Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 52(8) (2020) 501-504
DOI: 10.22060/ceej.2019.15856.6057

Numerical and experimental study of pitched steps effects in stepped spillway on the hydraulic parameters and energy dissipation in the skimming flow

Samira Akhgar [1*], Kiyoumars Roushangar [2]

[1]Ph.D. Student of Hydraulic Structures, Water Engineering Department, Faculty of Civil Engineering, Tabriz University, Tabriz, Iran.
[2]Associate Professor of Water Engineering, Faculty of Civil Engineering, Tabriz University, Tabriz, Iran.

ABSTRACT: One of the most prominent features of the stepped spillway performance is the considerable loss of energy during it compared with other types of spillway. Considering this feature, obtaining a more detailed view on the energy dissipation parameter and, finally, increasing its amount has been the focus of most studies related to this type of spillway. For this purpose, using a Flow-3D model, the effect of pitched steps (steps with hole) on the velocity and pressure variations, water height at downstream and energy dissipation has been investigated. As well as the appropriate model of the most energy dissipation in the laboratory was developed and studied. Numerical and experimental results show that pitched steps reduces the velocity to about (82-69%) and reduces the water height at the downstream by up to 33%, and the energy dissipation is increased to about 4 times. According to the pressure distribution profiles at the vertical edge of the step, it was observed that the amount of negative pressure in the vertical wall decreased by about 82%, and the positive pressure was approximately increased by 3 and 4 times. The negative pressure on the floor of the steps is turned into positive and the positive pressure near the edge is increased due to the presence of the hole. Also, the results showed that the error rate of the studied parameters in the numerical and experimental models was very low and acceptable, indicating a good fit between numerical and experimental data.

Review History:

Received: 2019-02-22
Revised: 2019-04-20
Accepted: 2019-04-26
Available Online: 2019-05-19

Keywords:

Stepped spillway
pitched steps
energy dissipation
pressure and velocity distribution
Flow-3D

1. INTRODUCTION

It is very important to dissipate the flow of energy from the spillway to prevent damage to the downstream. One of the best ways to dissipate energy is to use stepped spillways, which, with proper dissipation of flow, reduces the dimensions of the basin at downstream of stepped spillway.

Horner [1] was one of the first to start scientific research on stepped spillways. Christodoulou[2] concluded a series of experiments on stepped spillway physical models with a ratio of y_c / h=0.7 (step height to step length), he found that the factors affecting the energy dissipation are y_c / h and the number of steps *N*, where y_c is the critical depth and *h* is the height of the steps. Torabi et.al [3] investigated the performance of these spillways with roughness on steps of stepped spillway. The results showed that by increasing the roughness on the steps, energy increases by 20-15%. Roushangar et al. [4] investigated energy dissipation over stepped spillway by applying of intelligent methods and evolutionary algorithms and provided relationships for each of the nappe and skimming flow using laboratory data. Parsaie and et al. [5], respectively, studied the flow pattern over the Kamal Saleh dam and the cavitation on the Balarode spillway using a Flow-3D numerical model. The results show that the RNG k-ε turbulence model has a high ability in modeling the flow pattern and cavitation. Roushangar et al. [6], using data driven methods, examined the discharge coefficient of a stepped spillway for nappe and skimming flow and provided a relationship with the GEP method.

In this study , in order to increase and improve the efficiency of energy dissipation, the holes with different shapes and layers on stepped spillway steps created and effect of them on the changes in velocity and pressure, water level and energy dissipation has been investigated by The Flow-3D. Also, the appropriate model in terms of the most energy dissipation has been designed and studied in the laboratory.

2. METHODOLOGY

1.2 Numerical studies

In this study, a finite-volume numerical method (Flow-3D) was used to investigate the effect of creating hole on velocity and pressure changes in the floor and edges of the steps, the water level at the downstream and the energy dissipation on the stepped spillway. For this purpose, four shapes of the hole with two layers are investigated. The geometry and alignment of these wedges are shown in Fig.1.

To solve turbulence equations and numerical simulation of flow pattern in Flow-3D, the K-ε (RNG) turbulence model has been used. This model is more accurate than the Two-equation (K-ε) turbulence model for numerical simulation of the flow pattern on the stepped spillways, and the completion time of the simulation (uniformity of flow) in this model takes place sooner.

*Corresponding author's email:samira.akhgar66@yahoo.com

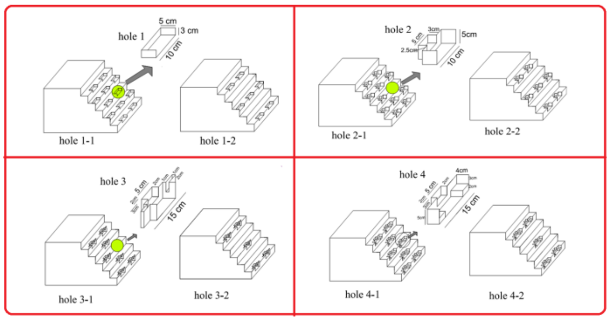


Fig. 1. Geometry and alignment of the holes on the stepped spillway in the numerical study

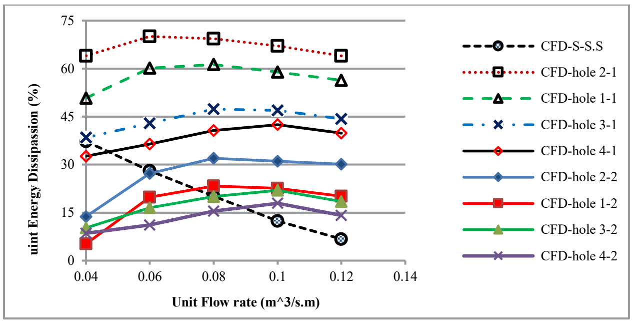


Fig. 3. Energy dissipation for standard stepped spillway and all holed stepped spillway in CFD study

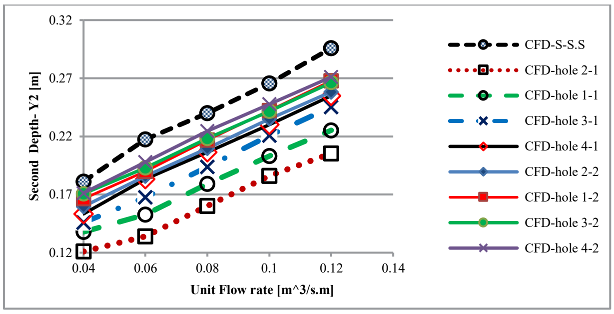


Fig. 2. Secondary water depth versus unit flow rate in Standard stepped spillway and stepped spillway with holed steps in CFD study

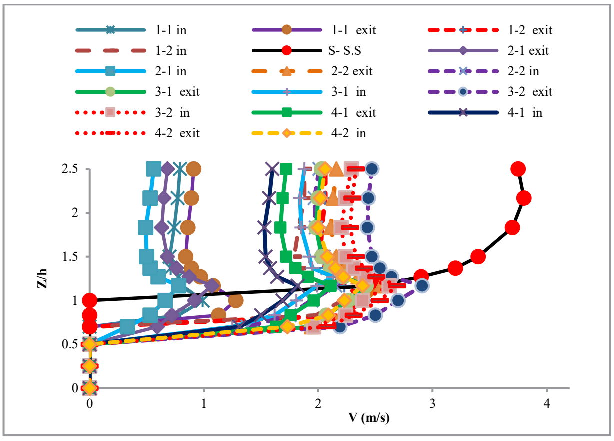


Fig. 4. Vertical profile of the flow velocity distribution in the vertical wall at x = 0 (*Z* is the distance from the floor of the step and *h* is the height of the step)

In order to validate the numerical model, the measured velocity values in the laboratory and the velocity in a numerical model for discharge of 60 liter/s were investigated that the mean relative error is obtained 8.57%.

2.2. Experimental study

In present study, experiments were done in the hydraulic laboratory of Tabriz University, Iran. The experiments were carried out in a Channel length=10 m, wide= 0.5 m, and high=0.8 m with a free flow system. A laboratory model of a simple stepped spillway had 50 cm wide, 60 cm height and which has 6 steps (w = h = 10cm). The discharge range was 10 to 60 lit/s.

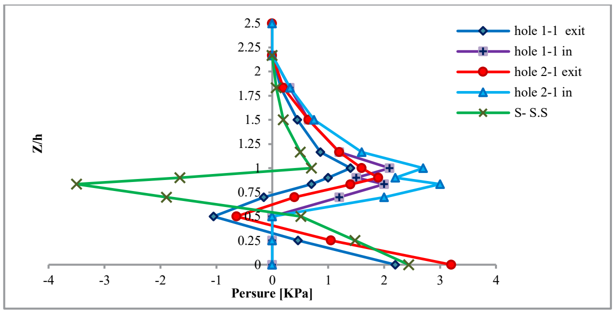
3. RESULTS AND DISCUSSION

1.3. Numerical studies

The aim of this study is investigation the effect of creating hole on the steps on the velocity and pressure variations in the floor and vertical wall of the step, changes in the water level at downstream of the spillway and energy dissipation. Fig. 2 shows the results of the secondary water depth versus unit flow rate for standard stepped spillway (SSS) and stepped spillway with holes (SSH) with different geometries and layouts. According to this Fig., it is seen that the stepped spillway with hole types 1 and 2 has a lower secondary depth than a standard stepped spillway. So that (hole 1-1) and (hole 2-1) reduced 29.6% and 33.1% of the secondary depths relative to the standard stepped spillway respectively. One of the reasons for the superiority of the two models is the volume of holes in the corresponding models. So that the percentage of hole volume (hole 2-1) and (hole 1-1) models are 14% and 8% respectively.

Fig. 3 shows the energy dissipation values for SSS and SSH of type 1 to 4. It is observed that in SSH of type 1 and 2, energy is more lost than SSS. So according to the numerical results, it is deduced that the that (hole 1-1) and (hole 2-1) have the least amount of secondary depth (3.3 and 4.1 times respectively) and therefore the highest amount of energy dissipation.

Fig. 4 shows the distribution profile of the flow velocity in the vertical wall for a flow rate of 60 lit/s. In this Fig., the intent of '*exit*' is defined as the place where the hole is and '*in*' is from the inside of the hole. In SSS, from the step stub to a height of 1 which is equivalent to the edge of the step, the surface is solid and the flow in the horizontal direction is not motion, so the velocity value is zero. After passing through the edge of the step a little bit from the wall, the velocity distribution increases, so that it reaches to its maximum value at 0.3 from the free surface flow. In SSH, from the step stub to a height of 0.5 and 0.8 which is equivalent to the edge of the hole, the surface is solid and the flow in the horizontal direction is not motion, so the velocity value is zero. After passing through the edge of the hole a little bit from the wall, the velocity



(a)

Fig. 5. Vertical profile of the Pressure distribution in the vertical wall at x = 0 in the in CFD study

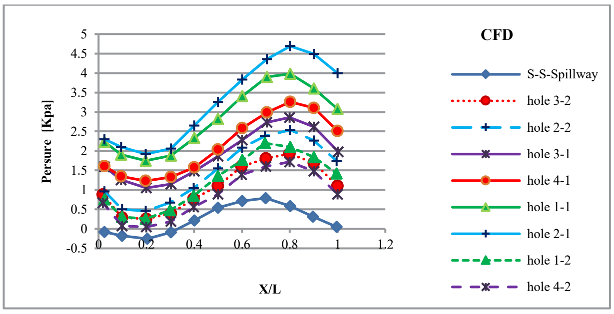


Fig. 6: Horizontal profile of the pressure distribution in the floor of the step (*X* distance from the step corner and *L* step length)

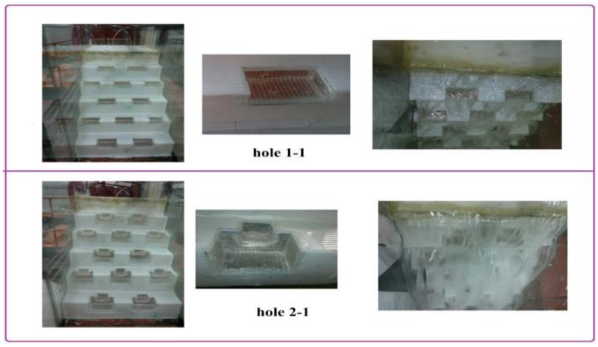


Fig. 7. the selected models of holed stepped spillway in the experimental study

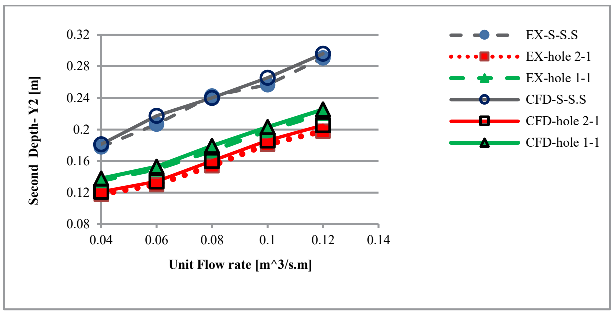


Fig. 8. Numerical and laboratory secondary water depth of a standard stepped spillway and selected holed stepped spillway

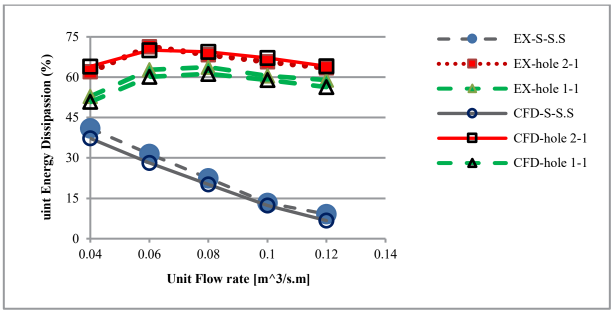


Fig.9. Changes of the energy dissipation for standard stepped spillway and selected holed stepped spillway

distribution increases, so that it reaches to its maximum value at 0.2 from the free surface hole. With the entrance of the flow into the main stream flow, the distribution velocity has a decreasing trend, so that it reaches the lowest value in 0.2 of the free flow. With regard to Fig. 8, it is seen that the velocity reduction for all models is 25% to 82%, that holes 1-1 and 1 hole 2-1, lead to the highest drop in velocity (82 % - 77%) and (75% -69%)respectively.

Fig. 5 shows the pressure variations in the vertical section of the step. By creating holes on the steps in hole 1-1 and hole 2-1 the negative pressure in the vertical wall was decreased about 70% and 82% respectively, and also positive pressure at the edge of the step increased 2 to 3 times where there is hole and increased 3 to 4 times in the hole.

Fig. 6 shows the pressure changes in the floor of the step. The maximum pressure value for SSS in 0.7 and for SSH at 0.8 in the floor of step occurs, and the minimum value in x / l = 0.2 occurs

2.3. Experimental studies

Fig. 7 shows the two selected models of hole1-1 and hole2-1 from the pitched stepped spillway that has the best numerical results. Fig. 8 shows the secondary water depth versus unit flow rate for SSS and SSH. The error percentage of the secondary depth of flow in the numerical and experimental models is very small, which it indicates a good fit between numerical and laboratory data.

Fig. 9 shows energy dissipation changes for SSS and SSH. According to this Fig., energy dissipation for SSH has increased compared to SSS. The energy dissipation for hole1-1 and hole2-1 compared to SSS is increased 3.2 and 4 times respectively.

4. CONCLUSIONS

The aim of this study is to investigate the effect of creating hole on the stepped spillway steps on changes in velocity and pressure on the floor and edge of the steps, changes in the surface water level at downstream of spillway and energy dissipation. Numerical studies of these models showed that SSH had the least secondary depth and therefore they have the most energy dissipation compared SSS. Also, for the more density of the holes, the better results are obtained. In fact, by reducing the distance between the holes, energy dissipation increases and the secondary depth decreases too. So that hole1-1 and hole2-1 reduced 29.6% and 33.1% secondary depths, respectively, and also (69%- % 75) and (77% -82%) reduced the velocity in the vertical wall of the step. As well as selected models with the above-mentioned, the amount of negative pressure in the vertical wall was decreased 70% and 80% respectively, and the positive pressure at the edge of the step for the same models was increased 2 to 4 times. The value of energy dissipation for SSH has increased compared to SSS so that hole1-1 and hole2-1 increased 3.3 and 4.1 times respectively. The percentage of holes volume in these spillways is 14.5% and 8% respectively. This is while the percentage of holes volume for other types and with arranges on all steps is up to 6.5%.

REFERENCES

[1] M.W. Horner, An analysis of flow on cascades of steps, University of Birmingham, 1969.

[2] G.C. Christodoulou, Energy dissipation on stepped spillways, Journal of Hydraulic Engineering, 119(5) (1993) 644-650.

[3] H. Torabi, A. Parsaie, H. Yonesi, E. Mozafari, Energy dissipation on rough stepped spillways, Iranian Journal of Science and Technology, Transactions of Civil Engineering, 42(3)(2018), 325-330.

[4] K. Roushangar, S. Akhgar, F. Salmasi, Estimating discharge coefficient of stepped spillways under nappe and skimming flow regime using data driven approaches, Flow Measurement and Instrumentation, 59 (2018) 79-87.

[5] A. Parsaie, S. Dehdar-Behbahani, A.H. Haghiabi, Numerical modeling of cavitation on spillway's flip bucket, Frontiers of Structural and Civil Engineering, 10(4)(2016) 438-444..

[6] K. Roushangar, S. Akhgar, F. Salmasi, J. Shiri, Modeling energy dissipation over stepped spillways using machine learning approaches, Journal of Hydrology, 508 (2014) 254-265.

HOW TO CITE THIS ARTICLE

S. Akhgar, K. Roushangar, Numerical and experimental study of pitched steps effects in stepped spillway on the hydraulic parameters and energy dissipation in the skimming flow, Amirkabir J. Civil Eng., 52(8) (2020) 501-504.

DOI: 10.22060/ceej.2019.15856.6057