

## **AN EXPERIMENTAL INVESTIGATION ON THE HYDRAULIC PERFORMANCE OF RECTANGULAR LABYRINTH WEIR: INFLUENCE OF CYCLE NUMBER**

**Musarrat Mubasshira Atiya<sup>1</sup> and K. M. Ahtesham Hossain Raju<sup>2\*</sup>**

<sup>1</sup> *Postgraduate student, BUET, Bangladesh, e-mail: [mm.atiyaa@gmail.com](mailto:mm.atiyaa@gmail.com)*

<sup>2</sup> *Associate professor, Department of Water Resources Engineering, Bangladesh University of Engineering & Technology, Dhaka-1000, Bangladesh, e-mail: [ahtesham@wre.buet.ac.bd](mailto:ahtesham@wre.buet.ac.bd)*

**\*Corresponding Author**

### **ABSTRACT**

A labyrinth weir is a type of non-linear weir used in hydraulic engineering to control water levels and discharge, consisting of defining characteristic of folded, zigzag, or serpentine plan shape, which significantly increases the length of the weir crest compared to a traditional linear weir occupying the same channel width. The distinctive folded, nonlinear design of labyrinth weirs allows for both superior discharge capacity at low water heads and significant energy dissipation at the weir crest. The experiments are conducted in the large tilting flume of 21.3 m long, 0.76 m wide, and 0.74 m depth in the Hydraulics and River Engineering Laboratory of the Water Resources Engineering Department, BUET. Physical models of rectangular Labyrinth weirs have been fabricated using 8 mm thick plastic board, with the weir height maintained at a constant height of 20.8 cm. Two laboratory-scaled models have been investigated encompassing two cycle (linear length 1.94 m, N=2) and three cycle counts (linear length 2.50 m, N=3) including a total of 10 experimental runs. The experiments involved five distinct discharge values, ranging from a minimum of 80 m<sup>3</sup>/hr to a maximum of 160 m<sup>3</sup>/hr, with data collected at 20 m<sup>3</sup>/hr. intervals with approach velocity varying from 0.12 m/s to 0.22 m/s. This study results inverse relationship between number of cycle and coefficient of discharge. The results indicate that two-cycle labyrinth weir yielded consistently higher coefficient of discharge values (ranging from 0.61 to 0.54) compared to its three-cycle model (0.55 to 0.46) due to nappe interference and local submergence for higher cycle. The study reveals that labyrinth weirs with fewer cycles possess a greater discharge capacity for a given width. It is expected that the study would contribute to a better understanding of labyrinth weir hydraulics, offering practical insights for their application in efficient hydraulic engineering in water resources management projects.

**Keywords:** *Rectangular Labyrinth Weir (RLW), Crest length, Cycle number, Co-efficient of discharge (C<sub>d</sub>).*

## **INTRODUCTION**

The labyrinth weir that is viewed from above has a zig-zag shape. The main objective is to extend the spillway so that the water level upstream of the weir is as low as possible or to increase the discharge capacity. Several studies have assessed the discharge capacity of labyrinth weirs. Shruti et. al (2024) examined an experimental and numerical investigation to improve the rectangular labyrinth weir performance. Prajakta et.al (2024) investigated experimental study and analysis of labyrinth weir. Mosbah and Ahmed (2022) performed experimental and numerical study on rectangular labyrinth weir. Rustiati et.al (2022) examined trapezoidal labyrinth weir to investigate the influence of number of cycles on the hydraulic characteristics of the weir. There are two types of model tests one-cycle and two cycle. Jamal et.al (2021) investigated experimental study of discharge coefficient of trapezoidal arced labyrinth weirs of widened middle cycle. Yousif et.al (2021) investigated characteristics of flow over rectangular labyrinth weirs with round corners. The purpose of this experimental study was to see how the height and effective length of round-cornered rectangular labyrinth weirs affect their discharge efficiency. Bilhan and Emin (2016) examined sharp-crested trapezoidal labyrinth weirs to investigate discharge coefficient. In the present study, discharge coefficients were experimentally determined for sharp crested trapezoidal labyrinth weirs of varying side wall angle ( $\alpha$ ). Ruqiya et.al (2022) examined flow over triangular labyrinth weirs. In the study, the hydraulic properties of flow over labyrinth triangular weirs models with sharp crest have been experimentally studied and compare their efficiency with suppressed rectangular weirs. Khameneh et.al (2014) performed the effect of increasing the numbers of cycles of labyrinth side weir. Kumar et al. (2011) used a triangular labyrinth weir to investigate the discharge coefficient ( $C_d$ ).

This paper intends to explore the effect of the number of cycles of rectangular labyrinth weir on the hydraulic characteristics of the weir, based on an experimental study. Analysis determines that the most hydraulically efficient labyrinth weirs are those with a lower number of cycles.

## **EXPERIMENTAL SETUP**

Experiment is carried out in the recirculating tilting rectangular flume (21.3 m x 0.76 m x 0.74 m) of the Hydraulics and River Engineering Laboratory, WRE, BUET. The side walls of the flume are vertical and made of vertical clear glass. Two pumps are there to supply water from the reservoir to the flume through a recirculation channel. Discharge measurements are taken from the electromagnetic flow meter in the unit  $\text{m}^3/\text{hr}$ . The experiments were conducted over a range of twelve distinct discharge values, from a minimum of  $80 \text{ m}^3/\text{hr}$ . to a maximum of  $160 \text{ m}^3/\text{hr}$ . Data was taken every  $20 \text{ m}^3/\text{hr}$ . of discharge value. Figure 1 show the schematic diagram of the experimental setup used in this study.

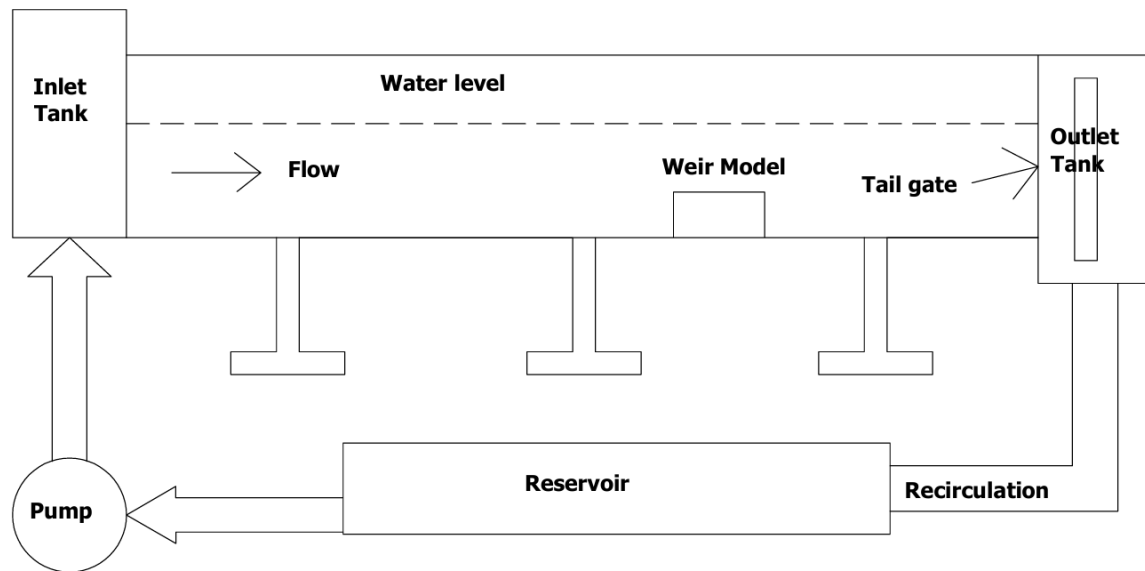


Figure 1: A schematic diagram of the experimental setup used in this study

The bed is painted by water resistant colour to avoid excess bed friction. A tail gate is provided at the end of the flume to control the depth of flow. The methodology of this study has been carried out according to following flow diagram as shown in Figure 2.

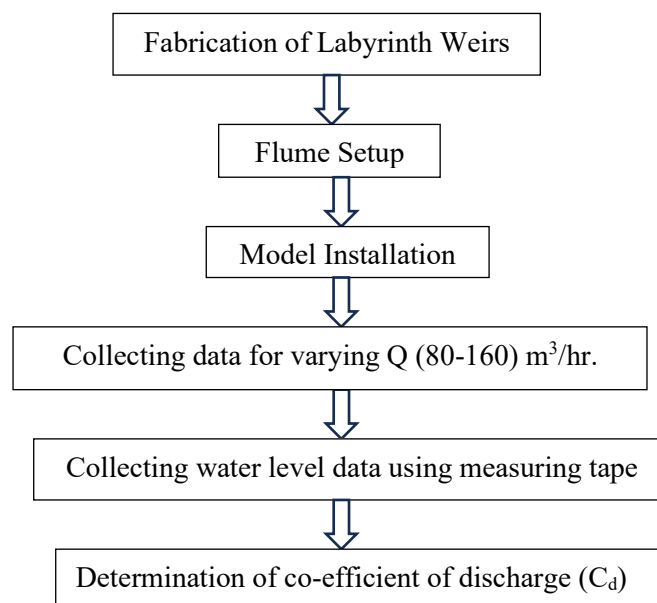


Figure 2: Methodology of the study

Physical models are fabricated using plastic board with an 8 mm thickness. A circular saw machine has been used to cut the plastic board to obtain precise dimensions. The physical models are assembled by small nails. Silicon glue is used to avoid water leaking through the models' joints. To construct the physical models for this experiment, detailed designs were first created using AutoCAD software. These designs specified the precise dimensions and geometric properties of each model. The complete schematic drawings for all configurations are provided in Figure 3 and Figure 4.

After each model installation, the flume is filled with water and allowed few min before testing to accommodate thermal expansion/contraction. The variations of upstream water level due to the weir is measured using measuring tape attached on the sidewall of flume. Data are collected over a flow

range corresponding to  $0.13 < H_T/P < 0.29$ . There are five discharges varying from low to high (80-160) m<sup>3</sup>/hr. for each model. Detailed methodology and experimental setup is available in Atiya (2025).

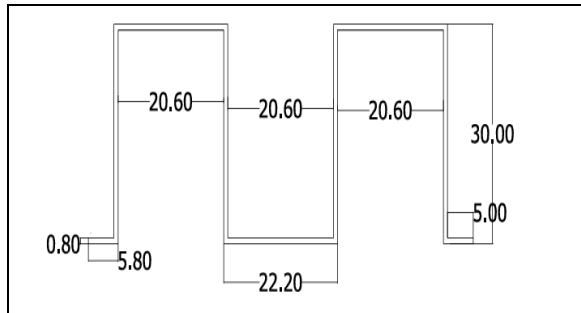


Figure 3: Schematic drawing and fabricated Rectangular Labyrinth Weir of two cycle

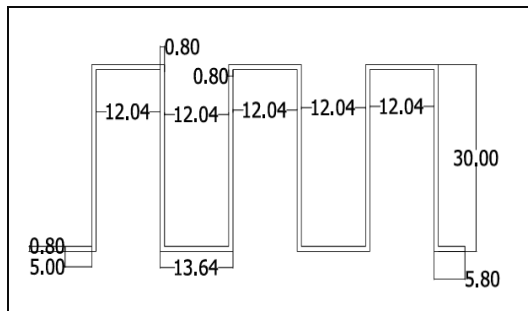


Figure 4: Schematic drawing and fabricated Rectangular Labyrinth Weir of three cycle

Data are collected by adjusting the flow rate ( $Q$ ). All data are entered directly into an Excel spreadsheet and logged in a notebook. After collecting all the data, co-efficient of discharge,  $C_d$  by using specific equations. Figure 5 shows the model during operation.

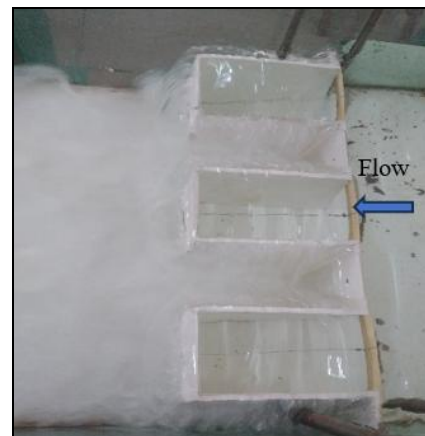
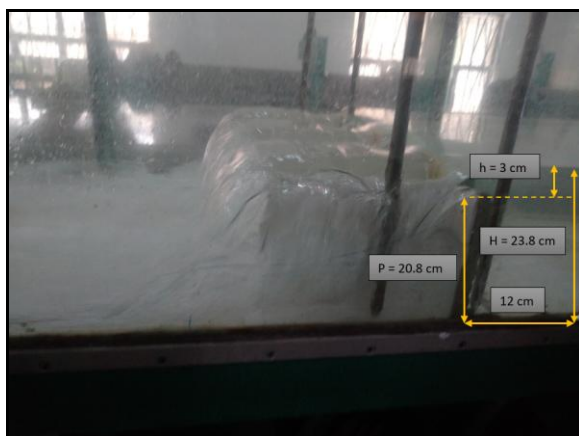


Figure 5: Laboratory test of the three cycle Rectangular Labyrinth Weir ( $Q = 80.5$  m<sup>3</sup>/hr.)

## THEORETICAL CONSIDERATION

A head-discharge relationship for labyrinth weirs is commonly performed using a general form of the weir equation, Eq. (1).

$$Q = \frac{2}{3} C_d L_c \sqrt{2g} H_T^{\frac{3}{2}} \quad (1)$$

$$H_T = \frac{V_u^2}{2g} + h \quad (2)$$

$C_d$  is the dimensionless discharge coefficient,

$L_c$  is the length of crest,

$g$  is the acceleration due to gravity, and

$H_T$  is the total upstream head

$V_u$  and  $h$  are the average cross-sectional velocity and piezometric head upstream of the weir relative to the weir crest elevation.

$$V_u = \frac{Q}{bH} \quad (3)$$

$b$  is the width of the flume

$H$  is the total upstream depth of water

Figure 6 show the effective parameter of Rectangular Labyrinth Weir

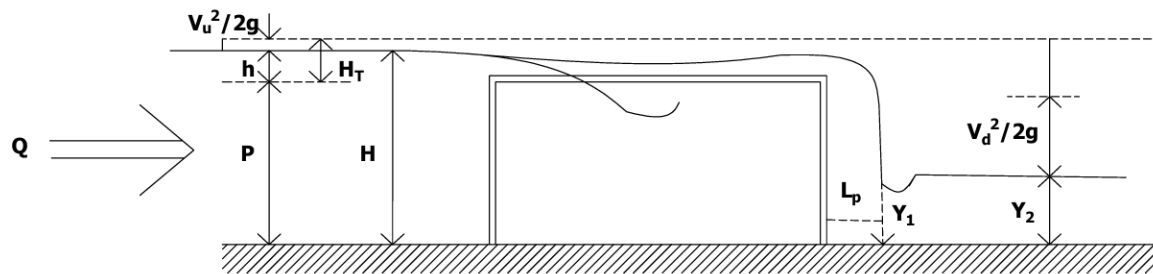


Figure 6: The effective parameters of Rectangular Labyrinth Weir

For a constant weir height ( $P = 20.8$  cm) and thickness ( $t_w = 0.8$  cm), the coefficients of discharge for the two-cycle RLW ( $L_c = 193$  cm) and three-cycle RLW ( $L_c = 250.2$  cm) are presented in Table 1 and Table 2, respectively.

Table 1: Calculation of  $C_d$  for two cycle Rectangular Labyrinth Weir

Run No.	Total U/s dept h of water, H (m)	h= H-P (m)	Flo wrate Q (m <sup>3</sup> /hr.)	U/s veloci ty, $V_u$ (m/s)	D/s veloc ity, $V_d$ (m/s)	Positi on of hydra clic jump, $L_p$ (m)	Fro ude nu mber, $F_r$	Total U/s head , $H_T$ (m)	Head wate r ratio , $H_T/P$	$C_d$ (Eq.1)
1	0.241	0.033	80	0.121	0.182	0.42	0.95	0.034	0.163	0.614
2	0.248	0.04	100	0.147	0.39	0.44	1.04	0.041	0.197	0.591
3	0.255	0.047	121	0.173	0.453	0.47	1.08	0.049	0.236	0.549
4	0.261	0.053	141	0.198	0.602	0.66	1.24	0.055	0.264	0.529
5	0.265	0.057	160	0.220	0.6	0.99	1.76	0.059	0.284	0.538

Table 2: Calculation of  $C_d$  for three cycle Rectangular Labyrinth Weir

Run No.	Total depth of water, H (m)	h=H-P (m)	Flow rate, Q (m <sup>3</sup> /hr.)	U/s velocity, $V_u$ (m/s)	D/s velocity, $V_d$ (m/s)	Position of hydraulic jump, $L_p$ (m)	Froude number, $F_r$	Total head, $H_T$ (m)	Head water ratio, $H_T/P$	$C_d$ (Eq. 1)
6	0.238	0.03	80.5	0.123	0.061	2.79	1.61	0.031	0.149	0.546
7	0.244	0.036	100.8	0.151	0.065	2.67	1.43	0.037	0.178	0.533
8	0.253	0.045	120.5	0.174	0.115	2.43	1.39	0.047	0.226	0.438
9	0.256	0.048	140.5	0.200	0.424	2.49	1.37	0.05	0.24	0.472
10	0.26	0.052	160	0.224	0.461	2.87	1.4	0.055	0.264	0.462

## RESULTS AND DISCUSSIONS

Figure 7 illustrates the relationship between the headwater ratio ( $H_T/P$ ) and the coefficient of discharge for two different types of rectangular labyrinth weirs: a two-cycle and a three-cycle configuration. The coefficient of discharge is a measure of hydraulic efficiency, with higher values indicating a more efficient weir. The graphical analysis indicates a clear negative correlation between the headwater ratio and the discharge coefficient. This observation corroborates the findings of several earlier studies that reported a similar inverse relationship (Idress and Al-Ameri, 2023; Bilhan and Emin, 2016; Rangeen and Shaker, 2022; Seamon, 2014). The decrease in  $C_d$  with increasing  $H_T/P$  for both weirs is a classic characteristic of labyrinth weirs, as higher flows intensify the energy losses from nappe interference.

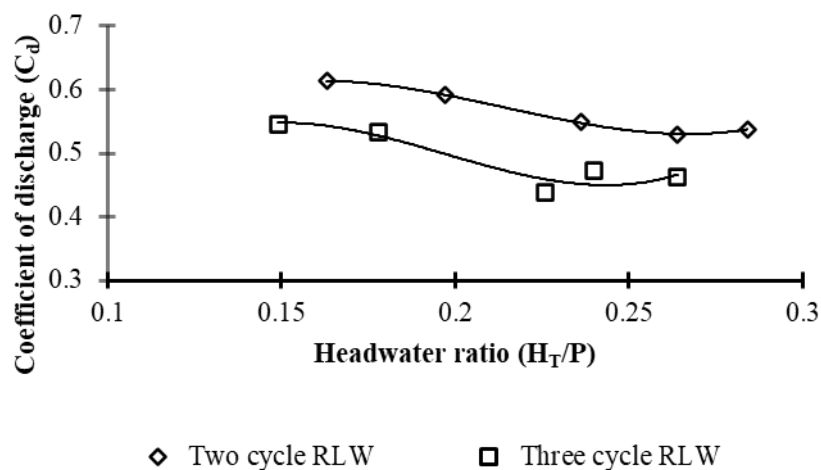


Figure 7:  $C_d$  vs  $H_T/P$  for two cycle and three cycle Rectangular Labyrinth Weir

The two-cycle RLW consistently exhibits a higher coefficient of discharge than the three-cycle RLW across the entire range of tested headwater ratios. The  $C_d$  values for the two-cycle weir range from approximately 0.53 to 0.61, while the values for the three-cycle weir are lower, ranging from about 0.44 to 0.55. The reason for this difference in performance likely lies in a phenomenon known as nappe interference. A labyrinth weir increases the crest length within a given channel width to pass more flow at a lower head. However, as the water flows over the complex, folded crest, the individual sheets of water (nappes) can collide with each other in the downstream collection channel. The analysis demonstrates a negative correlation between the number of weir cycles and the corresponding discharge coefficient. This trend, indicating a reduction in hydraulic efficiency with more cycles, corroborates the observations made by Rustiati (2022).

The trendline for the two-cycle RLW has an  $R^2$  value of 0.99, indicating an almost perfect fit to the experimental data. This suggests a very predictable and stable hydraulic behavior. The three-cycle RLW has an  $R^2$  value of 0.89, which represents a good correlation but also suggests more variability or instability in its performance compared to the two-cycle design.

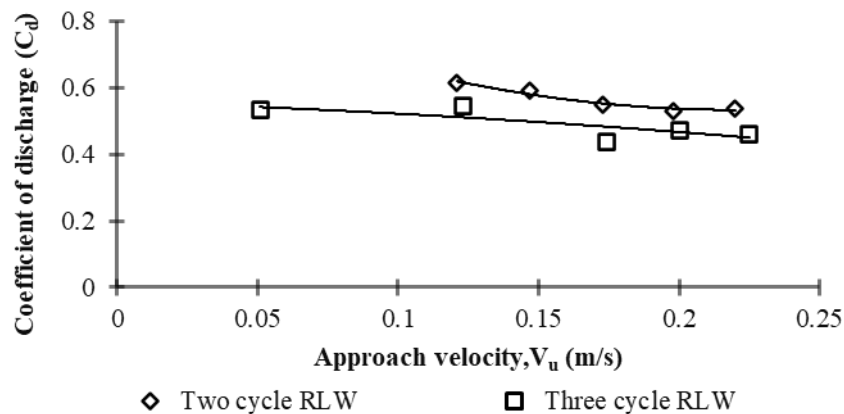


Figure 8:  $C_d$  vs  $V_u$  for two cycle and three cycle Rectangular Labyrinth Weir

Figure 8 compares the hydraulic efficiency of the two-cycle and three-cycle Rectangular Labyrinth Weirs by illustrating the relationship between their respective coefficients of discharge and the approach velocity. In short, it tells an engineer which weir design is better at passing water and how the speed of the incoming flow affects that performance.

The two cycle RLW is consistently more efficient than the three cycle RLW. This implies that a two-cycle design will allow more water to flow over it for the same upstream depth, making it a better choice for a spillway where maximizing flow capacity is the goal. For both weir designs, there is a slight negative correlation between approach velocity and efficiency. This observation corroborates the findings of several earlier studies that reported a similar inverse relationship (Azimi and Hakim, 2018). This is a crucial detail for accurate engineering calculations. An engineer cannot use a single  $C_d$  value. To accurately predict the flow rate over the weir, they must first know the approach velocity and then use this graph to find the correct, corresponding  $C_d$  value for that specific condition.

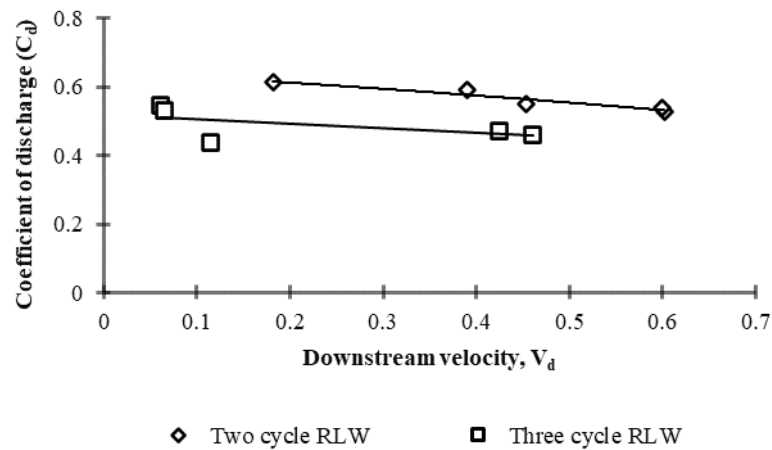


Figure 9:  $C_d$  vs  $V_d$  for two cycle and three cycle Rectangular Labyrinth Weir

Figure 9 illustrates the relationship between the coefficient of discharge and the downstream velocity ( $V_d$ ) for both the two-cycle and three-cycle Rectangular Labyrinth Weir. This graph's practical significance is to show how downstream flow conditions (submergence) negatively impact the hydraulic efficiency of the two weir designs. In simpler terms, it demonstrates that the efficiency of these weirs decreases as the water level or velocity downstream of the weir increases. This is the classic effect of submergence. When the downstream water level is high, it drowns the weir, which pushes back against the flow and significantly reduces the weir's capacity to pass water. Even under these submerged conditions, the two cycle RLW is consistently more efficient than the three cycle RLW. Its  $C_d$  values are always higher, meaning it is less affected by the submergence and can still pass more water than the three-cycle design. This graph provides the critical data to predict how much the weir's performance will drop when those downstream flood conditions occur. An engineer would use this data to avoid under-designing that means they can use the lower, submerged  $C_d$  value in their calculations to ensure a spillway can still safely pass a design flood, even when the river downstream is full.

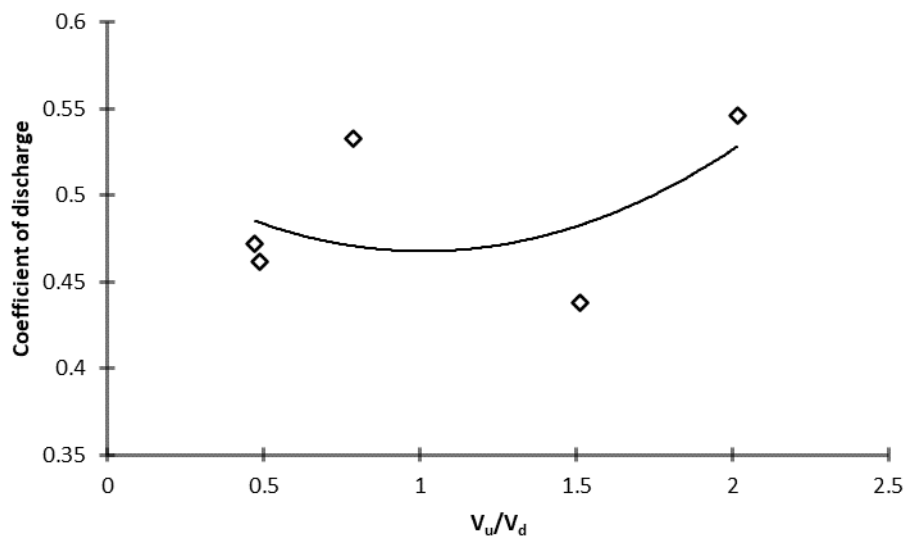


Figure 10:  $C_d$  vs  $V_u/V_d$  for three cycle Rectangular Labyrinth Weir

Figure 10 illustrates the relationship between the coefficient of discharge and the  $V_u/V_d$  for the three-cycle Rectangular Labyrinth Weir. A polynomial regression was selected over a linear trendline to better accommodate the data scatter. The polynomial fit demonstrated a stronger correlation, yielding a coefficient of determination of 0.22, which is higher than that of the linear trendline.

Two points are clustered at a  $V_u/V_d$  ratio of approximately 0.45, with  $C_d$  values around 0.46-0.47. The other three points are spread out at  $V_u/V_d$  ratios of approximately 0.8, 1.5, and 2.0. According to the trendline, the coefficient of discharge is at a minimum (around 0.47) when the  $V_u/V_d$  ratio is approximately 1.1. The  $C_d$  value is higher at both low  $V_u/V_d$  ratios (submerged flow) and high  $V_u/V_d$  ratios (free flow). This graph's practical significance is to pinpoint the least efficient and most unstable operating point for the three-cycle weir.

Figure 11 illustrates the relationship between the flow rate and position of hydraulic jump for both the two-cycle and three-cycle Rectangular Labyrinth Weir. This graph is essential for the safe and economic design of the weir's downstream protection. The three cycle RLW pushes the hydraulic jump significantly farther downstream ( $L_p$  is ~2.4–2.9) compared to the two cycle RLW ( $L_p$  is ~0.4–1.0). This means the three cycle RLW would require a much longer and more expensive stilling basin to prevent scour. The two-cycle design is far more compact, keeping the energy dissipation close to the weir structure, which is often more desirable and economical. In two cycle RLW as the flow rate increases, the jump steadily moves farther away but in three cycle RLW the behavior is more complex. The jump starts far away, moves closer as flow increases (to  $Q=120$ ), and then moves farther away again at higher flows. It shows a clear difference in the hydraulic behavior of the two designs, with the three-cycle weir being more problematic for managing downstream scour.

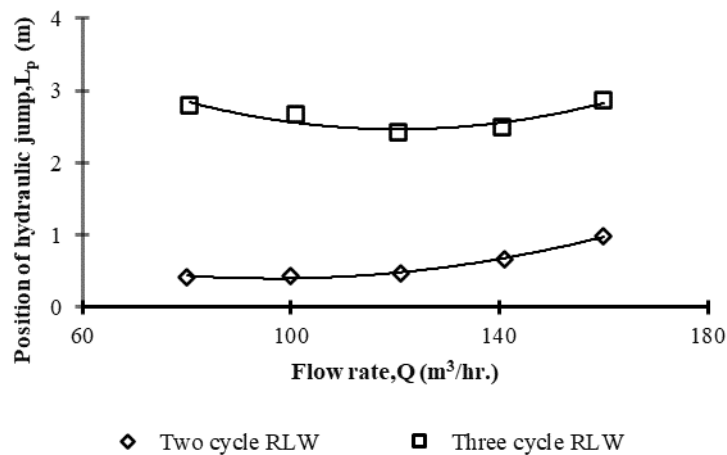


Figure 11:  $L_p$  vs  $Q$  for two cycle and three cycle Rectangular Labyrinth Weir

Figure 12 shows how the position of the hydraulic jump is directly controlled by the Froude Number of the flow coming off the weir (three cycle RLW). A polynomial regression was selected over a linear trendline to better accommodate the data scatter. The polynomial fit demonstrated a stronger correlation, yielding a coefficient of determination of 0.39, which is higher than that of the linear trendline.

As the Froude Number increases from 1.35, the position of the jump also increases, rising from about 2.5 to a peak. The trendline reaches its maximum  $L_p$  value of approximately 2.9 when the Froude Number is around 1.55. After this peak, as the Froude Number continues to increase, the  $L_p$  value starts to decrease slightly.

This graph's practical significance is to determine the minimum safe length of the stilling basin (or scour protection apron) required downstream of the three-cycle weir.

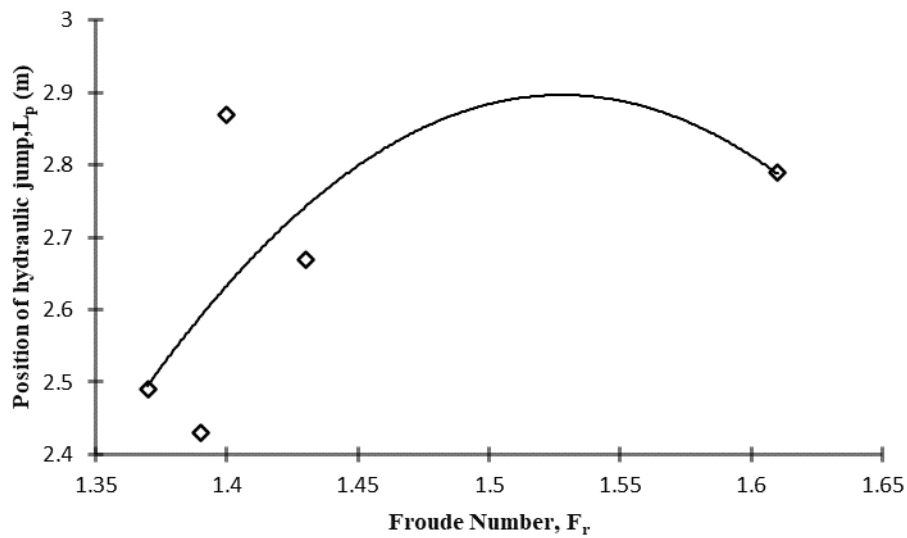


Figure 12:  $L_p$  vs  $F_r$  for three cycle Rectangular Labyrinth Weir

Figure 13 illustrates the percentage increase in the discharge coefficient at five different ranges of discharge. The formula is used to calculate the percentage increase of the 2-cycle RLW  $C_d$  value compared to the 3-cycle RLW  $C_d$  value,

$$\text{Percentage increase} = \left( \frac{C_{d(2 \text{ cycle})} - C_{d(3 \text{ cycle})}}{C_{d(3 \text{ cycle})}} \right) * 100 \quad (4)$$

The chart's primary purpose is to show how the magnitude of this increase in  $C_d$  varies with the flow rate. The 2-cycle weir consistently has a higher discharge coefficient than the 3-cycle weir. The increase generally ranges between 10% and 16%, with a notable spike to 25% at the flow rate of approximately 120 m<sup>3</sup>/hr.

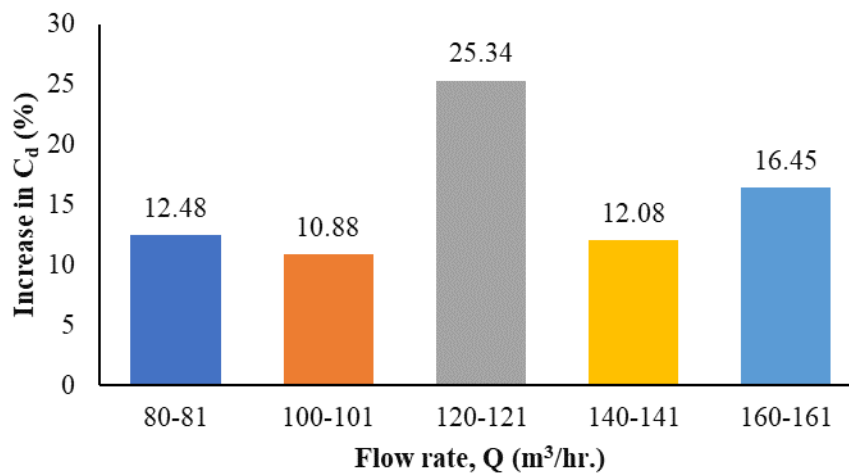


Figure 13: Percentage increases in coefficient of discharge of two cycle relative to three cycle Rectangular Labyrinth Weir at varying flow rates

## CONCLUSIONS

This study conducted a comparative hydraulic performance analysis of a two-cycle and a three-cycle Rectangular Labyrinth Weir. The experimental results lead to several definitive conclusions regarding hydraulic efficiency and energy dissipation characteristics:

1. The two-cycle RLW demonstrated consistently superior hydraulic efficiency compared to the three-cycle RLW under all tested conditions. The coefficient of discharge for the two-cycle weir was significantly higher across the entire range of headwater ratios, approach velocities, and downstream velocities. This superior performance is primarily attributed to reduced nappe interference in the less complex two-cycle geometry.
2. The hydraulic behavior of the two-cycle RLW was found to be highly stable and predictable, as evidenced by an  $R^2$  value of 0.99 for its  $C_d$  vs.  $H_T/P$  trendline. The three-cycle weir exhibited more variability ( $R^2 = 0.89$ ), suggesting more turbulent and less stable flow conditions.
3. The most significant practical finding relates to downstream scour protection. The three-cycle RLW pushes the hydraulic jump significantly farther downstream ( $L_p \approx 2.4\text{--}2.9$ ) than the two-cycle RLW ( $L_p \approx 0.4\text{--}1.0$ ). For a similar Froude number, the three-cycle weir would require a stilling basin that is 4 to 5 times longer to prevent scour.

In summary, while adding more cycles (from two to three) increases a weir's crest length, this study demonstrates that it results in a net negative effect on performance. The increased nappe interference in the three-cycle design reduces its hydraulic efficiency, and it creates a more problematic hydraulic jump that is pushed far downstream. The two-cycle RLW is not only more efficient at passing flow but is also a far more compact and economical design, requiring a significantly smaller and less costly stilling basin for safe energy dissipation.

## **ACKNOWLEDGEMENTS**

The authors would like to express their sincere gratitude to the Department of Water Resources Engineering, BUET, for providing access to the Hydraulics and River Engineering Laboratory for the completion of this research.

## **DECLARATION OF USE OF AI**

ChatGPT and Grammarly were used for grammar correction, sentence restructuring, and improving academic tone and clarity. All scientific decisions, data collection, analyses, and conclusions were made solely by the authors.

## **REFERENCES**

- Atiya M.M. (2025). "Experimental Investigation on Hydraulics and Energy Dissipation of Flow over Different Labyrinth Weirs" Master of Science, Water Resources Engineering, Bangladesh University of Engineering and Technology.
- Aghashirmohammadi G., Heidarnejad M., Purmohammadi M.H., Masjedi A. (2022). "Experimental and numerical study the effect of flow splitters on trapezoidal and triangular labyrinth weirs" Water science, Vol. 37, Issue 1, pp. 28-39.
- Aydina M. C., Emiroglu M. E. (2013). "Determination of capacity of labyrinth side weir by CFD" Flow Measurement and Instrumentation, ELSEVIER, Vol. 29, pp. 1-8.
- Azimi A.H., Hakim S.S. (2018). "Hydraulics of flow over rectangular labyrinth weirs" Irrigation Science, Springer.

Ben S. M., Ouamane A. (2022). "Performance of rectangular labyrinth weir – an experimental and numerical study" *Water Supply*, Vol.22, No.4, pp. 3628–3644.

Bilhan O., Emiroglu M. E. (2016). "Discharge Coefficient of Sharp-Crested Trapezoidal Labyrinth Weirs" *International Journal of Electronics, Mechanical and Mechatronics Engineering*, Vol.6, No.4, pp. 1305-1316.

Bilhan O., Emiroglu M. E., Miller C. J. (2016). "Experimental Investigation of Discharge Capacity of Labyrinth Weirs with and without Nappe Breakers" *World Journal of Mechanics*, Vol. 6, pp. 207-221.

Bilhan O., Emiroglu M. E. (2016). "Experimental Studies on Determination of Discharge Capacity of Circular Labyrinth Weirs Located on A Straight Channel" *International Journal of Electronics, Mechanical and Mechatronics Engineering* Vol.6 No.3, pp. 1227-1239.

Crookston, B. M and Tullis, B. P. (2013). "Hydraulic Design and Analysis of Labyrinth Weirs. I: Discharge Relationships." *Irrig. Drain Eng.*, Vol 139, No. 5, pp. 363-370.

Crookston, B. M., Tullis, B. P. (2011). "Discharge efficiency of reservoir-application-specific labyrinth weirs" *Journal of irrigation and drainage engineering*, ASCE, Vol.138, pp 564-568.

Emami S., Arvanaghi H., Parsa J. (2018). "Numerical Investigation of Geometric Parameters Effect of the Labyrinth Weir on the Discharge Coefficient" *Journal of Rehabilitation in Civil Engineering*, Vol.6, No.1, pp.1-9.

Farehe S.A.N., Javad M. (2023). "Investigation of labyrinth weirs discharge coefficient with the same length" *Flow Measurement and Instrumentation*, ELSEVIER, Vol. 94, No.1.

Feili J., Heidarnejad M., Masjedi A., AsadiLour M. (2021). "Experimental Study of Discharge Coefficient of Trapezoidal Arced Labyrinth Weirs of Widened Middle Cycle" *Flow Measurement and Instrumentation*, ELSEVIER, Vol. 79.

Idrees, A. K. and Riyadh A.A. (2023). "Investigating a new approach to enhance the discharge capacity of labyrinth weirs" *Journal of Hydroinformatics*, Vol.25, issue 2, pp. 300–317.

Khameneh H. Zahedi, Khodashenas S.R., Esmaili K. (2014). "The effect of increasing the number of cycles on the performance of labyrinth side weir" *Flow Measurement and Instrumentation*, ELSEVIER, Vol. 39, pp. 35-45.

Khode B.V., Tembhurkar A.R. (2010). "Evaluation and Analysis of Crest Coefficient for Labyrinth Weir" *World Applied Sciences Journal*, Vol.11, No. 7, pp. 835-839.

Mamok S. (2013). "Increase Spillway Capacity using Labyrinth Weir" *Procedia Engineering*, Vol. 54, pp. 440 – 446.

N B Rustiati, M G Ishak, A Tanga, Z G Pali (2023). "Influence of The Number of Trapezoidal Labyrinth Weir Cycles on The Hydraulic Characteristics of the weir" *IOP Conference Series: Earth and Environmental Science*, Vol 1157, Issue 1, pages 12051.

Namazi F. S. A., Mozaffari J. (2023). "Investigation of labyrinth weirs discharge coefficient with the same length" *Flow Measurement and Instrumentation*, ELSEVIER, Vol. 94.

Seamons, T. R. (2014). "Labyrinth Weirs: A Look into Geometric Variation and Its Effect on Efficiency and Design Method Predictions." *Master of Science, Civil and Environmental Engineering*, Utah State University.