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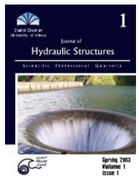

Experimentally determination of discharge coefficients of Ogee spillway under axial arc condition with convergent lateral walls

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Abstract

A dam spillway is a hydraulic structure that appropriately and safely diverts the outflow to downstream, so that the dam stability and passing of flood flows can be guaranteed. Compared to straight crest spillway, an Ogee spillway with curvature in plan in a fixed-width can pass more flow. Therefore under the low hydraulic heads and the need for a smaller place in plane, they are considered as an economical structure so that their application from several aspects are under developed. An experimental model of the Garmi-Chay Miane dam spillway was made in 1:50 scale. The water head over spillway crest was measured in the eight discharges values and consequently the efficiency of spillway were determined. For Q/Qd ranging from 0.63-1.13, discharge coefficient had ascendant trend with acceptable agreement against the diagram of USBR, while for Q/Qd between 1.13-1.51, due to the submergence of spillway, the discharge coefficient decreased.

Keywords: Convergent lateral walls, Curvature in the plan, Discharge Coefficient, Ogee Spillway, Physical modeling

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1. Introduction

The capacity of a spillway largely implies the length of spillway and the form of crest. The spillway with curvature in plane has some advantages over structures compare to straightforward spillway. Spillway with curvature in plan provides increased length of crest by fixed wide, thereby the capacity of upstream head increase. The result of the increase of capacity is that it has lower

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head spillways in upstream than linear spillway that helps the passing of flooding and increases the storage capacity of the reservoir under current conditions (Crookston, 2010). To control the upstream water head and flow capacity, spillway with curvature in plan are almost optimal design. For designers, choosing an optimized design for a particular position can be difficult, because the designing data are limited for much geometric design (Johnson and Savage, 2006).

Since early 1950, the behavior of weir has widely investigated by U.S. Army Corp of Engineers (Bahmani et al., 2010). Bradley (1945) identified four types of flow over dam with ogee profiles. Type. 1 categorized a rapid variable flow of the supercritical over weir; type 2 is a stationary hydraulic jump on weir; Type 3 is a submerged jump and type 4 for weir submergence. Cassidy (1965) obtained discharge coefficient, pressure distribution and water surface profiles for a particular form of spillway. The results of the numerical analysis of flow over spillway were almost identical with the experimental results, and the results of this research indicated a low impact of viscosity at the free surface. Savage & Johnson (2001) developed a study to compare flow parameters in a standard ogee spillway using a physical model, mathematical models and available research records. Finally, a reasonable harmony was observed between the physical and numerical models. Chatila and Tabbara (2004) examined a computational model of the flow over ogee spillway. In this study, regular profiles of the flow over ogee spillway were examined measured the fluid free surface for several levels of flow over weir. Finally, it was shown that the free surfaces of flow predicted by the numerical model were in good agreement with experimental profile of the flow in entire body of weir. Dargahi (2006) conducted an experimental and three-dimensional numerical study of weir with free flow surface. Through their study, the water surface profile and discharge coefficients were predicted based on the water head over the weir with the accuracy of 1.5 to 2.9. Also. Savage & Johnson (2006) studied physical and numerical comparison of flow over ogee spillway in the presence of tail water. The comparison showed that numerical modeling can accurately predict the rate of flow over the spillway and the pressure distribution on the spillway. The results of this study provide users of numerical models performance information that can be used to aid them in determining which tool to use to effectively analyze dams and their associated spillways. Tullis and Neilson (2008) carried out the performance of submerged ogee spillway and proposed a relationship for discharge calculation. The results showed that for submergence levels <0.70, the head-discharge relationship was relatively independent of the tail water elevation, but at higher submergence levels, this was not the case. For submergence values <0.8, the submergence head-discharge data were best predicted using the free-flow head-discharge relationship. For submergence values <0.8, the accuracies of all but one of the head discharge relationships were very poor. For such high submergence levels, more accurate methods are needed for predicting submerged ogee-crest head-discharge relationships. Hunt et al. (2008) evaluated the convergence effects of the lateral walls in stepped spillway. Overall results indicated that flow behavior of the two sides of spillway is the same; transverse waves through the body of spillway were not observed; Furthermore, the water surface profiles showed that flow depth next to wall rapidly increased at the beginning of the convergent part. Khosrojerdi (1997), studied broad crest weirs in direct and curvature illustrations. He suggested that the axial arc, in addition to the structural stability toward the upstream, leads to the increase of discharge coefficient. Also, Khosrojerdi and Mehrjerdi (2007) stimulated the field of passing flow over ogee spillway using fluent software in three-dimensional condition. According to the results, discharge coefficient, static pressure and flow rate within the ogee section is more in the upstream curvature than downstream curvature and direct spillway.

The most investigations performed in this area were about ogee spillway with direct crest and also a few studies have been conducted on spillway with curvature plan and convergent walls. The present study aims to determine the discharge coefficient over ogee spillway with curvature in plan and convergent walls by using experimental method.

2. Material and method

The experiments were conducted in Soil Conservation Watershed Management Research Institute- Tehran-Iran, using physical model of ogee spillway of Garmi Chay dam in scale 1:50. A reservoir with dimensions 2 m long, 1.80, width, 1.20 m depth were employed. A stilling basin with dimensions of 2 m length, 1.30 m width and 0.6 m height and then the stilling basin of the flume with dimensions 1.5 m long, 0.6 Width, 0.6 m depth were used. The ogee profile of Garmin Chai dam spillway has been designed according to USBR standard. An overview plan and section of the spillway is shown in Figs. 1 and 2. The geometry of spillway model is adjusted using Froude similarities. Spillway is curved and built using CNC milling machine with 0.05 mm precision by Teflon blocks. Lateral walls and downstream channel were built of Plexiglas. The experiments were carried out with eight discharges: 14.14, 16.97, 19.12, 22.62, 25.46, 28.28, 31.11 and 33.94 lit/sec. The water head over the spillway crest was measured about 4 to 5 times of H from the edge of crest-point gauge with 0.1 mm precision inside the reservoir, where the effect of surface water curvature was not significant. To Supply water, a pump capable of pumping up to 46 liters per second was used and to measure the discharge, a sharp triangular weir with apex angle of 90° was employed and water height on triangular weir was measured by point gauges. Figs. 3 and 4 illustrate general view of physical model of spillway with scale 1:50.

To determine the discharge of water passing over the ogee spillway, the Eq. (1) is used as follows (Ghodsian, 1998).

$$Q = \frac{2}{3} C_d \sqrt{2g}\, L H^{\frac{3}{2}} \qquad (1)$$

in which Q= spillway discharge; L= spillways crest length; H= head over the spillway crest; g= gravitational acceleration; and C_d= discharge coefficient.

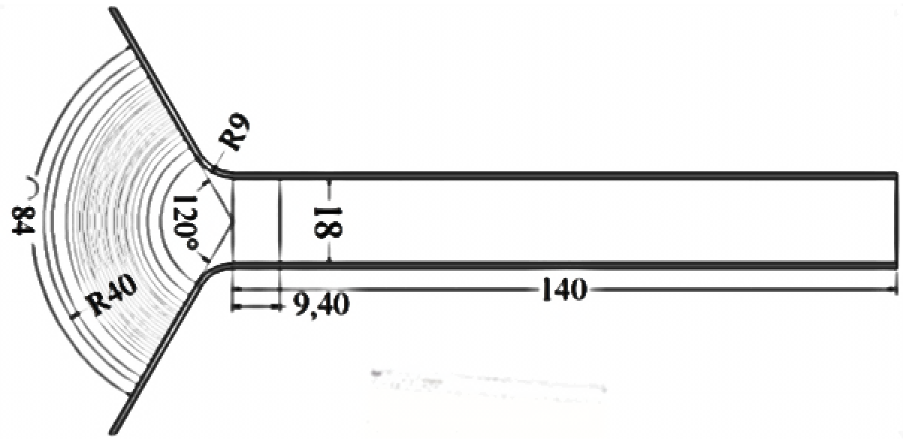

Fig.1 Spillway plan (Dimensions in centimeter)

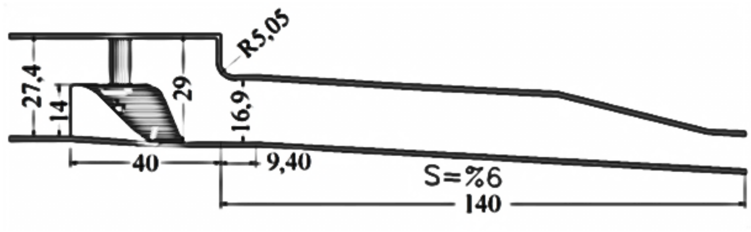

Fig.2 Spillway section (Dimensions in centimeter)

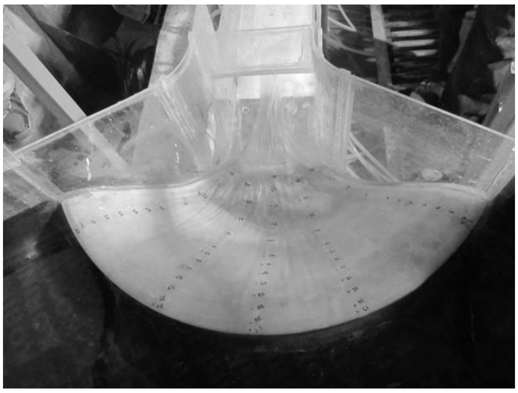

Fig. 3 A view of spillway physical model in scale 1:50

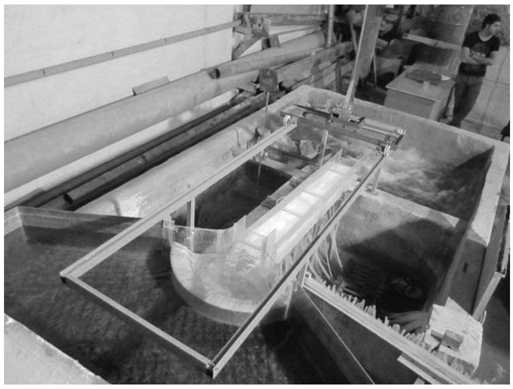

Fig. 4 A view of spillway physical model in scale 1:50

3. Results and Discussions

The relationship between the head over the spillway crest and discharge is shown in Fig.5. With the increase of the discharge, the head over the spillway crest also increases. It is observed that in the discharge range; 14.14 to 25.45 lit/sec, i.e. $0.63<\frac{Q}{Qd}<1.13$, the head over the spillway crest has increasing trend, and the discharge range; 25.45 to 33.94 lit/sec, i.e. $1.13<\frac{Q}{Qd}<1.51$, the head over the spillway crest increase with the more slope in which discharges is greater than 25.45 lit/sec, i.e. $\frac{Q}{Qd}>1.13$, the spillway will be submerged and its efficiency decrease.

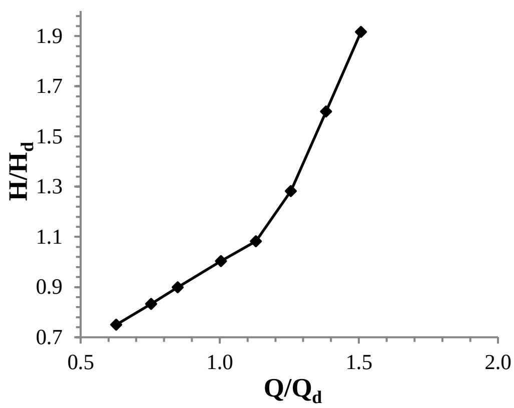

Fig. 5 The variations of head over the spillway crest for different discharge

Fig. 6 indicates that in discharges 0.63<$\frac{Q}{Qd}$<1.13, discharge coefficient has increasing trend which is in $\frac{Q}{Qd} = 1$, $\frac{C}{C_d} = 1$, and the discharge range 1.13<$\frac{Q}{Qd}$<1.51, due to the submerge of spillway, discharge coefficient decrease and the efficiency of spillway also decrease.

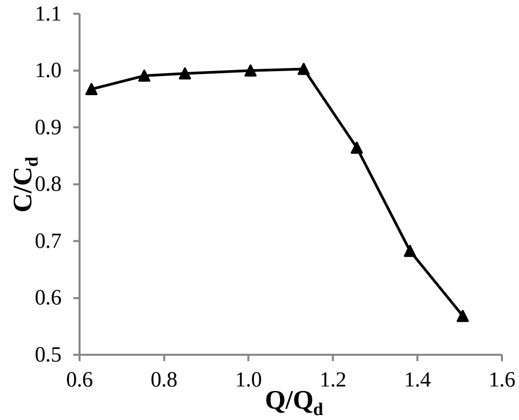

Fig. 6 Discharge coefficients for different discharge

Fig.7 shows the relationship between the head over the spillway crest and discharge coefficient, where physical model with scale 1:50, is compared to USBR standard. In$\frac{H}{H_d} = 1$, $\frac{C}{C_d}$ equals one. In the head range 0.75≤$\frac{H}{H_d}$≤ 1.08, the diagram of head to discharge coefficient has harmony with the diagram of USBR. But in the head range 1.08≤$\frac{H}{H_d}$≤ 1.92, due to the submerged of spillway; it has decreasing trend and the efficiency of weir decreases.

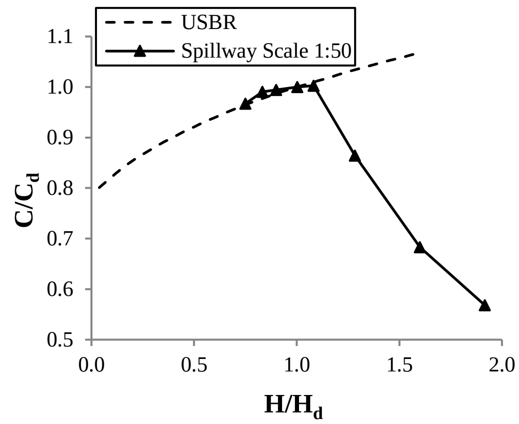

Fig. 7 A comparison of the discharge coefficients for other than the design head

Fig. 8 shows a comparison of the effect of tail water on the discharge coefficient changes in the physical model of spillway with scale 1:50 and USER standard. In this model, the spillway is submerged and its efficiency decreases within$\frac{h_d}{H} < 1$. However, in the diagram of USBR, in $\frac{h_d}{H} < 0.7$, the spillway is submerged. Discharge coefficient in submerged mode in spillway model with scale 1:50, is smaller than the discharge coefficient of USBR. Since the lateral walls of spillway are convergent and these convergent walls are connected to a covered downstream channel. As a result this convergence is caused submergence of the spillway in high discharges. The spillway submergence occurs in discharge $\frac{Q}{Qd} > 1.13$, whereas the discharge coefficient decreases in this stage.

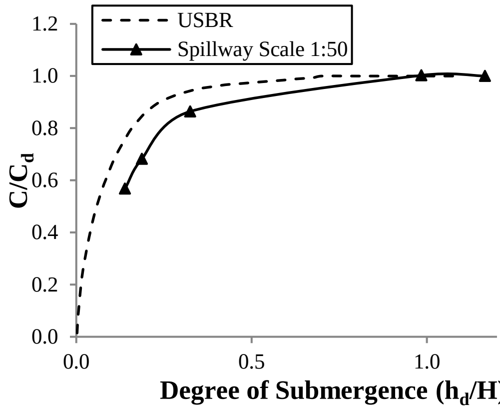

Fig. 8 A comparison of the ratio of discharge coefficients caused by tail water effects

4. Conclusion

This study was determined the discharge coefficient over ogee spillway with curvature in plan and convergent walls by using experimental method of ogee spillway of Garmi Chay dam in scale 1:50. The results showed that in discharges range $0.63 \leq \frac{Q}{Qd} \leq 1.13$, i.e. in the water level $0.75 \leq \frac{H}{H_d} \leq 1.08$, the increase of discharge coefficient and consequently the efficiency of spillway were observed and it has also an acceptable harmony with the diagram of USBR. But in discharges $1.13 \leq \frac{Q}{Qd} \leq 1.51$, i.e. in the water level $1.08 \leq \frac{H}{H_d} \leq 1.92$, due to the spillway submerge, the discharge coefficient ad as a result the efficiency of spillway decrease.

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