

Hydraulic Characteristics and Data-Driven Prediction of Discharge Coefficient in Rectangular Labyrinth Side Weirs

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ABSTRACT

Rectangular labyrinth side weirs are widely used as flow-diversion structures in irrigation and drainage systems due to their ability to enhance discharge capacity by increasing the effective crest length within limited channel widths. In the present study, laboratory experiments were conducted under subcritical flow conditions to investigate the discharge characteristics of a rectangular labyrinth side weir installed in a straight channel. The influence of key hydraulic and geometric parameters on the discharge coefficient (C_D) was systematically examined. A statistical F-test was applied to identify the relative significance of the governing dimensionless parameters affecting C_D . Based on the experimental dataset, a nonlinear regression model was developed to establish a predictive relationship between C_D and the dominant flow variables. The developed regression model showed good agreement with experimental data, with an overall correlation coefficient ($R = 0.8572$) and a low RMSE value of 0.1282 respectively, along with reasonable prediction accuracy reflected by low RMSE values. The outcomes of this study improve the understanding of discharge behaviour of rectangular labyrinth side weirs and provide a practical regression-based formulation that can assist in hydraulic design and performance evaluation of flow-diversion structures.

Keywords: Rectangular labyrinth side weir; Discharge coefficient; Three-cycle configuration; Nonlinear regression; Flow diversion

Symbols

B	Main channel section width (m)
C_D	Rectangular labyrinth side weir discharge coefficient
P	Elevation of the side weir crest from the channel bed (m)
L	Total effective length of the side weir opening (m)
h_1	Water depth along the centreline upstream of the side weir in the main channel (m)
V	Upstream flow velocity near the side weir (m/s)
G	Constant gravity acceleration
Q_1	Upstream discharge in the main channel (m^3/s)
Q_3	Discharge diverted through the side weir (m^3/s)

Fr Upstream Froude number

C_1, C_2, C_3, C_4 Coefficients

n_1, n_2, n_3 Exponents

R Correlation coefficients

INTRODUCTION

Side weirs are widely used as hydraulic control and flow-diversion structures in open-channel systems such as irrigation canals, urban drainage networks, flood-control works, and water and wastewater treatment facilities. Flow over a side weir is classified as spatially varied flow with decreasing discharge, in which the main-channel flow continuously reduces along the weir length. Due to this complex hydraulic behaviour, accurate estimation of diverted discharge is essential for reliable hydraulic design.

The classical formulation of side-weir flow was proposed by De Marchi (1934) under the assumption of constant specific energy along the crest. Subsequent experimental studies demonstrated that the discharge coefficient is not constant but depends strongly on flow conditions and geometric characteristics of the structure (Subramanya and Awasthi, 1972; El-Khashab and Smith, 1976; Ramamurthy et al., 1986; Swamee et al., 1994). These investigations also highlighted the limited discharge capacity of conventional straight-crested side weirs due to restricted crest length.

To enhance diversion capacity, labyrinth side weirs were developed by folding the crest into multiple cycles, thereby increasing the effective overflow length without increasing channel width. Experimental investigations have shown that labyrinth configurations significantly improve discharge performance under identical upstream head conditions (Khode et al., 2012; Dey et al., 2013; Thompson et al., 2016; Sangsefidi et al., 2017). Among different configurations, rectangular labyrinth side weirs are particularly attractive because of their structural simplicity and suitability for irrigation and drainage channels.

Recent studies based on experimental observations and regression analysis have attempted to describe the discharge behaviour of labyrinth side weirs. Shariq et al. (2019) reported strong dependence of the discharge coefficient on geometric parameters, while Norouzi et al. (2019) demonstrated the effectiveness of regression-based relationships for predicting discharge characteristics of trapezoidal labyrinth weirs. More recently, Wan et al. (2024) experimentally investigated stepped labyrinth side weirs and emphasized the influence of crest geometry on diversion efficiency. However, experimental investigations focusing on multi-cycle rectangular labyrinth side weirs remain limited, and the influence of governing dimensionless parameters has not yet been fully clarified.

Therefore, the present study experimentally investigates the discharge characteristics of a three-cycle rectangular labyrinth side weir operating under subcritical flow conditions. Based on the experimental dataset, a nonlinear regression equation is developed to relate the discharge coefficient to the dominant dimensionless parameters, and a statistical F-test is applied to identify their relative significance. The outcomes of this study aim to contribute to improved understanding of rectangular labyrinth side-weir hydraulics and to support reliable design and performance assessment.

Dimensional Analysis

Discharge coefficient (C_D) of labyrinth side weirs can be expressed as a function of average velocity of flow over the cross section of the channel (V), depth over the crest of rectangular labyrinth side weir (h_1) upstream depth of flow in channel (y_1), acceleration due to gravity (g), width of side weir (L), width of main channel (B), crest height of rectangular labyrinth side weir (p), number of cycles (N), dynamic viscosity of water (μ) and density of water (ρ).

Applying the Buckingham- π theorem, non-dimensional equations in functional forms can be written as below:

$$C_D = f(Fr, L/L, B/y_1, h_1/p, N) \quad (1)$$

To see the effect of various parameters on coefficient of discharge, C_D and to establish generalized relationship among the dependent and independent parameters of Eq. (1), experimental programmes are carried out in present study.

Experimental set up and Program

The experimental investigation was carried out in the Advanced Hydraulics Laboratory, Department of Civil Engineering, Aligarh Muslim University, Aligarh. The experiments were performed in a horizontal rectangular flume of 9.74 m length, 0.50 m width, and 0.38 m depth, operating under a recirculating flow system. Water was supplied to the flume through a 0.10 m diameter inlet pipe, and the flow depth in the main channel was regulated using a sluice gate installed at the downstream end. A rectangular labyrinth side weir was installed along the right wall of the main channel at a distance of 7.30 m from the inlet. The diverted flow passed into a secondary collection channel of 4.29 m length, 0.22 m width, and 0.38 m depth. A sharp-crested rectangular measuring weir (Weir-A) was provided at the downstream end of the diversion channel to measure the side-weir discharge. The remaining flow in the main channel, together with the diverted discharge, was conveyed to a return channel where another sharp-crested weir (Weir-B) was installed to measure the total discharge.

To ensure stable and uniform flow conditions, splitter plates and wave suppressors were installed upstream of the test section to reduce large-scale turbulence and surface disturbances. All experiments were conducted under free-flow conditions with fully ventilated nappes. The flow in the vicinity of the labyrinth side weir remained subcritical throughout the experimental program. Experiments were performed on a three-cycle rectangular labyrinth side weir with a chord length of 0.50 m. Three different crest heights, namely 11 cm, 14 cm, and 18 cm, were investigated. For each crest height, approximately 50–60 experimental runs were conducted by varying the discharge and controlling the upstream flow depth through the downstream sluice gate. Water surface elevations in the main channel and heads over the measuring weirs were recorded using a point gauge with a least count of 0.1 mm. The experiments covered a discharge range of approximately 0.01–0.60 m³/s. A photographs of the experimental setup and three cycle labyrinths are presented in Fig. 1 and Fig 2 shows the schematic diagram of three cycle labyrinth side weir.



Fig 1. Photographic view of experimental set up and three cycle labyrinth side weir

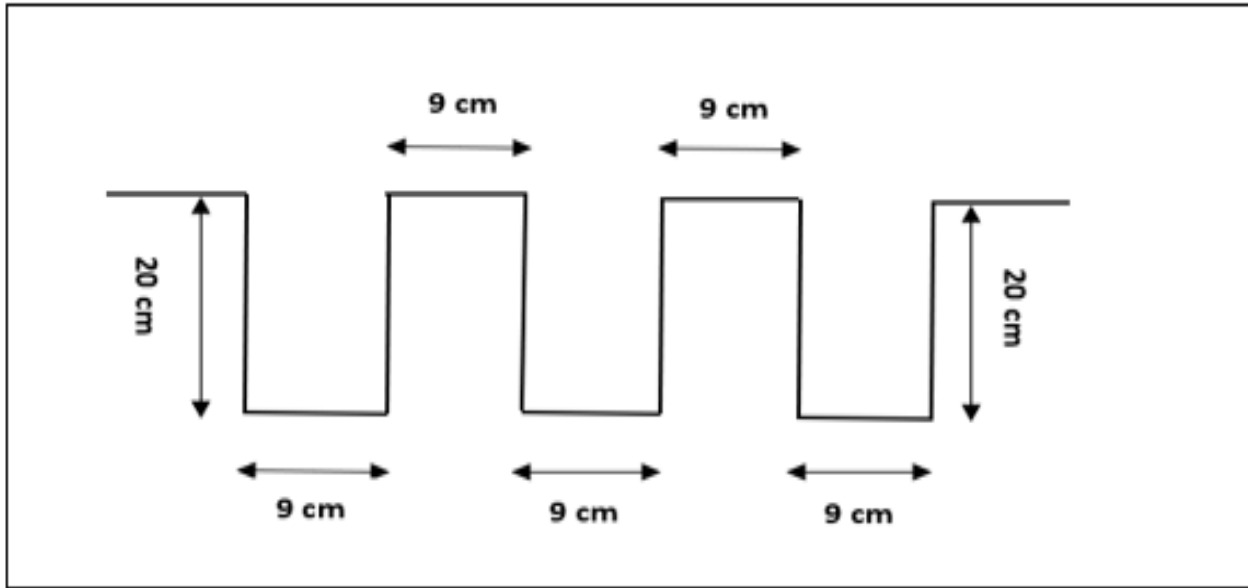


Fig 2. Schematic view of three cycle labyrinth side weir

Relative Importance of various parameters

An F-test was conducted to evaluate the relative importance of the independent variables in predicting the discharge coefficient (C_D). This test helps identify the contribution of each parameter to the dependent variable. Parameters with lower F-values were considered to have negligible influence.

The effect of the dimensionless parameters Fr , l/L , B/y_1 , h_1/p , and N on C_D was examined, as shown in Fig. 3. The results indicate that B/y_1 has the highest influence on the discharge coefficient, whereas the number of cycles (N) exhibits the lowest effect and may therefore be neglected compared to the other parameters.

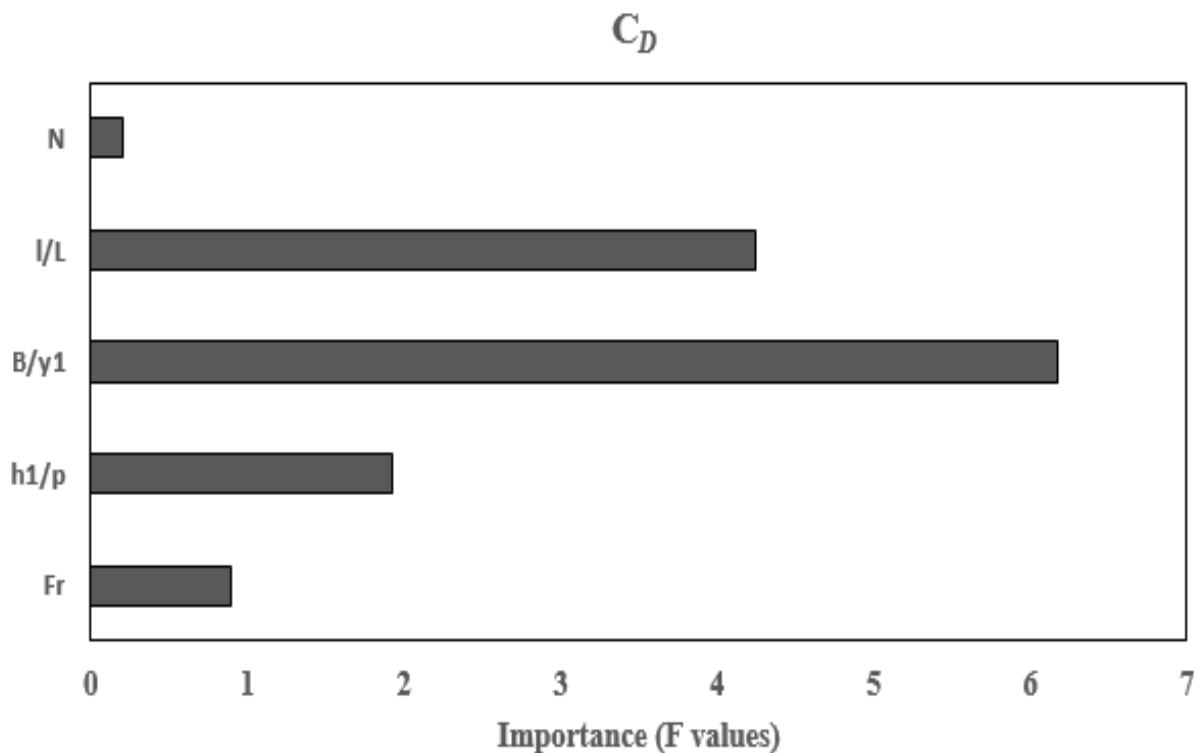


Fig. 3. F-test results for input parameter importance on discharge coefficient (C_D).

Effect of dimensionless parameter on C_D

The influence of different dimensionless parameters on the discharge coefficient (C_D) was examined in the present study, and the corresponding variations are illustrated in Fig. 4(a), (b) and (c).

The results show that C_D increases with an increase in the upstream Froude number (Fr) when other parameters remain constant, which can be attributed to enhanced lateral momentum transfer and stronger secondary flow toward the labyrinth side weir at higher flow intensities.

The discharge coefficient also increases with increasing relative channel width (B/y_1) indicating improved diversion efficiency under lower upstream flow depths. In contrast, an increase in the relative head over the crest (h_1/p) results in a reduction of C_D mainly due to intensified flow interference, local energy losses, and stronger flow separation near the side-weir boundary.

Overall, the findings confirm that the discharge behaviour of a rectangular labyrinth side weir is significantly governed by upstream hydraulic conditions and relative geometric parameters.

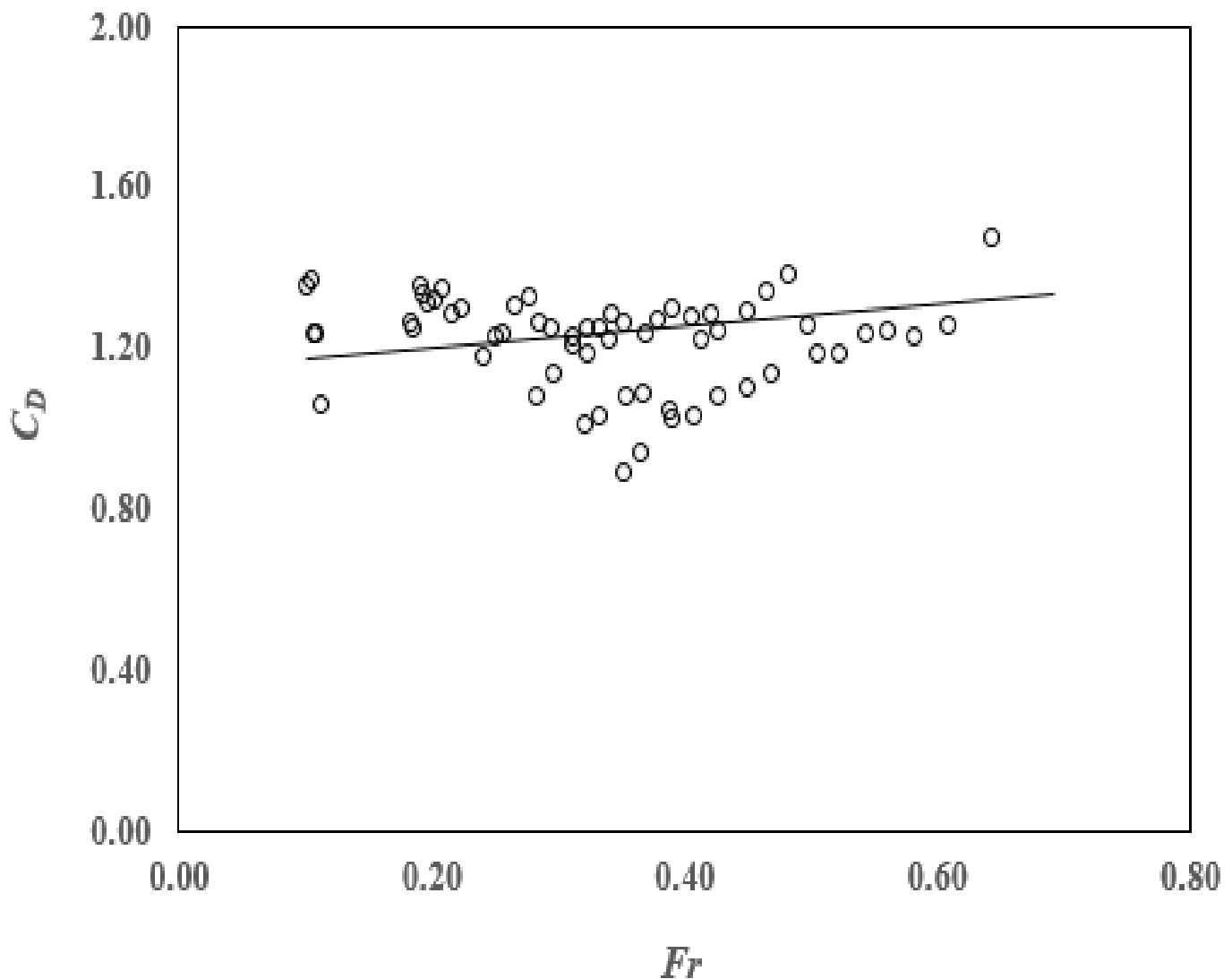


Fig.4(a) Variation of coefficient of discharge with upstream Froude number for 3 cycle rectangular labyrinth side weir.

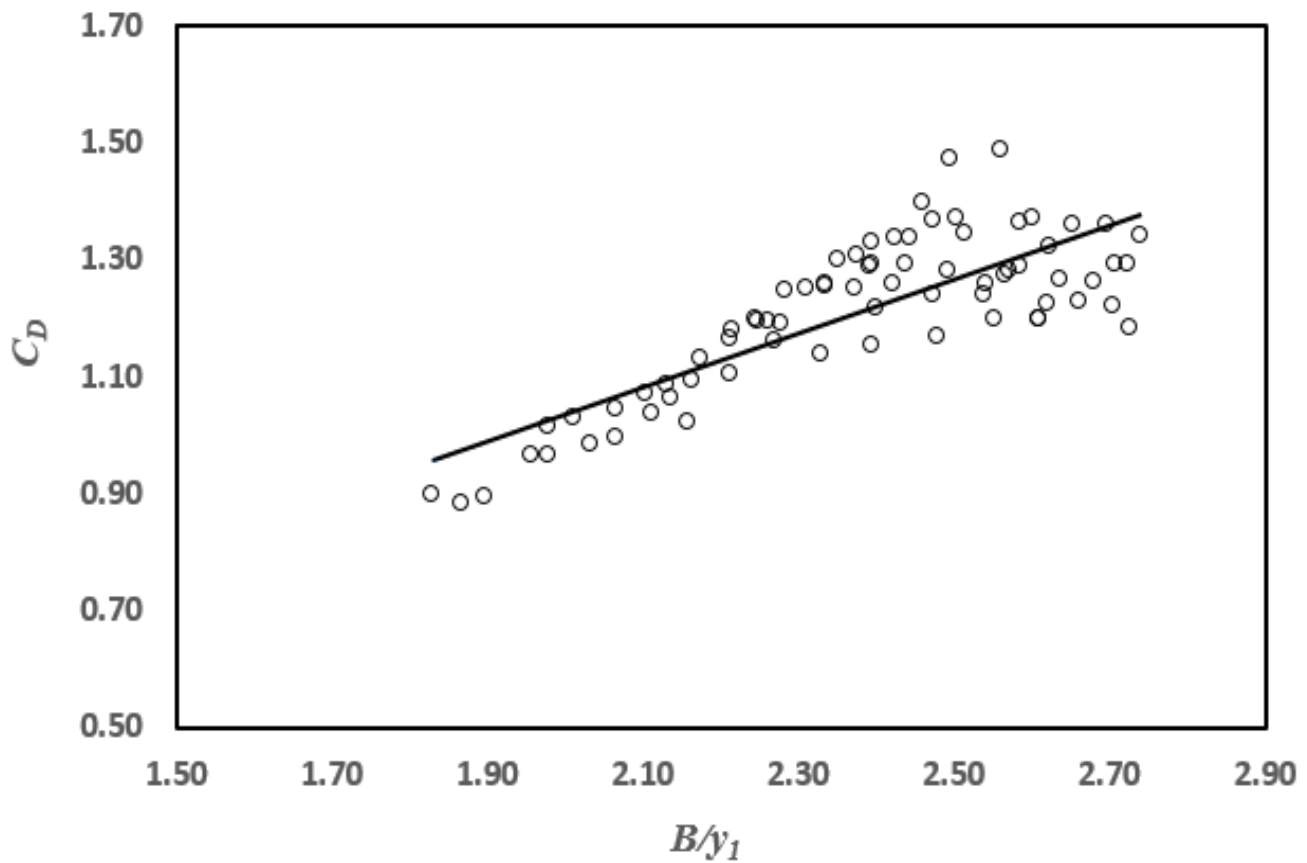


Fig.4(b) Variation of coefficient of discharge with B/y_1 for 3 cycle rectangular labyrinth side weir.

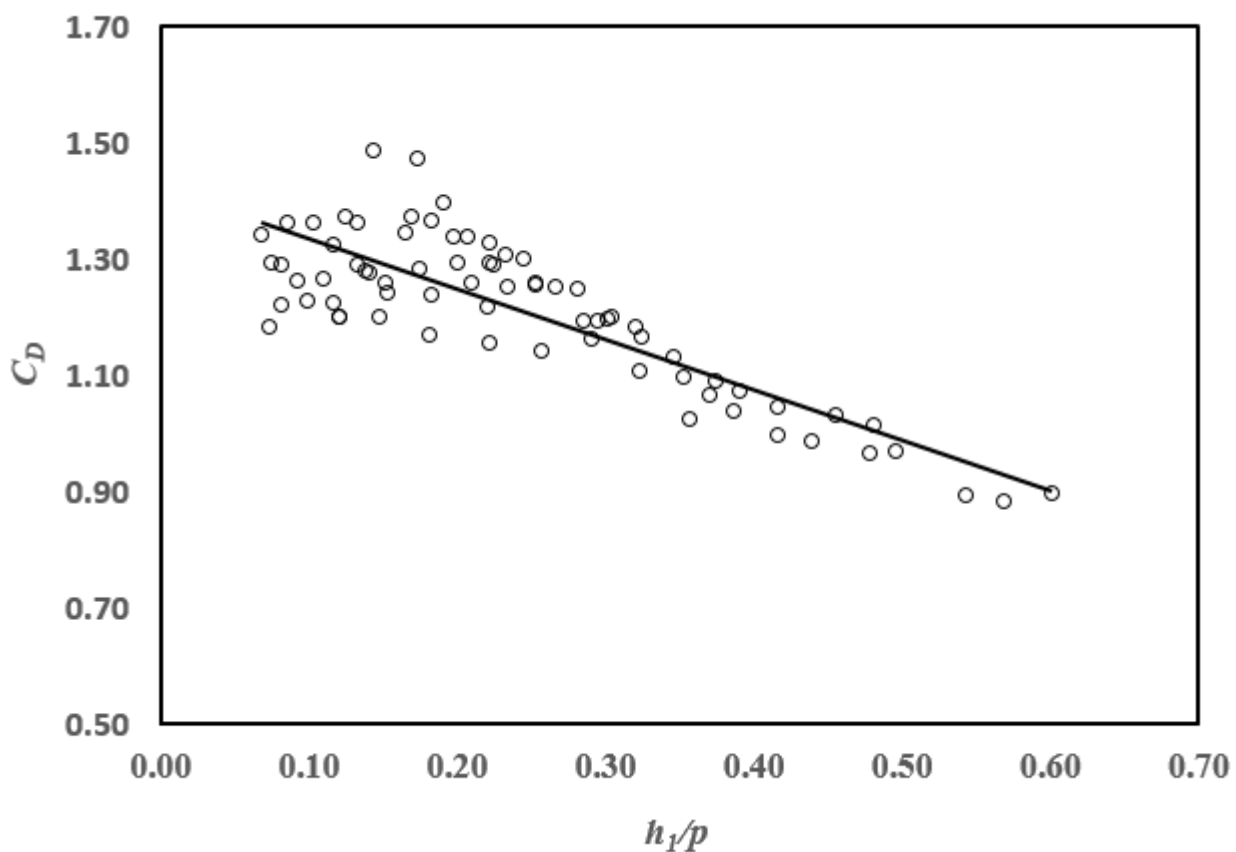


Fig.4(c) Variation of coefficient of discharge with h_1/p for 3 cycle rectangular labyrinth side weir.

Model Development

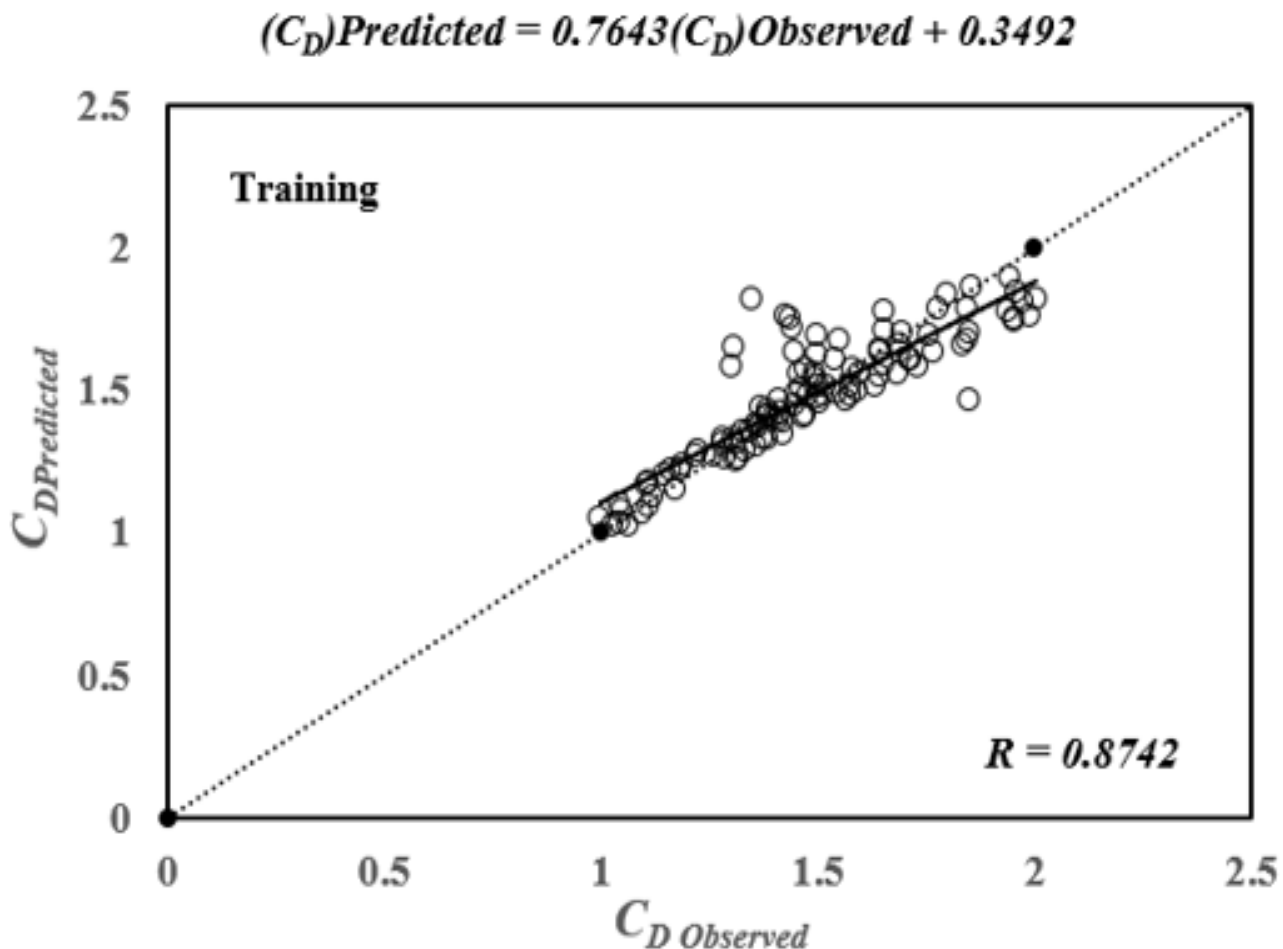
Based on the dimensional analysis and established formulations, the discharge coefficient (C_D) was expressed in a generalized power-law form as

$$C_D = c_1 + c_2 \left(\frac{B}{y_1} \right)^{n_1} + c_3 \left(\frac{h_1}{p} \right)^{n_2} + c_4 (Fr)^{n_3} \quad (2)$$

where c_1 – c_4 are regression constants and n_1 – n_3 are the associated exponents. The coefficients were determined using the experimental dataset after removing outliers exceeding three standard deviations through MATLAB routines. Approximately 80% of the data was used for model calibration and the remaining 20% for validation, following commonly adopted practices in hydraulic modelling studies. The resulting empirical relationship is expressed as

$$C_D = 1.5 + 0.60 \left(\frac{B}{y_1} \right)^{0.25} - 1.56 \left(\frac{h_1}{p} \right)^{0.53} - 0.49 (Fr)^{1.64} \quad (3)$$

The predictive performance of Eq. (3) was evaluated using the validation dataset, as shown in Fig. 4 (a) and (b). The regression model provided satisfactory agreement with the experimental data; however, its predictive capability is constrained by the complex and highly nonlinear hydraulic behaviour associated with flow over labyrinth side weirs.



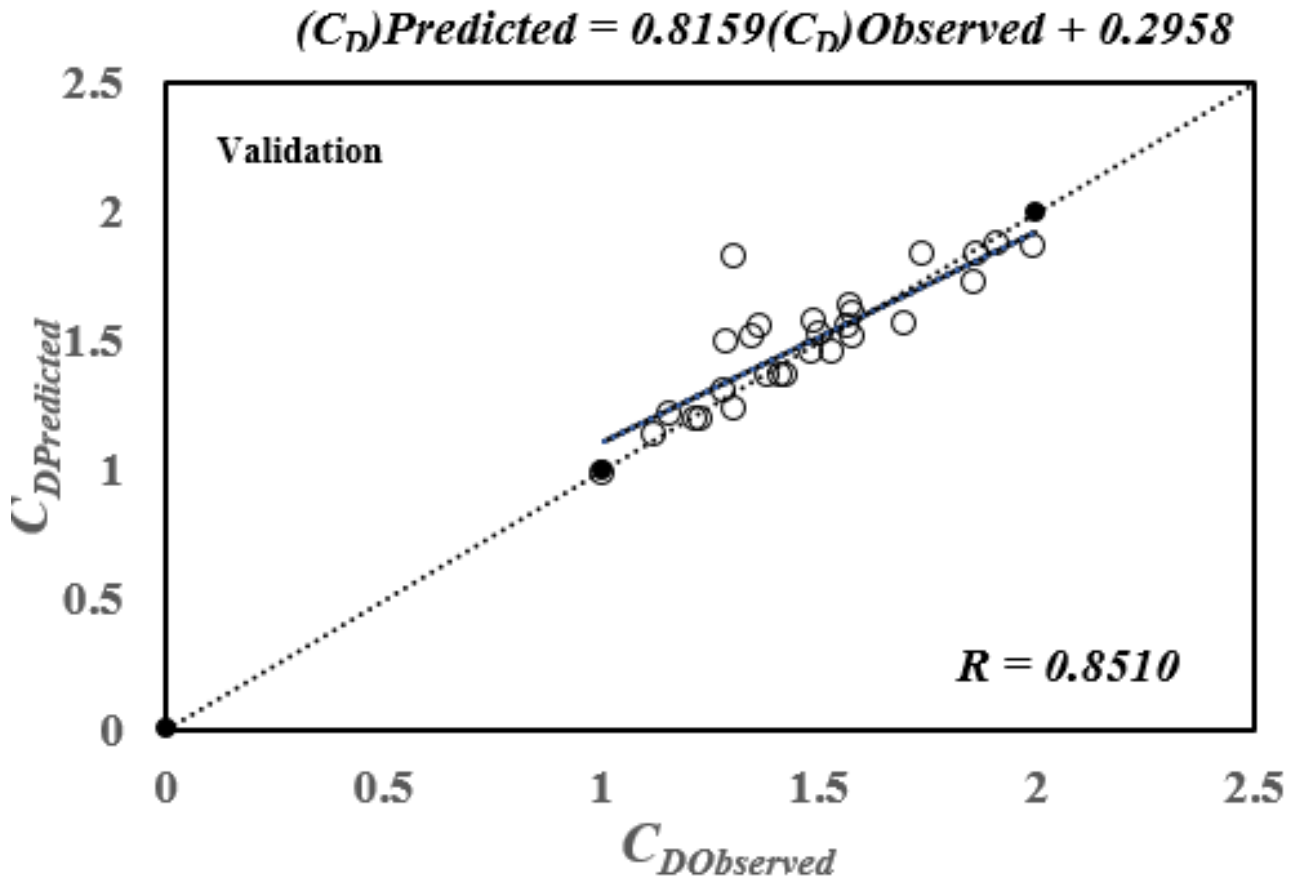


Fig. 5 Comparison between observed and calculated C_D values obtained from the regression model for (a) training and (b) validation datasets.

RESULTS AND DISCUSSION

The experimental results indicate that the discharge coefficient (C_D) of three cycle rectangular labyrinth side weirs is significantly influenced by hydraulic and geometric parameters. An increase in the upstream Froude number (Fr) leads to higher C_D values due to enhanced secondary flow and increased lateral momentum transfer toward the side weir, which improves flow diversion efficiency.

A positive relationship is also observed between C_D and the dimensionless parameter B/y_1 under constant geometric conditions ($B/L = 1.0$, $l/L = 2.8$, and $p = 14$ cm). Since the weir width remains unchanged, a reduction in upstream flow depth increases approach velocity, thereby strengthening lateral discharge and resulting in higher discharge coefficients.

In contrast, C_D decreases with increasing relative upstream head (h_1/p). Higher h_1/p values intensify turbulence, flow separation, and local energy losses near the crest region, reducing the effectiveness of lateral overflow. The combined influence of Fr , B/y_1 , and h_1/p on C_D is illustrated in Fig 3(a) (b) and (c) respectively.

Based on the experimental dataset, a nonlinear regression equation was developed to estimate the discharge coefficient of the rectangular labyrinth side weir. The regression model showed satisfactory agreement between observed and predicted C_D values, yielding an overall correlation coefficient of ($R = 0.8572$) and a low root mean square error ($RMSE = 0.12$). These results indicate that the proposed regression equation can reasonably represent the discharge behaviour of the rectangular labyrinth side weir within the investigated range of hydraulic and geometric conditions. However, its applicability is limited to the experimental domain considered in the present study

CONCLUSIONS

The present study experimentally examined the discharge characteristics of a rectangular labyrinth side weir installed in a straight rectangular channel. The results indicate that the discharge coefficient (C_D) decreases with increasing relative upstream head (h_1/p), whereas higher values of B/y_1 and Froude number (Fr) lead to an increase in C_D . These trends demonstrate the strong influence of hydraulic conditions and geometric parameters on the lateral diversion behaviour of labyrinth side weirs. Based on the experimental data, a nonlinear regression equation was developed to estimate the discharge coefficient. The regression model showed satisfactory agreement with the measured values within the investigated range of flow and geometric conditions, indicating its applicability for practical estimation of C_D . Overall, the findings of this study provide useful insight into the hydraulic performance of rectangular labyrinth side weirs and offer a reliable regression-based approach that can support preliminary design and performance evaluation in irrigation and drainage systems.

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