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Prediction of discharge coefficients for broad-crested weirs using expert systems

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ABSTRACT: Broad-crested weirs can be used to make discharge measurements in irrigation canals; the entrance of stepped weirs or chutes is sometimes designed as a broad-crested weir structure. These structures are also sometimes used for the dam body. In this study, the Artificial Neural Network (ANN) and M5 model tree methods are used to predict discharge coefficients (C_d) for broad-crested weirs. The results from these two models are compared with nonlinear regression equations. Four series of data obtained from different rectangular broad-crested weirs have been used and important dimensionless parameters have been defined. Results show that the ANN procedure is superior to the M5 model and regression approaches. The accuracy for ANN is quantified by R=0.966 and RMSE=0.038. All three methods are able to provide a reasonable prediction for C_d; the M5 model tree provides four linear equations that can be used to estimate C_d. The shape of the C_d contours shows that the effect of weir height (P) exceeds that of the weir length (L).

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1- Introduction

One problem hydraulic structures handle is flow rate management in channels and rivers. Water flow is commonly measured at locations such as offtakes and distribution ditches. Water-measuring devices such as weirs (including sharp and broad crested), flumes, orifices and velocity meters can be used. Among these options, engineers often prefer weirs because of their simplicity and low cost [1]. Broad-crested weirs can be used to conserve water for later times when the water is needed [2]. Broad-crested weirs are also used in irrigation canals for measuring discharge rates. This type of weir has a flat crest above which the flow lines are approximately straight and parallel [3]. Typically, broad-crested weirs are not considered very accurate for making discharge measurements [4]. According to Horton’s (1907) study [5], the discharge coefficient exclusively depends on the weir’s relative length (H1/L) and the effects of viscosity and surface tension can be ignored (H1 is the water head over the weir crest and L is the length of weir in direction of water). Daneshfaraz et al. [6] studied flow over a broad-crest weir with and without an opening in the body of the weir and with different slopes using Flow-3D software. Their results showed that the opening in the body of the weir leads to an increase in the discharge coefficient and a decrease in the upstream water level. More recently, with the collection of more data and with advances in the use of data mining approaches, new techniques have been developed to study weirs. Data mining models include techniques such as Machine Learning, clustering, Artificial Neural Network (ANN), Rule-Based Expert systems, Fuzzy Logic, Decision Extraction, and classification [7]. Salmasi et al. [8] utilized six methods: Gaussian process (GP) regression, support vector machine (SVM), artificial neural networks (ANN), generalized regression neural network (GRNN), random forest (RF) regression and random tree (RT) based models to predict discharge coefficients (Cd) in both submerged and free flow conditions of oblique sluice gates using experimental data. The model input parameters were the ratio of the upstream water depth to gate opening (y/a) and the inclined angle (β) for free flow and also the submergence rate (yt/a) for submerged flow. The ANN approach was the most accurate model compared to the others. Salmasi and Abraham [9] conducted a set of laboratory tests on compound broad-crested weirs. They estimated discharge coefficients using two artificial intelligence methods, i.e. Genetic Programming (GP) and Artificial Neural Network (ANN). The results of the investigation reveal that the variation of weir length is more effective than the variation of weir height in terms of their effect on the discharge coefficient. On the other hand, using M5 model tree can be used to separate data into groups and

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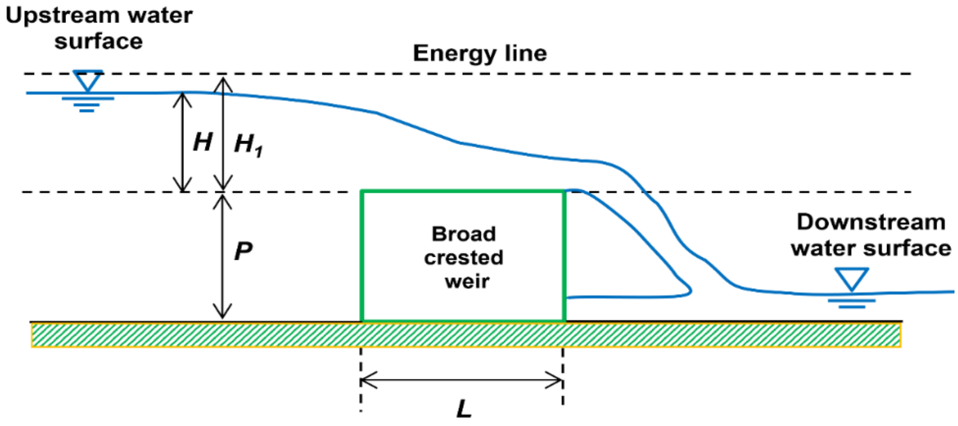

Fig. 1. Longitudinal section of the rectangular broad-crested weir

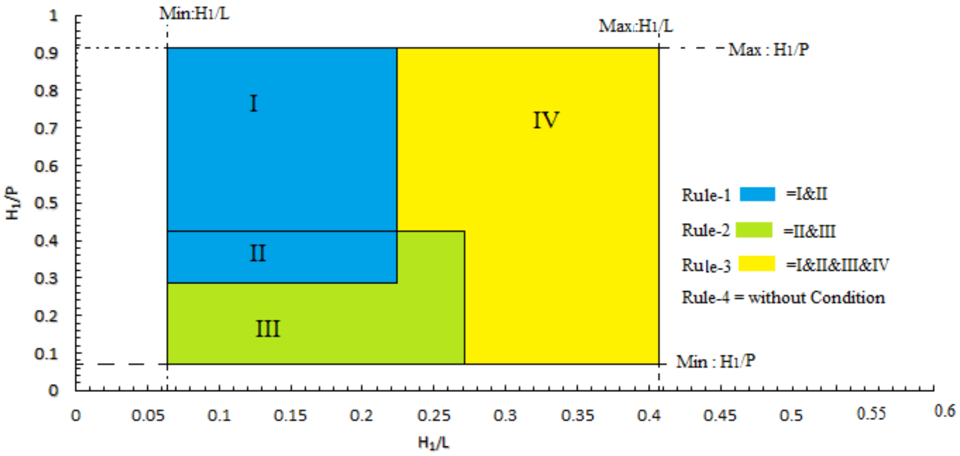

Fig. 2. Specified zones obtained from “If-then” rules

provide separate relationships or functions for each group. Partitioning the data into separate groups can help designers better understand the hydraulic behavior of flow (Nouri et al., [10]). In general, the advantage of using Machine Learning methods is that the relationships obtained can be used to accurately design weirs and the discharge coefficients can be extracted without the need for repeated experiments [11, 12].

In this study, in addition to studying rectangular broad crested weir discharge coefficients, the performance of two methods (ANN and M5 tree models) will be compared. These two methods will be compared with a regression method. The combined use of these three methods can lead to an improved understanding of the hydraulic performance for flow over broad-crested weirs.

2- Material and Methods

Four series of experimental data obtained from rectangular broad-crested weirs have been used in this study. The first sets of data are from experiments conducted at the University of Tabriz, Iran. The second series of data is from the Hager and Schwalt [4] study. The third series is from Goodarzi et al. [3] and the fourth series is from Badr and Mowla [13]. Based on research carried out by previous researchers, the following standard conditions have been suggested:

The upper corner of the broad crested weir should be sharp and the upstream face of the weir should be vertical. The weir surface should be smooth and horizontal. The length of the weir should be such that $0.1 < H1/L < 0.4$. The minimum water depth on the crest of the weir should be 50 mm so that surface tension effects can be ignored. The channel is rectangular and straight and has tail water; the channel geometry is prismatic and the flow over the weir is below the modular limit. Based on the above recommendations, an attempt was made to extract data from the laboratory model that meets all of the above conditions. Because of these restrictions, only 75 data points have been obtained. Figure 1 shows a longitudinal section of the rectangular broad-crested weir and various hydraulic parameters. In Figure 1, L is the weir length, P is the weir height, H is the water depth over the weir crest, and H1 is the total head.

3- Results and Discussion

Input data (H1/L, H1/P) are entered into the ANN, M5Rule, and nonlinear regression models. Figure 2 provides zones resulting from “If-then” rules. Based on Rules 1-4, four distinguishable regions can be specified for predicting Cd. These regions are shown in Figure 2 as I, II, III and IV.

The nonlinear regression result is shown in Eq. (1).

$$C_d = 0.33 - 0.204 \times \frac{H_1}{P} + 0.128 \times \frac{H_1}{L} + 0.0611 \times \left(\frac{H_1}{P}\right)^2 - 0.514 \times \left(\frac{H_1}{L}\right)^2 + 0.639 \times \frac{H_1}{P} \times \frac{H_1}{L} \qquad (1)$$

It can be seen that the ANN model, the M5-Rule model, and the nonlinear regression method are all able to predict the rectangular broad-crested weir discharge coefficient (Cd) with acceptable accuracy.

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