Proceedings of the Canadian Society for Mechanical Engineering International Congress 2021
CSME Congress 2021
June 27-30, 2021, Charlottetown, PE, Canada

A Sluice Gate Control Model to Maintain the Desired Downstream Depth by Controlling the Gate's Opening

Arash YoosefDoost[1*], William David Lubitz[1], Andrew Binns[1]
[1] School of Engineering, University of Guelph, Guelph, Canada
*YoosefDoost@Gmail.com

Abstract— Sluice gates are among the most common control structures used to control and/or measure the flow in open channels. In this study, a model is developed based on the Energy-Momentum method to control the sluice gate opening to maintain the desired downstream depth for a known upstream depth while a free hydraulic jump forms immediately after the gate. Evaluation of the model predictions with data from five lab experiments indicated a good accuracy for a wide range of channel widths (10 cm to 300 cm). Since the discharge coefficient is higher when the sluice gate operates under a free flow regime, this model can help operate sluice gates more efficiently. Moreover, by controlling the system to operate under free-flow, this model offers a simple solution to control sluice gates where the downstream depth is important, i.e., when several sluice gates are installed in series or in small/micro hydropower plants.

Keywords: Sluice Gate Opening Control, Downstream Depth, Free Flow, Discharge Coefficient

I. Introduction

Sluice gates are among the most common control structures in open channels [1] to control and/or measure the flow [2]. Sluice gates are important structures used to manage the condition and volume of flow in small/micro power plants. A channel controlled at its head by a gate is called a sluice, and a sluice gate is a movable gate allowing water to flow under it. Technically, a sluice gate could be defined as a bottom opening in a wall [1] similar to a sort of nozzle. In cases where a hydraulic jump forms, as the flow passes under the sluice gate, the subcritical flow upstream gradually accelerates to critical near the gap and goes to supercritical downstream. If the downstream "receiver" height is too high to keep the supercritical flow, flow "shocks" back to subcritical downstream of the gate [1]. Generally, flow through the sluice gates is categorized in free (F) and submerged (S) regimes. More details about distinguishing these two flow regimes are available in Section II. In addition, there are distinguishing condition curves that relate the upstream flow depth to the maximum tailwater depth [3].

Figure 1 shows the most important depths in a sluice gate system. Here, Y_U is the upstream depth, Y_G is the opening of the gate, Y_m is the minimum depth of flow after the sluicegate, Y_{J1} and Y_{J2} are the initial and secondary depth of the hydraulic jump and Y_D is the downstream depth.

For a specific discharge, ideally, the energy at sections U and m and the momentum at sections J1 and J2 are conserved. Therefore Y_U and Y_m are alternate depths and Y_{J1} and Y_{J2} are conjugate depths and can be calculated by the specific energy and momentum methods, respectively. The specific energy of cross-section i is defined as [4]:

$$E_i = Y_i + \frac{Q^2}{2gA_i^2} \tag{1}$$

Where Y_i is the depth of flow, A is the cross-sectional area, and Q is the volume flow rate (also called discharge).

There can be a supercritical and subcritical flow regime upstream and downstream of a hydraulic jump. This sets up a pair of depths that conserve momentum and are known as conjugate depths [4]. To form a hydraulic jump, the initial and secondary depths must satisfy the conjugate depth equation [5], so that

$$M_{J1} = M_{J2} \tag{2}$$

where M_i is the momentum function at $J1$ and $J2$ cross-sections. For any cross-sectional shape, at cross-section i, M_i is defined as [4]:

$$M_i = A_i\bar{Y}_i + \frac{Q^2}{gA_i} \tag{3}$$

where A is the cross-sectional area, $\bar{Y}$ is the depth of the centroid of the cross-sectional area from the top of the water surface, Q is the volume flow rate (also called discharge), and g is the gravitational constant (usually taken as 9.81 m/s^2).

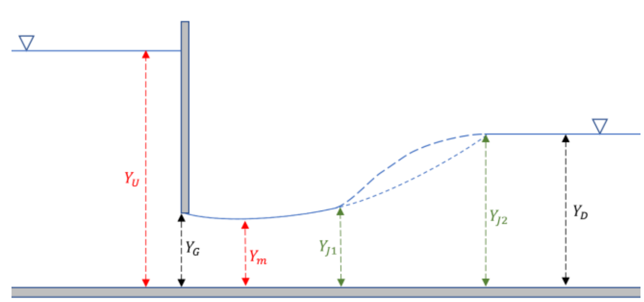

Figure 1. The important Depths in a Sluice Gate System

By definition, the contraction coefficient (C_c) is the ratio of the jet width to the orifice opening width [6] or the ratio of the cross-sectional area of the jet vena contracta to its opening area [7]. So, in a rectangular channel, it could be considered as the ratio of Y_m to Y_G. The other parameter that can be estimated by Figure 1 parameters is the sluice gate discharge coefficient (C_d) which is essential to estimate the volume of flow passing through the sluice gate (i.e., Eq. (5)). Therefore, many studies focus on determining the discharge coefficient (i.e., Eq. (6)). An early, significant study is Henry's 1950 experiment to estimate sluice gate discharge coefficient for free and submerged flows [8]. This study developed a relation between the gate discharge coefficient and the upstream water depth by neglecting energy losses and assuming a uniform velocity and a hydrostatic pressure distribution both upstream and at the vena contracta. Henry also provided a practical, widely-used graph of this relationship [8]. Figure 2 shows the rage of C_d for free and submerged flow regimes in sluicegates. Studies shows that C_d could be up to 0.611 [9]. According this figure the highest C_d occurs in the free flow regime.

In 1967 Rajaratnam and Subramanya used the energy-momentum (E-M) method to prove Henry's (1950) results [10]. In 1992, Swamee developed several relationships for free and submerged flows based on Henry's (1950) graph [9] to help prevent judgment errors when interpolating discharge coefficient curves and provide an analytical and/or numerical method for determining sluice gate discharge coefficient. Roth and Hager (in 1999) experimentally studied the effects of viscosity and surface tension on scaling the sluice gate operates in free-flow conditions. Their research included studies on contraction coefficient as well as other parameters such as the distribution of velocity and pressure on the gate and the channel bottom [11].

Lozano et al. in 2009 performed field studies on four rectangular sluice gates by measuring the water depth and gate opening values. They reported that the E-M method could give reasonable discharge estimations for three of the studied gates by calibrating the contraction coefficient. For the case that E-M method estimations were not satisfying, the sluice gate had a unique nonsymmetric flow condition and was located at the channel head [12].

Based on E-M equations, Habibzadeh et al. in 2011 applied a theoretical method to find an equation for the discharge coefficient of sluice gates in rectangular channels based on orifice-flow conditions applicable in both free and submerged flow conditions. In most sluice gate models, the energy losses are assumed negligible; however, Habibzadeh et al. reported that turbulent-related phenomenon causes significant energy loss for the submerged-flow condition. Besides, the recirculating region induces turbulence that results in energy loss in the upstream pool. They considered the magnitude of the energy-loss factor as a function of the sluice gate geometry and proposed that it could affect the discharge coefficient [13].

Due to the complexity of the submerged flow condition, many studies have focused on this topic. The submerged flow could be divided into two subcategories: 1. low and 2. high submerged regimes [3]. In 2011, Habibzadeh et al. proposed an equation to calculate a parameter called "transitional value of tailwater depth," based on several factors, including the contraction coefficient, upstream flow depth, gate's opening and the energy loss factor, which was considered 0.062. The free-flow regime is expected for downstream water depths with less than this value, while a submerged flow regime would be expected for higher downstream depths. They also proposed the "submergence ratio" as a function of the transitional value of tailwater depth and downstream depth. The flow is considered low submerged for submergence ratios between 0 to 20 and considered high submerged for values more than this range [13].

Castro-Orgaz et al. in 2010 proposed that for high submergence situations, the common E-M method is not practical. They proposed a new equation for submerged flow based on the energy-momentum method principles by applying correction factors on velocity and momentum [14]. However, in 2012 Bijankhan et al. showed this method has significant errors when the submergence is not significant [3]. In 2013, Castro-Orgaz et al. published a revised version of their 2010 research on estimating sluice gate discharge in submerged conditions [15].

Reviewing the studies about the flow through sluice gates under submerged conditions indicates that more investigations are needed to understand this phenomenon better. Generally, equations developed for submerged conditions associated with the discharge through the sluice gate to the tailwater depth. However, the accuracy of many of these equations is questionable when the width of the gate and channel is significantly different or when several gates are installed in series [16].

In this study, a model is developed to use for controlling the sluice gate opening to maintain the desired downstream depth for a known upstream depth while a free hydraulic jump forms immediately after the gate. This model controls the flow conditions to avoid the occurrence of the submerged flow after the sluice gate. Since the discharge coefficient is higher when the sluice gate operates under a free flow regime, this model helps operate sluice gates more efficiently. Since the discharge coefficient is higher when the sluice gate operates under a free flow regime, this model can be used to help operate sluice gates more efficiently. By controlling the system to operate under just one possible scenario (free hydraulic jump exactly after the

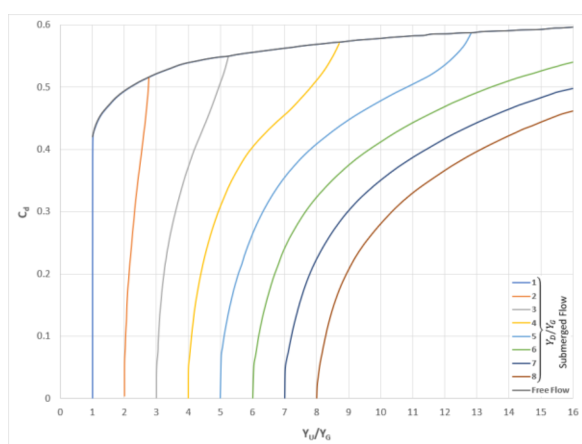

Figure 2. Range of C_d for free and submerged flow regimes in sluice gates. Adapted from [9]

sluice gate), this model avoids the uncertainties of the submerged flow regime. It also offers a simple solution to control the flow depths after sluice gates when several sluice gates are installed in series and/or in small/micro hydropower plans that controlling the inlet depths of turbines are important.

II. Methods & Materials

A. Theoretical Analysis

In sluice gates, some channel conditions can affect where the conjugate depths form. Downstream controls such as tailwater depth can strongly influence the jump formation location. Also, changing the tailwater depth can affect the jump upstream or downstream [5]. This leads to three possible scenarios where the hydraulic jump after the sluice gate is affected and could be controlled by the opening of the sluice gate (Y_G) and downstream water level (Y_D).

a) Instant[1] Free Hydraulic Jump (IFHJ)

Ideally, a hydraulic jump can form exactly after the gate if Y_D is the conjugate depth of the gate's opening or $Y_G = Y_{J1}$ and $Y_D = Y_{J2}$. In this situation, the downstream water level does not control the phenomenon [5]. This scenario is represented in Figure 3 [17]

b) Delayed[2] Free Hydraulic Jump (DFHJ)

As demonstrated in Figure 4 [17], if the downstream depth (tailwater depth) is less than the conjugate depth of the opening of the gate ($Y_D < Y_{J2}$), tailwater depth affects the flow regime after the gate (imposes some control), and the hydraulic jump moves downstream. In this case, after the gate's flow depth rises (and velocity decreases) because of frictional resistance until it reaches the new depth of $Y_{1J}^{'}$ which is the conjugate depth of the downstream depth ($Y'_{2J} = Y_D$). In other words, a free hydraulic jump initiates where the flow depth after the sluice gate would be the conjugate depth of the downstream depth. Therefore, the hydraulic jump initiates when the flow depth after the sluice gate rises enough from Y_G to Y'_{J1} which is the conjugate depth of the $Y_D = Y'_{J2}$ [5]. This scenario and its comparison with the former are represented in Figure 4 [17].

c) Submerged Hydraulic Jump (SHJ)

As demonstrated in Figure 5, if the downstream tailwater depth is more than the conjugate depth of the sluice gate opening ($Y_D > Y_{J2}$), the downstream depth controls the flow by forcing it to elevate to a depth above the original conjugate depth (Y_{J2}). Therefore, for $Y_D > Y_{J2}$ the jump would be pushed upstream, but the sluice gate prevents this, so the upstream conjugate depth cannot be reached, and a submerged (drowned) hydraulic jump forms [5].

B. Model Development

Technically, it is possible to control the downstream depth of sluice gates by trial and error. However, many possible scenarios and combinations make this approach not practical for designers or to generalize each experiment's results for different scales or to cover all possible scenarios. Since it is not easy to consider all possibilities in a design, it is a good idea to manage the system to run under a desired and predictable condition.

To develop a model for managing the sluice gate to estimate the required gate opening to maintain desired downstream depth for known upstream depth, three assumptions were considered: 1. The important factors that govern the flow in a sluice gate system are Y_U, Y_G and Y_D, 2. Ideally, when a free hydraulic jump forms exactly after the sluice gate, the downstream depth has no control on the flow and 3. An IFHJ forms when the downstream depth is the conjugate depth of the gate's opening.

These assumptions offer the advantage of minimizing the effective factors that need to be controlled to manage the system. Additionally, the problem is simplified by avoiding the uncertainties of SHJ and extra calculations for DFHJ. Therefore, the problem could be treated as a "what…if…" question, as in "what would be the opening of the sluice gate for a known upstream and desired downstream depth if there is an IFHJ after the sluice gate?" Offering such a controlled condition makes this model practical for applications such as when more than one sluice gate is installed in series by managing the system's possible scenarios during operation. Moreover, according to Figure 2, the highest values for C_d occurs in the free flow

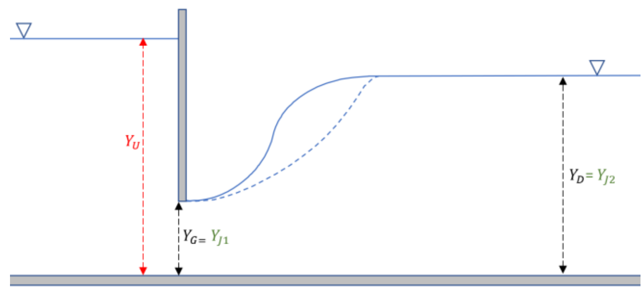

Figure 3. Instant Free Hydraulic Jump ($Y_D = Y_{J2}$)

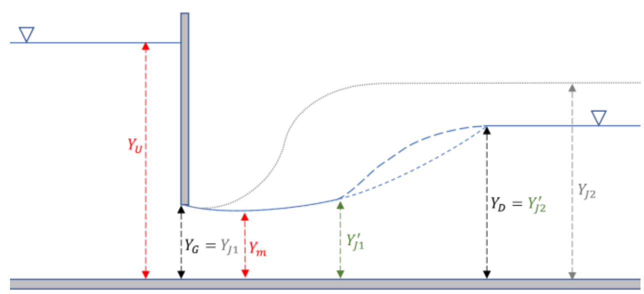

Figure 4. Delayed Free Hydraulic Jump ($Y_D < Y_{J2}$)

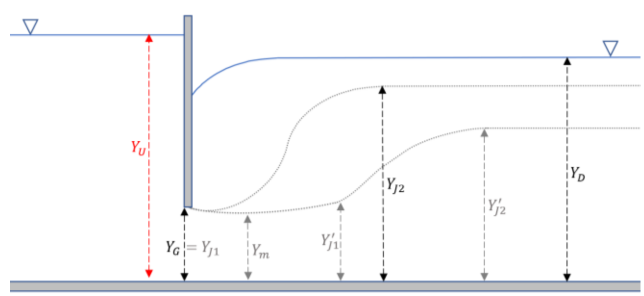

Figure 5. Submerged (Drowned) Hydraulic Jump ($Y_D > Y_{J2}$)

[1,2] These names are just to distinguish free hydraulic jump scenarios.

regime. Since this model manages the sluice gate to run under free flow, higher C_d values could be achieved.

As discussed, downstream depth has no effect when the sluice gate operates under a free flow regime. However, the system could be controlled by a desired downstream depth because if $Y_G = Y_{J1}$, ideally, a free hydraulic jump forms after the gate if $Y_D = Y_{J2}$. Such an approach makes it possible to rewrite Eq.(2) to solve for the sluice gate opening and downstream cross-sections as $f(Y_U, Y_G, Y_D)$. The rectangular cross-section is the most common in open channels, especially for sluices. Therefore, by assuming a rectangular channel with a constant width (b) and defining the unit discharge $q = Q/b$, and knowing that the centroid of a flow at depth Y in a rectangular channel is located at $\overline{Y} = Y/2$, this equation can be written as:

$$Y_G = \frac{2\,q^2}{Y_G Y_D g} - Y_D \tag{4}$$

Conventionally, for a rectangular channel, the sluice gate discharge is assumed to be a function of upstream depth (Y_U), gate's opening (Y_G), width (b) and the sluice gate discharge coefficient [9]:

$$Q = C_d Y_G b\sqrt{2gY_U} \tag{5}$$

One of the earliest and most-studied equations for calculating C_d with a good agreement with the experimental data is was presented by Swamee [9]:

$$C_d = 0.611\left(\frac{Y_U - Y_G}{Y_U + 15Y_G}\right)^{0.072} \tag{6}$$

Combining Eq. (4) with the unit discharge form of Eq. (5) and Eq. (6) leads to the following equation, which is just a function of Y_U, Y_G and Y_D and enables estimation of Y_G for a known Y_U and a desired Y_D:

$$Y_G = 1.4932\,\frac{Y_U Y_G}{Y_D}\left(\frac{Y_U - Y_G}{Y_U + 15Y_G}\right)^{0.144} - Y_D \tag{7}$$

Solving the model represented as Eq. (7) makes it possible to control the system to achieve IFHJ by managing the sluice gate opening to maintain the desired downstream depth. Also, it enables estimation of the required value of either of Y_U, Y_G or Y_D to maintain IFJH if the value of the other two is known. On top of that, Eq. (7) can be solved easily with a simple arithmetic calculation.

To study on this equation, a computer model was developed to solve it for all possible combinations of upstream and downstream depths. This computer model can solve the same problem with E-M method. This model was used to generate results for sluice gates with the same width as the models described for each lab experiment from the literature. Then the model estimations were validated with the real measurements of these lab experiments.

C. Validation Criteria

The accuracy of the developed model was validated with measurements from five lab experiments [8], [10], [16], [18], [19], which collectively cover rectangular channel widths between 10 cm to 300 cm. To compare the model results (estimations) with the lab experiments (measurements), a combination of visualizations and statistical tests were used. The correlation was evaluated by Pearson correlation, and error was measured using mean error percentage and mean absolute error percentage. In all the following equations, M_i is the measured (observed) value, E_i is the estimated value, $\overline{M}$ is the average of the observational data, $\overline{E}$ is the average of the estimated data, and n is the number of data in the dataset [20].

In statistics, correlation refers to any statistically significant relationship between two variables. The Pearson correlation coefficient measures the linear relationship between two random variables [21] and describes it in a range between -1 to +1. Values close to +1 indicate a fair and direct correlation, while values closer to -1 refer to a good but inverse relation between datasets. Values near zero indicate a lack of correlation [22]. The Pearson correlation is defined as [23]:

$$R = \frac{\sum_{i=1}^{n}(M_i - \overline{M})(E_i - \overline{E})}{\sqrt{\sum_{i=1}^{n}(M_i - \overline{M})^2}\sqrt{\sum_{i=1}^{n}(E_i - \overline{E})^2}} \tag{8}$$

The mean percentage error (MPE) is the average of percentage errors that a model calculates different from the measured values. MPE is defined as [24]:

$$\text{MPE} = \frac{100}{n}\sum_{i=1}^{n}\frac{E_i - M_i}{M_i} \tag{9}$$

The mean absolute percentage error (MAPE) is the average of absolute percentage errors and one of the most common accuracy measures [25] that is recommended in many textbooks (e.g. [24], [26]). MAPE is calculated as:

$$\text{MAPE} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{E_i - M_i}{M_i}\right| \tag{10}$$

III. Results and Analysis

The model was used to calculate the sluice gate relative openings needed to maintain desired downstream depths for sluice gates connected to channels with the same widths as used in the lab experiments in Refs. [10], [16], [18], [19] (range from 10 cm to 45.72 cm). The 300 cm wide channel model results were validated with the graph published based on the work of Henry [8], which is a well-known publication that is referenced by many studies on the flow through sluice gates. The developed model estimates the required Y_G for a desired Y_D and known Y_U. Since the available experimental data are reported as the relative C_d of Y_U/Y_G, the model estimations were translated into the form of the discharge coefficient using Eq. (6). Results of the

Table 1. Validation of the Accuracy of Model Estimations by Comparing C_D

Experiment Name	R	MPE (%)	MAPE (%)
Barghi [16]	0.986	2.01	2.01
Sawari [18]	0.936	-0.56	2.17
Alhamid [19]	0.933	3.81	3.81
Rajaratnam[10]	0.976	2.85	2.85
Henry [8]	0.994	1.20	1.20

validation process are represented in Table 1 and Figure 6.

Examining Figure 6 and noting that these graphs are over-zoomed to facilitate the comparison of model and experiments, the results indicate an excellent agreement between the estimations and the actual measurements for all cases. Table 1 indicates a similar conclusion, while even for the worst case, a high correlation of 0.93 and 3.86% of MPE and MAPE is observable.

IV. CONCLUSION

The main goal of this study was to develop a model to manage the system so that ideally, a hydraulic jump forms exactly at the apron and controls the flow to maintain the desired downstream water depth. This approach reduces the uncertainties by preventing the system from forming a submerged hydraulic jump.

The model was developed based on the Energy-Momentum method and the simplest equations to estimate the required Y_G to maintain IFHJ and a desired Y_D for a known Y_U. Results of this model were validated using five experiments. Results indicate a good accuracy of the developed model estimations for a wide range of channel widths (10 cm to 300 cm). Even in the worst case, model estimations indicate a high correlation (0.933) and low mean absolute percentage error (3.81%).

Controlling sluice gates to operate under free flow keeps the model as simple as possible for different applications and/or future developments and offers more discharge coefficient. The model developed here could facilitate managing the system when more than one sluice gate is installed in series by managing the possible system scenarios during operation. It offers a simple solution to manage and control the flow depths after sluice gates in small/micro hydropower plans and/or when several sluice gates are installed in series. The future work of this study is to develop an easier to use equation with acceptable accuracy for the same purpose.

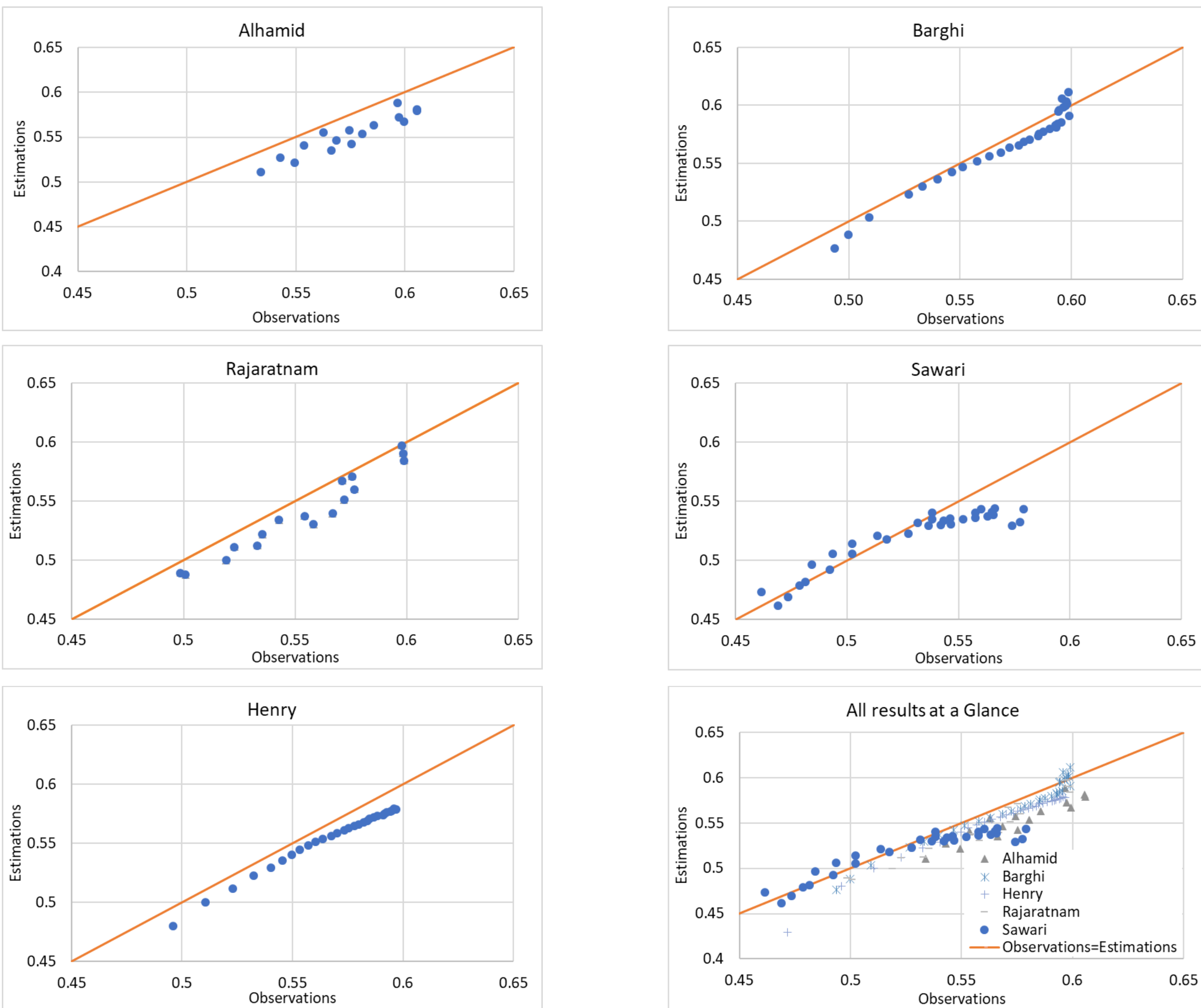

Figure 6. Comparison of Estimated Discharge Coefficient from Model with observations from five other experiments

NOTATION

The following symbols and abbreviations are used in this paper:

A_i	:	Area of cross-section i	(m^2)
b	:	Width of the channel/sluice gate	(m)
C_C	:	Contraction coefficient	(-)
C_d	:	Coefficient of discharge (discharge coefficient)	(-)
$DFHJ$	:	Delayed free hydraulic jump ($Y_D < Y_{J2}$ scenario)	
E_i	:	Specific energy of the cross-section i	
$E-M$	:	Energy-Momentum method	
g	:	Gravitational constant	(9.81 m/s^2)
$IFHJ$	:	Instant free hydraulic jump ($Y_D = Y_{J2}$ scenario)	
M_i	:	Momentum function of the cross-section i	
$MAPE$	:	Mean absolute percentage error	(%)
MPE	:	Mean percentage error	(%)
Q	:	Volume flow rate (discharge)	(m^3/s)
q	:	Unit discharge ($q = Q/b$)	(m^2/s)
R	:	Pearson correlation	
SHJ	:	Submerged hydraulic jump ($Y_D > Y_{J2}$ scenario)	
Y_D	:	Downstream depth	(m)
Y_G	:	Gate's opening	(m)
Y_i	:	Depth of flow at the cross-section i	(m)
$\bar{Y}_i$	:	Depth of the centroid of the cross-sectional area from the top of the water surface for the cross-section i	(m)
Y_{J1}	:	Initial depth of hydraulic jump	(m)
Y'_{J1}	:	The flow depth after the sluice gate that is raised enough the be the conjugate depth of the downstream in the DFHJ scenario	(m)
Y_{J2}	:	Secondary depth of hydraulic jump	(m)
Y'_{J2}	:	The conjugate depth of Y_{J1}' in DFHJ scenario	(m)
Y_m	:	The minimum depth of flow after the sluicegate	(m)
Y_U	:	Upstream depth	(m)

REFERENCES

[1] F. M. White, *Fluid Mechanics*, 7th ed. New York: McGraw-Hill, 2011.

[2] C. O. Silva and M. Rijo, "Flow Rate Measurements under Sluice Gates," *J. Irrig. Drain. Eng.*, vol. 143, no. 6, p. 06017001, 2017, doi: 10.1061/(asce)ir.1943-4774.0001177.

[3] M. Bijankhan, V. Ferro, and S. Kouchakzadeh, "New stage-discharge relationships for free and submerged sluice gates," *Flow Meas. Instrum.*, vol. 28, pp. 50–56, Dec. 2012, doi: 10.1016/j.flowmeasinst.2012.07.004.

[4] G. E. Moglen, *Fundamentals of Open Channel Flow*. Boca Raton, London, New York: CRC Press (Tylor & Francis Group), 2015.

[5] M. H. Chaudhry, *Open-Channel Flow*, 2nd ed. Boston, MA: Springer US: Springer, 2008.

[6] N. D. Katopodes, "Ideal Fluid Flow," in *Free-Surface Flow*, Oxford, United Kingdom: Elsevier, 2019, pp. 428–515.

[7] AMS, "Contraction coefficient - Glossary of Meteorology," *American Meteorological Society*, 2012. https://glossary.ametsoc.org/wiki/Contraction_coefficient (accessed Jan. 26, 2021).

[8] R. Henry, "Discussion to 'On submerged jets,'" *Trans. Am. Soc. Civ. Eng.*, vol. 115, pp. 687–694, 1950, [Online]. Available: https://books.google.ca/books?id=noJBAQAAIAAJ.

[9] P. K. Swamee, "Sluice-Gate Discharge Equations," *J. Irrig. Drain. Eng.*, vol. 118, no. 1, pp. 56–60, Jan. 1992, doi: 10.1061/(asce)0733-9437(1992)118:1(56).

[10] N. Rajaratnam and K. Subramanya, "Flow equation for the sluice gate," *J. Irrig. Drain. Div.*, vol. 93, no. 3, pp. 167–186, 1967.

[11] A. Roth and W. H. Hager, "Underflow of standard sluice gate," *Exp. Fluids*, vol. 27, no. 4, pp. 339–350, Sep. 1999, doi: 10.1007/s003480050358.

[12] D. Lozano, L. Mateos, G. P. Merkley, and A. J. Clemmens, "Field Calibration of Submerged Sluice Gates in Irrigation Canals," *J. Irrig. Drain. Eng.*, vol. 135, no. 6, pp. 763–772, Dec. 2009, doi: 10.1061/(asce)ir.1943-4774.0000085.

[13] A. Habibzadeh, A. R. Vatankhah, and N. Rajaratnam, "Role of Energy Loss on Discharge Characteristics of Sluice Gates," *J. Hydraul. Eng.*, vol. 137, no. 9, pp. 1079–1084, Sep. 2011, doi: 10.1061/(asce)hy.1943-7900.0000406.

[14] O. Castro-Orgaz, D. Lozano, and L. Mateos, "Energy and Momentum Velocity Coefficients for Calibrating Submerged Sluice Gates in Irrigation Canals," *J. Irrig. Drain. Eng.*, vol. 136, no. 9, pp. 610–616, Sep. 2010, doi: 10.1061/(asce)ir.1943-4774.0000233.

[15] O. Castro-Orgaz, L. Mateos, and S. Dey, "Revisiting the Energy-Momentum Method for Rating Vertical Sluice Gates under Submerged Flow Conditions," *J. Irrig. Drain. Eng.*, vol. 139, no. 4, pp. 325–335, Apr. 2013, doi: 10.1061/(asce)ir.1943-4774.0000552.

[16] A. Barghi Khazerloo, H. Khalili Shayan, J. Farhoudi, and A. R. Vatankhah, "Developing a New Method for Estimating of Discharge Coefficient of Sluice Gates under Free and Submerged Flow Conditions," *Water ans Soil Sci. (In Persian)*, vol. 26, no. 1, pp. 207–221, 2016.

[17] W. J. Kingston, "Effect of Tailwater Elevation on Jump Location," *Wikimedia Commons*, Nov. 05, 2011. https://en.wikipedia.org/wiki/File:Effect_of_Tailwater_Elevation_on_Jump_Location.png (accessed Nov. 27, 2020).

[18] H. Sawari, "The impact of baffle distance on the baffle gate distributors," University of Tehran, Tehran, Iran (in Persian), 2010.

[19] A. A. Alhamid, "Coefficient of Discharge for Free Flow Sluice Gates," *J. King Saud Univ. - Eng. Sci.*, vol. 11, no. 1, pp. 33–47, 1999, doi: 10.1016/S1018-3639(18)30989-9.

[20] A. YoosefDoost and W. D. Lubitz, "Development of an Equation for the Volume of Flow Passing Through an Archimedes Screw Turbine," in *Sustaining Tomorrow*, D. S.-K. Ting and A. Vasel-Be-Hagh, Eds. Cham, Switzerland: Springer, Cham, 2021, pp. 17–37.

[21] J. Lee Rodgers and W. A. Nicewander, "Thirteen Ways to Look at the Correlation Coefficient," *Am. Stat.*, vol. 42, no. 1, pp. 59–66, Feb. 1988, doi: 10.1080/00031305.1988.10475524.

[22] A. Yoosefdoost, I. Yoosefdoost, H. Asghari, and M. S. Sadeghian, "Comparison of HadCM3 , CSIRO Mk3 and GFDL CM2 . 1 in Prediction the Climate Change in Taleghan River Basin," *Am. J. Civ. Eng. Archit.*, no. March, 2018, doi: 10.12691/ajcea-6-3-1.

[23] J. Adler and I. Parmryd, "Quantifying colocalization by correlation: The pearson correlation coefficient is superior to the Mander's overlap coefficient," *Cytom. Part A*, vol. 77, no. 8, pp. 733–742, Aug. 2010, doi: 10.1002/cyto.a.20896.

[24] J. E. Hanke and D. Wichern, *Business Forecasting*, 9th ed. Prentice Hall, 2009.

[25] S. Kim and H. Kim, "A new metric of absolute percentage error for intermittent demand forecasts," *Int. J. Forecast.*, vol. 32, no. 3, pp. 669–679, Jul. 2016, doi: 10.1016/j.ijforecast.2015.12.003.

[26] B. L. Bowerman, R. T. O'Connell, and A. B. Koehler, *Forecasting, Time Series, and Regression: An Applied Approach*. Thomson Brooks/Cole, 2005.