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EXTENDED ABSTRACT

Evaluation of Energy Dissipation and Hydraulic Characteristics of Flow on Simple and Inclined Stepped Spillways using FLUENT Model

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Introduction

Stepped spillways are hydraulic structures which due to the high energy loss of flow have important role in reducing dimensions of stilling basin of downstream of the dams and consequently their economical design. The dam designers tended to study the characteristics of flow on this type of spillways in recent decades. Horizontal steps, inclined steps, and steps with end sills may be used in stepped spillways. The energy loss of flow on stepped chute depends on the total discharge per unit width of chute, the total flow head, the step height, the step length, the gravitational acceleration, and the height characteristics of the step. For the inclined step, the height characteristics is the increment of step above the horizontal level or the angles of step.

The objective of the study is to compare the relative energy dissipation between horizontal steps and inclined steps and find the optimal energy dissipation efficiency for flow on stepped chutes. In this paper, the effect of angles of inclined step, relative critical depth, and relative discharge on the relative energy dissipation over stepped spillways are investigated and discussed, too. To achieve this goal, first the FLUENT model's output results for simulation of flow passing over a stepped spillway are validated using the experimental data, and then effect of the of angles of inclined step is examined. Also, an equation for the estimate of the relative energy dissipation for inclined stepped spillways was developed.

Methodology

Using the physical models and experimental evaluation of the flow pattern on the stepped spillways demands high costs and mathematical models can help to identify the flow pattern on these structures. In this paper, Chen et al's (2002) experimental data were used for evaluating the accuracy of the FLUENT model results. A stepped spillway model made of plexiglass with a standard WES profile was tested in Chen et al's (2002) model. The spillway crest is 78.9 cm above the toe, and the design head of the spillway is H_d=59.7 cm. The standard spillway crest profile is described by the equation $y= 3.633x^{1.85}$, connected by three arc segments to the vertical upstream face. Below the tangency point, the spillway profile had a slope of 1V:0.75H, completed by an arc with a radius of 28 cm down to the horizontal channel at the toe. There were 13 steps on the whole stepped spillway. The calculation of the maximum absolute error of free water surface is 3 mm and root mean square error in the simulation of velocity profile and pressure respectively are 0.15 and 0.72. The model was validated, then the effects of discharge and steps slope on flow hydraulic characteristics were investigated.

Results and Discussion

After meshing and applying the boundary conditions for the selected experiments, the FLUENT model was applied and the water depth and velocity in toe of spillway was calculated,

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and then the relative energy dissipation was determined. The relative energy dissipation calculated with the proposed methods by Cahnson (1994), Chinnarasri and Wongwises (2006) and Boes and Hager (2003), too. The average error of FLUENT model's output for calculation of the relative energy dissipation for stepped spillway is 2.8% and for the proposed methods by Cahnson (1994), Chinnarasri and Wongwises (2006) and Boes and Hager (2003) are 3.7%, 5.4%, and 11.6%, respectively.

A new approach to increase the energy loss efficiency is to incline the step face in stepped spillway. The effect of the angles of inclined step for various discharges are shown in Figure 1. By increasing the angles of inclined step due to increased turbulence and rising vortices, the magnitude of energy dissipation increases. For example, for design discharge, where the steps are horizontal, the relative energy dissipation is 0.366 and for inclined step with 30-degree angle is 0.5.

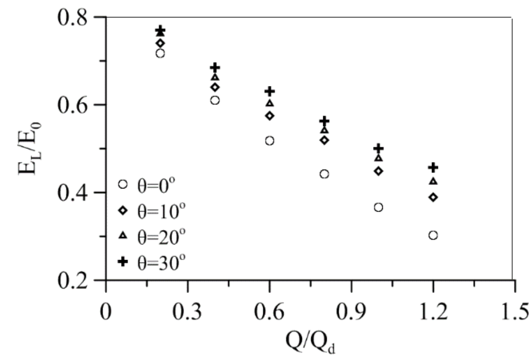

Fig 1- Effect of discharge and the angles of inclined step on relative energy loss

The relationship between relative energy loss (E_L/E_0) and y_c/Nh based on FLUENT model's output results presented in Figure 2. İf y_c/Nh be less than 0.03, the angles of inclined step has no effect on the relative energy dissipation. By reducing the y_c/Nh, the flow through the step is close to nappe flow regime, and increasing the angles of inclined step in nappe flow regime does not have effect on energy dissipation. By increasing the y_c/Nh, the effect of the angles of inclined step on energy dissipation will increase.

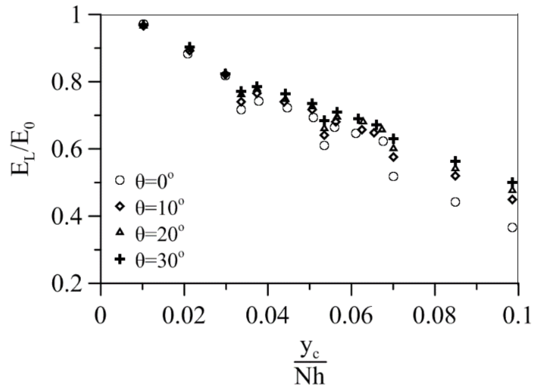

Fig 2- Effect of $y_c/(Nh)$ on energy dissipation for inclined steps

Using nonlinear regression analysis, the empirical correlation for relative energy loss on inclined steps is obtained by fitting the FLUENT model's output results and defined as:

$$\left(\frac{E_L}{E_1}\right)_{\theta>0} = \left(\frac{E_L}{E_1}\right)_{\theta=0} \left[e^{(\frac{\theta}{360})} \left(3.9\frac{y_c}{Nh} + 0.8\right) \right] \tag{1}$$

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It should be noted that in Equation (1), the $(E_L/E_1)_{\theta>0}$ and $(E_L/E_1)_{\theta=0}$ are the relative energy loss on inclined steps and horizontal steps, respectively. The relative energy loss on horizontal steps could be calculated with the proposed methods by Boes and Hager (2003). The average error of presented formula for relative energy loss calculation on inclined steps is about 3.1%.

Conclusions

The results showed that the maximum pressure takes place on the horizontal part of steps and it increased by increasing the discharge of the stepped spillway, but decreases the minimum pressure on the vertical part of steps. Therefore, chance of cavitation is more in high discharges and the vertical part of steps. The results also revealed that the rate of energy dissipation increased in skimming flow by increasing the bottom of steps slope increased due to increase in turbulence and enlargement of vortex. But the effect of increase in steps slope in skimming flow on energy loss is less significant. Using experimental data and output results of Fluent model to calculate energy dissipation in inclined stepped spillways presented formula that the average error is about 3.1%.

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