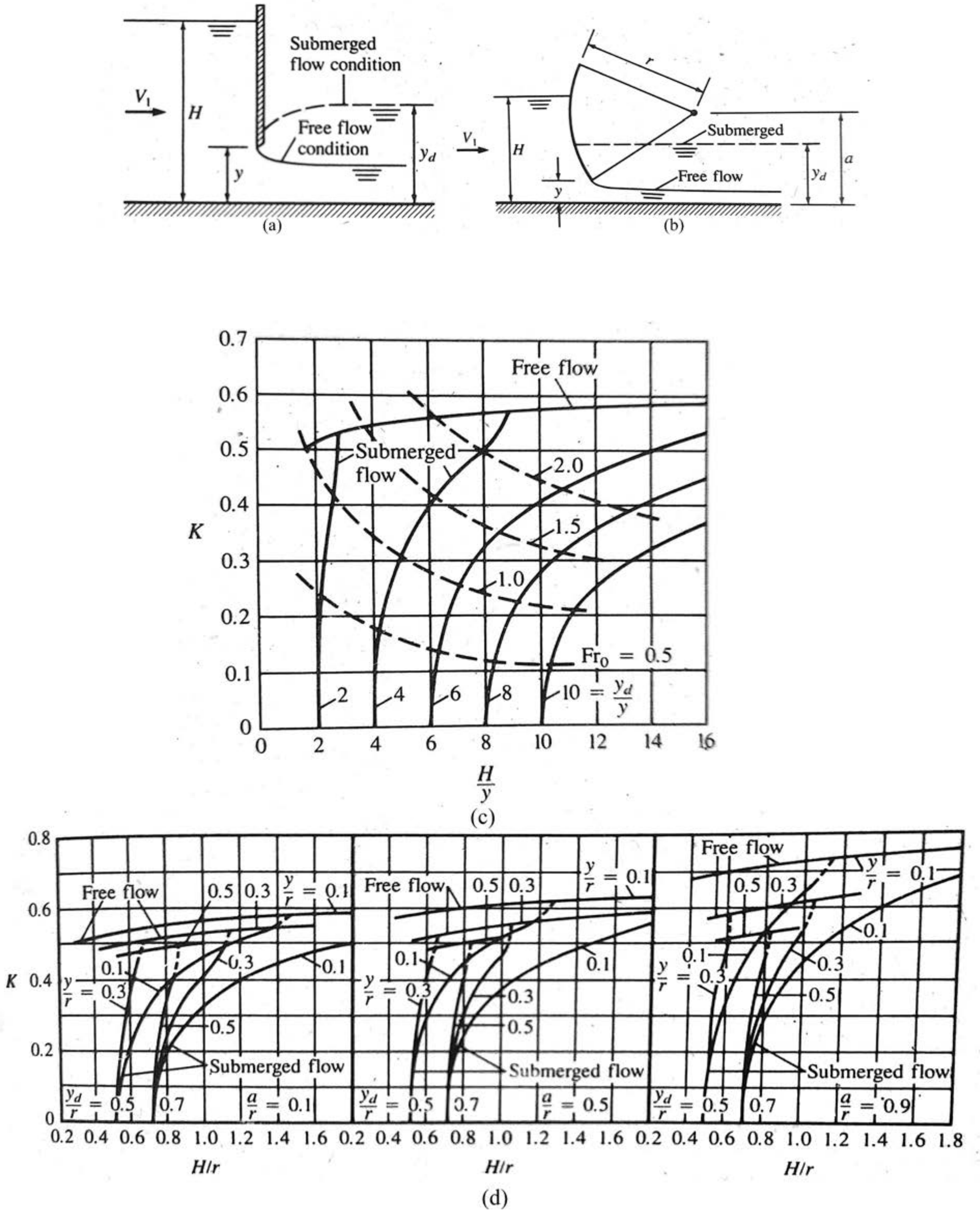


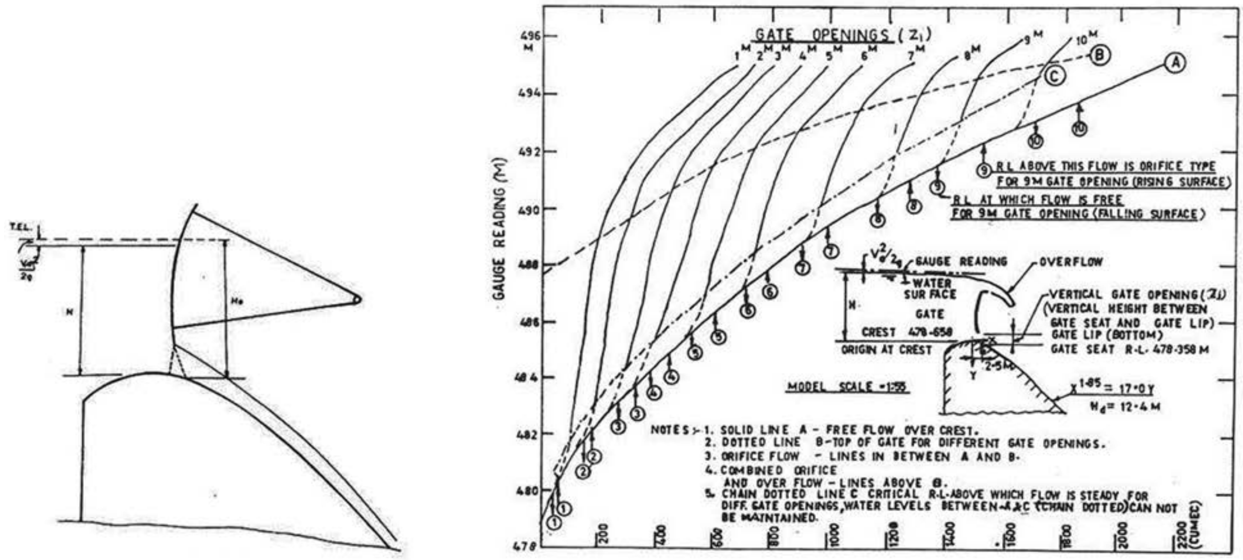
Figure 1. (a) Sluice Gate, (b) Tainter Gate, (c) C_d-values for Vertical Sluice Gate, (d) C_d-values for Tainter Gate under free and submerged flow conditions ($K = C_d$). (Source: Engg. Fluid Mechanics by Garde and Mirajgaonker 1977).

(Roberrson and Chaudhry 1993) for sluice gate and tainter gate are shown in for free and submerged flow conditions (Figure 1(c–d), respectively). It may be seen that K (= C_d) is 0.45 when H/y tends to 1, i.e. gates are fully opened.

K = (C_d) values in case of tainter gate (Figure 1c) are found to be higher than that in a vertical sluice gate due to reduction in head loss. Tainter gates are easy to operate since the trunion of the gate is above water surface and can be maintained easily as compared to vertical sluice gate. They are mostly used for flow regulation in ogee-type spillway for dams.

Figure 2(a) illustrates an ogee spillway used in Salal dam in India where the gate seat is slightly downstream of the spillway crest (Figure 2a). Discusser (Mazumder and Indraneil 1997) had an opportunity to test the scaled model of the spillway to find discharges under the following conditions as desired by NHPC who sponsored the project to Delhi college of engineering (now Delhi Technology University).

(i) Under free surface flow when the gates are fully opened (Line-A in Figure 2b).



(a) (b)

Figure 2. (a) Tainter Gate over Ogee Spillway in Salal Dam; (b) C_d-values for Tainter Gate under free and submerged flow. (Source: Mazumder and Indraneil 1997).

(ii) Under orifice flow conditions for different gate openings (between lines A and B in Figure 2b).
(iii) Under combined orifice and overflow for different gate openings (above line B in Figure 2b).

Case (i)
With R.L. of water surface: 483.5 m, Q = 275 m^3/sec, R.L. of Crest: 478.686 m, H = 4.664 m (neglecting velocity of approach), L = 15.24 m (single span model). Writing Eq. (3) as Q=$C_dLH^{3/2}$

$$C_d = Q/LH^{3/2} = 275/(15.24)*(4.664)^{3/2}$$
$$= 1.79 m^{1/2}/sec > 1.705 m^{1/2}/sec in B.C. weir$$

Case (ii)
For Q = 275 m^3/sec, W= height of gate opening = 3 m, R.L. of water surface: 486 m and hence
H = 486.0–478.686 = 7.314 m (neglecting velocity of approach). Writing orifice flow equation

$$Q = qL = C_d.L.W\sqrt{[2g(Y_0 - P_u)]} = C_d.W.L.\sqrt{(2gH)}$$

$$C_d = Q/[W.L.\sqrt{(2gH)}] = 275/[3 * 15.24 * \sqrt{(2 * 9.8 * 7.314)}]$$
$$= 0.50 > 0.45 in B.C. weir$$

It may be observed that the C_d-values for tainter gate is always higher than that in vertical sluice gate due to the fact that head loss is lower in tainter gate compared to vertical sluice gate.

Eqs. 30 and 34 in the paper under discussion are derived for determining threshold submergence (S/ = Y_t /Y_0). Authors, however, have not given any expression for S_3/ (feasible solution of eq. 30 mentioned by authors). Threshold submergence or critical submergence (S3/=S_{cr}) is important since any submergence (S) lower than S_{cr} will result in free flow, i.e when S<S_{cr} and flow is submerged when S>S_{cr}. C_d-values for free flow will always be higher than that in submerged flow. Authors have not provided any experimental value of S_{cr} (=S3/ in their

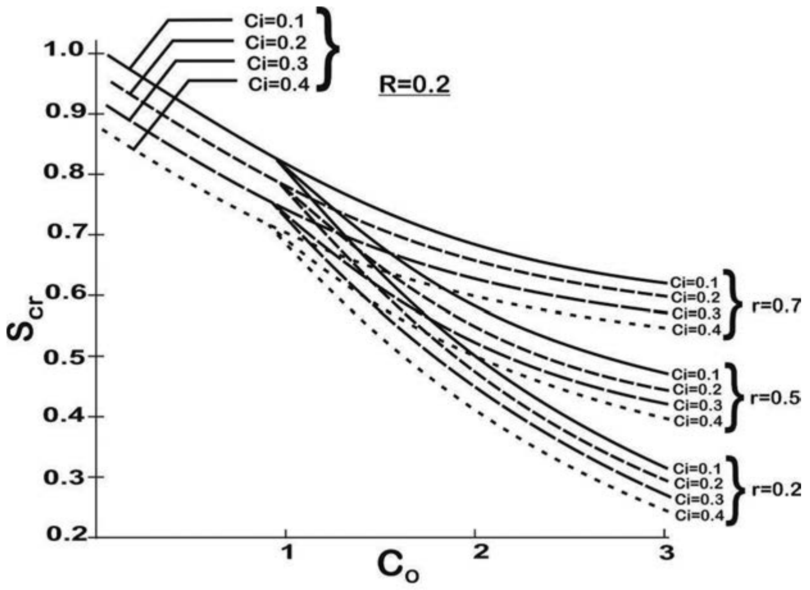


Figure 3. Variation of S_{cr} with C_i & C_o for different types of transitions (for *r*=0.2). (Source:Mazumder and Roy Indraneil 1999).

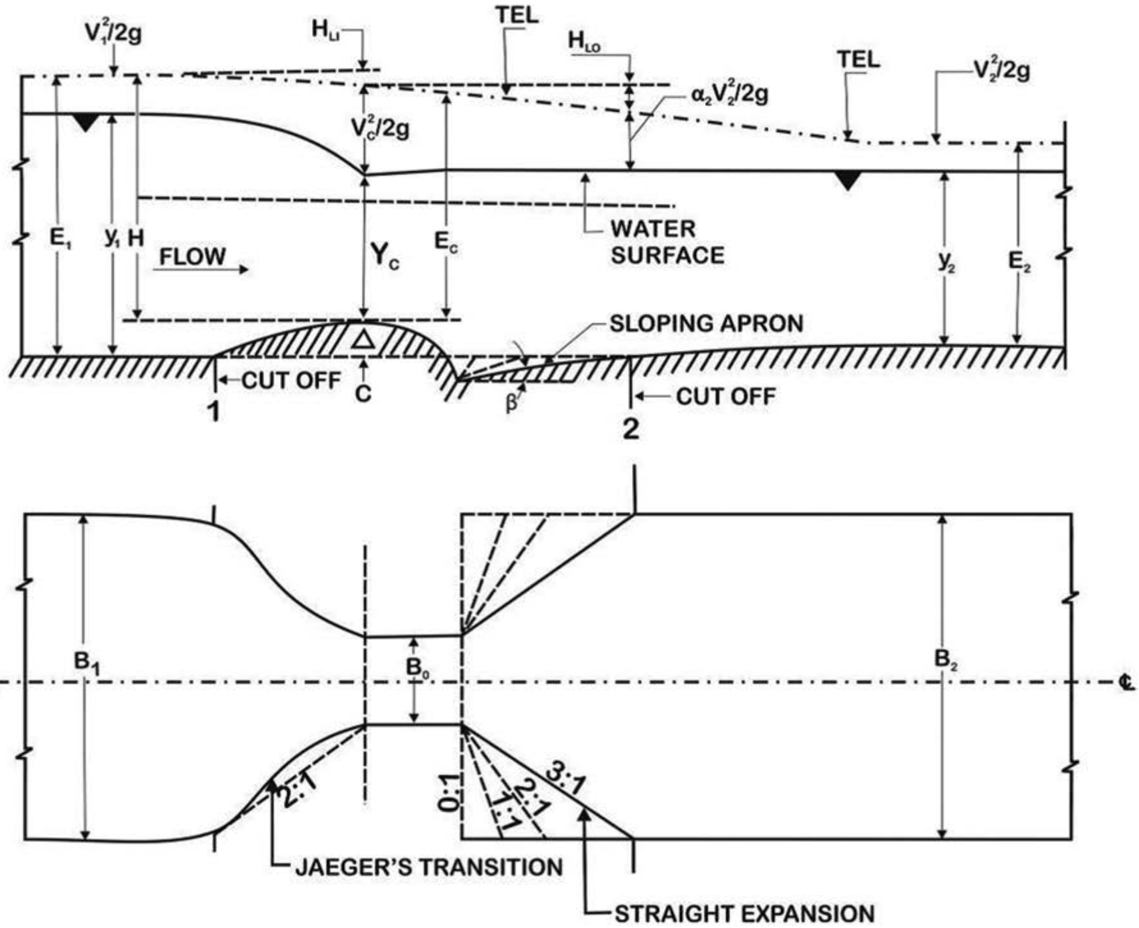


Figure 4. L-section (top) and plan (bottom) of an innovative flow meter in open channel. (Source: Mazumder & Debroy,1999).

paper under discussion) either for free or for submerged flow.

Mazumder (1966), Mazumder and Joshi (1981) investigated critical submergence (S_{cr}) of a flume type flow meter (e.g. Parshall flume) for free surface flow with level bed. An expression was developed for S_{cr} in terms of R, C_i and C_o for different types of inlet and outlet transitions, where R is the fluming or contraction ratio, C_i and C_o are the head loss co-efficients at inlet and outlet of the flow meter, respectively. Several experiments were performed to verify the results obtained theoretically and experimentally.

Figure 3 shows the experimental values of S_{cr} for different values of C_i and Co (for a given of $R = 0.2$) for different types of transitions provided at inlet and outlet of the flow meter. It may be seen that higher the head losses (i.e. higher the values of C_i and C_o) lower is S_{cr} and vice-versa.

In this context, discusser (Mazumder and Roy Indraneil 1999) wishes to mention that an innovative proportional type flow meter similar to Parshall (1926) flume was developed for a canal drop by simultaneous contraction of flow – both laterally and vertically as shown in Figure 4.

Unlike other types, this unique flow meter has an advantage that afflux upstream is minimum and the energy dissipater and flow diffuser are combined to reduce the cost of the structure. Flow separation was prevented by providing adverse slope to the basin floor (β_{opt}). In this innovative flow meter, flow occurs always as free flow within a given range of discharge (Q_{max} and Q_{min}) and C_d-values in Eq. (4) are constant ($C_d = 1.70\ m^{1/2}/sec$) for all flows within the design range by providing the optimum flume width (B_0) and corresponding height of hump (Δ) by using Eqs. (5) and (6), respectively. Adverse slope of the basin floor (β_{opt}) depending upon the rate of flaring of side walls of the basin (Φ) was determined by Eq. 7 (a&b).

$$B_0 = \left[0.7\left(Q_{max}{}^2 - Q_{min}{}^2\right)/\left(E_{1max} - E_{1min}\right)\right]^{3/2} \tag{5}$$

$$\Delta = E_{1max} - 3/2\left[\left(Q_{max}/B_0\right)^2/g\right]^{1/3} \tag{6}$$

$$\beta_{opt} = \tan^{-1}\left[\left(d_1{}^2 + d_2{}^2 + d_1 d_2\right)\tan\Phi\right]/\left[\left(bd_2 + Bd_1 + 2bd_1 + 2Bd_2\right)\right] \tag{7a}$$

$$= \tan^{-1}\left[2y_1/b\tan\Phi\left(1 + \alpha + \alpha^2\right)/\left(2 + 2\alpha r + \alpha + r\right)\right] \tag{7b}$$

Different symbols are: $B_0 = 2b=$ (Flume width), $B=B_2/2$, Q_{max} and Q_{min} are the maximum and minimum flow, E_{1max} and $E_{1\,min}$ are the upstream specific energies, y_1 and y_2 are upstream depths of flow corresponding to Q_{max} and Q_{min}, respectively, $\alpha=d_2/d_1$, $r = B_0/B_1$, $b=B_o/2$, $B=B_2/2$, $\alpha=d_2/d_1$ where d_2 and d_1 are the conjugate depths before and after the hydraulic jump in the basin.

Concluding Remarks:

Authors derived 39 equations for theoretical determination of C_c, ε, C_d and S values for a vertical sluice gate over a broad crested (B.C.) weir under free and submerged flow conditions. C_d-values in Fig. 8 of the paper under discussion are identical to Eqs. 1 and 2. C_d-values in tainter gate are higher than that in vertical type sluice gate due to reduced head loss. Discusser found C_d-values for tainter gate over an Ogee spillway in Salal dam. Dimensional value of C_d using formula $C_d = Q/LH^{3/2}$ was found to be 1.79 $m^{1/2}$/sec and non-dimensional C_d-value in orifice flow equation $C_d = Q/\left[W.L.\sqrt{(2gH)}\right]$ was found to be 0.50. Authors did not provide experimental value of critical submergence ($S_3^{/}$). Discusser has added Figure 3 for determining S_{cr} (=$S_3^{/}$). An innovative flow meter has been introduced by the discusser (Figure 4) for flow measurement.

Disclosure statement

No potential conflict of interest was reported by the author.

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