Al-Rafidain Journal of Engineering Sciences

Journal homepage https://rjes.iq/index.php/rjes

ISSN 3005-3153 (Online)

Experimental Measurement of the Discharge Coefficient for the Inclined Sluice Gates

Noor D. Salah[1], Wesam S. Mohammed-Ali [2]

[1] Civil Engineering Department, College of Engineering, Tikrit University, Tikrit 34001, Iraq
[2] Environmental Engineering Department, College of Engineering, Tikrit University, Tikrit 34001, Iraq

ARTICLE INFO

Article history:
Received 09 July 2025
Revised 11 July 2025
Accepted 27 July 2025
Available online 28 July 2025

Keywords:
Inclined sluice gate
height of sluice gate
coefficient of discharge
Free flow
Hydraulic structures

ABSTRACT

Sluice gates are hydraulic devices that regulate channel discharge or redirect water flow from primary to secondary channels. These gates may be positioned in many ways; Some gates are vertical, whereas others are tilted either in the direction of flow or against it, contingent upon their special design function. In this study, several models of sluice gates were considered in different positions in the direction of flow and against it. The sluice gate angles considered were 10°, 20°, 30°, 40°, and 45° in the direction of flow and against flow direction under free flow condition, with the reference position set at 90°, the study was examined how the inclination of the gate influence the amount of discharge coefficient and how the discharge coefficient was affected by the variation in upstream water depth and gate opening height, where the four gate opening heights were (1, 2, 3, and 4) cm. The aim of this research is to determine the discharge coefficient under inclined sluice gates in different positions; furthermore, a general equation of free flow under inclined sluice gates has been established. According to the findings, the discharge coefficient (Cd) increases as the inclination angle of the sluice gate in the direction of flow increases and decreases as the inclination angle of the sluice gate against the direction of flow increases. Also, increasing the gate opening (h) will reduce the discharge coefficient (Cd) to pass the same amount of water through the sluice gate. Finally, empirical equations were derived linking the discharge coefficient values passing under the vertical and incline sliding gates for various openings and conditions using the non-linear regression analysis in (SPSS) program. Additionally, the statistical indices (R2) and Nash–Sutcliffe efficiency (NSE) were used to test the reliability of these equations, and their results for the vertical sluice gate was 0.9868, 0.9766, the incline sluice gate with flow was 0.9897, 0.950 and the incline sluice gate against flow was 0.9793, 0.940 respectively. The analytical approach for estimating the coefficient of discharge under the vertical and inclined sluice gates showed a great fit with experimental findings.

1. Introduction

Life, ecological support, economic, and social progress are all dependent on water. Considering the climatic issues and the rising demand for water, Sustainable management of water resources is crucial, particularly in areas that are dry or mostly dry. Therefore, one of the most common ways to manage water and govern its distribution is through hydraulic structures, which play an important role in flood control and irrigation systems.

Sluice gates are an essential part of these facilities because they allow for highly precise flow and water output control by decreasing waste and increasing the effectiveness of distribution[1]. Among the engineering developments in the design of these gates is the design of the inclined sluice gate, which modifies the flow characteristics beneath the

Corresponding author E-mail address: nd230073en@st.tu.edu.iq
https://doi.org/10.61268/2fjyq340

gate by providing an inclination angle, deviating from the typical vertical form[2].

Since the discharge amount can be precisely estimated using the discharge coefficient, it is one of the most significant hydraulic statistics when evaluating flow under gates [3]. The gate's inclination angle and height directly affect the values of this coefficient, making its study essential for improving the design and operation efficiency of inclined gates in open channels [4] . These gates manage the water flow in channels, sluices, or rivers and are typically encountered in structures that controlled flood, dam outputs, and irrigation systems, and to improve water flow via the auxiliary channels by raising the level of water upward of the major canals, in addition to eliminate sediments at the canal's upstream that may have accumulated [5] . A theoretical overview of open channel flows and a sluice gate's upstream effect was published in several studies involving laboratory testing and theoretical methods conducted to ascertain the discharge coefficient. By solving the (Ordinary Differential Equations) and finding the values of the contraction and discharge coefficients (Cc, Cd), the hydraulics of flow via a gate was investigated [6]. Early study using a rectangular laboratory flume, the discharge coefficient of a gate for both free and submerged flow was studied experimentally. A total of 37 experiments were performed (submerged flow), and 20 experiments were conducted (free flow). The study examined the correlation between the discharge coefficient and the fluctuations in flow depths both upstream and downstream of the gate resulting in the formulation of an empirical equation [7]. Several research used the finite element method to theoretically examine the hydraulics of flow-exiting gates, and computer software was used to apply the results. the findings of these investigations demonstrated a remarkable capacity to reproduce the water surface, velocity, and pressure profiles in addition to calculating the contraction and discharge coefficients [8-12]. Also, calculations for the discharge and contraction coefficients were carried out using the Boundary Integral Equation Method (BIEM) and construct an illustration of the water surface profile for the spillway and the sluice gate [13]. A further experimental study was conducted in a rectangular flume to examine the flow beneath a gate. The results indicated that the discharge coefficient reduces as the ratio of gate opening to upstream flow depth (a/H1) increases [14]. Another investigation that demonstrated a high degree of concordance between experimental and theoretical values supported this conclusion. This study used Mathematica model software to determine the discharge coefficient of vertical sluice gates [15]. Furthermore, experimental and numerical investigations were conducted to examine the flow characteristics of the area upstream and downstream of sluice gates. Using two-dimensional Navier-Stokes simulations with a volume of fluid approach and Reynolds averaged [16]. Additionally, the discharge coefficient (Cd) of oblique/inclined sluice gates was evaluated using intelligent models and experimental data, they found that because of increased flow line convergence under the gate, raising the gate inclination angle led to larger discharge coefficients by using (ANN) models in free flow condition [17]. Artificial Neural Networks (ANNs) modeling approach with back propagation algorithm was applied to analyze the flow characteristics below vertical and inclined sluice gates, 420 datasets from past experimental studies on free and submerged flow were collected. Using a non-linear equation, Cd for free flow was calculated [3]. The effect of vortex formation upstream inclined sluice gate has been studied for several gate openings vertical and inclined opposite flow direction, it was found that the average discharge coefficient for the vertical gate was 0.645 while these values reduced to 0.59 and 0.564 for gate inclined (30° and 45°) opposite flow direction respectively [18]. In fact, experimental research was conducted to evaluate the performance of five models in determining flow regime conditions, computing the flow rate and discharge coefficient (Cd). In order to examine every aspect of the research plan for analyzing sluice gate performance, a numerical model was utilized where the flow through a sluice gate remains constant but changes depending on the downstream and upstream conditions, the flow rate, and the location of the gate [19]. A physical model was used to analyze the water surface profile surrounding a vertical sluice gate in order to study the properties of free flow beneath the gate. The findings included a number of graphs showing the connection between gate opening, specific energy, and flow depth with discharge. Additionally, it was determined that the two most important variables influencing the water surface profile beneath the sluice gate are discharge and gate opening [20]. Different research investigated the effects of a sluice gate that is vertical, oblique, angled upstream, or angled downstream assignments on the coefficient of discharge (Cd). A numerical modeling technique was utilized in this study using the program (FLOW-3D), in order to model free-surface flows. The research emphasizes how important it is to position sluice gates strategically in order to optimize water management efficacy [21]. Furthermore, several studies have examined how the sluice gate's inclination affects the discharge coefficient. Thus, an experimental investigation was conducted to examine the performance of sluice gate inclination. A rectangular lab flume was used for the experimental study and a correlation between the sluice gate's inclination and the direction of flow was discovered the discharge coefficient value increases and reduces when the inclination is different from the direction of flow [22]. According to the study of earlier research from the above review, the previous studies clearly show how sluice gates affect the discharge coefficient under different flow conditions while the present study is unique cause it is the only one that investigates multiple cases of sluice gate inclination, both in the direction of flow and against it. Therefore, the aim of this study is to investigate the effect of sluice gate inclination in both directions on the discharge coefficient values under multiple free flow conditions.

2. Coefficient Discharge Formulation

The discharge coefficient (Cd) is regarded as a crucial component of flow characteristics. The discharge coefficient, in open channels and elsewhere, is the ratio of the field-measured discharge to the theoretical (calculated) discharge

$$Cd = \frac{Q_{actual}}{Q_{theoretical}} \qquad (1)$$

The discharge may be quantified and calculated for vertical sluice gates through the coefficient of discharge utilizing the equation below [23] [24] [25].

$$Q = C_d \,.\, \mathrm{b} \,.\, h \,.\, \sqrt{2.\,g.\,y_1} \qquad (2)$$

In the above scenario, the variables were defined Q (discharge), Cd (discharge coefficient), b (sluice gate width), h (the opening of sluice gate), g (gravity acceleration) and y_1 (upstream water depth).

Contraction coefficients (Cc) may also be a component of the discharge coefficient (Cd) behind the sluice gate and the ratio of the water depth immediately following the sluice gate upstream at the gate opening height is known as the coefficient of contraction.

$$Cc = \frac{y_2}{h} \qquad (3)$$

In this case, the coefficients of contraction (Cc), the downward water depth (y_2), and the gate opening (h) are all represented.

In theory, the contraction coefficient associated with sharp-edged vertical sluice gates can vary from 0.598 to 0.611. However, research and experimental findings indicate that its value falls between 0.61 to 0.74, According to Henderson (1966), engineering applications can make use of the contraction coefficient (0.61) [26] .

The contraction coefficient may be used to calculate the discharge coefficient for free flow using the following continuity and energy equations in the upstream section:

$$Cd = \frac{C_c}{\sqrt{1+\frac{C_c \cdot b}{y_1}}} \qquad (4)$$

In this case, the discharge coefficient is represented by (Cd), while the contraction coefficients are represented by (Cc), Sluice gate opening is represented by (b), while upstream water depth is reflected by (y_1).

3. Dimensional Analysis

Through the illustrated figures 1, 2, and 3, the positions of the vertical sluice gate and the inclined sluice gate with flow direction and against flow direction used in the study were demonstrated. Also, finding the crucial dimensionless factors that control the system's behavior is made easier with the use of dimensional analysis the main parameters influencing the discharge coefficient (Cd).

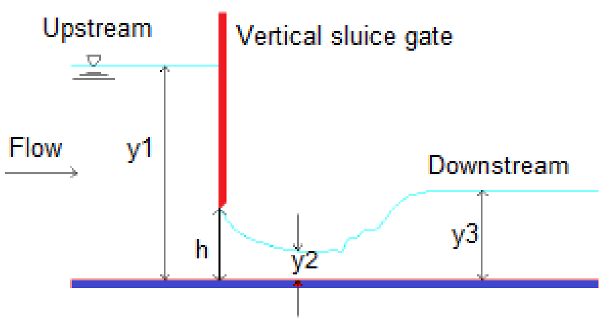

Figure 1. The Vertical Sluice Gate

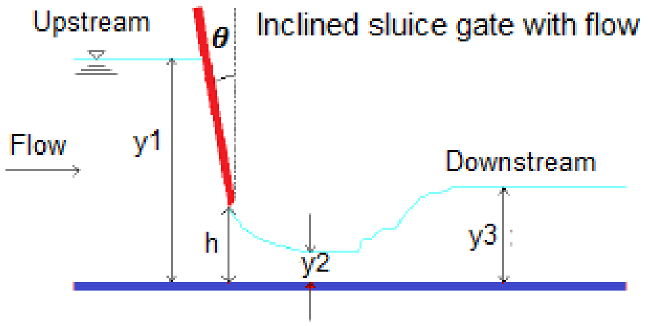

Figure 2. The Inclined Sluice Gate with Flow direction

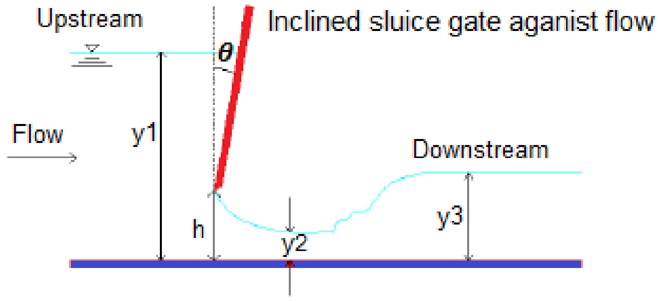

Figure 3. The Inclined Sluice Gate Against Flow direction

Based on their impact and integration into the experimental processes, the variables included in the dimensional analysis were selected as shown in figures 1, 2 and 3. Therefore, the discharge can be expressed as a function of the following variables:

$$Q = f\ (h, b, \theta, y_1, y_2, g, \rho) \qquad (5)$$

Table 1 lists all the parameters that impacted the discharge coefficient and provides an overview of the experimental model employed in this study.

Table 1 lists all the parameters that impacted the discharge coefficient and provides an overview of the experimental model employed in this study.

Table 1: The Dimensional Analysis of the MLT System's Present Study Parameters

Variables	Definition	Dimension
Q	Flow discharge	$L^3\ T^{-1}$
ρ	Density of fluid	$M\ L^{-3}$
g	Gravity acceleration	$L\ T^{-2}$
θ	Angle of inclination	-----
b	Width of the gate	L
h	Opening of the gate	L
y_1	upstream height	L
y_2	downstream height	L

By applying the Buckingham Pi theorem and π/theorem to the dimensional analysis procedure, the number of π groups is as follows: 8-3=5 (m = 3, number of dimensions), and the following formula may be constructed if the variables (ρ, g, y_1) are initial repeated variables:

$$f_2(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5) = 0 \quad (6)$$

$$\pi_1 = {y_1}^{a_1} g^{b_1} \rho^{c_1}\ Q \quad (7)$$

$$\pi_2 = {y_1}^{a_2} g^{b_2} \rho^{c_2}\ h \quad (8)$$

$$\pi_3 = {y_1}^{a_3} g^{b_3} \rho^{c_3}\ b \quad (9)$$

$$\pi_4 = {y_1}^{a_4} g^{b_4} \rho^{c_4}\ y_2 \quad (10)$$

$$\pi_5 = \theta \quad (11)$$

The dimensional analysis method is used to estimate the value of π_1

$$\pi_1 = y_1^{a} g^{b} \rho^{c} Q$$

$$M^0 L^0 T^0 = (L)^{a_1} (LT^{-2})^{b_1} (ML^{-3})^{c_1} (L^3T^{-1})^1$$

For : $c_1 = 0$

For L: $a_1 + b_1 - 3c_1 + 3 = 0$; $a_1 + b_1 + 3 = 0$

For T: $-2b_1 - 1 = 0$; $b_1 = -\frac{1}{2}$; $a_1 = \frac{5}{2}$

Where: $$\pi_1 = \emptyset\,(\pi_2, \pi_3, \pi_4, \pi_5) \quad (12)$$

Then: $$\pi_1 = \frac{Q}{g^{1/2} * {y_1}^{5/2}} \quad (13)$$

Likewise, the following results from the examination of the other non-dimensional parameters:

$$\pi_2 = \frac{y_1}{b} \quad (14)$$

$$\pi_3 = \frac{y_1}{h} \quad (15)$$

$$\pi_4 = \frac{y_1}{y_2} \quad (16)$$

$$\pi_5 = \theta \quad (17)$$

By substituting the value of π with its equivalent variables, the equation becomes:

$$\frac{Q}{(g^{1/2} * {y_1}^{5/2})} = f\left(\frac{y_1}{b}, \frac{y_1}{h}, \frac{y_1}{y_2}, \theta\right) \quad (18)$$

Since the discharge coefficient is a dimensionless parameter and is analogous to π_1, it can be substituted in its place, resulting in the following equation:

$$Cd = f\left(\frac{y_1}{b}, \frac{y_1}{h}, \frac{y_1}{y_2}, \theta\right) \quad (19)$$

Corresponding author E-mail address: nd230073en@st.tu.edu.iq
https://doi.org/10.61268/2fjyq340

4. Experimental Works

The experimental work was conducted in the hydraulics laboratory of the Department of Environmental Engineering, College of Engineering, Tikrit University. laboratory flume has across-section that is rectangular and has dimensions of (30) cm in depth, (6.5) cm in width, and (2.5) m in length as shown in figure 4. Clear fiber-class plastic walls enclose the flume that are (25) cm high carried by steel stand, it is connected to two basins at both the upstream and downstream ends, each measuring (80) cm in length, (30) cm in width and (50) cm in depth. The basin's dimensions are (1 * 0.8 * 0.7) m, the tank provides water to the flume by pump with manual valve at maximum discharge (5200) l/hr. This discharge calculates accurately by using flowmeter and the point gage with accuracy of (0.05) cm was employed to determine the water's depth both upward and downward during level measurements. The sluice gate used in the study was manufactured and made from fiber class, with dimensions of (6.5) cm in width, (50) cm in height, and (10) mm in thickness. It had a slope edge with (45°) and was positioned in center of flume. The sluice gate was installed vertically (90°) and inclined at angles of (10°, 20°, 30°, 40°, and 45°) with the flow direction and against the flow direction with four gate openings (h) were used, measuring (1, 2, 3, and 4) cm. Nine discharges (Q) were passed for each sluice gate opening height ranging from (1000 – 5000) l/hr.

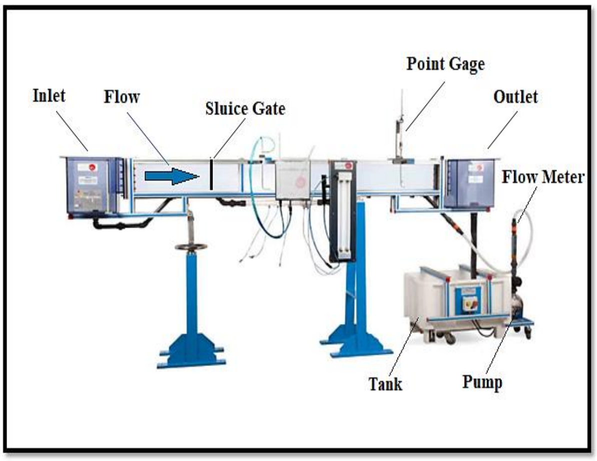

Figure 4. Flume in the Laboratory Used for the Experiments

The results of the dimensional analysis of the variables affecting the discharge coefficient beneath sluice gates served as the basis for the laboratory tests, the following diagram in Figure 5 represents the Methodology for the laboratory experiments performed on the sluice gate under different positions adopted in this study.

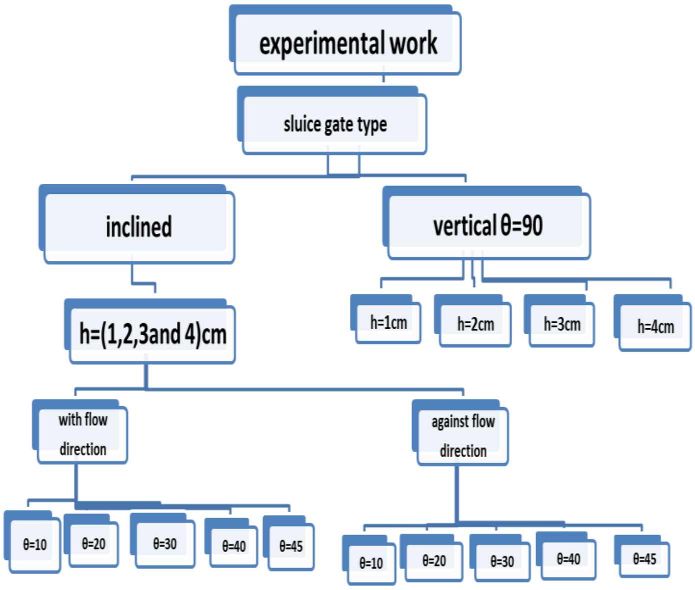

Figure 5. Block Diagram of the Sluice Gate Angle and the Opening

5. RESULTS AND DESCUSSION

Based on the results obtained from the dimensional analysis, relationships were developed between the discharge coefficient (Cd) and the influencing parameters identified through the dimensional analysis. It is evident that the experimental and numerical solution findings are in good agreement, since the experimental data were utilized for validation in order to derive the optimally fitted equations for (Cd) value prediction, when the gate positioned vertical or with flow direction and against it, the following are each flow condition's results.

5.1 Discharge Coefficient (Cd) Equation for Sluice Gate:

After entering the statistical data and dimensionless coefficients for the sluice gates into the (SPSS) program, and then performing regression non-linear analysis on the data, the following empirical equations were obtained.

- $\boldsymbol{Vertical\ Sluice\ Gate}$

$$Cd = \frac{\left(\frac{y_1}{h}\right)^{2.03}}{\left(\frac{y_1}{b}\right)^{0.05} \cdot \left(\frac{y_1}{y2}\right)^{1.77}} \quad (20)$$

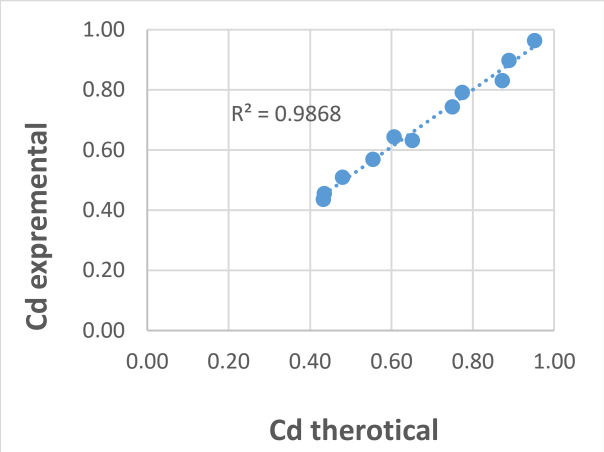

Figure 6. Fitting of Coefficient Discharge Experimental and Theoretical for Vertical Sluice Gate

- $\boldsymbol{Inclind\ Sluice\ Gate(with\ flow)}$

$$Cd = \frac{\left(\frac{y_1}{h}\right)^{1.75} . (\theta)^{0.12}}{\left(\frac{y_1}{b}\right)^{0.03} \cdot \left(\frac{y_1}{y2}\right)^{1.43}} \quad (21)$$

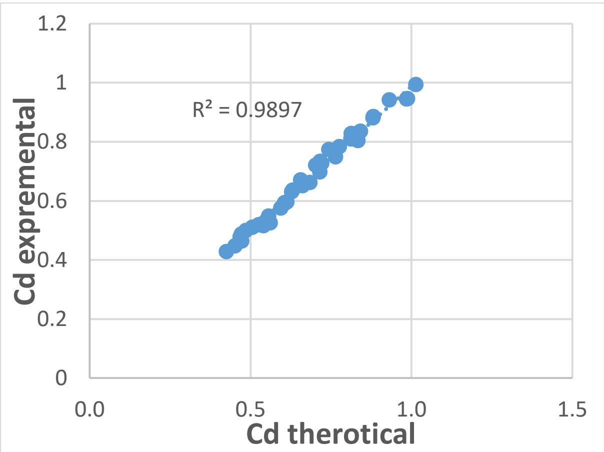

Figure 7. Fitting of Coefficient Discharge Experimental and Theoretical for Inclined Sluice Gate with Flow Direction

- - $\boldsymbol{Inclind\ Sluice\ Gate(against\ flow)}$

$$Cd = \frac{\left(\frac{y_1}{h}\right)^{2.3}}{\left(\frac{y_1}{b}\right)^{0.13} . \left(\frac{y_1}{y2}\right)^{1.99} . (\theta)^{0.03}} \quad (22)$$

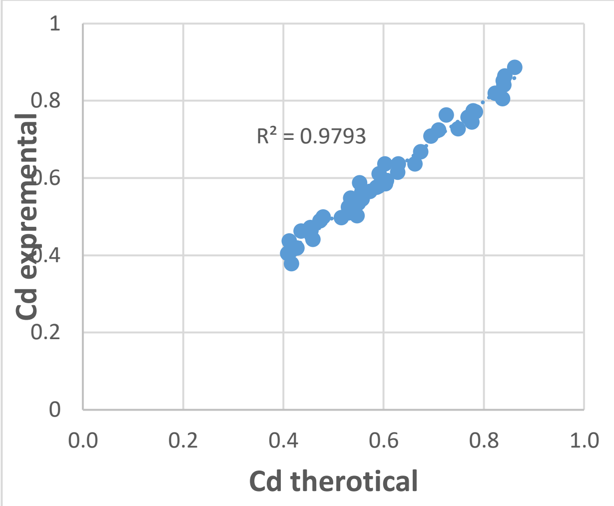

Figure 8. Fitting of Coefficient Discharge Experimental and Theoretical for Inclined Sluice Gate Against Flow Direction

After deriving the empirical equations using the (SPSS) software, the accuracy and efficiency of these equations were evaluated using the remaining 30% of the data.

In order to improve accuracy and verify the derived equations, the Nash-Sutcliffe Efficiency (NSE) measure was used. This measure is considered one of the widely used statistical methods and is among the most reliable and widely spread methods in the world for evaluating model effectiveness[27] [28]. Its formula is as follows:

$$NSE = 1 - \frac{\sum\left(Cd_{exp.} - Cd_{Spss}\right)^2}{\sum\left(Cd_{exp.} - \overline{Cd_{exp.}}\right)^2}$$

where $Cd_{exp.}$ is the measured discharge coefficient experimentally, Cd_{Spss} is the calculated discharge coefficient from the regression model, $\overline{Cd_{exp.}}$ is the average measured discharge coefficient experimentally.

The results of coefficient of determination (R^2) and Nash-Sutcliffe Efficiency (NSE) were close to one, indicating a good correlation and agreement between the experimental and

theoretical results that obtained from the empirical equations.
The statistical coefficients for the current study can be presented in the Table 2.

Table 2 The Statistical Parameters Results (R^2 & NSE)

Type of sluice gate	Coefficient of determination (R^2)	Nash-Sutcliffe Efficiency (NSE)
Vertical	0.9868	0.9766
Inclination with flow	0.9897	0.950
Inclination against flow	0.9793	0.940

5.2 *Comparison of the Discharge Coefficient (Cd) in the Present Study with Previous Research Studies*

The studies that focus on estimation the discharge coefficient for inclined sluice gates are very limited compared to those on vertical gates. The present study is the only one that uniquely considers multiple cases of sluice gate inclination both in the flow direction and against it. It can also be observed that there is a variation in the discharge coefficient values reported in the mentioned studies, this variation can be attributed to several reasons, including: The type of sluice gate used and the method of its installation, the surrounding experimental conditions, the flow characteristics and finally, the dimensions of the channel used in the experiments [6] [14].
Figure 9, 10 compare the coefficient of discharge equation estimated for free flow condition under vertical and inclined sluice gate in the present study with equations formerly published from previous studies and there was a significant degree of concordance between the present study's findings and those of earlier research.

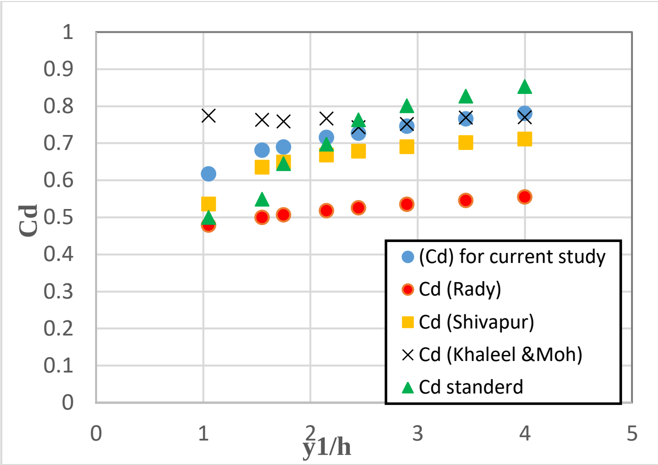

Figure 9 Comparison of Discharge Coefficient for Present study with other Researches for 45° Inclined Sluice Gate

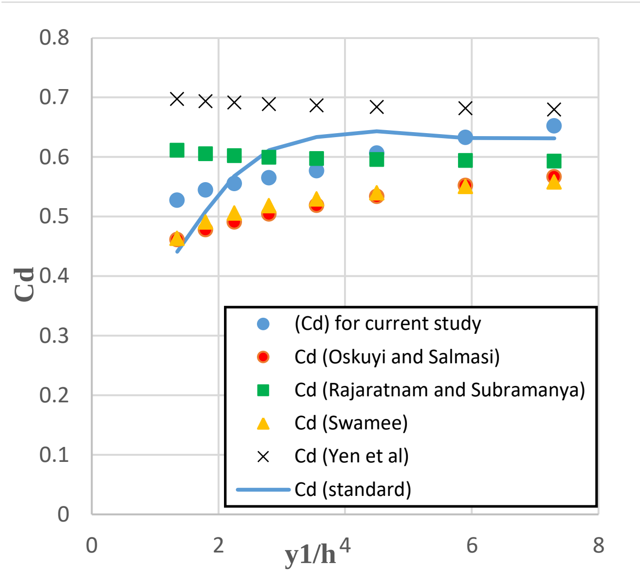

Figure 10 Comparison of Discharge Coefficient for Present study with other Researches for 90° Vertical Sluice Gate

6. Conclusions

Designing and operating water supply systems and hydropower plants both depends significantly on sluice gates. Therefore, they are considered a fundamental and important element in the sustainable development of water resources and energy generation. However, the purpose of this study is to verify earlier findings on the discharge coefficient as long as to determine an analytical equation to estimate the discharge coefficient (Cd) with a different sluice gate operating indicate, this illustrates how various gate inclination and the gate opening scenarios could impact the discharge coefficient value. the following conclusions were drawn as follows:

- The difference in the gate's inclination angle significantly influences the discharge coefficient, where the discharge coefficient (Cd) increases as the inclination angle of the sluice gate with flow direction increases and decreases as the inclination angle of the sluice gate against flow direction increases.
- Indicating that the sluice gate opening has a clear effect on the discharge coefficient, the discharge coefficient (Cd) increases as the sluice gate height (h) decreases.
- There is a positive correlation between the discharge (Q) and the discharge coefficient (Cd), with the discharge coefficient increasing as the discharge does.
- The relationship between the discharge coefficient (Cd) and the parameters (y_1/h), (y_1/b) and (y_1/y_2) is a positive relationship for the same angle. In case of the same discharge, the discharge coefficient decreases as the ratio (y_1/h), (y_1/b) and (y_1/y_2) increases in both situations, when the sluice gate was positioned either in the direction of flow or against it.

This process might be employed for additional inquiry to resolve the effect of the sluice gate's inclination and openings height on the discharge coefficient using the C.F.D program.

Acknowledgment

The authors express their gratitude to the Department of Civil Engineering at Tikrit University's College of Engineering for supporting this study by setting up the equipment required to carry out all of the experiments in the college labs.

References

[1] V. T. Chow, " Handbook of applied hydrology," ed: Taylor & Francis, 1965.

[2] E. Weyer, "System identification of an open water channel," *Control engineering practice,* vol. 9, pp. 1289-1299, 2001.

[3] R. A. E.-H. Rady, "Modeling of flow characteristics beneath vertical and inclined sluice gates using artificial neural networks," *Ain Shams Engineering Journal,* vol. 7, pp. 917-924, 2016.

[4] C. Erdbrink, V. V. Krzhizhanovskaya, and P. M. Sloot, "Free-surface flow simulations for discharge-based operation of hydraulic structure gates," *Journal of Hydroinformatics,* vol. 16, pp. 189-206, 2014.

[5] W. Boiten, "Flow measurement structures," *Flow Measurement and Instrumentation,* vol. 13, pp. 203-207, 2002.

[6] D. D. Fangmeier and T. S. Strelkoff, "Solution for gravity flow under a sluice gate," *Journal of the Engineering Mechanics Division,* vol. 94, pp. 153-176, 1968.

[7] N. Rajaratnam and K. Subramanya, "Flow equation for the sluice gate," *Journal of the Irrigation and Drainage Division,* vol. 93, pp. 167-186, 1967.

[8] L. T. Issacs, "Numerical solution for flow under sluice gates," *Journal of the Hydraulics Division,* vol. 103, pp. 473-481, 1977.

[9] J. H. Masliyah, K. Nandakumar, F. Hemphill, and L. Fung, "Body-fitted coordinates for flow under sluice gates," *Journal of Hydraulic Engineering,* vol. 111, pp. 922-933, 1985.

[10] J. I. Finnie and R. W. Jeppson, "Solving turbulent flows using finite elements," *Journal of Hydraulic Engineering,* vol. 117, pp. 1513-1530, 1991.

[11] J. Montes, "Irrotational flow and real fluid effects under planar sluice gates," *Journal of Hydraulic Engineering,* vol. 123, pp. 219-232, 1997.

[12] A. A. Khanoosh, E. H. Khaleel, and W. S. Mohammed-Ali, "The resilience of numerical applications to design drinking water networks," *International Journal of Design & Nature and Ecodynamics,* vol. 18, pp. 1069-1075, 2023.

[13] A. H. Cheng, P. L. Liu, and J. A. Liggett, "Boundary calculations of sluice and spillway flows," *Journal of the Hydraulics Division,* vol. 107, pp. 1163-1178, 1981.

[14] A. Roth and W. H. Hager, "Underflow of standard sluice gate," *Experiments in fluids,* vol. 27, pp. 339-350, 1999.

[15] N. N. Oskuyi and F. Salmasi, "Vertical sluice gate discharge coefficient," *Journal of Civil Engineering and Urbanism,* vol. 2, pp. 108-114, 2012.

[16] L. Cassan and G. Belaud, "Experimental and numerical investigation of flow under sluice gates," *Journal of Hydraulic Engineering,* vol. 138, pp. 367-373, 2012.

[17] F. Salmasi, M. Nouri, P. Sihag, and J. Abraham, "Application of SVM, ANN, GRNN, RF, GP and RT models for predicting discharge coefficients of oblique sluice gates using experimental data," *Water Supply,* vol. 21, pp. 232-248, 2021.

[18] M. S. Khaleel and A. Y. Mohammed, "A simple technique for preventing vortex with some aspects of flow under inclined sluice gates," *Türk Hidrolik Dergisi,* vol. 2, pp. 1-7, 2017.

[19] A. Yoosefdoost and W. D. Lubitz, "Sluice gate design and calibration: Simplified models to distinguish flow conditions and estimate discharge coefficient and flow rate," *Water,* vol. 14, p. 1215, 2022.

[20] M. A. M. Razi, D. Tjahjanto, W. A. W. Mohamed, and N. B. B. Ishak, "Investigation of the properties of flow beneath a sluice gate," in *International Conference on Civil Engineering (ICCE08)*, 2008.

[21] R. Daneshfaraz, H. Abbaszadeh, P. Gorbanvatan, and M. Abdi, "Application of sluice gate in different positions and its effect on hydraulic parameters in free-flow conditions," *Journal of Hydraulic Structures,* vol. 7, pp. 72-87, 2021.

[22] M. S. Khaleel and A. Y. Mohammed, "Hydrulic Study for Performance of the Vertical and Inclined Gates and Compound on Weir," Master of Science, Irrigation and Drainage Engineering, Mosul, 2002.

[23] W. Baines, "Discussion of diffusion of submerged jets," *Trans. Am. Soc. Civil Engrs,* vol. 115, p. 679, 1950.

[24] C. Tsai, "Drainage analysis of the gate in Bu-Dai salt collecting yard during Sarah Typhoon," *Department of Hydraulic And Ocean Engineering Rep,* 1990.

[25] P. K. Swamee, "Sluice-gate discharge equations," *Journal of Irrigation and Drainage Engineering,* vol. 118, pp. 56-60, 1992.

[26] H. Rouse, "Open Channel Flow. By FM HENDERSON. Macmillan, 1966. 522 pp. $14.95," *Journal of Fluid Mechanics,* vol. 29, pp. 414-415, 1967.

[27] M. F. Yass, "Hydrodynamic-Morphological Investigation for the Riverbank Stability of Tigris River within Salah Al-Din Governorate," Tikrit University, 2024.

[28] W. S. Mohammed-Ali, "Minimizing the detrimental effects of hydro-peaking on riverbank instability: The lower Osage River case," Missouri University of Science and Technology, 2020.