Discharge Coefficient of a Compound Weir with a Triangular underneath Gate for Different Geometric and Hydraulic Conditions

Abdulrahman Seraj Almalki
Civil and Environmental Engineering Department, College of Engineering and Computing in Al-Qunfudhah, Umm Al Qura University, Mecca, Saudi Arabia
ASAMALKI@uqu.edu.sa (corresponding author)

Received: 25 March 2024 | Revised: 17 April 2024 | Accepted: 7 December 2024

 DOI: https://doi.org/10.48084/etasr.7299

ABSTRACT

It is common practice in the field of irrigation systems to use composite hydraulic structures, which are constituted of two distinct parts. The initial component, represented by two rectangles, is responsible for the overflow regime, while the subsequent component, represented by a triangular gate, is responsible for the underflow regime. In order to measure, direct, and control the flow, both components are required. The present study investigates the flow through a combined two-rectangle weir with a below-triangular gate across the channel, which serves as a control structure. The weir's upper rectangle has a constant width, designated as b_1 and measuring 20 cm, while the lower rectangle has a variable width, designated as b_2 and comprising the values of 8 cm, 10 cm, and 12 cm. The depth of the lower rectangle, z, is also a variable with values of 6 cm, 9 cm, and 11 cm. The dimensions of the triangular gate are 15 cm in height and 0, 60, 90, or 120 degrees in vertex angle. The aforementioned dimensions were employed interchangeably as geometric conditions and the disparate water heads h_2 as hydraulic conditions. Additionally, the compound weir devoid of a gate ($\theta = 0$) was used for varying water heads. The results demonstrated that the dimensions of the weir and gate had an impact on the discharge that went through the two rectangular weirs and gates. In terms of discharge capacity, the combined structure was observed to be more effective than a classic weir, with the ability to convey a discharge that was two to ten times greater. An empirical formula was developed to predict the discharge coefficient, C_d, for the combined structure, based on the given geometric and hydraulic conditions. It should be noted that the results and analysis of this study were limited to the tested dataset.

Keywords-compound weir; triangular gate; coefficient of discharge; combined structure; open channels; discharge measurement

I. INTRODUCTION

The principal function of hydraulic structures, such as weirs and gates, is to regulate the flow of open channels. The capacity to retain floating materials represents one advantage of employing gates as a standalone mechanism. However, this potential issue can be circumvented by integrating gates with weirs. However, the use of weirs alone can result in sedimentation issues. These problems can be mitigated by employing a combination of weirs and gates. In comparison to the condition of each individual weir or gate, the hydraulic condition of this combined weir and gate is distinct. The combined structure effectively addresses all issues that arise when the weir and gate are independently operated. Given that the flow occurs simultaneously over the weir and below the gate, numerous studies have been conducted with the objective of accurately estimating both the discharge and the discharge coefficient, C_d. Moreover, the weir lower rectangular width b_2, the gate vertex angle θ, the upstream water head, the combined structure width, and height were among the geometrical characteristics of combined structures that were examined by authors in [1, 2] under various hydraulic conditions. An equation for determining the discharge over a sharply crested triangular weir was provided by authors in [3]. Moreover, a number of empirical equations have been formulated for estimating the discharge over a range of weir types [4-6]. The estimation of the discharge for the triangular gate of the combined structure, which consists of a rectangular weir and a triangular gate [7], formed the basis for the estimation of the discharge equation [8]. It was determined that the triangular gate exerts a significant influence on the combined discharge. The results of the experiments conducted on rectangular compound sharp-crested side weirs demonstrated that there was no significant upstream Froude number and that the discharge coefficient exhibited a linear relationship [9]. The flow through the combined structure, comprising a vertical weir with a below-gate, was investigated by comparing the numerical output from the Flow 3D software results with the results of experimental runs [10]. Additionally, the flow characteristics across a combined triangular weir with a sharp-crowned rectangle were further examined [11]. Two triangular sections with disparate notch angles were integrated to construct a structure that was employed to quantify the flow rates for varying discharges [12]. The flow characteristics of a combined structure comprising a triangular weir and a rectangular gate were examined [13]. The researchers concluded that the discharge coefficient, which was directly proportional to the vertical separation between the lower weir edge and the upper gate edge, was inversely related to the weir angle. The flow beneath the inverted rectangular sharp gate and over the rectangular sharp crested weir was examined in detail [14]. The combined discharge was found to be significantly influenced by both surface tension and viscosity. The flow characteristics of a triangular weir with a below-rectangular gate were studied in order to gain further insight into the behavior of such structures [15].

Experimental runs were performed to examine the flow dynamics over a trapezoidal weir with a below-rectangular gate [16]. It was determined that the discharge coefficient of the combined structure exhibited an increase with an expansion in the distance between the upper edge of the gate and the lower edge of the weir. The combined structure, comprising a triangular gate and a rectangular weir, was subjected to investigation with a view to determining its coefficient of discharge [17]. Authors in [18] examined the combined flow beneath gates and over sharply crested weirs. In order to ascertain the discharge coefficient, authors in [19] conducted an experiment using a combination of a triangular weir and a rectangular gate structure. In order to create empirical equations that compute the combined weir discharge coefficient for various geometric and hydraulic properties, a compound weir comprising two rectangles divided by sloping sides and a below circular gate below was used for the experimental runs [20-23]. The principal objective of this study is to ascertain the discharge coefficient of the combined structure. In contrast to the conventional use of individual weirs and gates, the compound weir and triangular gate structure represents a relatively novel approach that has been proposed by numerous researchers. The primary advantage of the combined system is the reduction of sedimentation and deposition upstream of the system, which is particularly beneficial when the discharge measurement and irrigation channel flow control are involved. The combined weir and gate structure is a self-cleaning discharge measurement device, which makes it an inexpensive and low-maintenance option. The current study examined the hydraulics of the below triangular gates and combined overflow weirs through experimental means. To develop an accurate equation for determining the discharge coefficient for this combined structure, the dimensions of the weir and gate were used interchangeably, as well as a weir without a gate.

II. THEORETICAL STUDY

The integrated structure is presented in Figure 1, which comprises a compound weir with a gate of the below-triangular configuration. The combined discharge coefficient, C_d, can be calculated using the list of independent variables:

$$C_d = f(h_1, h_2, h_3, b_1, b_2, z, \theta, B, H, \rho, g.\mu, \sigma) \qquad (1)$$

where: C_d is the coefficient of discharge, h_1 is the upper rectangle part of the compound weir's head of water, h_2 is the lower rectangle part of the compound weir's water head, h_3 is the triangular gate water head, b_1 and b_2 are, respectively, the widths of the upper and lower rectangular parts of the compound weir, z is the lower rectangle part of the compound weir height, θ is the triangular gate vertex angle, B and H are, respectively, the combined structure width and height, ρ is the density of water, g is the acceleration gravity, μ is the viscosity of the water, and σ is the water surface tension. If the dimensionless groups affect the simultaneous coefficient of discharge C_d , the compound weir with the below triangular gate can be obtained by applying π-Buckinghum's theory and its properties to (1):

$$C_d = f\left(\frac{h_1}{H}, \frac{h_2}{H}, \frac{h_3}{H}, \frac{b_1}{B}, \frac{b_2}{B}, \frac{Z}{H}, \theta, R_e, W_e\right) \qquad (2)$$

It was assumed that the Reynolds and Weber numbers, designated as R_e and W_e, respectively, did not affect the combined structure other than to result in a very low head. It should be noted that a variety of dimensionless groups can be produced by combining the non-dimensional groups indicated above. A significant body of research has been directed towards examining the relationships identified in the existing literature between the water depth and discharge for gates and weirs.

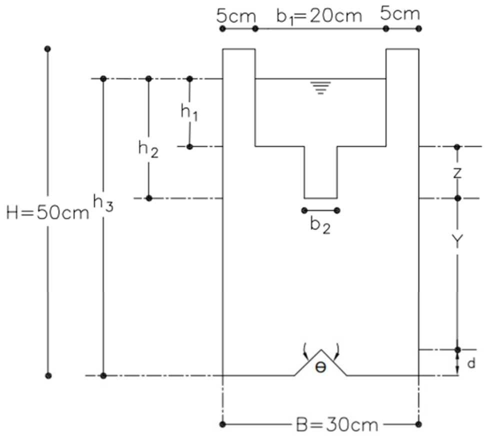

Fig. 1. Sketch for the compound weir with the below triangular gate.

The equation for the flow over weirs, which is widely known and used in the field of hydrology, was initially developed in [24], and subsequently rewritten using the superposition principle:

$$Q_w = \frac{2}{3}\sqrt{2g}(b_1 - b_2)h_1^{3/2} + \frac{2}{3}\sqrt{2g}\, b_2 h_2^{3/2} \qquad (3)$$

where Q_w is the theoretical discharge through the compound weir only. The theoretical discharge through the gate only, was given in [25] as:

$$Q_g = d^2 tan\frac{\theta}{2}\sqrt{2gh_3} \qquad (4)$$

where Q_g is the gate theoretical discharge.

$$Q_{th} = Q_w + Q_g \qquad (5)$$

$$Q_{act} = C_d\, Q_{th} \quad (6)$$

$$Q_{act} = C_d \left(\frac{2}{3}\sqrt{2g}(b_1 - b_2)h_1^{3/2} + \frac{2}{3}\sqrt{2g}\, b_2 h_2^{3/2} + d^2 tan\frac{\theta}{2}\sqrt{2gh_3} \right) \quad (7)$$

where C_d is the combined structure coefficient of discharge.

III. EXPERIMENTAL SETUP

To achieve the objective of this study, experimental trials were conducted using a rectangular flume with dimensions of 4.0 m in length, 0.30 m in width, and a height of 0.50 m. In the experimental trials, the non-tilting type was deployed. The independent experimental setup employs a closed water cycle. A three-horsepower pump was employed to facilitate effective water circulation within the flume. The experimental run was observed with ease due to the fact that the side walls of the flume are composed of transparent glass sheets. Baffle vertical plates were positioned at the entrance of the channel to regulate the flow and prevent vortex motion, thereby controlling the fluctuations in the flume's entry. The exit water from the combined structure was collected in a type F13 hydraulic bench. As shown in Figure 2, the volume of water collected in the hydraulic bench was divided by the corresponding time interval to determine the actual discharge. The mean of the three recorded discharge values was calculated in order to determine the actual discharge for each experimental run. The dimensions of the triangular gate head h_3 and the weir heads h_1 and h_2, were determined using a Vernier-type gauge with an accuracy of 1 mm. To ensure the accuracy and precision of the data, a calibration procedure was conducted prior to each experimental run. The channel's flow was maintained at a constant rate by precisely adjusting the depth rod to the water's surface. The discharge was maintained at a constant level throughout each experimental run. In the course of the experimental investigations, a compound weir comprising two rectangles with a below-triangular gate made of acrylic glass with varying lower rectangle part width b_2 and depth z was employed. Three lower rectangle widths b_2 of 8 cm, 10 cm, and 12 cm, and three values of z, 6 cm, 9 cm, and 11 cm, were applied to the compound weir.

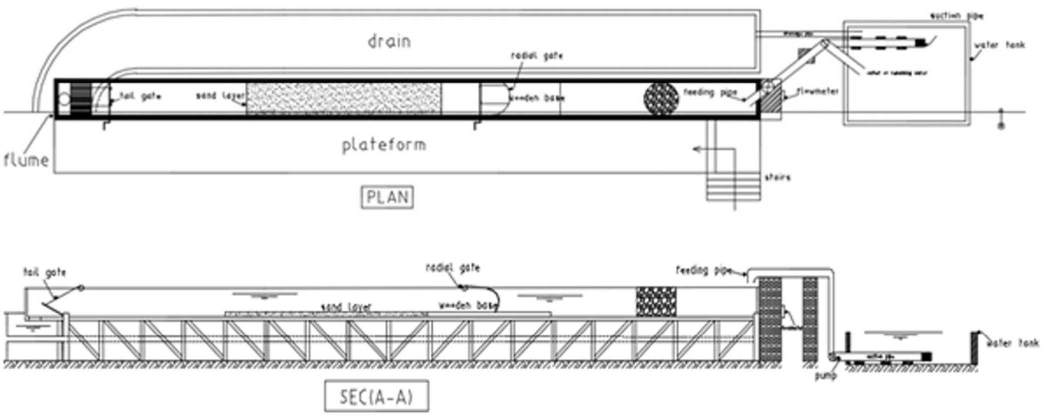

Fig. 2. Plan elevation of the flume.

In the case of the triangular gate with a height of 15 cm, three vertex angles were employed, namely θ = 60°, 90°, and 120°. Additionally, a scenario was considered in which the compound weir was used without the triangular gate, with θ = 0°. It is notable that the aforementioned measurements were applied uniformly. Once the calibration process was complete, the water heads on the compound weir's upstream side were measured to ascertain the precision of the discharge measurement. A point gauge with an 1 mm vernier scale was employed for the measurement of the water heads. In accordance with the methodology outlined in [3], the point gauge was fixed at a distance of four times the maximum head over the compound weir. In order to determine the discharge, the head over the weir at that section was measured, as the bottom boundary effect necessitates free flow through it.

A. Experimental Program and Procedure

A total of 36 combined structure models were constructed from acrylic glass sheets with varying triangular gate vertex angles θ and weir lower rectangle widths b_2 and heights z, as detailed in Table I. In this study, three values for the width of the lower rectangular part of the compound weir b_2 were used interchangeably with three values for the lower rectangular part of the compound weir height z. The width values were 8 cm, 10 cm, and 12 cm, while the height values were 6 cm, 9 cm, and 11 cm. These values were used with the below triangular gate vertex angles θ of 0, 60, 90, and 120°. To investigate the objectives of this study, 216 experimental runs were conducted, with six runs carried out for each setup and varying water heads. Table I provides a list of the programs that were subjected to testing. The following procedures were completed in accordance with the established protocols during the course of the experimental runs. The model was affixed at the midpoint of the flume length. Until each head over the weir reached the desired level, water was gradually introduced into the flume. To ensure that the system reached a steady state, a constant flow rate was maintained throughout the experimental run over the weir and the downstream gate. The hydraulic bench was employed to calculate the actual discharge for each experimental run by dividing the volume of water collected by the corresponding time. At the conclusion of each experimental run, the pump was deactivated. The aforementioned methodology was then applied to the remaining combined structure models.

TABLE I. THE EXPERIMENTAL PROGRAMS

Triangular gate vertex angles θ^o	Lower weir width, b_2 (cm)	Lower weir height, z (cm)
0 (Compound weir only)	8	6, 9, 11
	10	6, 9, 11
	12	6, 9, 11
60°	8	6, 9, 11
	10	6, 9, 11
	12	6, 9, 11
90°	8	6, 9, 11
	10	6, 9, 11
	12	6, 9, 11
120°	8	6, 9, 11
	10	6, 9, 11
	12	6, 9, 11

IV. RESULTS AND DISCUSSION

The objective of the present study is to demonstrate the impact of the combined structure discharge coefficient C_d on the geometry of the compound weir, which incorporates two rectangles and a below-triangular gate as hydraulic controlling devices. In the course of the proposed experimental runs, a variety of values for the dimensions of the lower weir rectangle, b_2 and z, respectively, and the vertex angle of the below triangular gate θ were employed. A regression analysis was employed to develop a combined structure discharge coefficient equation, subsequent to the analysis of the experimental results.

A. *Using only the Compound Weir to Calculate the Discharge Coefficient (θ = 0)*

For the vertex angle of the below triangular gate, θ equal to zero, Figures 3-5 display the relationships between the water head ratio, h_2/H, and the compound weir coefficient of discharge C_d for different values of each of the lower rectangle edge width b_2, and height z.

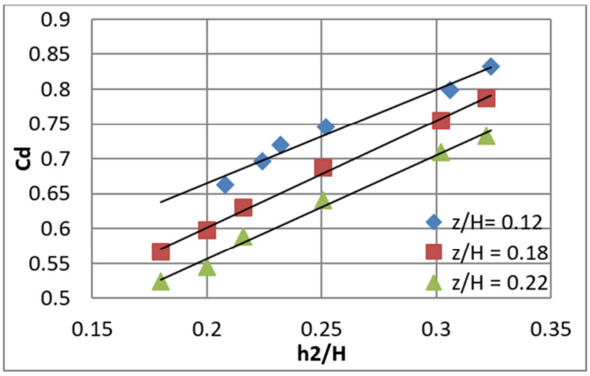

Fig. 3. Relationship between h_2/H and the compound weir C_d for z/H = 0.22 and $\theta = 0^o$.

It was demonstrated that the coefficient of discharge C_d for the compound weir has a directly proportional relationship with the water head ratio h_2/H. The coefficient of discharge C_d, was observed to increase from 0.637 to 0.823, 29.2%, when the head h_2, was increased from 10.5 cm to 16.5 cm, 57.14%, for a lower rectangle width b_2 of 10 cm and depth z of 9 cm. As presented in Figure 6, the discharge coefficient C_d likewise increases as the lower rectangle width b2, increases. To provide an example, for a head h_2 of 12.5 cm and a depth z of 9 cm, an increase in the lower rectangle width b2 by 50%, from 8 cm to 12 cm, results in a 7.74%, 0.762 to 0.821, increase in C_d. This is due to the fact that an increase in the water head h_2 or the lower rectangle width b_2 results in a higher rate of increase for the values of the theoretical discharge Q_{th} than for the values of the actual discharge Q_{act}. This, in turn, leads to an increase in the discharge coefficient value.

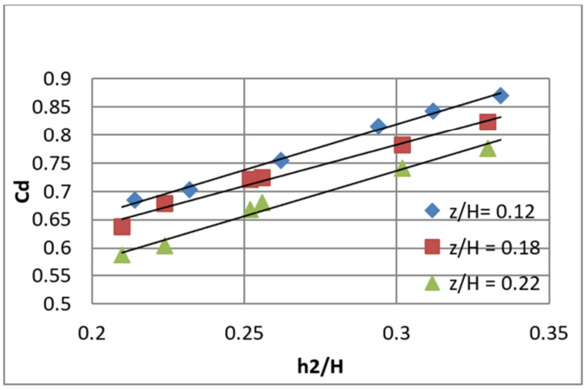

Fig. 4. Relationship between h_2/H and the compound weir C_d for z/H = 0.18 and $\theta = 0^o$.

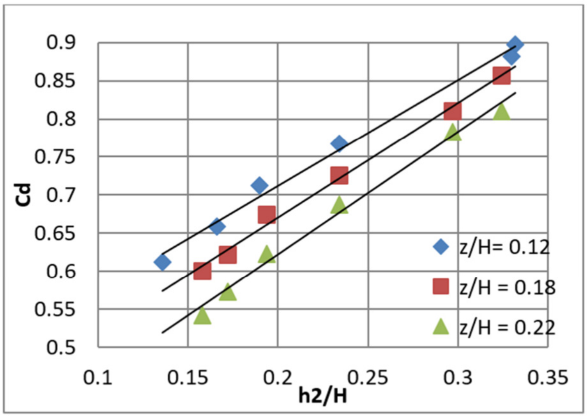

Fig. 5. Relationship between h_2/H and the compound weir C_d for z/H = 0.12 and $\theta = 0^o$.

However, as the depth of the lower rectangle z, increases, the discharge coefficient of the compound weir decreases, as depicted in Figure 7. For a water head of 12.5 cm and a lower rectangle width of 10 cm, an increase in the lower rectangle depth from 6 to 11 cm results in a decrease in the compound weir discharge coefficient from 0.865 to 0.808. This represents an 83.33% increase in z, which corresponds to a 7.05% decrease in C_d. The compound discharge coefficient C_d was found to be satisfactory when compared to previous studies in the context of the compound weir flow without a gate. Figure 8 presents a high degree of correlation between the measured discharge coefficient C_d, and the calculated coefficient derived from previous studies, which served as a model verification.

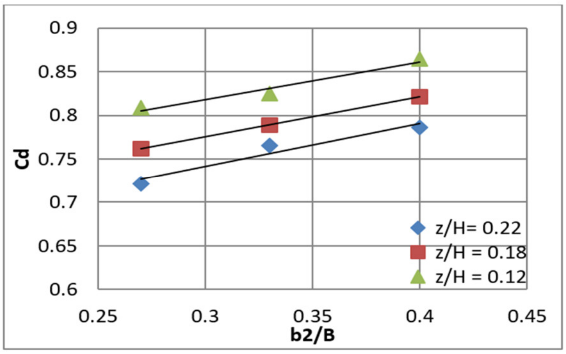

Fig. 6. Relationship between b_2/B and the compound weir C_d for h_2/H = 0.25 and $\theta = 0^o$.

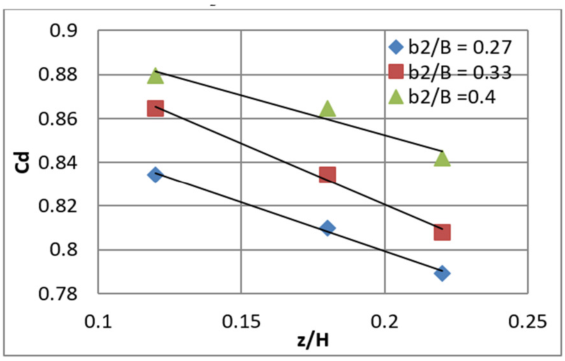

Fig. 7. Relationship between z/H and the compound weir C_d for h_2/H = 0.25, and $\theta = 0^o$.

B. Discharge Coefficient C_d using the Combined Structure for the Different Triangular Gate Vertex Angle (θ = 60, 90, 120^o)

The discharge coefficient C_d for the combined structure has been considered in this section for triangular gate vertex angles θ of 6 ^{o}, 90^o, and 120^o. For each triangular vertex angle, the relationships between h_2/H and C_d were fitted for three different values of z/H of 0.12, 0.18 and 0.22. The relationships between b_2/B and C_d were also fitted for different z/H and the relationships between z/H and C_d were plotted for different b_2/B. Based on the analysis of the results, it was shown that, as in the case of using only the compound weir, an increase in the water head ratio h_2/H results in an increase in the combined structure coefficient of discharge C_d, as observed in Figures 9-17. For example, for a b_2 value of 8 cm, θ value of 60^o, and z value of 9 cm, varying h_2 from 7.5 to 14.9 cm results in changes in C_d from 0.591 to 0.717, i.e. increasing the water head h_2 by 98.67% results in increasing the combined structure discharge coefficient *Cd* by 21.32%.

Moreover, as portrayed in Figures 18-20, a direct proportional relationship was identified between C_d and the compound weir lower rectangle width b_2. To examine this further, the combined structure discharge coefficient C_d was observed to change from 0.68 to 0.71 when the lower rectangle width b_2 was altered from 8 to 12 cm for an angle of 60°, a height of 9 cm, and a height of 12.5 cm. This led to the conclusion that a 50% increase in h_2 resulted in a 4.41% increase in C_d.

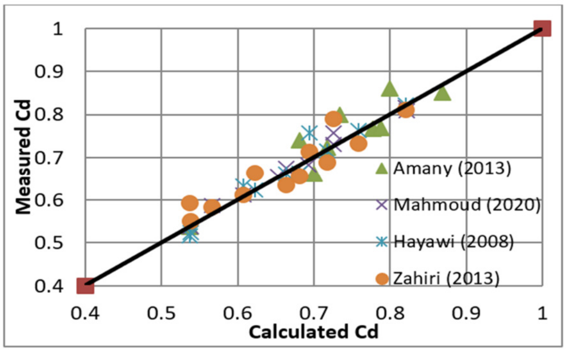

Fig. 8. Comparison of the calculated and measured C_d for $\theta = 0^o$.

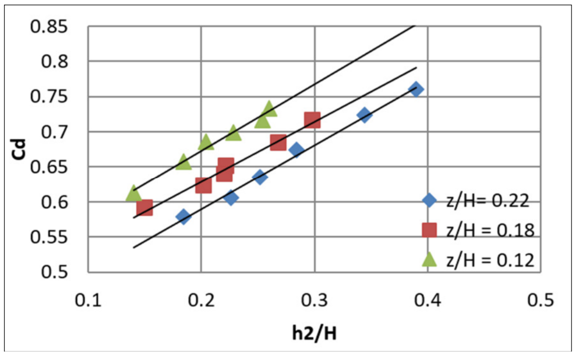

Fig. 9. Relationship between C_d and h_2/H for b_2/B = 0.40 and θ = 60^o.

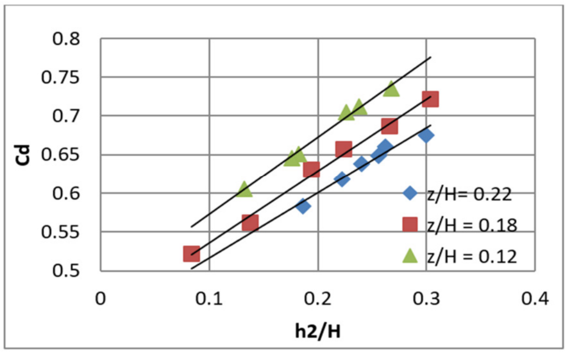

Fig. 10. Relationship between C_d and h_2/H for b_2/B =0.33 and $\theta = 60^o$.

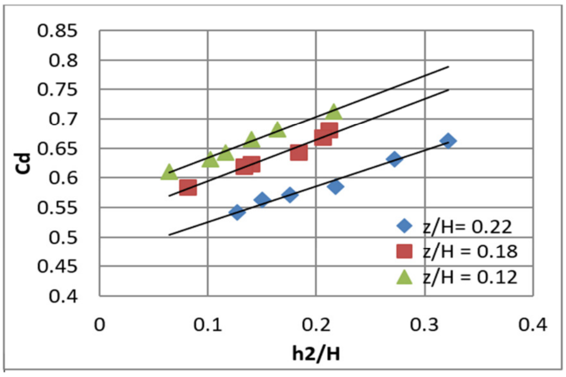

Fig. 11. Relationship between C_d and h_2/H for b_2/B = 0.27 and $\theta = 60^o$.

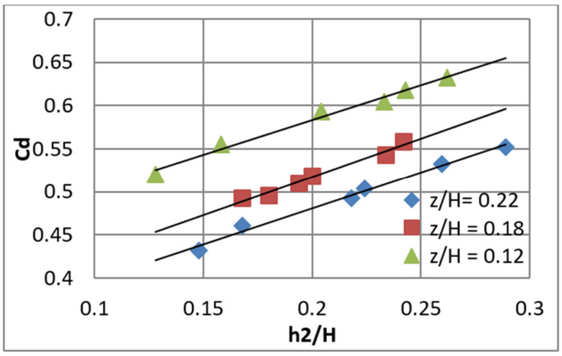

Fig. 12. Relationship between C_d and h_2/H for $b_2/B = 0.40$ and $\theta = 90^o$.

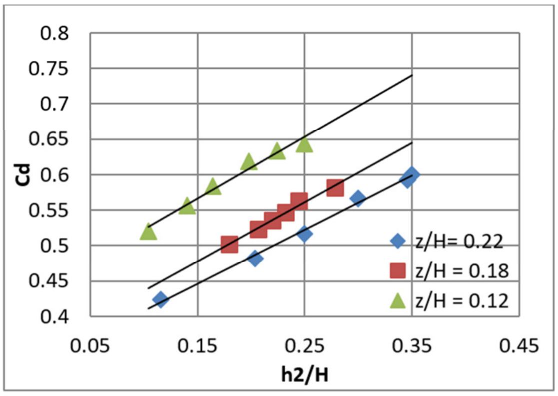

Fig. 13. Relationship between C_d and h_2/H for $b_2/B = 0.33$ and $\theta = 90^o$.

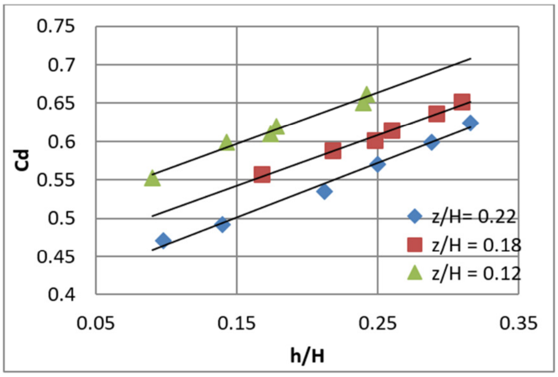

Fig. 14. Relationship between C_d and h_2/H for $b_2/B = 0.27$ and $\theta = 90^o$.

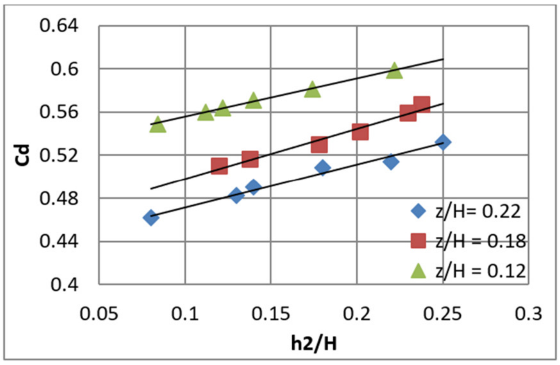

Fig. 15. Relationship between C_d and h_2/H for $b_2/B = 0.40$ and $\theta = 120^o$.

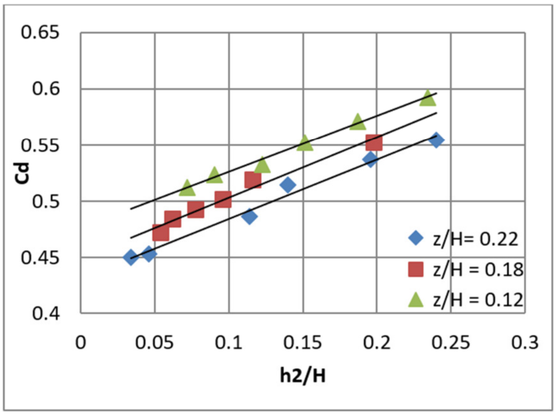

Fig. 16. Relationship between C_d and h_2/H for $b_2/B = 0.33$ and $\theta = 120^o$.

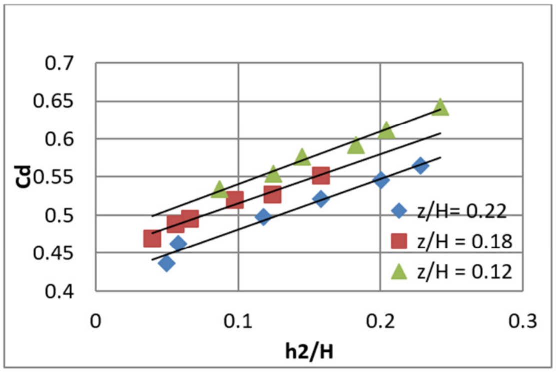

Fig. 17. Relationship between C_d and h_2/H for $b_2/B = 0.27$ and $\theta = 120^o$.

Conversely, the weir's lower rectangle height z, and the combined structure's discharge coefficient C_d, are inversely proportional to one another. An increase in the lower rectangle height z, from 6 to 11 cm was observed to result in a reduction in C_d from 0.71 to 0.672 for a θ of 60^o, h_2 of 12.5 cm, and b_2 of 8 cm. This indicates that an 83.33% increase in z yields a 5.65% decrease in C_d, as illustrated in Figures 21-23.

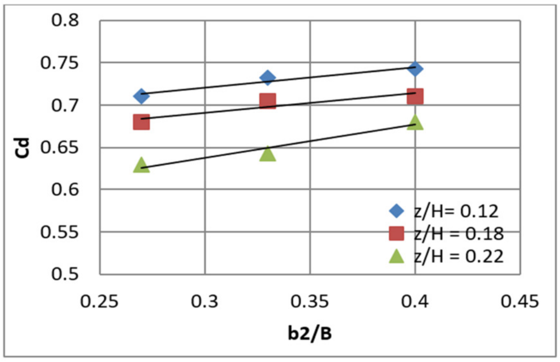

Fig. 18. Relationship between C_d and b_2/B, for $h_2/H = 0.25$, $\theta = 60^o$.

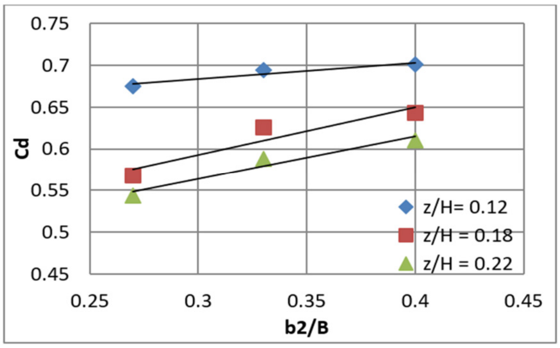

Fig. 19. Relationship between C_d and b_2/B, for $h_2/H = 0.25$, $\theta = 90^o$.

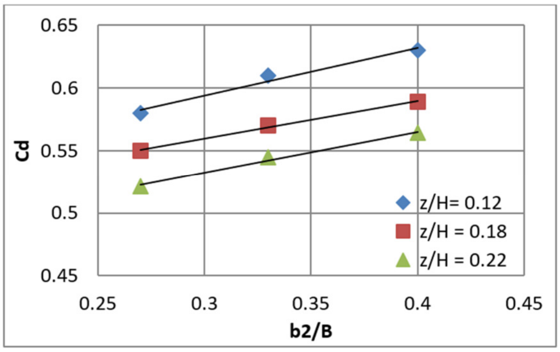

Fig. 20. Relationship between C_d and b_2/B, for $h_2/H = 0.25$, $\theta = 120^o$.

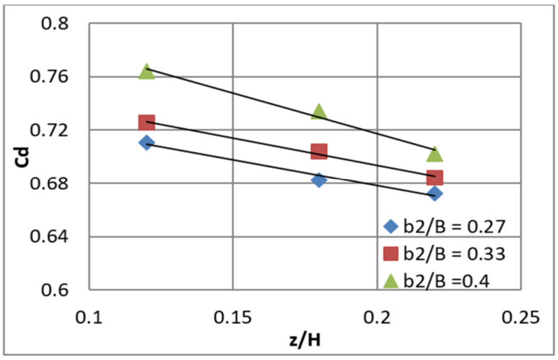

Fig. 21. Relationship between C_d and z/H, for $h_2/H = 0.25$, $\theta = 60^o$.

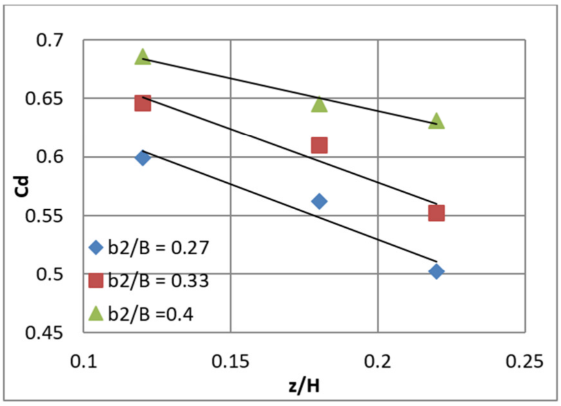

Fig. 22. Relationship between C_d and z/H, for $h_2/H = 0.25$, $\theta = 90^o$.

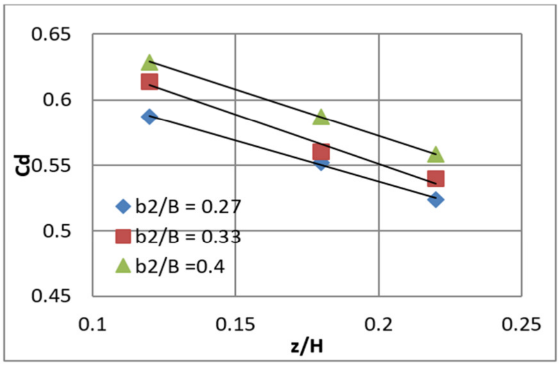

Fig. 23. Relationship between C_d and z/H, for $h_2/H = 0.3$, $\theta = 120^o$.

C. General Equation Developing

A dimensionless group regression method was used to analyze and develop a general empirical equation based on the obtained experimental results. In order to estimate the combined structure coefficient of discharge C_d, a comparison was conducted between the dependent values of C_d and the computed dimensionless groups. A significant correlation was identified between the dimensionless groups h_2/H, b_2/B, z/H, and C_d:

$$C_d = 0.347 + 0.743\left(\frac{h_2}{H}\right) + 0.231\left(\frac{b_2}{B}\right) + 0.333\left(\frac{Z}{H}\right) - 0.052\,(\theta_{rad}) \quad (9)$$

The experimentally obtained results are compared to the calculated values of the combined structure coefficient of discharge C_d, as shown in Figure 24, in order to validate the proposed equation. The results demonstrate a satisfactory degree of agreement between the experimental and calculated values.

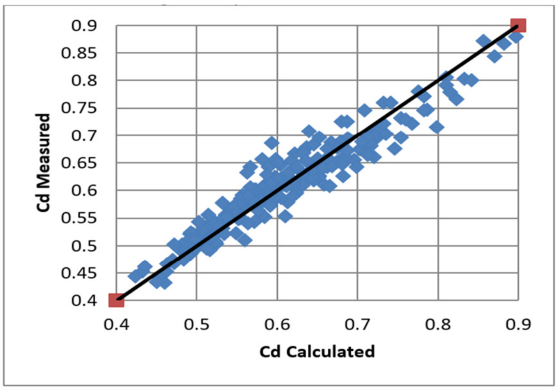

Fig. 24. Measured and calculated C_d for the combined structure flow.

V. CONCLUSIONS

Experimental runs were performed to investigate and develop a general equation for estimating the coefficient of discharge for a combined structure, designated as Cd, which consists of a compound weir with a below-triangular gate, under a range of geometric and hydraulic conditions. This configuration represents a novel and straightforward combination for a combined structure. Following the data analysis, the obtained results led to the following conclusions:

- The combined structure conveyed a greater discharge than the conventional rectangular notch weir, with a factor of two to ten based on the weir-gate geometric and hydraulic conditions. This suggests that, in comparison to the conventional weir, the combined structure is more effective in terms of discharge capacity.
- For a given value of b2, z, and the vertex angle of the triangular gate θ, the coefficient of discharge for the combined structure exhibited an average value of 0.6603, with a range from 0.4235 to 0.8971. As the water level over the compound weir h_2/H increases, the values in question also increase.
- As the ratio of the lower rectangular edge width to the width of the entire weir structure b2/B is increased, the coefficient of discharge values of the combined structure increase for a given height of the lower rectangular part of the weir z, water head h2, and angle of the triangular gate vertex θ.
- The coefficient of discharge values of the combined structure were found to exhibit an inverse proportionality with the weir lower rectangular part height ratio z/H, for a given weir lower rectangle width b2, water head h2, and gate vertex angle θ.
- For a given ratio of head to water height h2/H, width of lower rectangular part b2/B, height of weir z/H, and gate vertex angle θ, the coefficient of discharge values of the combined structure may be calculated using the developed general empirical equation.

REFERENCES

[1] F. Granata, F. Di Nunno, R. Gargano, and G. de Marinis, "Equivalent Discharge Coefficient of Side Weirs in Circular Channel—A Lazy Machine Learning Approach," *Water*, vol. 11, no. 11, Nov. 2019, Art. no. 2406, https://doi.org/10.3390/w11112406.

[2] S. Salehi and A. H. Azimi, "Discharge Characteristics of Weir-Orifice and Weir-Gate Structures," *Journal of Irrigation and Drainage Engineering*, vol. 145, no. 11, Nov. 2019, Art. no. 04019025, https://doi.org/10.1061/(ASCE)IR.1943-4774.0001421.

[3] M. G. Bos, *Discharge measurement structures*. Wageningen, Netherlands: International Institute for Land Reclamation and Improvement (ILRI), 1989.

[4] S. Emami, J. Parsa, H. Emami, and A. Abbaspour, "An ISaDE algorithm combined with support vector regression for estimating discharge coefficient of W-planform weirs," *Water Supply*, vol. 21, no. 7, pp. 3459–3476, Apr. 2021, https://doi.org/10.2166/ws.2021.112.

[5] A. B. Altan-Sakarya, M. A. Kokpinar, and A. Duru, "Numerical modelling of contracted sharp-crested weirs and combined weir and gate systems," *Irrigation and Drainage*, vol. 69, no. 4, pp. 854–864, 2020, https://doi.org/10.1002/ird.2468.

[6] P. Ackers, W. R. White, and J. A. Perkins, *Weirs and Flumes for Flow Measurement*. New York, NY, USA: John Wiley & Sons, Ltd, 1978.

[7] A. Alhamid, "Discharge equation for simultaneous flow over rectangular weirs and below inverted triangular weirs," *Arab Gulf Journal of Scientific Research*, vol. 14, no. 3, pp. 595–607, Jan. 1996.

[8] N. Rajaratnam and K. Subramanya, "Flow Equation for the Sluice Gate," *Journal of the Irrigation and Drainage Division*, vol. 93, no. 3, pp. 167–186, Sep. 1967, https://doi.org/10.1061/JRCEA4.0000503.

[9] A. Zahiri, H. Md. Azamathulla, and S. Bagheri, "Discharge coefficient for compound sharp crested side weirs in subcritical flow conditions," *Journal of Hydrology*, vol. 480, pp. 162–166, Feb. 2013, https://doi.org/10.1016/j.jhydrol.2012.12.022.

[10] S. A. Sarhan and S. A. Jalil, "Analysis of Simulation Outputs for the Mutual Effect of Flow in Weir and Gate System," *Journal of University of Babylon for Engineering Sciences*, vol. 26, no. 6, pp. 48–59, Apr. 2018, https://doi.org/10.29196/jubes.v26i6.1050.

[11] M. M. Muhammad and S. A. Abdullahi, "Experimental Study of Flow over Sharp Crested Rectangular-Triangular Weir Models," in *Nigeria Engineering Conference*, Zaria - Nigeria, Jan. 2014.

[12] M. Piratheepan, N. E. F. Winston, and K. P. P. Pathirana, "Discharge Measurements in Open Channels using Compound Sharp-Crested Weirs," *Engineer: Journal of the Institution of Engineers, Sri Lanka*, vol. 40, no. 3, Jul. 2007, https://doi.org/10.4038/engineer.v40i3.7144.

[13] H. Abd, A.-M. Hayawi, A. Abd, A. Yahia, and G. Abd, "Free Combined Flow Over a Triangular Weir and Under Rectangular Gate 1," *Damascus University Journal*, vol. 24, no. 1, pp. 9–22, 2008.

[14] A.-A. M. Negm, A. m. Al-Brahim, and A. a. Alhamid, "Combined-free flow over weirs and below gates," *Journal of Hydraulic Research*, vol. 40, no. 3, pp. 359–365, May 2002, https://doi.org/10.1080/00221680209499950.

[15] A. A. Alhamid, A.-A. M. Negm, and A. M. Al-Brahim, "Discharge Equation for Proposed Self-cleaning Device," *Journal of King Saud University - Engineering Sciences*, vol. 9, no. 1, pp. 13–23, Jan. 1997, https://doi.org/10.1016/S1018-3639(18)30664-0.

[16] S. I. Khassaf and M. Haheeb, "Experimental Investigation for flow through combined trapezoidal weir and rectangular gate," *International Journal of Scientific & Engineering Research*, vol. 5, no. 4, pp. 809–814, Apr. 2014.

[17] A. A. G. Alniami, D. G. A. M. Hayawi, and H. a. M. Hayawi, "Coefficient Of Discharge For A Combined Hydraulic Measuring Device," *Al-Rafidain Engineering Journal*, vol. 17, no. 6, pp. 92–100, Dec. 2009, https://doi.org/10.33899/rengj.2009.43616.

[18] J. M. Samani and M. Mazaheri, "Combined Flow over Weir and under Gate," *Journal of Hydraulic Engineering*, vol. 135, no. 3, pp. 224–227, Mar. 2009, https://doi.org/10.1061/(ASCE)0733-9429(2009)135:3(224).

[19] B. Balouchi and G. Rakhshandehroo, "Using Physical and Soft Computing Models to Evaluate Discharge Coefficient for Combined Weir–Gate Structures Under Free Flow Conditions," *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, vol. 42, no. 4, pp. 427–438, Dec. 2018, https://doi.org/10.1007/s40996-018-0117-0.

[20] M. A. R. Eltoukhy, F. Abdelhaleem, T. H. Nasralla, and S. Shaban, "Effect of Compound Weir and below Circular Gate Geometric Characteristics on its Discharge Coefficient," *International Journal of Scientific & Engineering Research*, vol. 11, no. 10, pp. 1115–1130, Oct. 2020.

[21] M. O. A. Alsaydalani, "Discharge Coefficient of a Two-Rectangle Compound Weir combined with a Semicircular Gate beneath it under Various Hydraulic and Geometric Conditions," *Engineering, Technology & Applied Science Research*, vol. 14, no. 1, pp. 12587–12594, Feb. 2024, https://doi.org/10.48084/etasr.6605.

[22] S. S. Ibrahim, R. A. Jafer, and B. M. A. S. Ali, "An Experimental Study of a Combined Oblique Cylindrical Weir and Gate Structure," *Engineering, Technology & Applied Science Research*, vol. 13, no. 2, pp. 10483–10488, Apr. 2023, https://doi.org/10.48084/etasr.5646.

[23] A. A. Mahessar, A. N. Laghari, S. Qureshi, I. A. Siming, A. L. Qureshi, and F. A. Shaikh, "Environmental Impact Assessment of the Tidal Link Failure and Sea Intrusion on Ramsar Site No. 1069," *Engineering, Technology & Applied Science Research*, vol. 9, no. 3, pp. 4148–4153, Jun. 2019, https://doi.org/10.48084/etasr.2686.

[24] C. E. Kindsvater and R. W. Carter, "Discharge Characteristics of Rectangular Thin-Plate Weirs," *Journal of the Hydraulics Division*, vol. 83, no. 6, pp. 1453–36, Dec. 1957, https://doi.org/10.1061/JYCEAJ.0000142.

[25] M. L. Albertson, Y. B. Dai, R. A. Jensen, and H. Rouse, "Diffusion of Submerged Jets," *Transactions of the American Society of Civil Engineers*, vol. 115, no. 1, pp. 639–664, Jan. 1950, https://doi.org/10.1061/TACEAT.0006302.