Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 51(5) (2019)307-310
DOI: 10.22060/ceej.2018.14250.5602

Experimental Study of Hydraulic Performance of Stepped Spillway with a Curve Axis Affected by Downstream Channel Width Changes

A. Foroudi[1], K. Roushangar[1*], M. Saneie[2]
[1] Faculty of Civil Engineering, University of Tabriz, Tabriz, Iran
[2] Soil Conservation and Watershed Management Research Institute, Tehran, Iran

ABSTRACT: Realization of the advantages of a higher degree of energy dissipation have created an increasing interest in stepped spillways. This study using a three dimensional, 1:50 scale, physical model was conducted to investigate the impact of variation downstream channel width of the converging stepped spillways with a curve axis. For this purpose, the converging stepped spillway with a curve axis was constructed and tested in four ratio of downstream channel width to spillway width ($\frac{W_{ch}}{W}$) ranging from 0.214 to 0.286. The results of the experiments indicated that in the converging stepped spillway by increasing total upstream head, the discharge coefficient will go up for each of the width ratio ($\frac{W_{ch}}{W}$) and also before submergence stage for the spillway, the discharge coefficient is independent of downstream channel width variations. By contrast, when the spillway was submerged, there is a decrease in the coefficient of discharge can be caused by tailwater submergence and it causes the differences in the discharge coefficient for each of the widths ratio ($\frac{W_{ch}}{W}$). Also, the obtained data demonstrates that as $\frac{W_{ch}}{W}$ increases, the flow depth and static pressure decreases at the bottom and the toe of the spillway model. Moreover, it was observed that as discharge increases, the energy dissipation decreases for all models, but model with higher ratio of $\frac{W_{ch}}{W}$ lead to reduce more energy dissipation in higher discharge. In addition, model with width ratio of $\frac{W_{ch}}{W}=0.286$ due to passing the probable maximum flood in the Maximum allowable head can be selected as the best model.

Review History:

Received: 3/26/2018
Revised: 4/26/2018
Accepted: 5/17/2018
Available Online: 6/12/2018

Keywords:

Physical model
Stepped spillway
Curve axis
Hydraulic performance
Energy dissipation

1. INTRODUCTION

Spillway is one of the most important components of the dam that many failures of dams have been attributed to their inadequate capacity and the safety of dams is important in direct and close relationship with the capacity of the spillway, so the spillway must be a strong, reliable and high-performance structure that can be ready for exploitation at any moment. Fig. 1 illustrates a stepped Spillway with a Curve Axis with its important hydraulic and structural elements.

According to Fig. 1, W and P are the spillway height and spillway width respectively; h is the height of the step; θ is the convergence angle of training walls; H is the total upstream water head on the spillway; and d is the flow depth in the downstream channel.

Given the increasing importance of these spillways, numerous researches and studies relating to hydraulic performance and the factors affecting energy dissipation over stepped spillways has been conducted.

Accordingly, the hydraulic flow over the stepped spillway has been reported in three types: 1. Nappe flow regime 2. Transition flow regime 3. Skimming flow regime [1, 2]. The effective criteria in generating various types of flow in stepped spillway, including the geometry of the steps (length of the steps and the height of the steps) and the amount of discharge passing over the spillway [3]. Reference [4] conducted experimental investigation on energy dissipation over the stepped spillways, the results showed that for a constant

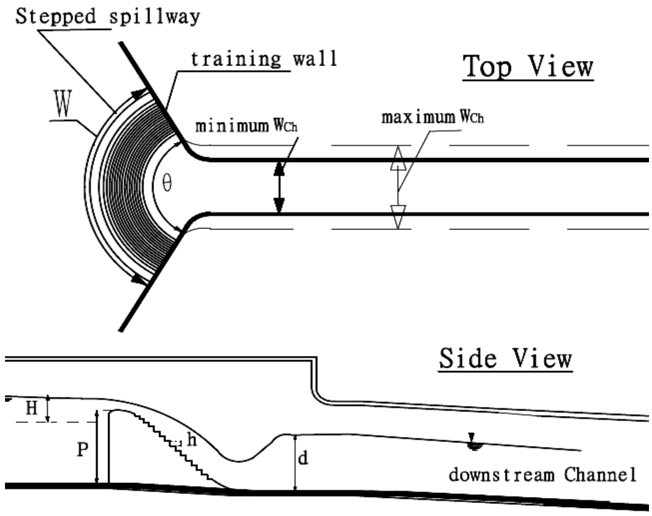

Fig. 1. Schematic of a typical converging stepped spillway with curve axis

*Corresponding author's email: kroshangar@yahoo.com

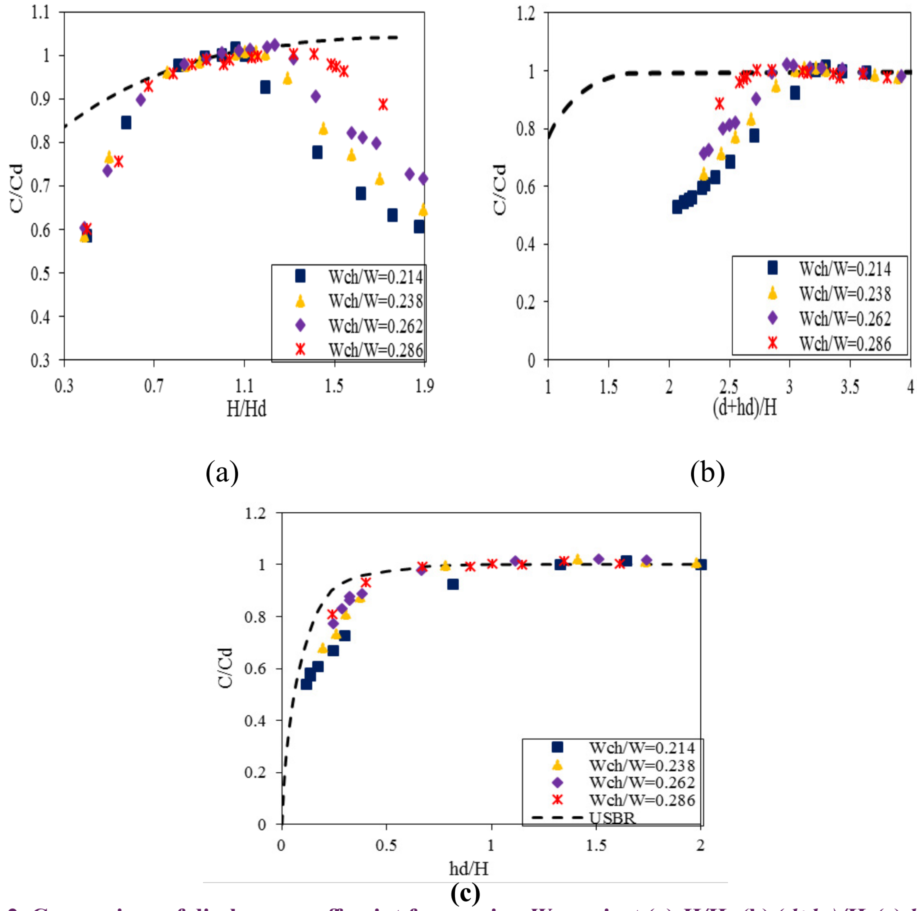

Fig. 2. Comparison of discharge coeffeceint for varying W_{ch} against (a) H/H_d, (b) $(d+h_d)/H$, (c) h_d/H

total upstream head, the increase in the number of steps significantly increases the energy dissipation. The recent and relevant references that dealt with laboratory investigations [5-8] addressed the main characteristics of the flow and then several relationships for flow and energy dissipation over stepped spillways has been proposed. However, surveys show that despite the numerous researches, the hydraulic performance of stepped spillway with a curve axis has not been considered. Consequently, in this paper, the effects of downstream channel width changes on hydraulic performance are studied.

2. DIMENSIONAL ANALYSIS

It is possible to express discharge of stepped spillways with a curve axis in terms of the fallowing parameters:

$$f\,(Q,\, H,\, W,\, W_{ch},\, P,\, h,\, H_d,\, g,\, \rho,\, \mu,\, \sigma,\, h_d,\, d, \alpha,\, \vartheta)=0 \tag{1}$$

where f is a functional symbol; Q is the discharge; H_d is the design head; g is the gravitational acceleration; ρ and μ are density and dynamic viscosity, respectively; σ is the surface tension; h_d is high difference between the water surface elevation in the crest and downstream flow depth; and α is the angle between the upstream face and the horizontal; Equation 1 represents a physical phenomenon. Centered on the Buckingham Π theorem, this equation may be expressed in a dimensionless form as:

$$\Pi_1 = \phi(\Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9, \Pi_{10}, \Pi_{11}, \Pi_{12}) \tag{2}$$

where Π_1 to Π_{12} Π_{10} are the dimensionless. Considering Q, H, and ρ as dimensional independent parameters, according to the procedure suggested by Reference [9].

$$\Pi_1 = \frac{gH^5}{Q^2},\quad \Pi_2 = \frac{H}{P},\quad \Pi_3 = \frac{H}{H_d},\quad \Pi_4 = \frac{h_d}{H},\quad \Pi_5 = \frac{W}{H},$$
$$\Pi_6 = \frac{d+h_d}{H},\quad \Pi_7 = \frac{\mu H}{\rho Q},\quad \Pi_8 = \frac{\sigma H^3}{\rho Q^2},\quad \Pi_9 = \frac{h}{P},\quad \Pi_{10} = \frac{W_{ch}}{W},$$
$$\Pi_{11} = \theta,\quad \Pi_{12} = \alpha \tag{3}$$

Considering that some groups must be combined to deduce the dimensionless parameters commonly applied in hydraulics, Equation 3 is expressed as follows:

$$\frac{3\sqrt{3}}{2\Pi_5(2\Pi_2)^{0.5}} = \psi\left(\Pi_2, \Pi_3, \Pi_4, \Pi_6, \frac{1}{\Pi_7}, \frac{\Pi 8}{\Pi 1}, \Pi_9, \Pi_{10}, \Pi_{11}, \Pi_{12}\right) \tag{4}$$

where ψ is a functional symbol. Substituting Π_1 to Π_{12} Π_9 from Equation 3 into 4 gives:

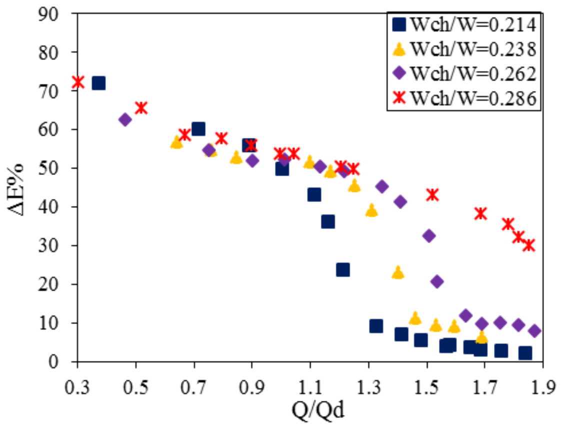

Fig. 3. Energy dissipation over the stepped spillway With varying downstream channel width

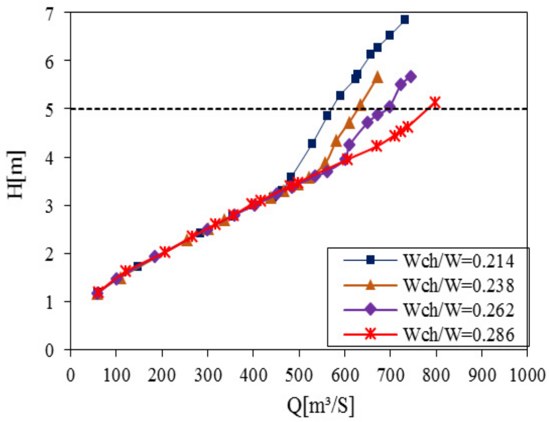

Fig. 4. Energy dissipation over the stepped spillway With varying downstream channel width

$$\frac{Q}{\frac{2}{3}WH\sqrt{\frac{2}{3}gH}} = \psi\left(\frac{H}{P}, \frac{H}{H_d}, \frac{h_d}{H}, \frac{d+h_d}{H}, \frac{\rho Q}{\mu H}, \frac{\sigma}{\rho g H^2}, \frac{h}{P}, \frac{W_{ch}}{W}, \theta, \alpha\right) \quad (5)$$

With regard to the exclusion of unaffected parameters according to the suggestions of references [10, 11], Equation 6 is expressed as follows:

$$C_d = \psi\left(\frac{H}{H_d}, \frac{d+h_d}{H}, \frac{h_d}{H}, \frac{W_{ch}}{W}\right) \quad (6)$$

3. EXPERIMENTAL RESULTS

3.1 Discharge coefficient

C_d variations for varying W_{ch}'s are presented against H/H_d in Fig. 2a. As can be seen, before the submergence stage for the spillway, $(H/H_d) < 1.3$, heads lower than the design head will result in a decrease in C_d , But in the range of $(H/H_d) > 1.3$, as the width ratio decreases, C_d will declines faster due in part to the local submergence at the downstream. Fig. 2b is a plot of downstream floor conditions on the C_d. As shown in this Figure, in the range of $\frac{d+h_d}{H} > 3.2$, the ratio of the discharge coefficient to the ratio of the downstream channel width is equal to 1, which means that in this range, the downstream floor position has no effect on the discharge coefficient. By contrast, in the range of $2 < \frac{d+h_d}{H} < 3.2$, the discharge coefficient ratios are less than 1 and it indicates the effect of downstream apron condition on the coefficient of discharge and so, as W_{ch} increases, the discharge coefficient increases. Fig. 2c demonstrates that the C_d values were affected by tail-water conditions against the discharge coefficient of free flow conditions. As can be noticed, in the range of $\frac{h_d}{H} < 0.7$, C_d is affected by the variation width ratio due to tail-water submergence. By contrast, in the range of $\frac{h_d}{H} > 0.7$, variation of W_{ch}'s has no significant effect on the discharge coefficient.

3.2 Energy dissipation

Fig. 3 shows the energy dissipation variations for varying W_{ch}'s. It was observed that as discharge increases, the energy dissipation decreases for all models. Moreover, in the range of $\frac{Q}{Q_d} > 1.1$, the model with higher degree of $\frac{W_{ch}}{W}$ reduce more energy dissipation.

3.1 Discharge-stage

Total upstream head data of spillway for all of the tested W_{ch}'s is presented against Q in Fig. 4. From Fig. 4, it can be inferred that $\frac{W_{ch}}{W} = 0.286$ with ability to pass the Q_{PMF} in the Maximum allowable head can be selected as the best model.

4. CONCLUSIONS

General qualitative and quantitative results of the present study are summarized as the fallowing:

1- In the converging stepped spillway by increasing total upstream head, the discharge coefficient will go up for each of the channel width ratio (W_{ch}/W) and until the downstream flow is at either supercritical or critical stages, the discharge coefficient is independent of variation of channel width. By contrast, at the submergence stage for the spillway, the difference in the discharge coefficient can be due to tailwater submergence occurring in the spillway.

2- Energy dissipation over converging stepped spillway decreases for all models, but model with higher ratio of $\frac{W_{ch}}{W}$ lead to decline more energy dissipation in higher discharge.

3- The width ratio of $\frac{W_{ch}}{W} = 0.286$ can be selected as the best model due to its ability to pass the probable maximum flood in the Maximum allowable head.

REFERENCES

[1] H. CHANSON. Self-aerated flows on chutes and spillways. Journal of hydraulic engineering, 119.1993, 220-243.

[2] CHANSON, Hydraulic design of stepped channels and spillways, Department of Civil Engineering, University of Queensland, 1994.

[3] N. Rajaratnam, Skimming flow in stepped spillways. Journal of Hydraulic Engineering, 116(4) (1990) 587-591.

[4] F. Salmasi, M. Bina, H. Musavi, Energy dissipation on stepped spillways. 6th International Conference on Civil Engineering, Isfahan University of technology, Isfahan, Iran, 2003[In Persian].

[5] H.M. Vali Samani, M.R. Nazarzadeh, Evaluation of the principles of hydraulic flow and design of stepped spillways, Technical University press, Tehran, 38(2) (2004) 339-347 [In Persian].

[6] H. Chanson, Jet flow on stepped spillways. Journal of

Hydraulic Engineering, 121(5) (1995) 441-448.

[7] H. Chanson, R.L. Whitmore, Investigation of the gold creek dam spillway, Australia,1996

[8] M. Chamani, N. Rajaratnam, Characteristics of skimming flow over stepped spillways. Journal of Hydraulic Engineering, 125(4) (1999) 361-368.

[9] Mohammadzadeh-Habili, J., Heidarpour, M., Afzalimehr, H.: Hydraulic characteristics of a new weir entitled of quarter-circular crested weir. Flow Measurement and Instrumentation 33, 168-178 (2013).

[10] Ranga Raju, K.G., Asawa, G.L.: Viscosity and surface tension effects on weir flow. Journal of the Hydraulics Division 103(10), 1227-1231 (1977).

[11] USBR, US, Bureau of Reclamation: Design of small dams, 3rd ed. Technical Service Center, Denver, USA (1977/1987)

HOW TO CITE THIS ARTICLE

A. Foroudi, K. Roushangar, M. Saneie, Experimental Study of Hydraulic Performance of Stepped Spillway with a Curve Axis Affected by Downstream Channel Width Changes, Amirkabir J. Civil Eng., 51(5) (2019) 307-310.

DOI: 10.22060/ceej.2018.14250.5602