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Study of variations in discharge coefficients for broad-crested weirs with sloped upstream and downstream faces using numerical simulation

F. Malekzadeh, F. Salmasi*, H. Arvanagi

Department of Water Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran

ABSTRACT: Weirs are structures that are important for measuring flow and controlling water levels. Research has shown that the discharge coefficient is not constant and depends on the crest length, the height of the weir, the upstream head, and the upstream and downstream slopes. In this study, the effect of these parameters on the discharge coefficient (C_d) is investigated by numerical simulation. The current study presents numerical simulation using the ANSYS FLUENT software. The total number of simulations is 432 which includes: 4 upstream slopes, 4 downstream slopes, 3 weir heights, 3 upstream heads (h_1) and 3 weir crest lengths. It was found that the downstream face slope has little effect on C_d. For $0.1<H_1/w<0.4$ by decreasing the upstream slope, C_d increases, where H_1 is the water head on the weir crest and w is the length of the crest. Also, for the same range, by decreasing the height of the weir (p), the C_d increases. For $0.16<H_1/p<2$, as the length of the crest decreases, the C_d increases. By comparing the numerical simulation results to physical measurements, multi-variable regression equations for estimating C_d are presented. In addition to C_d, extraction of other more detailed information such as water level profiles and velocity profiles at different locations are provided.

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1- Introduction

Weirs are hydraulic structures that can be used for flow measurement and water level control in water channels. A wide variety of weir designs have been developed for various applications [1]. Based on the thickness of their crests, weirs are classified as sharp-crested (thin-crested) and broad-crested weirs. Sharp-crested weirs have small crest thicknesses. For the broad-crested weir, however, the weir's crest is very broad compared with other dimensions. With sharp-crested weirs, the water surface is only in contact with the sharp crest of the weir, while for broad-crested weirs, the water flows across the whole thickness of the crest. Sharp-crested weirs are usually classified by their geometric shape which include: rectangular, triangular, trapezoidal, spherical and parabolic shapes [2].

Hager and Schwalt (1994) studied broad-crested weirs with vertical walls [3]. They installed a number of piezometers to measure pressure. Some were installed on the surface of the upstream vertical wall and others were installed on the horizontal part of the weir. One of the significant results obtained by Hager and Schwalt (1994) was a sudden drop in the downstream water level at low discharge. While in high discharge, the flow level upstream decreased gradually and increased downstream flow level. Fritz and Hager (1998) obtained discharge coefficients and flow data for broad-crested weirs with 2:1 (vertical: horizontal) slopes [4]. They showed that flow separation decreases in the presence of a slope. Johnson (2000) showed that the discharge coefficient for both broad-crested and sharp-crested weirs for $H_1/w<0.2$ collapsed to a single curve where H_1 is the upstream head and w is the length of the weir crest [5].

Farhoudi and Shah Alami (2005) studied the effects of the upstream face slope of a broad-crested weir; they reported that by decreasing the upstream face slope, its discharge coefficient increased [6]. They recommended a 25^o slope of the upstream face. Gogus et al. (2006) made experiments on rectangular broad-crested weirs with compound cross-sections [7]. These weirs have one small rectangular part that is used to transfer low discharges, and another rectangular part with a larger width. Compound cross-section (the combination of two different parts) is used to transfer higher discharge rates. The study of rectangular broad-crested weirs with compound cross-sections was also provided by Salmasi et al. (2013). There, laboratory data were used to measure the discharge and estimations were found using a genetic algorithm [8].

The current study presents numerical simulation using the ANSYS FLUENT software. These numerical simulations are carried out to find C_d for broad crested weirs in irrigation canals. Broad crested weirs with upstream and downstream

*Corresponding author's email: Salmasi@tabrizu.ac.ir

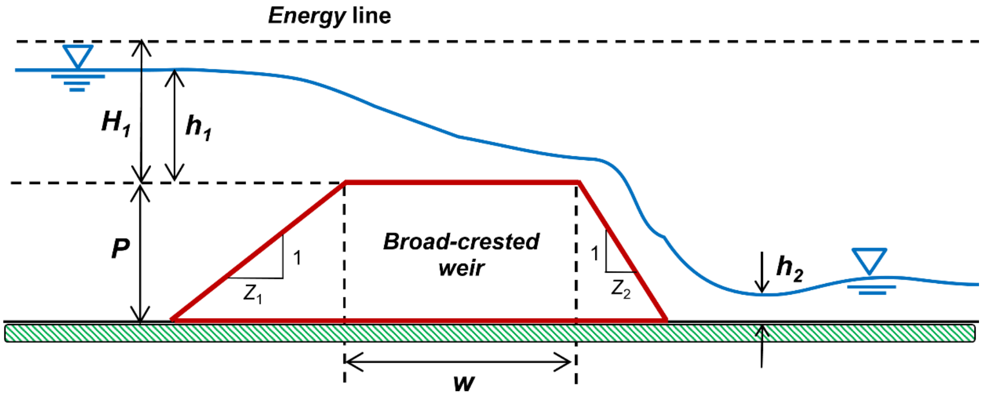

Fig. 1. Geometrical and hydraulic parameters of the broad-crested weir

face slopes are considered as well as conventional vertical faces. Validation is based on a comparison of the simulations with experimental results. In addition, flow details such as pressure fields and velocity vectors are used for comparing different geometrical shapes. The novelty of the present study relates to full consideration of all geometrical parameters of rectangular broad-crested weir for estimation of C_d. These parameters include: upstream slopes (z_1), downstream slopes (z_2), weir heights (p), upstream heads (h_1) and weir crest lengths (w).

2- Material and Methods

The free flow over the broad-crested weir is simulated by ANSYS FLUENT in 2D. By changing geometrical parameters (upstream slope, downstream slope, height, crest length and upstream head) the variation of discharge coefficients and velocity and pressure profiles can be obtained.

In Figure 1, the longitudinal cross-section of the rectangular broad-crested weir and hydraulic parameters are illustrated. In Table 1, the geometrical properties of broad-crested weirs are listed. The total number of simulations is 432 which includes: 4 upstream slopes, 4 downstream slopes, 3 weir heights, 3 upstream heads (h_1) and 3 weir crest lengths.

3- Results and Discussion

In this study, changes in the discharge coefficient for broad-crested weirs were investigated. The independent variables included upstream slope, downstream slope, crest length, crest height and head on the crest. The numerical simulation method was employed using ANSYS FLUENT software. An attempt was made to test different multivariate regression equations for discharge coefficients (dependent variable) and other variables (independent variables). Then, the discharge coefficients obtained in the simulated broad-crested weirs were compared with the laboratory data of Sargison and Percy (2009); Bijankhan et al. (2013); Zerihun (2020) [9-11]. Some important results are as follows:

Considering the relative error percentage in comparison with the laboratory data, it is concluded that FLUENT software simulates the flow on broad-crested weirs with high accuracy. In this study, the highest discharge coefficient occurs for weir with conditions z_1=15°, z_2=30°, p=0.1 m, w=0.5 m and H_1=0.2 m and the lowest discharge coefficient occurs for weir with conditions z_1=90°, z_2=15°, p=3 m, w=0.5 m and H_1=0.05 m. For values of $0.1<H_1/w<0.4$, the discharge coefficient increases with decreasing height and with decreasing upstream slope. Downstream slope has little effect on the flow discharge coefficient [12]. For values of $0.16<H_1/p<2$ the discharge coefficient increases with decreasing the length of the crest and C_d increases with decreasing upstream slope. Numerical simulations showed better agreement with Bijankhan et al. (2013)'s study than the others. The values of R^2, RMSE and RE% from this comparison are 0.8602, 0.139 and 10%, respectively. Among different tested multiple regression equations, nonlinear Eq. (22) is preferred for the prediction of C_d. Accuracy criteria R^2, RMSE and RE% were calculated to be 0.94, 0.06 and 0.56%, respectively.

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