Discharge Coefficients for Rectangular Suppressed and Submerged Sluice Gates

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ABSTRACT

Two sizes of sluice gates were tested in submerged conditions with a variety of flow rates and gate openings. A new equation was developed for flow rate prediction.

BACKGROUND

Pertinent hydraulic variables for submerged and free flow conditions are frequently illustrated as in Fig. 1 for a horizontal channel bottom.

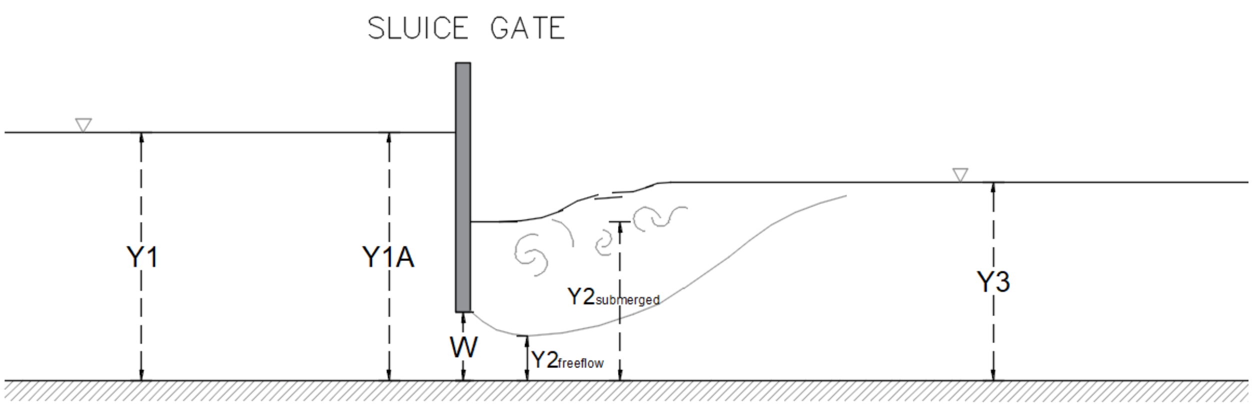

Fig. 1. Profile view of a sluice gate – horizontal floor

$Y2_{freeflow}$ is defined as the shallowest water depth downstream of the gate for a free-flow condition. $Y2_{submerged}$ is defined as the shallowest depth downstream of the gate for a submerged condition. *Y3* is the water depth downstream of the gate after notable turbulence.

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A simplified equation to compute the flow rate through a submerged rectangular sluice gate using a discharge coefficient is:

$$Q = C_d \, W \, B \, (2g\Delta H)^{0.5} \qquad \text{(Eq. 1)}$$

where

C_d = the effective discharge coefficient
B = gate width
W = gate vertical opening
g = gravitation acceleration constant
ΔH = change in head across the gate = $Y1$-$Y3$ (from Fig. 1)

Most practicing irrigation engineers in the United States use a constant C_d value such as 0.61 - 0.63 for all submerged sluice gates, regardless of entrance conditions and relative openings and gate sizes. The HEC-RAS default value for C_d is 0.8 (Brunner 2016). However, various researchers have found that the C_d value is not constant but is a function of various parameters.

Henry (1950) generated a graph depicting a discharge coefficient based on upstream water depth (as opposed to the head difference) as a function of gate openings and upstream and downstream water levels. Swamee (1992) converted those graphics into formulas. Kubrak et al (2020) used experimental data and modifications to the work of Swamee (1992) and concluded that a flow rate accuracy of about 10% could be obtained.

Belaud et al (2009) noted that the contraction coefficient C_c (a major component of C_d) for submerged flow depends upon the relative gate opening, a, where:

$$a = W/Y1 \qquad \text{(Eq. 2)}$$

Bos (1989) and USBR (1997) note that the C_d value depends upon entrance conditions and provide the following equation for a C_d (called C_{dBos} here) for a submerged orifice with the bottom and sides being fully suppressed and velocity head is ignored:

$$C_{dBos} = 0.61(1+ .15(B+2W)/(2B+2W)) \qquad \text{(Eq. 3)}$$

The C_{dcomb} developed in this technical note combines the idea of relative submergence from Bos (1989) and the idea of $W/Y1$ from Belaud et al (2009).

RECENT TESTING

Testing was conducted in a 1220 mm × 1220 mm flume at the Water Resources Facility of the Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo (Cal Poly). Two suppressed sluice gates were constructed. One gate was 374 mm wide; the other was 1115 mm wide. Fig. 2 shows vertical dimensions of the experimental configuration. Details of dimensions, data, and construction can be found at www.itrc.org/reports/sluicegate.htm. This technical note only provides some background and the results.

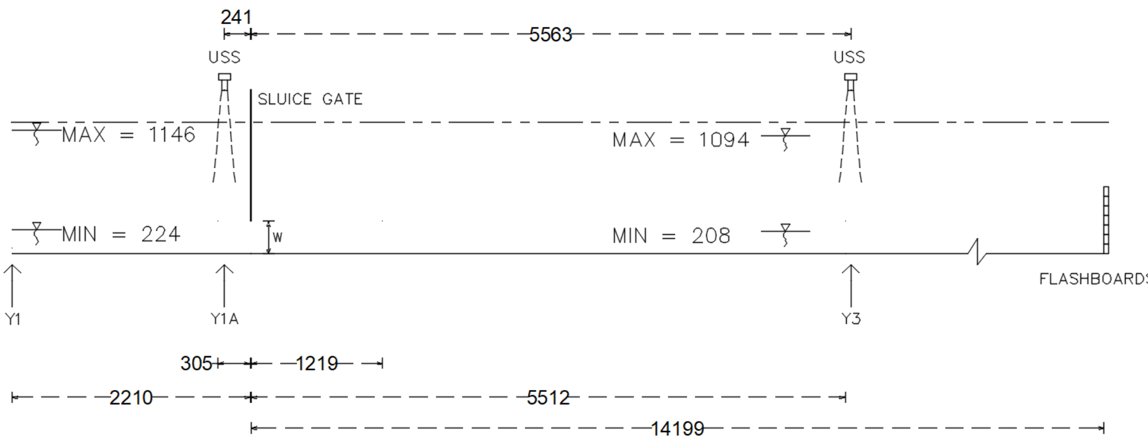

Fig. 2. Profile of test configuration. Units are mm.

RESULTS

An equation to determine a new C_{dcomb} is as follows:

$$C_{dcomb} = (0.7206a^2 - 0.0867a + 0.3988)\,(1 + .9B/(B+W)) \quad \text{(Eq. 4)}$$

Fig. 3 utilized ITRC test data and shows a comparison of flow rate predictions using three different C_d values: (i) C_{dcomb} (ii*)* the C_d of Bos (1989), and (iii) the completely different C_d and forumula of Henry (1950). The use of the new C_{dcomb} equation appears promising.

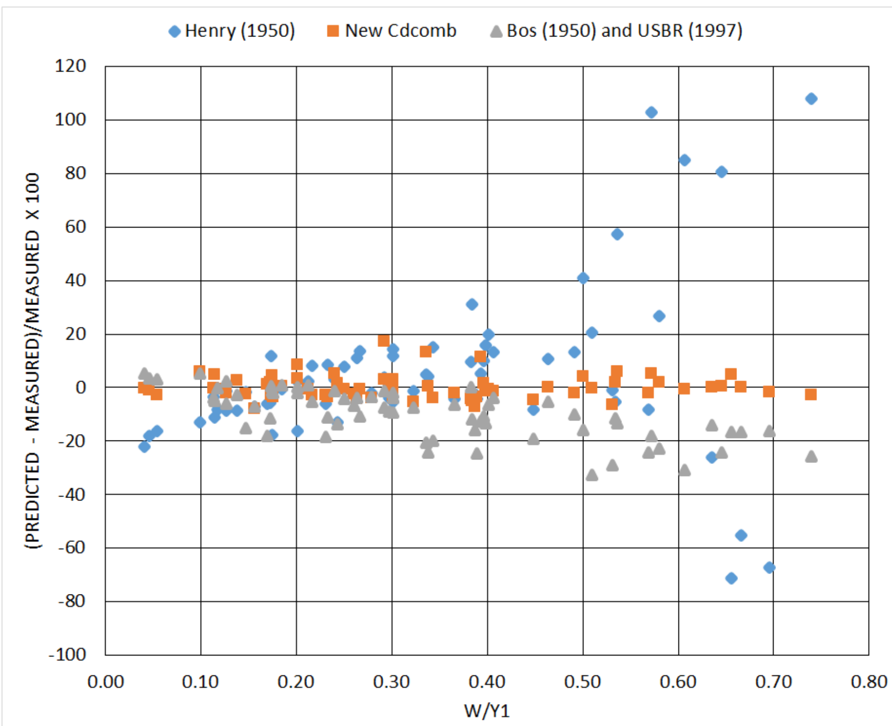

Fig. 3. Comparison of predicted versus measured submerged sluice gate flows using three techniques for estimating a discharge coefficient

Test results indicate that the use of the new equation for the discharge coefficient requires the following conditions to be met:

1. The vertical walls are parallel at the entrance of and downstream of the gate.
2. The vertical walls and floor are suppressed.
3. If a stilling well is used, its access tube must not be close to the jetting action immediately upstream of, or downstream of, the gate.
4. The downstream water level should be measured downstream of obvious turbulence.
5. The difference in head across the gate must be greater than 42 mm.
6. The water level immediately downstream of the gate must provide at least 120 mm of submergence over the top of the gate opening.
7. The new discharge coefficient should only be used if its value is less than 0.85.

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