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The Computation of the Discharge and Discharge Coefficient of the Subcritical Flow in the Trapezoidal Flumes with Prismatic Pier under Free-flow Conditions

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ABSTRACT: One of the simple and cheap ways for flow measurement in canals is to use flumes. In this study, the efficiency of trapezoidal flumes with prismatic piers for flow measurement in trapezoidal canals was investigated. Laboratory investigations on four prismatic piers installed in the trapezoidal canal floor with an adjustable side slope were conducted. Based on the results of conducting several experiments, in the first analysis, a relationship and graph to calculate the discharge for each side slop and a relationship for all of the investigated side slopes were separately presented using dimensional analysis. In the second analysis the relationship and graph to calculate the discharge coefficient for each side slope and a single relationship for all of the investigated side slopes were separately obtained through the simultaneous use of the concept of energy principle and dimensional analysis. To investigate the accuracy of the obtained relationships, the statistical parameter of Mean Absolute Relative Error (MARE) was used. In the first analysis the mean value of the relative error to estimate the discharge in the investigated side slopes (z=0.268, 0.4663, 0.7 and 1) were 8.8, 10, 7.7 and 8.3 percent, respectively. Also in the second analysis, the value of this statistical parameter to estimate the discharge in the investigated slopes were 6.5, 10, 1.8 and 3.4 percent respectively and based on the single relationship for all of the investigated side slopes was 9%. Therefore, to calculate the discharge, the second analysis (the simultaneous use of the concept of energy principle and dimensional analysis) was recognized to be more appropriate than the first analysis (dimensional analysis).

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1- Introduction

Despite the introduction of complicated and advanced methods for flow measurement in channels, research is still ongoing on increasing the accuracy of simple and cheap flow measurement equipment such as weirs and flumes. The basis of flow measurement in flumes is to pass the flow through a narrowed, raised section or a combination of them. The characteristics of the flow while passing through these sections, which are also called control sections, are changed and conditions are provided to obtain the discharge by measuring the depth of the flow at a specific points. Extensive studies on flow hydraulics in flumes were done by various researchers including Belanger (1849), Bazin (1896), Parshall (1900), Balloffet (1951), Ackers and Harrison (1963) and Ackers and White (1978) [2]. The flume introduced by Parshall is one of the common flumes that is still used in irrigation canals. A lot of research has been done to create the control section in channels by many researchers, which has led to the presentation of relationships and diagrams for calculating the flow discharge. Among such researches, the researches of Heger 1986, Samani and Magallanez 1992, 1993 and 2000, Peruginelli and Bonassi 1997, Gole 2006, Hayawi 2012, Carolo 2016, Farro 2016, Lotfi Kolavani 2018, Bijankhan 2019 and Mohammadi 2019 can be mentiond[3-14]. In this research, in order to obtain the flow rate calculation relationship in trapezoidal channels, experiments were conducted on trapezoidal flumes with prismatic piers in free flow conditions.

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2- Methodology

The effective factors in the flow around the prismatic pier in trapezoidal flumes are schematically presented in Fig. (1). Considering the effective factors in the flow around prismatic pier in trapezoidal flume (Fig. 1) the flow was analyzed based on dimensional analysis and energy principle and relations (1) and (2) were obtained (equation 1 is based on dimensional analysis and equation 2 is based on the principle of energy). These relationships were used to calculate.

$$Fr' = \frac{Q}{\left[(B-b)y_2 + zy_2^2\right]\sqrt{g\frac{(B-b)y_2 + zy_2^2}{B-b+2zy_2}}} = f\left(\frac{y_1}{B_c}\right) \quad (1)$$

$$C_d = a\left[Fr_1\left(\frac{y_1}{B_c}\right)\right]^n \quad (2)$$

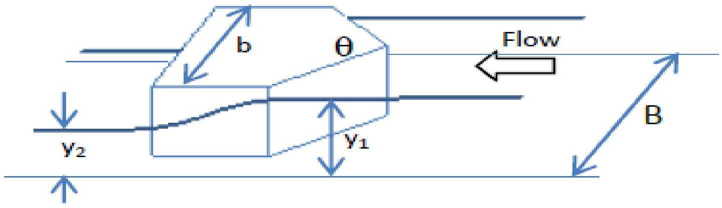

Fig. 1. Effective factors of the flow around the prismatic pier

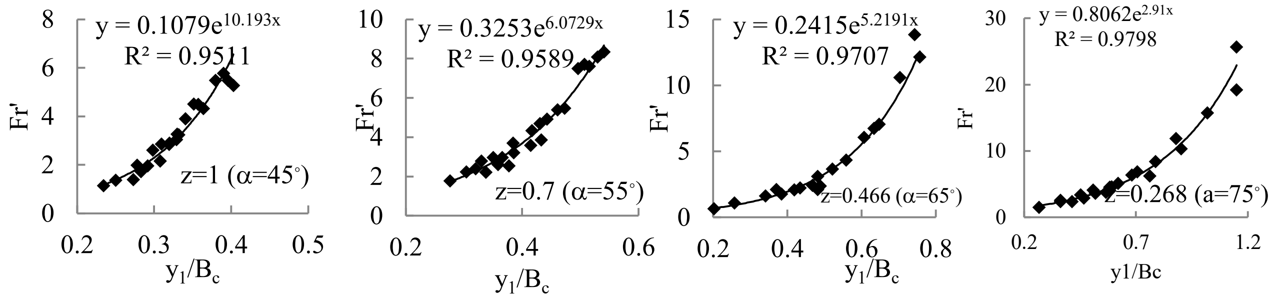

Fig. 2. Variations of y1/Bc versus Fr' at different lateral slopes

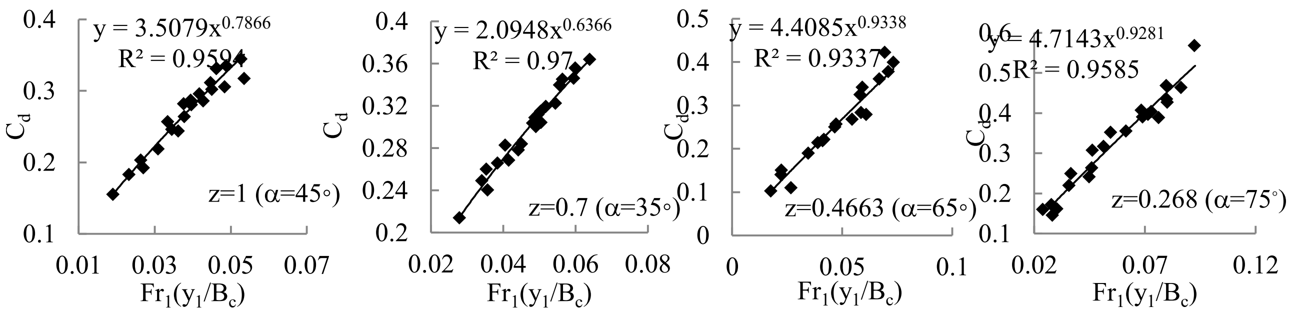

Fig. 3. Changes of Cd vs. Fr1(y1/Bc) at different side slopes

Where Bc= B+2zy1-b, y1 is the flow depth upstream of the prismatic pier, z is the side slope of the flume, Fr is the Froud number of flow and Cd is discharge coefficient of prismatic pier. The experiments were carried out in a laboratory channel in the hydraulic laboratory. This laboratory channel has a length of 6 meters, a width of 0.46 meters and a height of 0.70 meters, and its side and longitudinal slope can be adjusted. Four prismatic piers (with widths of 36, 38, 40 and 42 cm) and four side slopes (with angles of 15, 25, 35 and 45 degrees to the horizon) were considered.

3- Results and Discussion

The data of 96 experiments were first analyzed based on dimensional analysis (Relation 1) and then based on the principle of energy (Relation 2). Based on the dimensional analysis, the changes of Fr' versus the dimensionless ratio y1/Bc in different side slopes are shown in Figure 2. It is clear from all four graphs in figure (2) that the value of Fr' increases with the increase of y1/Bc. Proginelli and Bonassi presented the relationship between the Froude number and the depth of the dimensionless flow as a linear relationship [7]. Based on the principle of energy and flow coefficient, the changes of the flow coefficient (Cd) were evaluated against the dimensionless parameter Fr1(y1/Bc) in different side slopes (Figure 3). According to figure (3), in all side slopes, with the increase of Fr1(y1/Bc), the amount of Cd also increases, because the amount of Cd is directly related to the flow discharge.

To check the accuracy of the obtained relationships (presented in fig 2 and 3)the mean absolute relative error (MARE) was used. The values of this statistical function are presented in table (1). According to this table, it is clear that the amount of error in the calculation of Cd is lower than Fr'.

Table 1. MARE values in different side slopes to calculate Fr' (eq.1) and Cd (eq.2)

Side slope (z)	1	0.7	0.4663	0.268
MARE in Fr´	0.083	0.077	0.1	0.088
MARE in C_d	0.034	0.018	0.1	0.065

Considering that the construction of trapezoidal channel with 1:1 side slope is much more common, therefore, using the relationship to calculate Cd and Fr' (Eq. 3 and 4) and then to calculate the flow discharge in these channels, (with MARE equal to 3.4% and 8.3% respectively, Table 1) can be suitable.

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Fr'. Considering that the construction of trapezoidal channel with 1:1 side slope is much more common, therefore, using the relationship to calculate Cd and Fr' (Eq. 3 and 4) and then to calculate the flow discharge in these channels, (with MARE equal to 3.4% and 8.3% respectively, Table 1) can be suitable.

$$Fr' = 0.1079\exp\left(10.193\frac{y_1}{B_c}\right), \quad (MARE = 0.083) \tag{3}$$

$$C_d = 3.5079\left(Fr_1\frac{y_1}{B_c}\right)^{0.7866}, \quad (MARE = 0.034) \tag{4}$$

4- Conclusion

In this research, in order to create flow control sections in trapezoidal channels, prismatic bases with different dimensions were installed in the central axis of the channel floor. The flow passing through the control section was checked with two methods, dimensional analysis and energy principle, and finally, the relationships for calculating the discharge coefficient in each side slope (in each flume) were obtained. The experiments were carried out in 4 side slopes and with 4 prismatic piers of different dimensions in the subcritical flow regime and in free flow conditions For each side slope, relations were obtained to calculate the discharge. The accuracy of the obtained relationships was checked using statistical function of the mean absolute of relative error (MARE). Because of construction of trapezoidal channel with a side slope of 1:1 is more common, therefore using of relations (3) and (4) to calculate the flow rate in these channels is suggested.

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