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A numerical study on the behavior of a supercritical flow over piano key side weirs

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ABSTRACT: Side weirs are a type of hydraulic structures that can be utilized as a divert structure, controller and distributing flow discharge in Floods and high velocity flows. The flow type over these structures is spatially varied flow with decreasing discharge. Due to use of side weirs for transferring and discharge control in flood flows with high velocities, it is very likely to have a supercritical flow over side weirs. Piano key and labyrinth side weirs are used, where the weir opening length is limited. An advantage of these kind of side weirs is the weir's effective length relative to its opening. The most carried out studies on the Piano key weirs are limited to the experimental investigations. Considering the limited conditions and high cost of the laboratory works in one hand and recent developments of the numerical models, on the other hand, it is necessary to use the well known fluid dynamics software to simulate the side weir flows. In this study side weirs with different plans have been simulated by FLOW-3D. The FLOW-3D numerical model has been calibrated and verified for simulating side weirs using the experimental results. In this study, discharge coefficient for piano key side weirs in supercritical flow is presented. To obtain an optimized shape of the piano key side weirs the different shapes of the keys are also compared. These These results this study can be used for design of the piano key side weirs.

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1. INTRODUCTION

Side weirs are hydraulic structures used for different purposes in water distribution systems[1]. Piano key weirs are more advanced than labyrinth and rectangular linear weirs and due to this matter, Its expected that the side orientation would improve the hydraulic function of the weir relative to the case of frontal orientation . In addition to their advantages over direct weirs, like increasing discharge coefficient, the use of piano key side weirs may be the best solution to the topographic restrictions for construction possibility and cost reduction[2].

2. THEORETICAL BACKGROUND

Schmitt equation has been used for obtaining discharge coefficient. In the Schmitt method special energy is considered constant along the side weir. Also the average energy head for upstream and downstream $(H_0 = \frac{H_1+H_2}{2})$ of the weir has the form[3]:

$$Q = \frac{2}{3} C_d \sqrt{2g} W H_0^{1.5}$$

$$H = y + \alpha \frac{V^2}{2g} - P \qquad (1)$$

$$H_0 = \frac{H_1 + H_2}{2}$$

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In these equations, Q is discharge, Cd is discharge coefficient, g is the gravity acceleration, w is weir's width, H0 is the energy equivalent height for the crest, H1 and H2 are energy equivalent height for upstream and downstream of the weir.

3. METHODOLOGY

Before starting the numerical analysis of the flow in different conditions, Its necessary to check the software's ability in modelling 3D flow on the piano key side weir. Experimental data obtained by Karimi et al (2017) has been used for verification. These experiments has been conducted for subcritical flows In a glass canal , which has the length 10 m, width 60cm, and height 60 cm after checking the results obtained from the software and their conformity with the experimental data, new data can be produced in the framework of a numerical laboratory[2]. Fig. 2 shows the geometrical characteristic of the weirs and Table 1 shows the geometric and hydraulic change range of the studied cases for evaluating effective parameters on the discharge coefficient.

4. RESULTS

Fig. 3 Shows the change of discharge coefficient relative to the upstream Froude number. Due to the increase of velocity and Froude number, the kinematic energy in the direction of the main channel is high and secondary flow has more limited

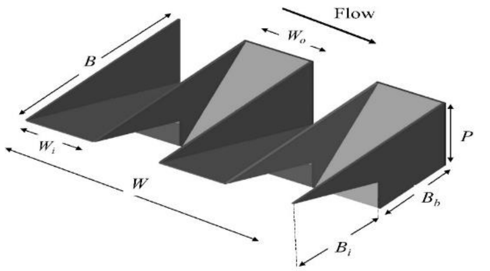

Fig. 1. 3D sketch of a Piano Key side weirs

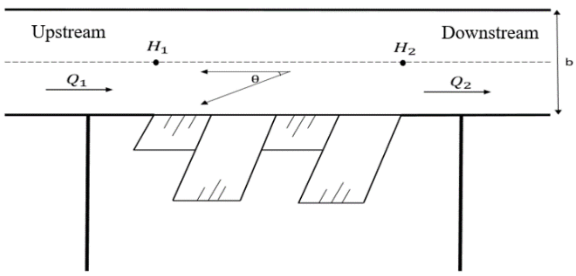

Fig. 2. Schematic view of geometrical characteristic of the main channel and the side weir

Table 1. Geometrical and hydraulic characteristics of Simulated piano key side weirs

Number of test	θ	$P(m)$	$b(m)$	$Q_1(lit/s)$	Fr_1	$\frac{W}{b}$	$\frac{P}{H_0}$
60	0-150	0.1,0.15,0.2	0.3,0.6,0.9	78-310	1.2-3	0.2-3	0.42-0.96

time to form and flow over the weir. As a result it can be seen that with increasing Froude number, discharge coefficient decreases.

In Fig. 6, The effect of different angles in piano key side weirs is evaluated. The difference in different cases is only in their placement angle and geometric properties of the weir and the main channel is the same in all cases. Evaluating the performance of the weir implies that the maximum discharge in all three cases is the angle 120 degree. The main cause of this increase is discharge passing the weir in the angle 120 degree is that the flow lines and the weir keys are aligned. It should be noted that in present experiments streamlines exit the channel approximately with the angle 30 degree and so when the weirs angle is 120 degree, the angle between flow lines and weir is approximately 90 degree which causes maximum discharge passing the unit length of the weir. And so after 120 degree, the discharge coefficient decreases.

In this section, it has been tried to present an equation for discharge coefficient of piano key side weirs based on the obtained results, for supercritical flow and using the software SPSS:

$$C_d = -0.8 + (Fr_1)^{-0.65} + 0.37\left(\frac{P}{H_0}\right) + 0.1\left(\frac{W}{b}\right) - 0.12\theta \qquad (2)$$

5. CONCLUSION

In piano key side weirs, with increase of Froude number, the discharge coefficient decreases. Also, based on the results

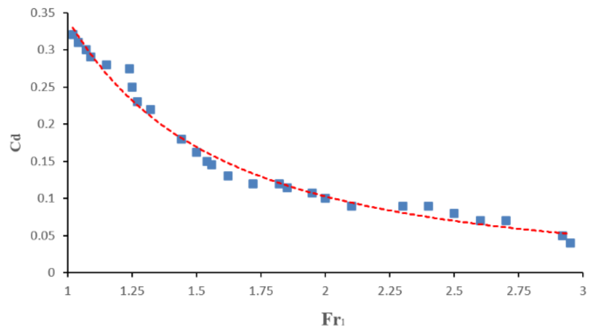

Fig. 3. Variation of the discharge coefficient with Froude number

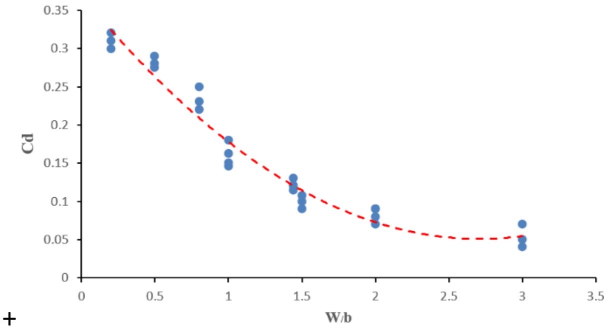

Fig. 4. Variation of the discharge coefficient with W/b

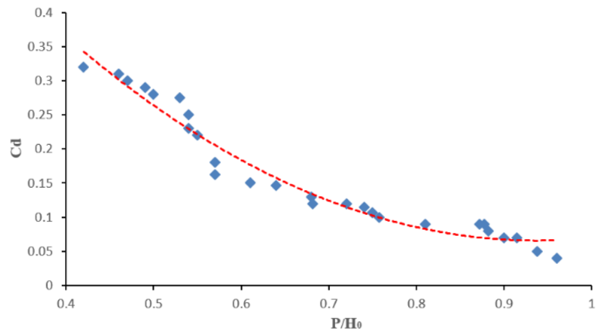

Fig. 5. Variation of the discharge coefficient with P/Ho

of the simulations on oblique piano key side weirs with constant opening width, the piano key weir with the angle 120 degree showed the most passing discharge. This increase in discharge is more than 20% relative to the same rectangular side weirs. Equation 2 is presented for estimation of the discharge coefficient in supercritical flow over piano key side weirs.

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