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Investigation of different geometric shapes of sills on the discharge coefficient of a vertical sluice gate

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ABSTRACT: Gates in dams and irrigation canals are used for control of discharge or water surface regulation. To determine the discharge under a gate, a discharge coefficient (C_d) should be determined. This study investigates the effect of sill shape under the vertical sluice gate on C_d. Both of sill shape and sill height were investigated. The investigated shapes comprise polyhedral and non-polyhedral sills. The results showed that circular sill was the most effective and triangular sill was also the proper shape of polyhedral in increasing C_d. Circular sill increases C_d at least 23% up to a maximum of 31%. In addition to shape, sill height was also important in the determination of C_d. Using dimensionless parameters and regression analysis, an equation for prediction of C_d in free flow condition with and without sill was presented. The developed equation coincides with the published previous researches.

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1. INTRODUCTION

Flood controlled structures are used to control of discharge or water surface regulation in irrigation canals, rivers and the water released from the dams. These structures have different types that gates are one of the most important ones [1]. Flow-through gates are divided into two types: (i) free surface flow and (ii) submerged outflow. Discharge equation for each of two categories is different. Gates are extensively used in irrigation canals, at the top of the spillway of dams and at the exit of water from the lake to the river. The most important and usable underpass gates are sluice and radial gates. Estimation of the flow discharge under gates is an essential problem in many water engineering projects. The accurate estimation of the flow discharge test requires a suitable discharge coefficient selection.

By applying energy equation, discharge coefficient (C_d) appears in Eq. (1):

$$q = C_d . G \sqrt{2g(H - Z)} \quad (1)$$

where H is upstream water depth, Z is sill height, G is gate opening, q is discharging per unit width of canal and g is acceleration due to gravity.

Characteristics of the flow under the gates have been largely studied theoretical and experimental by many researchers, including Henry [2], Henderson [3], Rajratnam and Subramanya [4], Rajratnam [5], Swamee [6] and Ohatsu and Yasuda [7]. Figure 1 shows a longitudinal cross-section of a vertical sluice gate with a circular sill in free flow condition.

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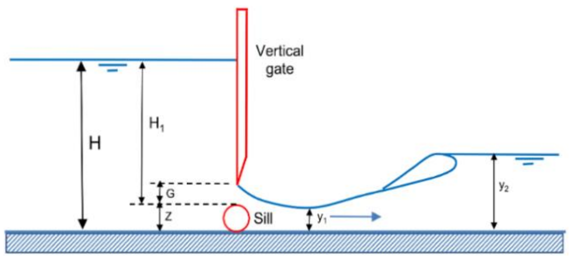

Fig. 1. Sluice gate with free flow condition

Golmohammadi and Beyrami [8] carried out the energy equation and the concept of increasing the pressure head created by water surface profile, to obtain equations for the estimation of the contraction coefficient (C_c) and discharge for free flow under sluice and radial gates. Based on the proposed equations, with a depth of water in the upstream of the gate and the opening of the gate, it is possible to easily and accurately calculate the contraction coefficient (C_c) and discharge for free flow under sluice gates. Khalili Shayan et al. [9] examined the characteristics of free and submerged flow from the sluice and radial gates by using energy and momentum equations, and experimental data of other researchers.

The present study tends to investigate the effect of height and shape of the sills on the coefficient of discharge (C_d) in vertical slid gates under free flow condition. The experiments were performed in a horizontal rectangular flume with 9.4 m length. Also, the regression equation for estimating the coefficient of discharge for both sill and non-sill gates was

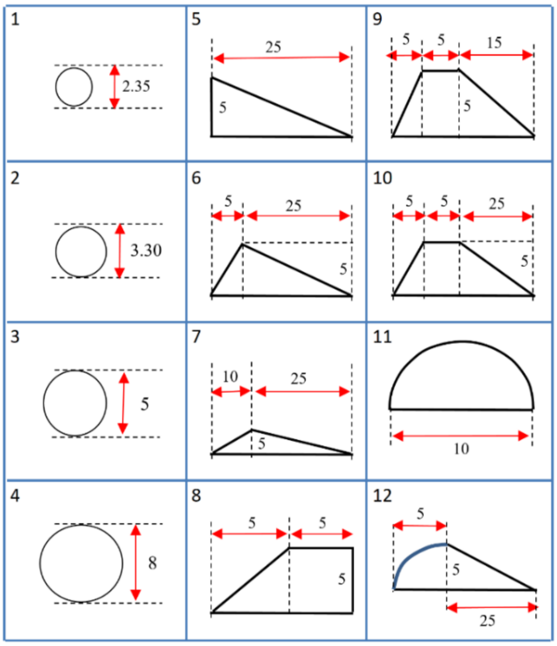

Fig. 2. Different geometric tested sills (all units are centimeters)

presented and its performance was compared with the data of other researchers.

2. METHODOLOGY

In the present study, experiments were performed in a flume with Plexiglas walls. The flume was 9.4 m long and 30.5 m wide. The depth of the flume was 110 cm for 2.7 m at the beginning and the depth was 53 cm for the rest of the flume. The flume was equipped with two control gates, one relating to the vertical gate on the section studied and the other at the end of the flume. The flow was equipped with a pump with a maximum capacity of 50 liters per second and flow was measured by a calibrated triangular weir at downstream. Flow depths were measured with point gauge with a measurement precision of ± 0.1 mm. In addition to non-sill cases, twelve different sills were studied in this study. These sill cross- sections have five different shapes: triangular, trapezoidal, circular, semicircular and rounded faces with a triangular downhill (Figure 2). Nine of these sills were 5 cm high and circle sills were 2.35 cm, 3.3 cm and 8 cm in height. Different flow discharges were considered between 12 to 26 liters per second and 4 gate openings. Therefore, 180 runs were tested.

The dimensionless analysis shows that C_d is a function of the following parameters:

$$F_1(\rho, Q, b, g, \mu, H, Z, G, \emptyset) = 0 \quad (2)$$

where φ is sill shape factor and can be related to sill wetted perimeter (p) and sill hydraulic radius (R_s) as Eq. (3):

$$\emptyset = F_2\left(R_s, p\right) \quad (3)$$

With some simplification and neglecting Reynolds number, Eq. (4) is obtained:

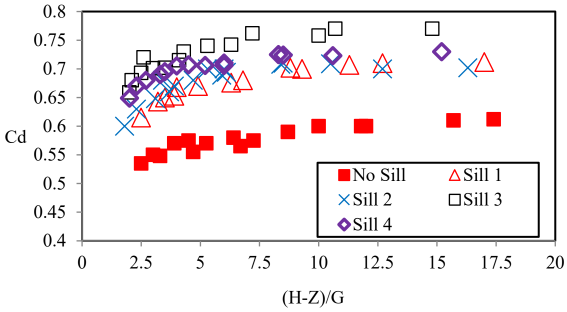

Fig. 3. Comparison of discharge coefficient for sluice gate with circular sills and without sill

$$C_d = F_4\left(\frac{\mathrm{H}_1}{\mathrm{p}}, \frac{\mathrm{Z}}{\mathrm{G}}, \frac{R_s}{G}, \frac{R_s}{H_1}\right) \quad (4)$$

3. RESULTS AND DISCUSSION

As previously mentioned, four circular sills with diameters of 2.35, 3.3, 5 and 8 cm were tested. Figure 3 shows that the sill height is important for calculating C_d. The gate with a sill had a coefficient of discharge greater than the gate without sill. Also, when the sill height rises, C_d increased to a certain amount, then C_d was reduced. The threshold criteria were with a height of 5 cm for circular sill that provides the highest discharge coefficient.

Figure 3 shows that with decreasing gate opening (G), the discharge coefficient (C_d) was increased. By reducing the opening of the gate, the flow-through gate was converged, and with the increase of the velocity of the current, the hydrostatic pressure was reduced. So tt the pressure reaches less than $\gamma_w H_1$, where γ_w is the specific gravity of the water. Reduction in water pressure and water suction increases C_d. Rajaratnam and Humphries's [10] studies showed that pressure decline due to gate installation was created 5 times the opening of the gate (5G) in upstream of the gate.

In Figure 4, the discharge coefficient of the gate with a circular sill having 5 cm in diameter (sill 3) is compared with non-sill type. Circle sill has increased discharge coefficient at least 23% and a maximum of 31%. Also, in Figure 4, two equations with determination coefficients (R^2) equal to 0.87 and 0.91 have been fitted for gate with sill and gate without sill respectively.

For polyhedral sill (sill No. 12), the downstream slope and the shape of the crest are the main parameters of the shape. While this is not the case for non-polyhedral forms. Therefore, a form factor is required which in this study wetted perimeter (p) and hydraulic radius $\left(\mathbf{R_s} = \frac{\mathbf{A}}{\mathbf{P}}\right)$ were chosen (A is the sill cross-section area). Using nonlinear regression analysis, Eq. (5) was obtained:

$$\mathbf{C_d} = 0.63\left(\frac{\mathbf{H_1} - \mathbf{G}}{\mathbf{H_1} + 15\mathbf{G}}\right)^{0.0649} \frac{\left(1 + \frac{\mathbf{Z}}{\mathbf{G}}\right)^{0.3618}\left(1 + \frac{\mathbf{H_1}}{\mathbf{P}}\right)^{0.0434}}{\left(1 + \frac{\mathbf{R_s}}{\mathbf{G}}\right)^{0.5169}\left(1 - \frac{\mathbf{R_s}}{\mathbf{H_1}}\right)^{0.3887}} \quad (5)$$

Eq. (5) can be used for both gates with sill and gate

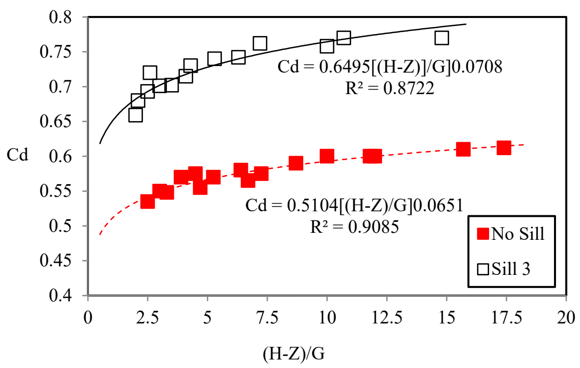

Fig. 4. Discharge coefficient for vertical slide gate in two types (with circular sill under the gate and without sill)

without sill in free flow condition. Based on Eq. (5), C_d can be predicted with a maximum error less than 6%. For gate without a sill, Z will be zero, P will be infinite, and H_1 is equal to H.

4. CONCLUSION

In the present study, 12 sills with different geometric sections were tested under the vertical slide gate. These sections have consisted of circular, semicircular, triangular, trapezoidal and rounded faces with triangular in the tail. Graphs and correlation equations were obtained based on 180 laboratory data. The results showed that the presence of the sill under the vertical gate had a positive effect on the flow characteristics. This means that it increases the coefficient of discharge. The shape and height of the sill were an important factor in increasing the discharge coefficient. For the tested forms, it is concluded that the circle sill is most effective in comparison with all other forms and the triangular sill is most effective compared to the polyhedral sill shapes. An equation for calculating the coefficient of discharge was obtained. The equation includes flow parameters, gate openings and sill shape parameters. This equation predicted discharge coefficient with acceptable accuracy and for common sill can be used within the range in which the equation is developed.

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