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Experimental Study of Discharge Coefficient of U-Shaped Sluice Gate under Free and Submerged Flow Conditions

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Abstract

Sluice gates are among the flow control structures that are used to measure and control the flow in water conveyance channels. In this research work, the geometrical and hydraulic parameters affecting the discharge coefficient of the sluice gate (U-shaped) are investigated experimentally. The results obtained show that in the free flow condition, for a constant flow rate, the upstream depth increases with the decrease of the gate opening. Also, with the increase of gate opening, the gate discharge coefficient decreases. For different inlet flow rates, the range of Froude number changes, from 0.02 to 0.5, which causes the reduction of gate discharge coefficient by about 50%. The results of submerged flow conditions show that the discharge coefficient increases with the increase of y_1/b ratio. For the range of y_1/b changes from 0.5 to 3, the value of the gate discharge coefficient for different flow rates changes from 0.35 to 0.7. Also, an increase in the upstream Froude number leads to a decrease in the gate discharge coefficient. According to the results, with the increase of y_3/b, for three slopes of zero, 0.4 and 0.8%, the change trend of C_d is increasing and is in the range of 0.55-0.65. For gate opening of 3 cm and flow rates of 3, 6, and 9 m^3/hr, the gate discharge coefficient is obtained 0.57, 0.59, and 0.61, respectively. The slope of the channel bed has no effect on the discharge coefficient of the gate in both free and submerged flow conditions.

1. Introduction

With respect to the many uses of gates, especially in dams and water intakes and their importance in flow measurement and also providing facilities for water management in the network, in 2002, a committee composed of ASCE for accurate measurement of flow in channel gates (Wahl, 2004). One of the most famous and widely used and simplest hydraulic structures that can be used to measure flow in open channels is sluice gate. The accuracy of the application of this structure in estimating the flow in the conditions of field application in free flow has been evaluated as acceptable (Clemmens et al., 2003). For the first time, Woycicki (1935) presented an equation to determine

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the changes in the contraction coefficient of the sluice gate in free flow conditions, obtained from the laboratory results. Henry (1950) also presented a diagram to estimate the discharge coefficient of sluice valves in free and submerged flow conditions, which is still considered as a reference in this field. In research using energy and momentum equations, relationships were presented to estimate the discharge coefficient in free and submerged conditions and the results of Henry (1950) were confirmed (Rajaratnam and Subramanya, 1967). Based on the graph provided by Henry (1950), and Swamee (1992) presented some relations for the discharge coefficient in free and submerged flow conditions. The presented relations avoided the errors caused by the interpolation of the discharge coefficient curve. He also presented an analytical and numerical method to estimate the flow coefficient of sluice gate in free flow conditions. Golmohammadi and Beyram (2011) considered the flow rate passing through the gate in the submerged and free state as the average flow rate calculated from the energy relationship between the upstream of the gate and the position of maximum contraction and the flow rate calculated from the momentum. Finally, due to the existing hypotheses, using the Boyalski's laboratory data, they obtained the correction coefficients that are multiplied by the obtained theoretical discharges. This method was called the combination of energy and momentum (M-E) equations. Golmohammadi and Beyram (2011), based on the energy equation and the concept of pressure increase due to the concave curvature of the water surface, provided relations to estimate the compression coefficient and flow rate in sluice and radial gates with free flow. Based on the presented relationships, with the upstream water depth of the gate and the amount of gate opening, it is possible to easily and accurately calculate the contraction coefficient and flow rate in sluice gate with free flow. Habibzadeh et al. (2011) presented an equation to estimate the discharge coefficient of the gate in free and submerged conditions with the combined of energy and momentum equations and the effect of the energy loss. While presenting the average values of the energy loss coefficient of the gate in the free and submerged flow conditions, they stated that the effect of the energy loss of the gate on increasing the accuracy of the estimation of the discharge coefficient is significant. Cassan and Belaud (2012) investigated the characteristics of the flow upstream and downstream of the sluice gate using laboratory data and numerical model. First, they checked the accuracy of the output of Fluent hydrodynamic model by using the laboratory data related to the velocity profile in free flow and submerged conditions, and then using the numerical model, relationships for the contraction coefficient and energy loss of the sluice valve in free flow conditions and submerged presented. Oskuyi and Salmasi (2012) produced 5200 data to determine the discharge coefficient of vertical sluice gate by using two equations of energy and movement and simultaneous solution with the Mathematica software. Then two regression equations were obtained by the SPSS software for free and submerged flow conditions. The results obtained showed that the proposed method is consistent with the diagram of Henry (1950).

Khalili Shayan and Farhoudi (2013) estimated the discharge coefficient of the sluice gate by using energy, momentum relationships and determining the average values of the energy loss coefficient in the free and submerged flow conditions, which are dependent on the relative opening and the relative depth of the tailwater. Azamathulla et al. (2013) using GEP presented an accurate flow equation for free flow conditions passing under a lateral sluice gate. Their results showed that the discharge coefficient is related to the Froude number of the main channel, the upstream depth ratio, and the opening of the gate. According to their results, the discharge coefficient equation obtained using GEP and the available data provided better results compared with other existing equations for the sluice gate. The error of calculated discharge coefficient compares to observed value was within the range $\pm 5\%$. By Khalili Shayan and Farhoudi (2013), the characteristics of the flow passing under sluice and radial-gates in free flow conditions were investigated using the energy and momentum equations. According to the results, in free flow conditions, an equation for estimating the energy loss coefficient of the gate was presented, and its use in increasing the accuracy of estimating the discharge coefficient in free conditions was investigated. Daneshfaraz et al. (2016) used the FLOW-3D software to simulate and check the water discharge coefficient of the gate in order to study the characteristics of the flow under the vertical gate. Naghaei and Monem (2016) investigated different hydraulic conditions and operation of the salon gate by developing a mathematical model and adapting it to the ICSS hydrodynamic model. In this research work, it was found that the discharge coefficient is a function of the relative opening and submergence of the gate. Silva and Rijo (2017) investigated various methods including models based on energy-momentum equations, orifice flow rate relations, and dimensional analysis based on the Buckingham method in determining the discharge coefficient. According to their results, models based on energy and momentum equations showed better results in the free, submerged, and partially submerged flow conditions. They stated that, for different sluice gate openings, for the submerged and partially submerged flow conditions, there was no improvement in the discharge estimation results. *Heidari et al. (2020)* investigated the effect of the sill shape and position on the discharge coefficient of the radial gate. The results showed that the construction of sill increases the discharge coefficient, and the height and shape of the sill is the most important factor. In rectangular and semi-circular sills, in the case where the ratio of the height of the sill to the opening of the gate is equal to 2, the discharge coefficient of the radial gate is 2.7% and 13.3% higher than the case without the sill, respectively. Kianmehr et al. (2020) used 107 tests along with 529 tests of other researchers to determine the flow characteristics of side gates under the sub-critical flow conditions. The results showed that the discharge coefficient of the side gate in free flow conditions depends on the ratio of the flow depth to the gate opening and the Froude number of the upstream flow, and in submerged conditions, it depends on the ratio of the flow depth to the depth of the intake channel and the ratio of the flow depth to the gate opening. The proposed relationship for estimating the discharge coefficient in the free and submerged flow conditions had an average relative error of 2.96% and 5.33%, respectively.

Salmasi and Norouzi Sarkarabad (2020) investigated the effect of sill shape on sluice discharge coefficient. Based on the results, the circular sill is the most effective shape, and the triangular sill is one of the best multi-faceted sills. The circular sill increases the discharge coefficient by at least 23% and at most 31%. Also, in addition to the shape, the sill height plays an important role in the discharge coefficient. Kubrak et al. (2020) evaluated the volumetric discharge of the flow passing under the sluice gate. They used a 1:2 model of an irrigation channel with a sluice gate for the experiments. They also used the Swamee (1992) model to determine the discharge coefficient. Daneshfaraz et al. (2016) investigated the different positions of the sluice gate and its effects on the hydraulic parameters in free flow conditions using the Flow 3D numerical model. Their results showed that statistical parameters, the RMSE, RE, and AE for the RNG model were lower than the k-ε, k-ω and LES models, and were more accurate compared to the laboratory data. For a constant flow rate, with the increase of the gate angle towards the upstream side, the gate discharge coefficient increased compared to the vertical gate. Also, the flow coefficient had an inverse relationship with the downstream angle of the gate. In the condition of inclined gate, by increasing the angle of the gate with the vertical axis, due to the increase in the area of the flow passing through the gate, the flow coefficient decreased. In addition to the mentioned research work, many researchers also conducted research in the case of sluice, radial gates, cylindrical weir–gate, and long-throated flumes. (Emamgholizadeh and Assare, 2008; Abdelhaleem, 2017; Aydin and Ulu, 2017; Parsaie et al., 2018; Parsaie et al., 2019).

Among the possible flow conditions in water conveyance networks are flows with very low Froude numbers, which according to the research of the sources, these conditions in U-shaped channels have received less attention from the researchers. Therefore, the purpose of this research work is to investigate the effect of hydraulic and geometrical parameters on the discharge coefficient (C_d) of U-shaped sluice gate at very low Froude numbers in the free and submerged flow conditions.

2. Materials and Method

2.1. Experimental flume

This research work was carried out in the hydraulic laboratory of Shahrood University of Technology in 2017, in a rectangular metal-glass flume with length of 500 cm, width of 8.6 cm, and depth of 34 cm. The slope of the flume bed was adjustable, and its tank volume was 280 liters. The water in the tank was transferred to the upstream tank of the laboratory flume through a pipe with a diameter of 40 mm and using a centrifugal pump with an electric motor with a power of 1.02 kW. The flow rate entering the channel was controlled using a check valve, and the flow rate entering the channel was read by a rotameter flow-meter with an accuracy of 0.2 m^3/hr (Figure 1).

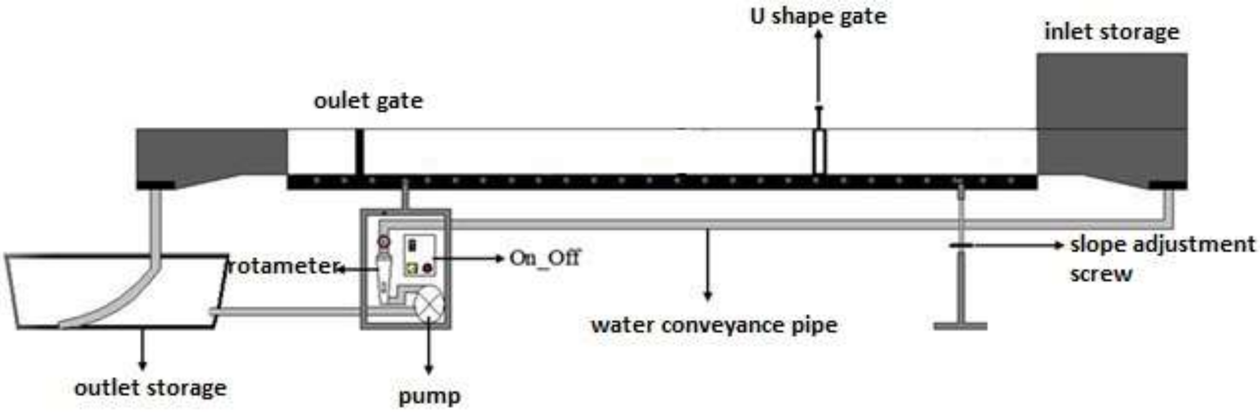


Figure 1. Sketch of experimental flume.

In the present study, a U-shaped channel cross-section was considered, and for this purpose, a polyca tube with a radius of 4.25 cm was installed on the bottom of the channel. The sluice gate was made of Plexiglas with a length of 30 cm, a width of 8.5 cm, and a thickness of 3 mm. One side of the gate was semicircle with a radius of 4.25 cm, and was installed at a distance of 1.5 m from the beginning of the channel. Plastic tape was used to seal the gap between the gate and the channel wall.

2.2. Dimensional analysis

The parameters affecting the discharge coefficient of the vertical sluice gate in the free and submerged conditions are opening height (w), water height behind the gate (y1), flow rate (Q), gate curvature radius (R), flume width (b), downstream depth (y3), channel bottom slope (S), viscosity (μ), gravity acceleration (g), and water density (ρ).

By using dimensional analysis based on the Buckingham π theorem, the dimensionless parameters affecting the flow coefficient of the gate in two free and submerged conditions were obtained as Equation (1).

$$C_d=f\,(y_1/b,\ w/b,\ R/b,\ y_3/b,\ S,\ gb^5/Q^2,\ b\mu/\rho Q) \qquad (1)$$

C_d is the discharge coefficient of the vertical sluice gate, y1/b is the ratio of the upstream depth of the gate to the width of the flume, w/b is the ratio of the opening of the gate to the width of the flume, R/b is the ratio of the radius of curvature of the gate to the channel width, y3/b is the ratio of the downstream depth to the width of the channel, S is the slope of the flume bed, gb5/Q2 is the Froude number, upstream of the gate, and bμ/ρQ is the Reynolds number upstream of the gate (Figure 2). Because R was constant in all experiments, the dimensionless parameter R/b was omitted. Also, the flow upstream of the gate was turbulent (Reynolds number was in the range of 1000 to 11000), so the effect of viscosity was insignificant, and the parameter of number Reynolds (Re1) was omitted. Finally, the effective dimensionless parameters in the gate discharge coefficient in the two conditions of free and submerged flow can be defined as relations 2 and 3:

- Free flow

$$C_d=f\,(y_1/b,\ w/b,\ S,\ Fr_1) \qquad (2)$$

- Submerged flow

$$C_d=f\,(y_1/b,\ w/b,\ y_3/b,\ S,\ Fr_1) \qquad (3)$$

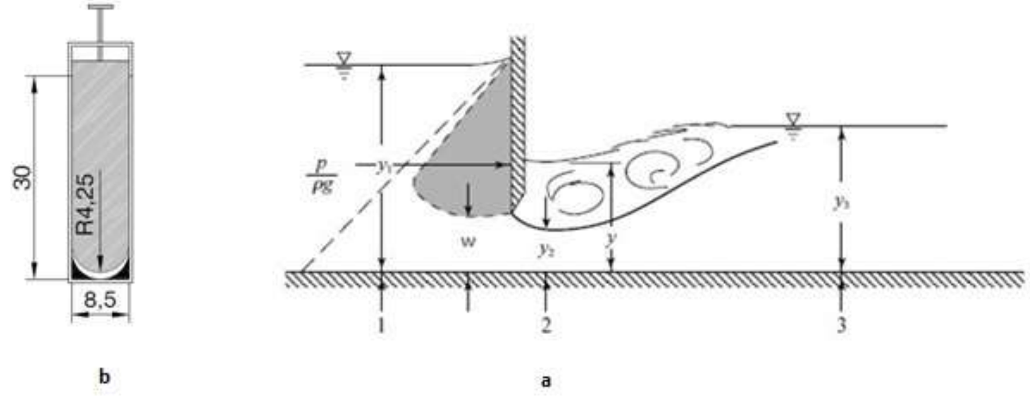


Figure 2. a) Flow passing through the gate in submerged condition, b) U-shaped gate.

2.3. Theoretical equations

In the free and submerged flow conditions, various equations for the flow passing under the sluice gate have been presented, some of which are mentioned in the following:

$$q=\frac{2}{3}C_d\sqrt{2g}\left[h_0^{\frac{3}{2}}-(h_0-a)^{\frac{3}{2}}\right] \qquad (4)$$

$$q=C_d a\sqrt{2gh_0} \qquad (5)$$

$$q=C_d a\sqrt{2g(h_0-h)} \qquad (6)$$

$$q=C_d a\sqrt{2g(h_0-\frac{a}{2})} \qquad (7)$$

In Equations 4 (Henry, 1950), 5(Rajaratnam and Subramanya, 1967), 6 and 7, **q** the flow rate per unit of channel width, **a** gate opening, **h_0** the upstream depth, **C_d** the flow coefficient, and **h** the depth of the flow attached to the gate after it.

In order to calculate the discharge coefficient, the theoretical relationships related to free and submerged flow were used. The effective parameters were measured in the laboratory, and the discharge coefficient was calculated with the relationships.

2.4. Parameters and test procedure

Tests carried out for flow rates of 2, 3, 4, 5, 6, 7, 8, and 9 m^3/hr, gate opening (w) 1, 2, 3, 4, and 5 cm, bed slopes 0, 0.2, 0.4, 0.6, 0.8, and 1%, in free and submerged conditions. In the free condition, after setting w, the downstream gate of the flume was fully opened, then the electro pump was turned on; after a few minutes that the flow was stable the readings were made. In the submerged condition, after the formation of free flow, the gate at the end of the flume closed slowly so that the flow downstream of the gate was submerged. After stabilizing the depth of the downstream flow and making sure that the flow is stable, the data collection was done. The depth of the flow upstream and downstream of the gate was measured using a depth gauge with an accuracy of 0.1 mm.

3. Results and Discussion

3.1. Free flow

3.1.1. Effect of y_1/b on C_d

Figure 3 shows the changes of the flow coefficient against the ratio of the upstream depth of the gate to the width of the channel. According to the results, with the increase of y_1/b ratio, the discharge coefficient increased. For a constant flow rate, the upstream depth increases with the reduction of the gate opening, although the speed passing under the valve increases but the area of the flow passing under the gate is significantly reduced, which led to the reduction of the flow rate passing under the gate, so the flow coefficient increased. For the range of y_1/b changes from 0.5 to 3, the gate discharge coefficient for different flow rates changed from 0.35 to 0.7, which was about 2 times. Of course, with the increase of the flow rate entering the channel, the range of changes in the discharge coefficient decreased; for example, for a flow rate of 7 m^3/hr, the discharge coefficient changed from 0.4 to 0.56, which increased about 40%.

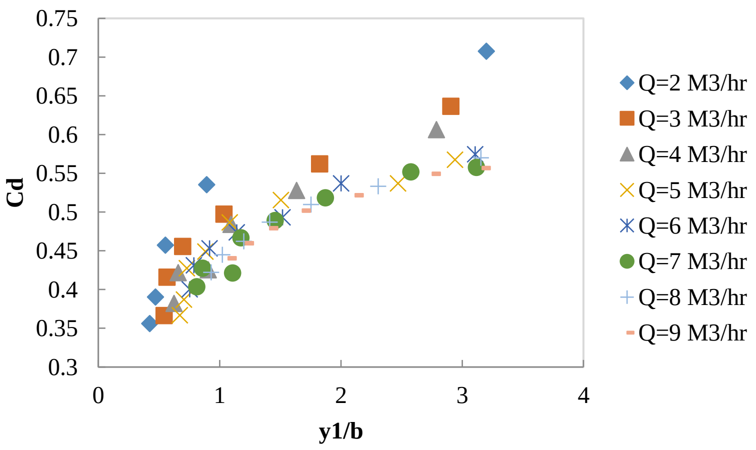


Figure 3. Variations of discharge coefficient against y_1/b in free flow conditions.

3.1.2. Effect of w/b on C_d

The changes of w/b against C_d for a constant slope showed that for a constant flow rate, the gate discharge coefficient decreased with the increase of the gate opening. For different flow rates, as w/b changed from 0.04 to 0.59, the discharge coefficient changed in the range of 0.7-0.36, which decreased almost 50%. For a constant inlet flow rate, with the increase of the gate opening, the area of the flow passing under the gate increases, which is more effective compare to decrease of the speed of the flow, and ultimately led to an increase in the flow rate passing under the gate, so the gate discharge coefficient decreased. According to Figure 4, for flow rates of 2, 3, 4, 5, 6, 7, 8, and 9 m^3/hr, the discharge coefficient decreased about 49%, 42%, 38%, 35%, 30%, 29%, 26%, and 21%, respectively.

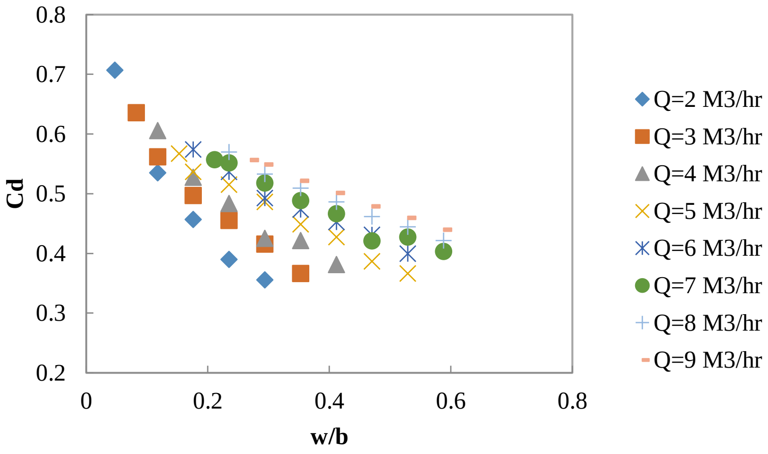


Figure 4. Variations of C_d against w/b under free flow conditions.

3.1.3. Effect of Fr_1 on C_d

Figure 5 is shown, variation of the gate discharge coefficient against the Froude number upstream of the gate, for a constant slope. The results showed that, with the increase of the Froude number, the discharge coefficient of the gate decreased. For a constant inlet flow rate, with increasing gate opening, the depth of flow upstream of the gate decreased and the flow velocity upstream of the gate increased, which resulted in an increase in the Froude number. The increase in Froude number and the increase in the cross-section of the flow passing under the gate led to an increase in the flow rate passing under the gate, which caused a decrease in the gate discharge coefficient. For different inlet flow rates, the range of Froude number changed from 0.02 to 0.5, which caused the reduction of gate discharge coefficient about 50%. According to Figure 5, changing the flow rate had no effect on the decreasing procedure of the gate discharge coefficient.

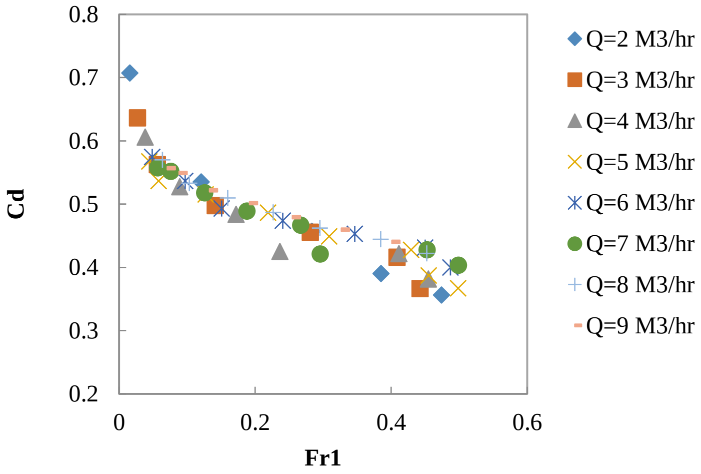


Figure 5. Variations of C_d against Fr_1 in free flow conditions.

3.1.4. Effect of bed slope (S) on C_d

Figure 6 shows the changes of discharge coefficient against bed slope for openings of 0.015, 0.025, and 0.035 m. Evaluation the results showed that, for a constant flow rate, increasing the slope of the channel had no effect on the gate discharge coefficient. With the increase of the gate opening, although the changes trend of the discharge coefficient was constant but its value decreased, because with the increase of the gate opening, the area of the passing flow increased. According to the results, the maximum value of the discharge coefficient for three gate openings, 0.015, 0.025, and 0.035 m was around 0.64, 0.62, and 0.59, respectively. Also, for a constant gate opening, the value of the discharge coefficient at zero slope was less than other values of the bed slope. When the amount of gate opening is low, by increasing the slope of the bed, there is a possibility of backwater due to conflict of the flow on the gate, and the passing flow through the gate decreased, which led to decrease of discharge coefficient.

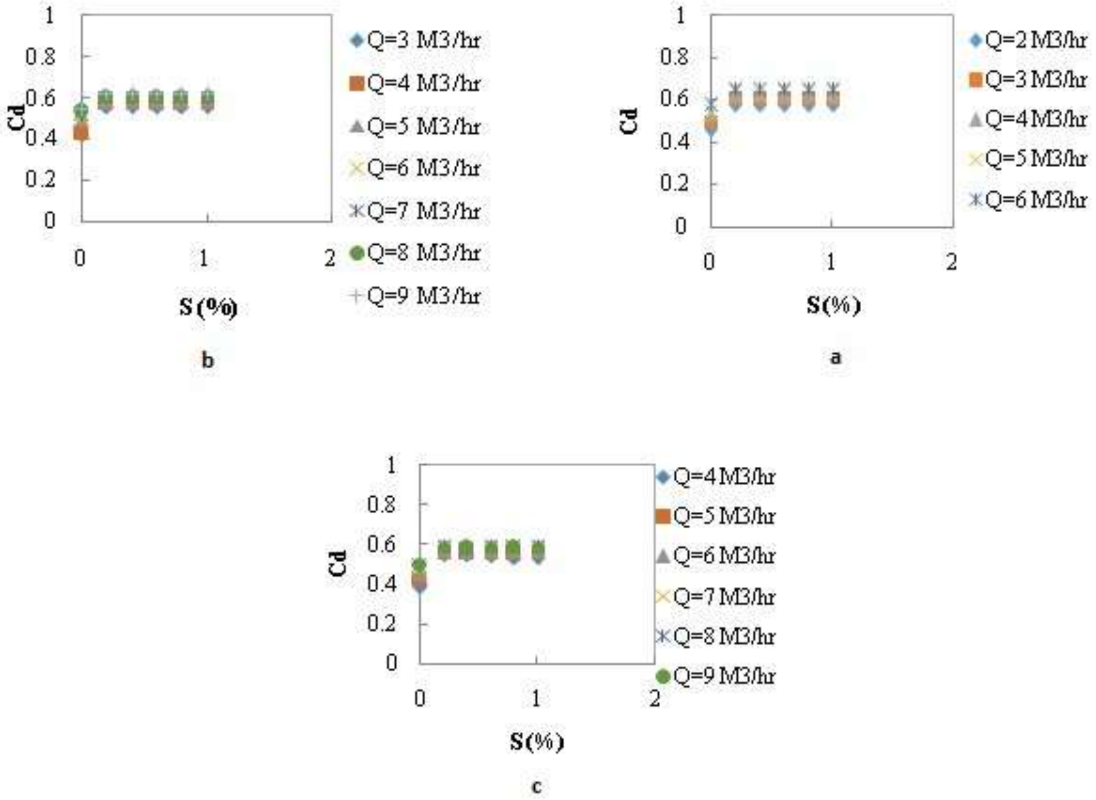
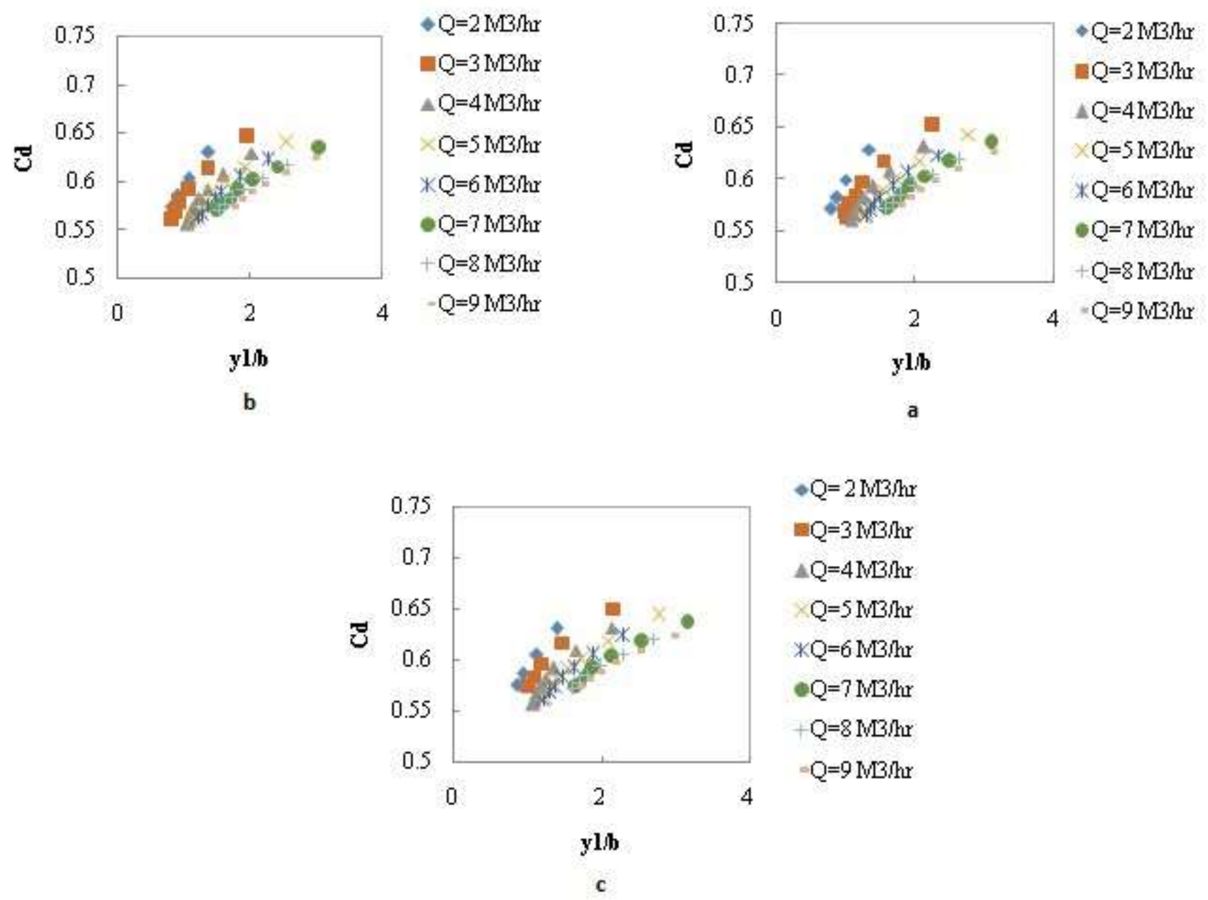


Figure 6. Variations of C_d against S a) gate opening 0.015 m, b) gate opening 0.025 m, c) gate opening 0.035 m.

3.2. Submerged flow

3.2.1. Effect of y_1/b on C_d

Figure 7 shows the changes of y_1/b against C_d for three bed slopes of 0, 0.4 and 0.8%. The results showed that for a specified inlet flow rate, with the reduction of the gate opening, the upstream depth of the flow increased, which resulted in an increase in the speed of the flow passing under the gate. Reducing the opening of the gate caused a decrease in the area of the flow passing under the gate, which was more effective compared to increase in the flow speed, and the flow rate passing under the gate decreased and the flow discharge coefficient increased. Evaluation of the results for different slopes showed that the change of slope had no more effect on the discharge coefficient, so that the maximum value of the discharge coefficient for slopes of 0, 0.4%, and 0.8% was around 0.65, 0.64, and 0.65, respectively.



b

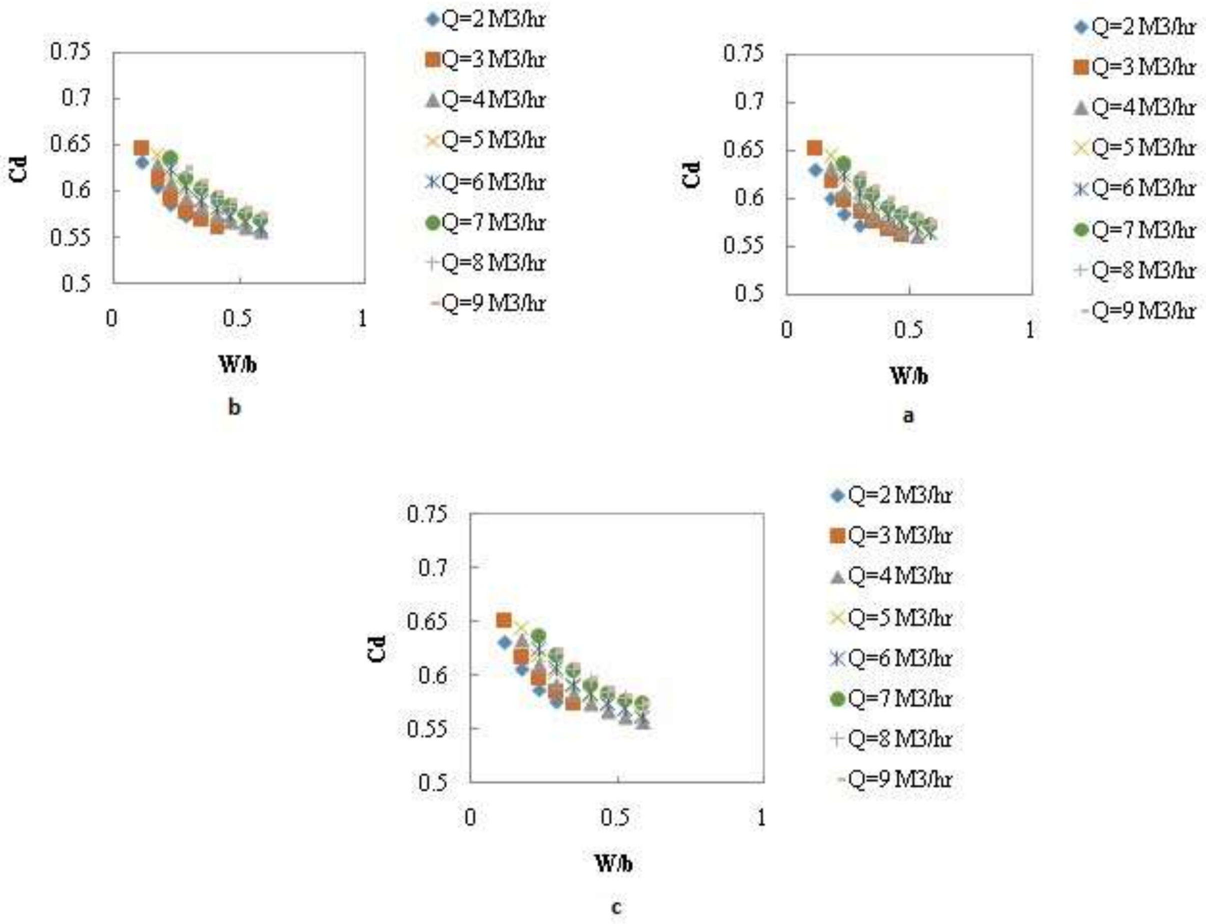
a

c

Figure 7. Variations of C_d against y_1/b a) bed slope zero, b) bed slope 0.4, c) bed slope 0.8.

3.2.2. Effect of w/b on C_d

Variations of w/b against C_d for different slopes showed that with the increase of the gate opening, the area of the flow passing under the gate increased but the flow speed decreased due to decrease of the depth upstream of the gate. Therefore, the flow rate passing under the gate increased, which caused the reduction of the gate discharge coefficient. Figure 8 shows the changes of C_d against w/b for different slopes. According to the results, the bed slope of the channel had no a considerable effect on the discharge coefficient, so that for three slopes of zero, 0.4, and 0.8% the range of changes of the discharge coefficient was in the range of 0.65-0.56, 0.64-0.56, and 0.65-0.56, respectively.



b

a

c

Figure 8. Variations of C_d against w/b a) zero bed slope, b) 0.4 bed slope, c) 0.8 bed slope.

3.2.3. Effect of Fr_1 on C_d

Figure 9 shows the changes of C_d against the upstream Froude number for different bed slopes. The results showed that for a constant flow rate, with the increase of the gate opening, the depth of the upstream flow decreased, so the upstream Froude number increased. Therefore, the increase of the upstream Froude number had a direct relationship with the opening of the gate, which caused an increase in the area of the flow passing under the gate and the flow rate passing under the gate, so the gate discharge coefficient decreased. According to the results, the trend and range of changes of C_d against Fr_1 for different slopes are similar, so changing the bed slope of the channel had no effect on the discharge coefficient. For example, amount of reduction of the gate discharge coefficient for Froude number changes in the range of 0.1 to 0.2 for zero, 0.4, and 0.8 slopes were about 7%, 8%, and 7%, respectively.

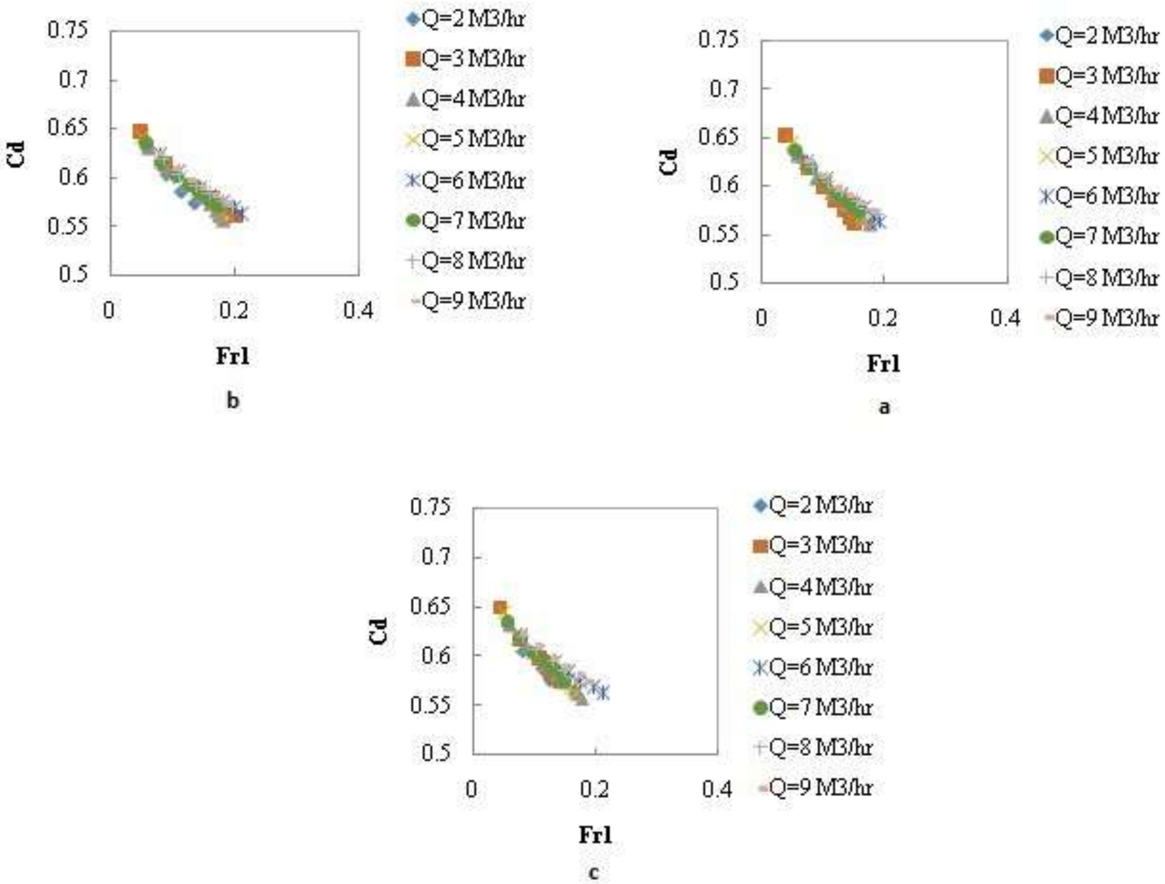


Figure 9. Variations of C_d against Fr_1 a) zero bed slope, b) 0.4 bed slope, c) 0.8 bed slope.

3.2.4. Effect of y_3/b on C_d

The results showed that for a constant gate opening, with the increase of y_3/b, the difference in the level of the upstream and downstream water levels decreased, resulting in a decrease in the speed of the flow passing under the gate and the flow rate passing through the gate decreased. Thus, the discharge coefficient of the gate increased. Also, by increasing the gate opening, the area of the gate opening and the flow rate passing under the gate increased, which led to reduce of the discharge coefficient of the gate. According to the results, the trend and range of C_d changes were similar for different slopes. For example, for three slopes of zero, 0.4, and 0.8%, the C_d increased and was in the range of 0.55-0.65 (Figure 10).

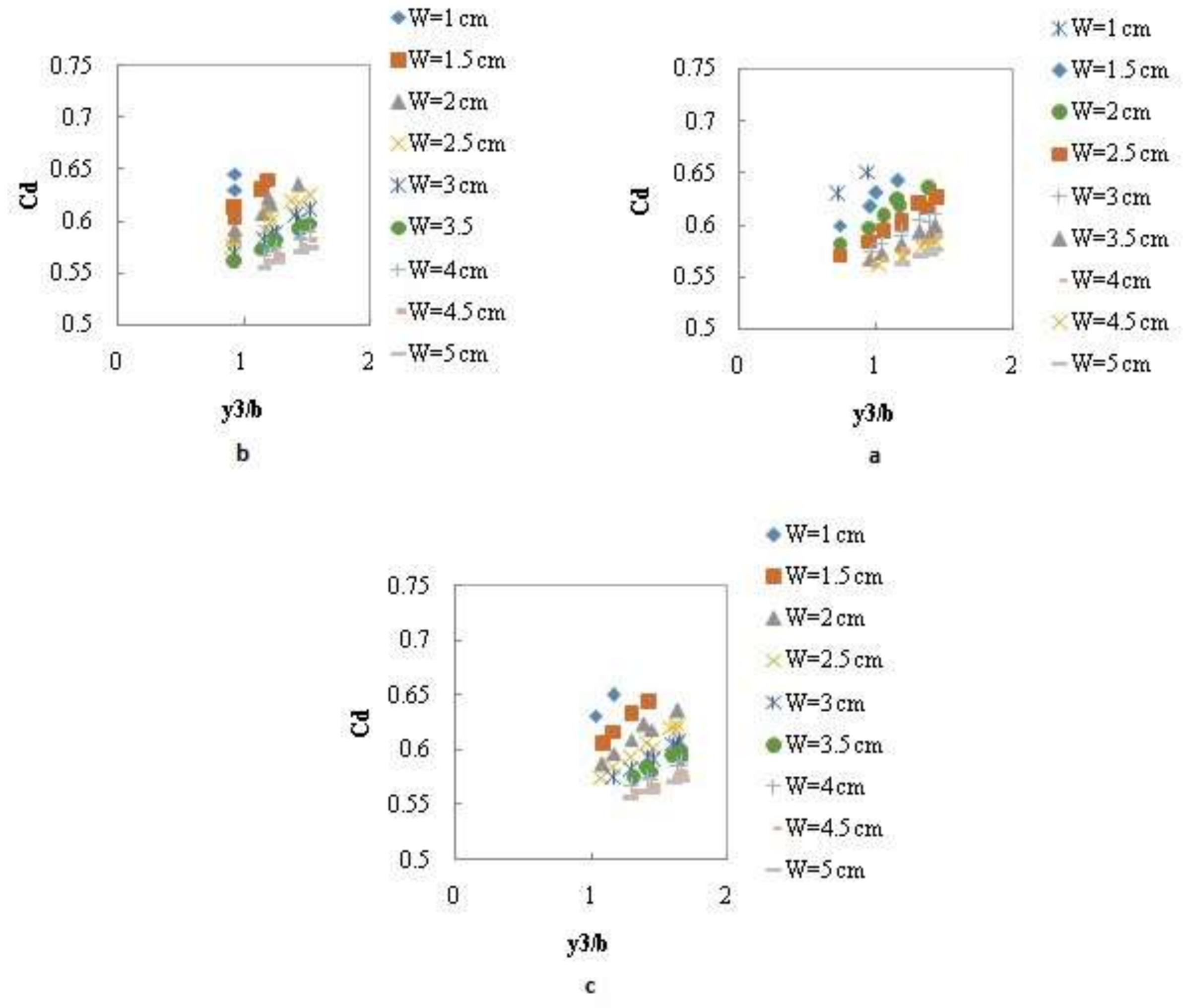


Figure 10. Variations of C_d against y_3/b a) zero bed slope, b) 0.4 bed slope, c) 0.8 bed slope.

3.2.5. Effect of S on C_d

The results showed that changing the bed slope of the channel had no effect on the gate discharge coefficient. For a constant bed slope, with the increase of the gate opening, the flow area and the flow rate passing through the gate increased, which resulted in a reduction of the discharge coefficient. Also, the evaluation of the results related to different flow rates showed that the change in the flow rate had no effect on the gate discharge coefficient and the variations of the C_d was insignificant because the flow rate and the upstream depth had limited changes, so the speed of changed slightly. For example, for a gate opening of 3 cm, for flow rates of 3, 6, and 9 m^3/hr, the gate discharge coefficient was 0.57, 0.59, and 0.61, respectively (Figure 11).

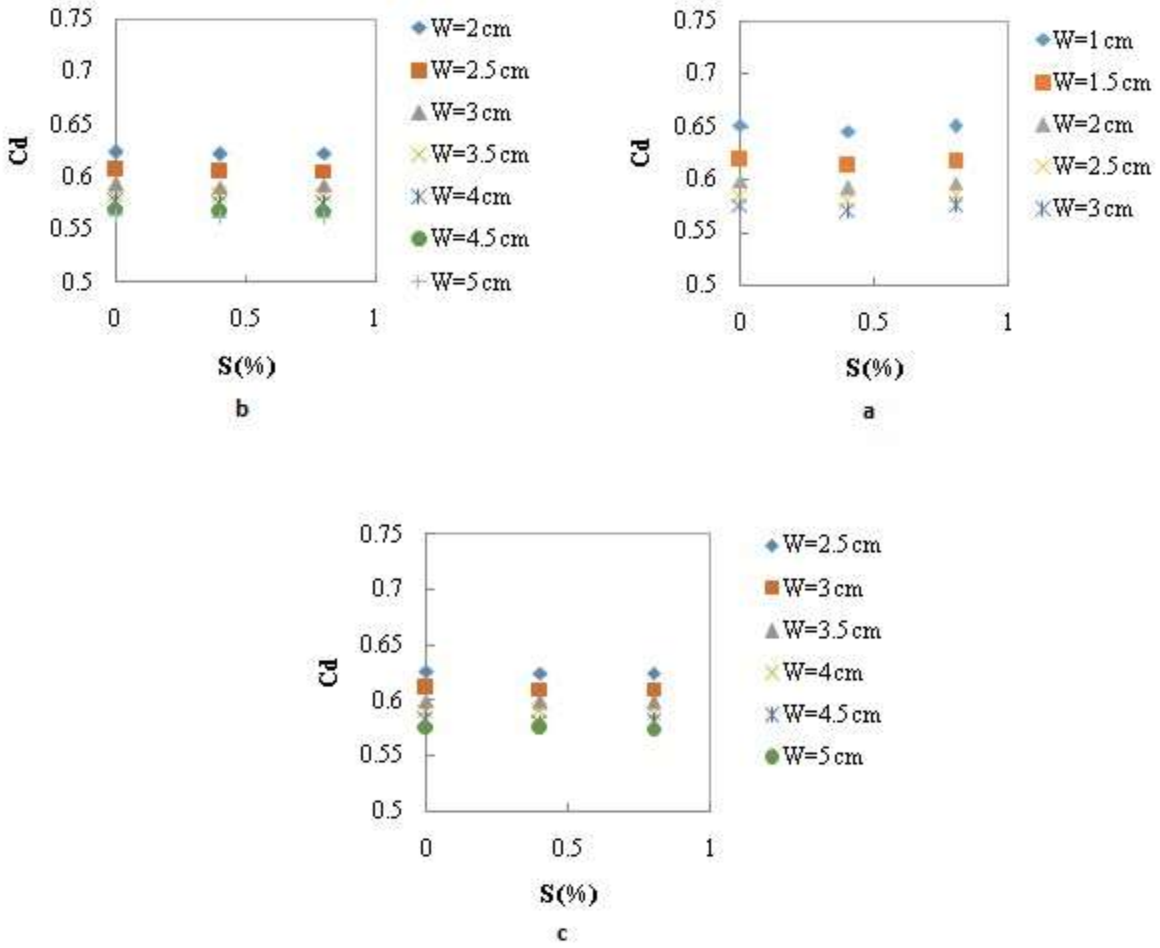


Figure 11. Variations of C_d against S a) flow rate of 3 m^3/hr, b) flow rate of 6 m^3/hr, c) flow rate of 9 m^3/hr.

3.3. Comparison with results of other researchers

The comparison of the results of the present research with the results of other researchers in the free and submerged flow conditions is shown in Figure 12. According to the figure, the results for free flow are in good agreement with the results of Henry (1950), so that for different ratios of y_1/w, the error was less than 7%. But the difference of the results with the comprehensive relationship of flow rate for the orifice, which can be used for gate, was more, so that the error for some ratios was around 20%, maybe it is because of that type of relationship that is dedicated to the orifice. For submerged flow conditions, the results showed a good agreement with the results of Rajaratnam and Subramanya (1967), and the error was equal or less than 10%. The results related to the free flow and submerged conditions were compared with the results of Henderson (1966) and Swamee (1992). According to Figure 12, the trend of discharge coefficient changes in the current research work is similar to the discharge coefficient changes in the study of Henderson (1966) and Swamee (1992) but the difference in the results is large. The reason is that in the equations presented by Henderson (1966) and Swamee (1992), the discharge coefficient in free and submerged flow conditions is a function of the contraction coefficient with the power of 1, while the power of other parameters involved in these equations are smaller than 1, and this indicates the great effect of the contraction coefficient. In these studies, the contraction coefficient for simple sluice gate was considered as 0.611, while for U-shaped sluice gates in U-shaped channels, no value of this coefficient was provided in different sources. Thus, in the result comparisons, for the U-shaped gate, 0.611 was considered, which caused this difference.

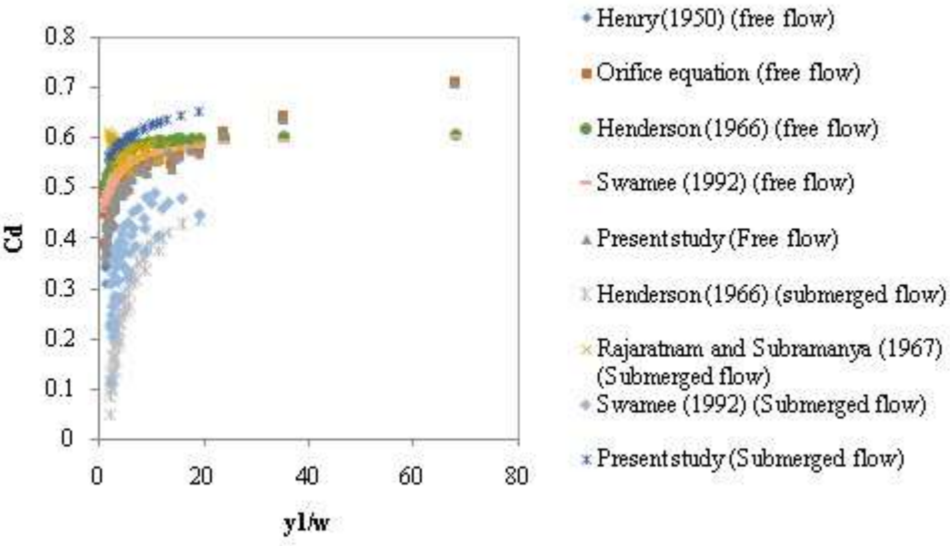


Figure 12. Comparison of results of discharge coefficient in free and submerged flow conditions with results of other researchers.

4. Conclusions

In this research work, the changes in the flow coefficient of the vertical sluice gate against different geometric and hydraulic parameters were investigated in a laboratory in the free and submerged flow conditions. The results related to the free flow conditions showed that for a constant flow rate, the upstream depth increases with the decrease of the gate opening, so the gate discharge coefficient increased. For a constant flow rate, the discharge coefficient decreased with the increase of gate opening. The discharge coefficient for different flow rates changed in the range of 0.7-0.36. An increase in the Froude number led to an increase in the flow rate passing under the gate, which caused a decrease in the gate discharge coefficient. For different inlet flow rates, the range of Froude number changes was from 0.02 to 0.5, which caused the reduction of gate discharge coefficient about 50%. Evaluation the results showed that for a constant flow rate, increasing the bed slope of the channel had no effect on the discharge coefficient of the gate. Of course, with the increase in the gate opening, although the trend of changing the discharge coefficient was constant but its value decreased. The results of submerged flow conditions showed that for a specified inlet flow rate, by reducing the gate opening, the area of the flow passing under the gate decreased, which resulted in an increase in the gate discharge coefficient. By increasing the gate opening, the area of the flow passing under the gate increased, so the flow rate passing under the gate increased, which caused the reduction of the discharge coefficient of the gate. The increase in the upstream Froude number had a direct relationship with the gate opening, which caused an increase in the flow rate passing under the gate and a decrease in the gate discharge coefficient. The amount of reduction of gate discharge coefficient for changes in Froude number in the range of 0.1-0.2 for zero, 0.4, and 0.8 bed slopes were about 7%, 8%, and 7%, respectively. Also, by increasing the gate opening, the flow rate passing under the gate increased, which led to decrease of the gate discharge coefficient. Analyzing the results showed that changing the bed slope of the channel had no effect on the flow coefficient of the gate. For a constant bed slope, with the increase of the gate opening, the flow rate passing through the gate increased, which resulted in a decrease in the discharge coefficient. Also, the comparison of the results of this research work with the results of other researchers showed a good agreement.

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