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Experimental and Numerical Investigation on Discharge Coefficient Relationships sharp-crested U Shape Plan Form Weirs

F. Mohammadi[1*] , Y. Hassanzadeh[2], K. Roshangar[2]

1 Faculty of Pardis Engineering, University of Tabriz, Tabriz, Iran
2 Faculty of Civil Engineering, University of Tabriz, Tabriz, Iran

ABSTRACT: In this research, the relationships of the discharge coefficient of the sharp-crested U shape plan form labyrinth weirs (one cycle) have been investigated experimentally and numerically. Also, from 3 groups of weirs with heights of 10, 12.5, and 15 cm and at each height, the length of different arches to the values of 40.82, 45 and 48.10 cm have been tested. The main purpose of the present study is to determine the overflow discharge from the weir by providing relationships for the discharge coefficient experimentally. Dimensional analysis was used by π Buckingham method to extract the relationship. Three-dimensional simulation of weirs was performed numerically with equations governing the finite volume method using FLOW-3D software, then compared with laboratory results. The results of the present study show that the proposed relationship can predict discharge values with very high accuracy and an error of 4.79% in the ratio of the head-to-height weir of 0.1 to 1.2. As the length of the weirs arch increases, the flow interference increases, and the discharge efficiency decreases. Although with increasing the length of the weirs, the length of the crest increases, the weirs efficiency decreases, the maximum throughput efficiency decreases in this case, it is at 7.01%. With constant arc length and increase in weirs height, it was observed that the throughput efficiency decreases significantly, which shows a maximum volume of flow through the weirs of 4.82%.

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1. INTRODUCTION

Weirs are structures used in canals, rivers, and lakes to measure flow, control discharge during floods, and measure the overflow surface of a weir in free-flow conditions. The labyrinth weir is an example of Polyhedron weirs that increases the effective length of the weir to a straight length due to the fracture in the plan [1]. Heidarpour et al. (2007) Investigation of Polyhedron Weirs with Rectangular Plan and U-Shape weirs, they also studied the comparison of polygonal weirs with a rectangular plan and U-shaped with linear weirs. The researchers stated that if the corners of the weir become curved and the weir becomes U-shaped, the nappe interference of the will be reduced and the performance of the weir will be improved [2]. Bilhan et al. (2018) used experimentally and numerically simulation (CFD) of 3-cycle semicircular labyrinth weirs in two conditions with and without nappe breaker at the apex of the labyrinth. Also, these researchers stated in their results that the use of nappe breakers improves the discharge coefficient reduction by about (2.1-2.2%), which can be neglected [3].

In previous studies, according to several geometric models that have been studied experimentally by various researchers on labyrinth weirs, the effect of different heights and lengths of trapezoidal labyrinth weirs has also been investigated; however, the existence of the effect of different arch lengths, different weir heights under free-flow conditions has not been investigated experimentally in U-shaped labyrinth weirs in plan (single cycle). Therefore, the study of the U-shaped sharp-crested labyrinth weir in the plan (single cycle) has not been done, so it is necessary to study these weirs. In this research, the experimental results of the U-shaped sharp-crested labyrinth weir in plan (single cycle) with different arch lengths and heights, as well as three-dimensional numerical simulation of flow over the weir in free-flow condition have been investigated. Using dimensional analysis and π theory, the parameters affecting the selection relations and the dimensionless relations of the discharge coefficient are developed and the hydrodynamic analysis of the parameters affecting the discharge coefficient is performed. The accuracy of experimental results and proposed relationships have also been compared and evaluated by statistical analysis.

2. METHODOLOGY

The experiments of this research were performed in the hydraulic laboratory of the Faculty of Civil Engineering, University of Tabriz, in a rectangular-horizontal flume with a length of 10 m, a width of 0.4 m, and depth of 0.8 m, in free-flow conditions. The flume has walls made of Plexiglas and a metal floor, which was used to provide a flow from a pump with a maximum flow of 80 liters per second. The flow measurement was performed by ultrasonic flowmeter

*Corresponding author's email: firouzm1979@gmail.com

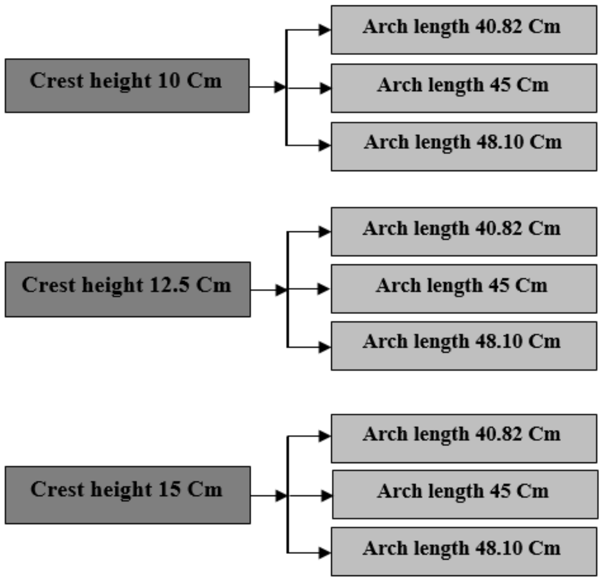

Fig. 1. Flowchart of experiments performed in the present study

Table 1. Numerical three-dimensional simulation models in the present study

Weir height (P)	Arch length (L_R)	The ratio of head to weir height (H/P)						
10	40.82	0.2	0.4	0.6	0.7	0.8	1	1.2
10	45	0.2	0.4	0.6	0.7	0.8	1	1.2
10	48.10	0.2	0.4	0.6	0.7	0.8	1	1.2
12.5	40.82	0.2	0.4	0.6	0.7	0.8	1	1.2
12.5	45	0.2	0.4	0.6	0.7	0.8	1	1.2
12.5	48.10	0.2	0.4	0.6	0.7	0.8	1	1.2
15	40.82	0.2	0.4	0.6	0.7	0.8	1	1.2
15	45	0.2	0.4	0.6	0.7	0.8	1	1.2
15	48.10	0.2	0.4	0.6	0.7	0.8	1	1.2

in the canal feed pipeline, which was located between the upstream and downstream reservoir and in a straight line with a maximum error of 2%.

FLOW-3D software is used for numerical solution and the governing non-permanent equations are numerically solved by the finite volume method. In this software, the level/volume component of the obstacle expression (FAVOR) algorithm is used to define the geometry in the finite volume method. This algorithm considers the in-field barriers in computational cells as a small value between zero and 1, so that if the whole cell is filled by the barrier, The value of the volume component or level will be equal to 1. The free flow rate is determined using the fluid volume component (VOF) algorithm.

In the present study, 9 physical models according to Table 1 and 63 numerical simulations according to Table 1 have been used.

3. RESULTS AND DISCUSSION

Non-linear multivariate regression analysis of laboratory results using SPSS software was used to extract the head-discharge relationships (SPSS Version 23).

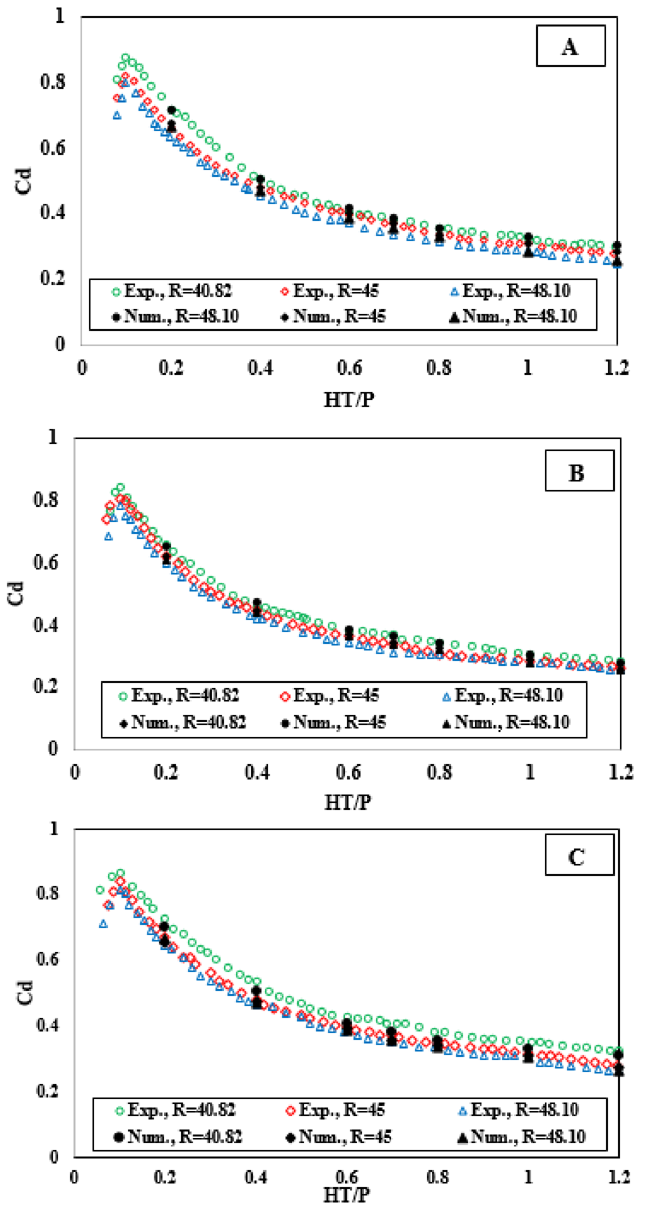

Fig. 2. Changes in discharge coefficient (Cd) with the ratio of head height to weir height (HT / P) for different arch lengths, A) P=10 (cm) B) P=12.5 (cm) C) P=15

Non-linear multivariate regression analysis of laboratory results using SPSS software was used to extract the head-discharge relationships (SPSS Version 23). Equation (1) is obtained using the experimental data of the present study, which can be seen in Fig. 1, for the sharp-crested U-shaped plan form weirs. Thus, about 80% of the experimental data were randomly selected to extract the equation and used to fit the relationship, and the remaining 20% was used to calibrate the relationship.

In Fig. 2, in addition to the experimental data, the relationships defined for each weir are presented and compared, which is very accurate. According to previous researches, the recommended design interval in the present

Table 2. Calibrated coefficients for weirs with different arch lengths for equation (1)

Weir height (P)	Arch length (L_R)	*a*	*b*	*c*	*d*	*e*
10	40.82	-70.783	0.003	0.574	-8.083	71.035
	45					
	48.10					
12.5	40.82	-486.864	0.00047	-65.742	0.006	553.025
	45					
	48.10					
15	40.82	1.186	-0.15	0.326	-6.977	-0.946
	45					
	48.10					

study, as well as the proposed relationship of estimating the flow discharge over the weir, is the point after the peak of the head-flow diagram to the head-to-height ratio of 1.2.

$$C_d = a\left(\frac{h}{p}\right)^b + c\left(\frac{L_R}{W}\right)^d + e \qquad (1)$$

Equation (1): The discharge coefficient of the U-plan form shaped sharp-crested weirs is apparently related only to the h / p and LR / W parameters. However, according to Table 2, the constant coefficients are variable for each height of the weir; in other words, they are a function of the height and arch length of the weirs.

To determine the comprehensive equation, these coefficients in terms of height and length of the weir arch are extracted as follows:

4. CONCLUSIONS

In this study, sharp-crested U-shaped weirs in the plan with the geometry defined in Table 1 under free-flow conditions have been investigated physically and numerically. Finally, the relationships developed for this research were presented using π Buckingham analysis of dimensionless parameters to predict the discharge coefficient in the free flow condition of sharp-crested U-shaped plan form weirs. The proposed relationships with the experimental results of the present study were evaluated by statistical analysis. The summary of the results of the present study is as follows:

The proposed discharge coefficient relationships have good capability in terms of accuracy and efficiency ad have an average error between experimental and numerical results of 4.79%. Also, the design range of the proposed relationships was $0.1 \leq HT / P \leq 1.2$, which is a wider design range compared to previous studies.

As the arch length of the weir increases, the nappe interference increases, and the discharge efficiency decreases, although as the arch length of the weir increases, the crest length increases. However, an effective increase in crest length is not achieved, so the discharge efficiency is affected by the increase in nappe interference, and by increasing the arch length of the weirs and then increasing the nappe interference region, the weir efficiency decreases.

With constant arch length and variable considering the height of the weirs, it was observed that with increasing the height of the weirs, the discharge efficiency decreases. By comparing the two conditions of increasing the length of the arch and increasing the height of the weirs can be stated Which is more sensitive in sharp-crested U-shaped plan form weirs in hydraulic performance (discharge efficiency) in case of increasing arch length.

The sensitivity of the U-shaped plan form labyrinth weirs to nappe interference is greater than the increase in arch length, and this sensitivity increases with increasing arch length.

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