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Experimental Investigation of Discharge Coefficient in Tainter (Radial) Gate with Sill in Free Flow Conditions

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ABSTRACT: In the present study, the effect of sill on the discharge coefficient (C_d) of radial gates in a free flow condition has been investigated. Variable geometric parameters of these sills are length, upstream slope, downstream slope and sill height. In addition, the effect of sill location on C_d was investigated so that in case 1, with an open gate, the sill was located in front of the gate. In case 2, the sill is located under the gate and not in front of it. In total, 43 physical models of different shapes of sills and different sizes of sills were used. The results showed that when the radial gate is open and sills are in front of the gates (case 1), the sill operates as a barrier and reduces Cd. But in case 2, the semicircle shape has a better performance and increases C_d by about 30%. Also, the rectangular and trapezoidal sills always increase Cd. In these sills, increases in Cd depend on the sill length to its height (L/Z). Small values of L/Z increase the discharge coefficient up to 25%. Finally, for circular and semicircular sill shapes, two regression equations were presented which can be used by designers.

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1- Introduction

Gates are structures that are used for various purposes including connecting and disconnecting flow, setting up discharge, or water level adjustments [1]. Among the most widely used gates is the radial/tainter gate for dewatering and controlling discharge. Because the required force to lift the gate is large, hydraulic designers use radial gates to control water level and adjust discharge. The radial gate has a cylindrical shell, therefore the resultant pressure forces from water entering the gate pass through its axis and do not create a torque around it. Therefore, the force required to raise the gate need only be countered by the weight of the gate.

The radial gate operates in both submerged and free flows and for each of these conditions certain parameters are involved. The sill can also improve gate operation however it can lead to a negative impact on its performance [2]. Several studies have been conducted to investigate the effect of a sill on flow. Sarhan [3] investigated the effect of prismatic sill height on discharge coefficient in a submerged flow condition. Four prismatic sills with different heights were studied. The results showed that with increasing height of prismatic sills, the discharge coefficient increases. Saad [4] used circular crested sills under a gate and investigated the effect of this type of sill on supercritical free flow characteristics. Results showed that for gates equipped with a sill, the geometric shape of the sill is the most effective factor for affecting the discharge coefficient. Saeid et al. [5] investigated the impact of a trapezoidal shape sill under the gate in a submerged flow. In that study, the downstream slope of the sill and its height were changed. Neveen [6] conducted a laboratory study in a flume 250 cm in length, width of 15 cm, and depth of 30 cm and examined the effect of a circular-crested sill on the discharge coefficient. The results of the study showed that the most effective factor in affecting the discharge coefficient is the ratio of b/z (z = sill height and b is width of sill). In a laboratory study, Fahmy Salah [7] investigated sills with radial gates. The impact of sill height on discharge coefficient, contraction coefficient, jump length, velocity and the energy of flow were studied. They showed that the sill height is the main factor in contraction coefficient variation. By increasing the sill height, the discharge coefficient will increase. The use of submerged radial gates equipped with sills required a long stilling basin. Emre and Aydin [8] numerically investigated the impact of sills on submerged flow. The results of this study indicate that if a sill is located downstream of a gate, it reduces the velocity of the flow.

The purpose of this study is to carry out a laboratory investigation on the effect of a sill on the discharge coefficient of a radial gate in free flow conditions. For this purpose, 43 physical models with triangular, circular, semicircular, trapezoidal and rectangular sills were tested. Due to changes in flow discharge, 740 experiments were carried out. The results are based on correlating equations with dimensionless

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parameters. It should be noted that in previous studies in relation to the sill, most trapezoidal sills have been used. For the first time in this study, various types of sills have also been investigated.

2- Material and methods

The radial gate in this study is shown in Figure 1. All experiments were carried out at the Hydraulic Laboratory in university of Tabriz. The laboratory equipment used in this study includes: a water supply system, a laboratory canal, a water depth measurement system, a physical model of radial gate, and 14 physical sill models. The flume used in this research has a length of 8 meters, a width of 80 cm, and a 50 cm height.

A precise water gauge was used to measure water depth in upstream and downstream of the radial gate. The physical model of the radial gate is made of sheet metal which has a radius of 30 cm. The installation height is 30 cm from the bottom of canal. The height of the gate arc and the maximum height of water that can be placed behind the gate is 42 cm.

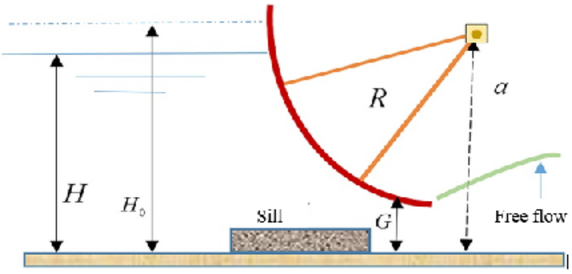

Figure 1. Example of the studied gate with rectangular sill

To determine the discharge coefficient, the Buckingham π theorem will be relied upon. Since there are four effective parameters, according to Buckingham theorem, C_d of radial gate without a sill is equal to:

$$C_d = f(H, G, a, R) \tag{1}$$

Because we have four parameters, therefore according to Buckingham theorem, we will have three dimensionless parameters.

$$\Pi_1 = \frac{H}{R}, \Pi_2 = \frac{a}{R}, \Pi_3 = \frac{G}{R} \tag{2}$$

Combining Π_2 and Π_3 yields θ as shown in Equation 3:

$$\theta = \Pi_2 - \Pi_3 = \frac{a-G}{R} \tag{3}$$

Then C_d of radial gate without a sill is expressed by:

$$C_d = f\left(\frac{H}{R}, \theta\right) \tag{4}$$

In dimensional analysis of discharge coefficients of radial gates with sills, it is important to accommodate other flow and gate properties that affect the performance. An expression relating discharge to these parameters is provided in Equation 5.

$$C_d = f\left(\frac{H}{R}, \theta, \psi_1, \psi_2, DSS, USS\right) \tag{5}$$

Where Ψ_1 and Ψ_2 are respectively, the sill shape coefficient and dimensionless height of the sill. It is noteworthy that C_d in the gate with a sill will be found in the laboratory whereas for free flow, it will be obtained from Equation 6. In this study the width of the flume is 80 cm.

$$C_d = \frac{Q}{bG\sqrt{2g(H-Z)}} \tag{6}$$

3- Results and discussion

To fully investigate the effect of sill on C_d, sills were placed on the floor of the canal and under the gate. In case 1, after gate opening sill is located in front of flow discharge and in the case 2 the sill is placed under the edge of gate. In case 1, sills number 2 to 7 were placed under the gate. For these states, the discharge coefficient of gate decreases sharply; this behavior is contrary to the discharge coefficient behavior without a sill. It is apparent that the sill acts as a barrier and reduces the flow rate under the gate. Reduction in flow rate corresponds to an increase in flow losses and reduction in the discharge. Figure 2 shows the results of this model experiments and illustrates the differences between discharge coefficients in the model with and without a sill. When the gate is closed, the sill is positioned underneath it. However, as the gate opens, the sill is no longer directly underneath (it is then in front of the gate). Placing the sill before the gate on the water flow path is a barrier to water flow and reduces discharge coefficient.

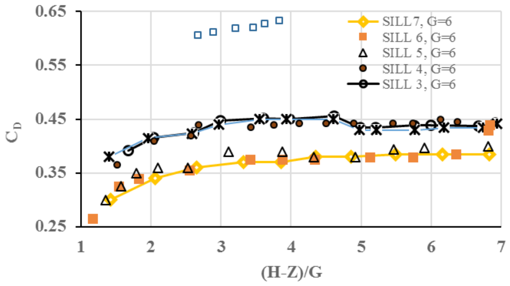

Figure 2. Variation of C_d versus (H-Z)/G in sill position corresponding to case 1

In the next mode (case 2), sills numbers 1 to 9 were placed under the gate. For these cases, the sill is underneath the gate regardless of whether the gate is open or closed. With this configuration, it is possible to study the effect of height and shape of sill on the discharge coefficient. To investigate the effect of sill height on C_d, four circular sill heights of 2.1, 3, 6 and 9 cm were employed for a gate opening of 3 cm. Additionally, four circular sill heights of 1.5, 2.1, 3 and 6 cm with a gate opening of 1.5 cm were used.

The results are shown in Figures 3 and 4. As shown in Figures 3 and 4 for a fixed gate opening with increasing sill height, it is seen that the discharge coefficient increases; however, when the sill height reaches a threshold value, the discharge coefficient begins to decrease (compare sills with height of 1.5, 3 and 6 cm). The opposite of this mode is also true, for a fixed sill height, initial increases in the gate opening leads to discharge coefficient increases until coefficient threshold value is reached. Thereafter, further increases in the gate opening do not lead to increases in the discharge.

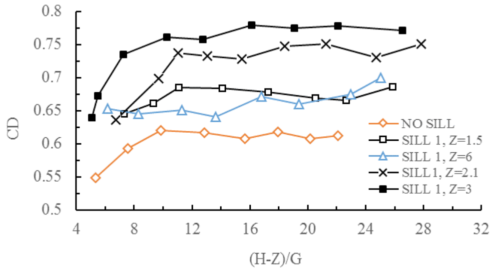

Figure 3. Variation of C_d versus (H-Z)/G in circular sill at gate opening of 1.5 cm

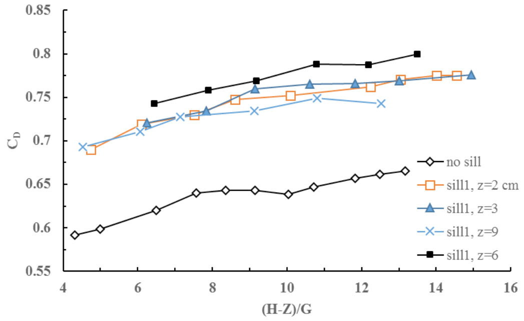

Figure 4. Variation of C_d versus (H-Z)/G in circular sill at gate opening of 3 cm and different sill height (Z)

4- Conclusions

The results of the study can be summarized as follows:

1. Triangular and circular sills for which a closed gate is tangent to the sill and the sill is upstream of the gate when the gate is open; the sill acts as a barrier, and causes a decrease in the discharge coefficient. For triangular and circular sills, when the gates open, the sills are positioned under the gate. The sills increase the discharge coefficient but after the heights are increased beyond a threshold, the discharge coefficient begins to decrease. The optimal rate of gate opening to sill height (G/Z) is equal to 0.5.
2. For a triangular sill, if the sill is always under the gate opening, the upstream slope of 1:2 (V:H) and downstream slope of 1:0 (V:H) has the most impact on discharge coefficient.
3. In non-polyhedral sills that include circular, semicircular and circular quadrant, if the sill is always under the gate, a semicircular sill has the most impact on flow discharge coefficient.
4. To investigate the effect of sill shape on discharge coefficient, the semicircular sill (which among non-polyhedral sills had the most impact) and triangular sills with various upstream and downstream slopes were employed. Results showed semicircular sills have the most impact on increasing discharge coefficient.
5. For triangular sills with low values of L/Z, the discharge coefficient increases whereas with large values of L/Z the discharge coefficient is low.
6. Among trapezoidal sills, a sill with upstream slope of 1:3 (V:H) has the most impact on discharge coefficient. Investigating the effect of downstream slope of trapezoidal sill indicated that trapezoidal sills with downstream slope of 1:3 (V:H) has the greatest impact on increasing the discharge coefficient.

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