AN EXPERIMENTAL STUDY ON THE EFFECT OF VORTEX BREAKERS THICKNESS ON DISCHARGE EFFICIENCY FOR THE SHAFT SPILLWAYS

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ABSTRACT: *The shaft spillway is one of the spillways used in the dams. In the longitudinal profile of the weir, its crest is circular; the shaft is connected to one knee with an angle, and there is a water tunnel at the end transferring the water to the dam downstream. One of the problems of these spillways is the presence of vortex at the entrance and energy drop. In this study, some tests were conducted to investigate the influence of anti-vortex blades thickness on the efficiency of flow rate. The results showed that increased thickness of the blades causes a reduction in the spillway outlet discharge. Increased blades thickness from 3 to 5 mm reduces the efficiency of the flow rate up to 24%.*

Keywords: anti-vortex blade, discharge, shaft spillways, dam

INTRODUCTION

According to importance of these spillways in dikes which the possibility of showing other spillway is expensive and impossible, using strategies to increase discharge and discharge coefficient of shaft spillway is so important, and also making the best use of effective parameters can have more effect on increasing discharge and discharge coefficient of shaft spillways.Figure1 shows view of shaft spillway.

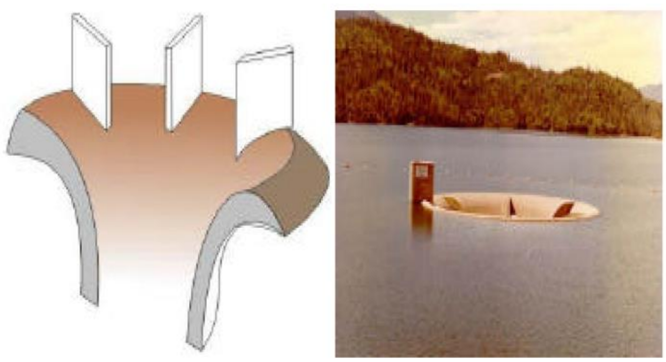


Figure 1: View of the spillway

Shaft spillways include various configurations of crest designs, with or without gates, all of which transition into a closed conduit (tunnel) system immediately downstream from the crest. The closed conduit system on a shaft spillway is in lieu of the open channel chute used on conventional spillways. All configurations of shaft spillways have many of the same disadvantages. A drop inlet spillway can be used advantageously at damsites in narrow canyons where the abutments rise steeply or where a diversion tunnel or conduit is available for use as the downstream leg. Another advantage of this type of spillway is that near maximum capacity is attained at relatively low heads; this characteristic makes the spillway ideal for use where the maximum spillway outflow is to be limited. This characteristic also may be considered disadvantageous, because there is little increase in capacity beyond the design head should a flood larger than the selected inflow design flood occur. However, this would not be a disadvantage if this type of spillway were used as a service spillway in conjunction with an auxiliary or emergency spillway. Discharge characteristics of a drop inlet spillway are shown on figure2. Once the layout of the spillway was defined, its condition of operation is strongly influenced for the surrounding area (topography, hillsides, dams, etc). Constructive and economical aspects usually determine the need of locating these spillways close to dams or hillsides. The distance (Ra) from the spillway to a hillside or dam has a strong influence on the approximation conditions of the flow and the discharge that will establish the beginning of the submergence. Even though the perfect location would be the one able to ensure a radial flow on the crest of the spillway, this is usually only possible in the upstream sector of the perimeter (in front of the reservoir). The flow on the remaining crest of the spillway is characterized for tangential components of the velocity, because of the interaction of two opposite currents. These currents are also responsible for a slight increase of the free surface and the presence of a jet whose trajectory moves away from the spillway profile [1]. Tang et al. predicted the large eddy simulation around groyne in straight paths, also sub grid scale model combining with Poison equation is used to analyze the secondary flow near the groyne and finite volume method was used to isolate the Navier-Stokes equations [2]. Through experimental investigation of the effect of the bend arc radius on shaft spillway flow hydraulic, Youssefvand *et al.* [3]) suggested that by increasing the radius of the bend R/d in shaft spillway, the coefficient of discharge increases, while by increasing depth of submergence, the coefficient of discharge is decreasing [3]. Nohani and Naghshineh, by experimental evaluation of the effect of the angle of the vortex breaker blades on the discharge coefficient of shaft spillway showed that the maximum impact of vortex breaker blade is 5 blades state and the angle 60 Degrees [4]. They also examined the position of the vortex breaker blades in different angles 30, 60 and 90 on the discharge coefficient and concluded that the vortex breaker blades at an angle of 60 degrees have the maximum impact and with an angle of 90 degrees have the minimum impact. Nohani an experimental evaluation on the shaft spillways with sharp and flat edge concluded that by placing the vortex breaker blades up to 20%, the discharge coefficient will be increased. Also the discharge coefficient in the shaft spillways with cutting edge is more than the flat edge [5]. Hosseini and Alemi have examined the hydraulic performance of shaft and ogee spillways using numerical modeling [6]. The results showed that although the comparison of flow parameters shows a desired and good agreement between the results, but the use of numerical models in real samples has limitations such as the number and dimensions of the network, computational time, climate precise modeling. Bagheri et al. have examined the effect of making the crest of the weir multifaceted on the shaft spillway discharge coefficient with 90 different tests on the spillway in the crest control mode by making a physical model of the shaft spillway [7]. Analysis of experimental data showed that making the crest of the weir multifaceted increases the passing discharge and increases discharge coefficient through the shaft spillway and the largest increase was obtained when the crest of the weir was made three-dimensional. emamgheis and Nohani, investigated the effect of sharp triangular vortex breaker blades with rectangular body on the efficiency of shaft spillway discharge [8]. They showed that the sharp vortex breaker with rectangular body has greater impact on the efficiency of spillway discharge than the triangular vortex breaker. Also, when the length of the vortex breakers is more, the impact of shape on increasing the spillway discharge will increase, so that it can be seen that a 10 percent increase in vortex breaker length for sharp vortex breaker with a rectangular body increases the efficiency of discharge in spillway by 15 percent. Creation of strong vortices in the entrance is among the main problems faced with these types of weirs. Using vortex breaker blades is an effective method to control the vortex, which is used in many dams to increase the flow rate and the discharge coefficient. Figure 3 shows the location of the creating vortex core and the parameters influencing the flow hydraulics at the shaft spillways.

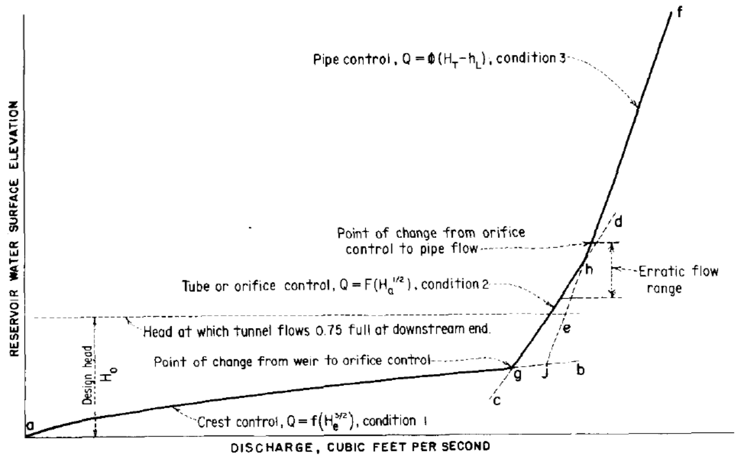


Figure 2: nature of flow and discharge characteristics of a shaft spillway

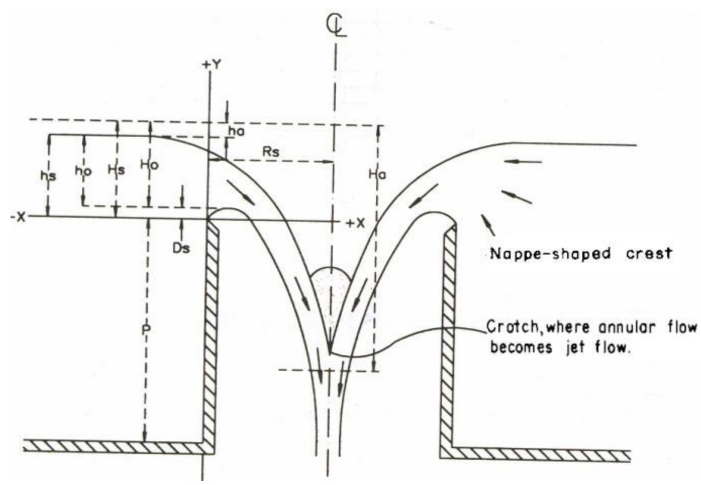


Figure 3: The vortex core and the parameters that influence the flow of hydraulic in shaft spillway

MATERIALS AND METHODS

Vortex formation in a squeeze tube is a fully 3D problem that should be considered along with simplifying assumptions of motion equations. In this study, the vortex which is created in the entry of shaft spillway is affected by the following parameters:

$$H = f(d, Q, \Gamma . \nu, \sigma, \rho, g) \qquad (1)$$

Where H is the upstream water elevation of spillway (deep submergence), d pipe diameter , Q discharge, Γ the vortex parameter, equal to $2\pi r V_\theta$, V_θ tangential velocity of the radial distance, r the distance from the axis of the shaft spillway, υ kinematic viscosity, σ surface tension, ρ density, g acceleration of gravity using the relationship given by Buckingham and assuming variables such as Q , d, ρ , as repeated variables, the equation is as following:

$$\frac{H}{d} = f_1(\frac{\Gamma d}{Q}, \frac{\nu d}{Q}, \frac{d^5 g}{Q^2}, \frac{\sigma d^3}{\rho Q^2}) \quad (2)$$

By replacing $Q = \left(\frac{\pi d^2}{4}\right)(V)$ that V is the average velocity of flow, in shaft spillway given:

$$\frac{H}{d} = f_2(\frac{\Gamma d}{Q}, \frac{\nu}{Vd}, \frac{dg}{V^2}, \frac{\sigma}{\rho V^2 d}) \quad (3)$$

In equation 5, value $\frac{\Gamma d}{Q}$ is equal to the rotation number (N_Γ). $\frac{\nu}{Vd}$ Is equal to the inverse Reynold`s number (R_e^{-1}), $\frac{\nu}{Vd}$ is equal to the inverse square of the Froud number (Fr^{-2}), $\frac{H}{d}$ is the submergence number, and $\frac{\sigma}{\rho V^2 d}$ is equal to inverse Weber number (W_e^{-1}). As a result, the following dimensionless parameters have an influence on vortex in shaft spillways:

$$\frac{H}{d} = f_2(N_\Gamma, R_e^{-1}, Fr^{-2}, W_e^{-1}) \quad (2)$$

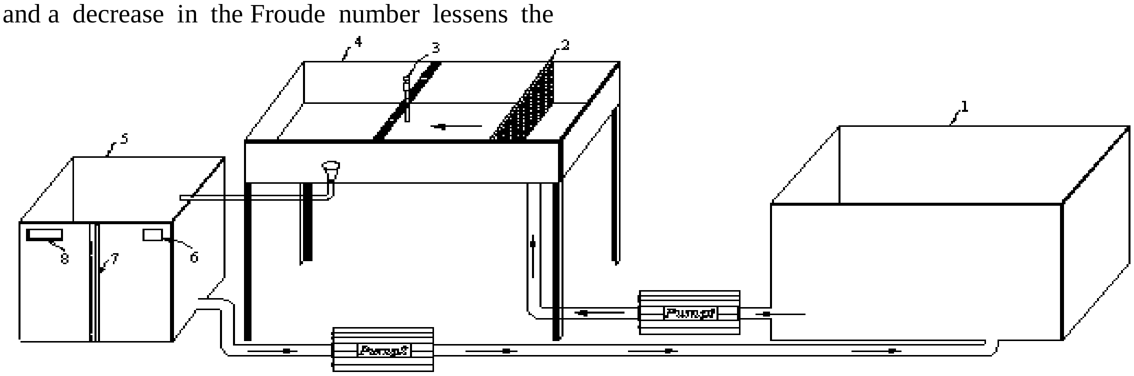
According to the conditions proposed by Dagget and Keulegan and Jain et al. the effect of Reynolds and Weber numbers on the vortex may be negligible. Given the following equation, the discharge coefficient of vertical intakes and the square root of submergence number are reversely related [9, 10].

$$C_d = \frac{4Q}{\pi d^2 \sqrt{2gH}} = \frac{4Q}{\pi d^{2.5} \sqrt{2g\frac{H}{d}}} \quad (5)$$

As mentioned above, the vortex in shaft spillways is affected by the following factors:

Structural geometry, flow parameters and fluid properties.

Zomorredian stated that an increase in the circulation number helps reduce spillway discharge coefficient in a shaft spillway, and a decrease in the Froude number lessens the impact of the circulation number on spillway discharge coefficient [11]. Therefore, the factors that reduce the tangential velocity of approach zone increase shaft spillway discharge coefficient. To study and achieve the objectives of the study, the physical model was made according to Figure (1) in the hydraulic laboratory of Water and Power Authority of Khuzestan and was tested. To supply the water required for the tests, a pond with a volume of 2000 liters with steel sheet with a thickness of 3 mm is used. Connecting the basin reservoir to the spillway reservoir is done by a field-tee on which two valves were used to adjust the inlet discharge. Conveyance of water from the basin to the spillway reservoir is done by a pump with a discharge coefficient 250-1000 liters per minute. After pumping from the basin reservoir, water is entered into the triangular spillway size 0.2 × 0.2 × 0.2 meters and the internal angle of 60 ° for the accurate measurement of the input discharge. The exact value of the bulk discharge is calculated using the scale in the reservoir of the triangular spillway and a graduated glass in the downstream end of the tunnel. To control the volatility and turbulence inside the reservoir, two buffer systems were used, a buffer is considered when the water enters the reservoir of the triangular spillway and the second one is considered as chamber. In this chamber, which is like a metal mesh screens, a series of straw was used to slow the flow that the water passes through the second buffer and entered the reservoir of the shaft spillway. The reservoir of the shaft spillway is sizes 1.2 × 1.1 × 1.2 meter which is completely enclosed from three sides and on the other hand, to observe the phenomenon inside the reservoir, a glass sheet with a thickness of 10 mm and a scale connected to reservoir glass was used to measure the height of the water on the shaft spillway. Shaft spillway in the reservoir according to Figure (4) is made of Teflon with a crest diameter of 35 cm, crest length of 1.1 m, guttural diameter 7 cm, bend diameter 10.16 cm, height 28.2 cm and diameter of downstream tunnel 7.62 cm do the reservoir discharge. At the end of the downstream tunnel, two gate valves were sued: one to enter the graduated glass for the calculation of discharge and the other to return the water to the basing reservoir.



1. Main reservoir 2. Baffle screen 3. Digital depth gage 4. Main flume 5. Time-volume reservoir 6. Pump switch 7. Piezometer 8. Screen

Figure 4: Outline of hydraulic physical model used in the laboratory

MATERIALS AND METHODS

Two sets of experiments were performed in the laboratory of Islamic Azad University, Dezful Branch, to evaluate the effect of thickness of the anti-vortex blades on the flow rate and flow rate coefficient of the spillway outlet flow. A4: Measurement of flow rate and the flow rate coefficient in condition of using six vortex breaker blades with a thickness of 3 mm and perpendicular to the spillway. A5: Measurement of flow rate and the flow rate coefficient in condition of using six vortex breaker blades with a thickness of 6 mm and perpendicular to the spillway. After each series of experiments, the output flow rate was measured by a triangular weir installed at the downstream outlet channel. Then, using Equation 5, the flow rate coefficient was calculated and the corresponding graphs were plotted. The results of the experiments are summarized in Tables 1 and 2. Figure 5 shows changes in the flow rate for the shaft spillways with 3 and 6 mm in thickness. As can be seen, with increasing water height, the flow rate of outlet flow becomes more than the overflow, and the flow rate is higher than the case in which 6 vortex breaker blades with a thickness of 6 mm were used. With increasing the flow depth, the distance between the lines increases, which indicates the reduced effect of blades thickness in greater depths. The use of thicker blades will reduce the efficiency of outlet feed rate up to 24%. Figure 6 shows the flow rate coefficient changes with increasing depth and thickness of the vortex breaker blades. As can be seen, with increased thickness of the vortex breaker blades, the flow rate coefficient would decrease up to 19. 2%. With increased thickness of the anti-vortex blades, the effective length of the spillway reduces (equal to the spillway length minus the thickness of each blade), and thus, the discharge and discharge coefficient of the shaft spillway would decrease.

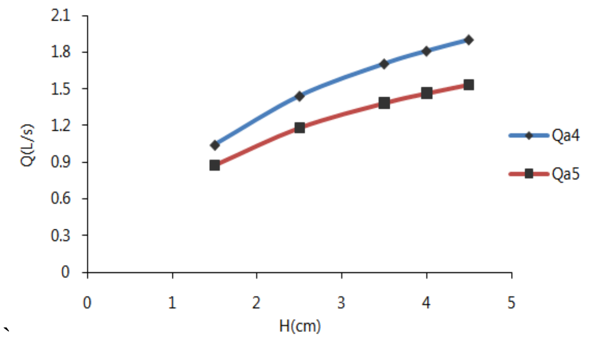
Table 1: the shaft spillway discharge results with 9.56cm diameter

H (Cm)	Q_{a4} (L/S)	Q_{a5} (L/S)
1.5	1.041	0.877
2.5	1.442	1.183
3.5	1.705	1.384
4	1.809	1.464
4.5	1.902	1.535

Table 2: Calculate the discharge coefficient of shaft spillway with 9.56cm diameter

H (Cm)	Cd_{a4}	Cd_{a5}
1.5	1.458	1.223
2.5	1.123	0.957
3.5	0.904	0.782
4	0.816	0.713
4.5	0.652	0.739

In the above tables, H is the water height in cm over the shaft spillway; Q is the passing flow rate through the spillway in liters per second; Cd is the flow rate coefficient, and "a" and "b" are indices related to the tests performed.



5: Variations flow rate with increasing the depth and thickness of the blade anti-vortex

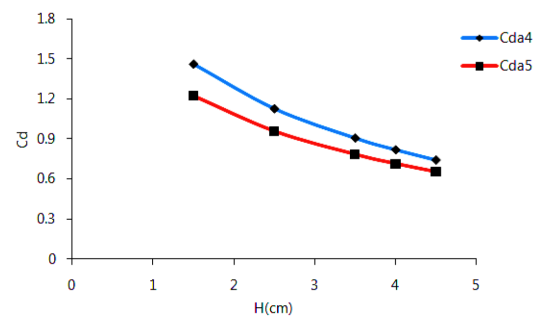


Figure 6: flow rate Coefficient Variations with increasing the depth and thickness of the blade anti-vortex flow

CONCLUSIONS

To investigate the thickness influence of the vortex breaker blades on the outlet flow rate efficiency of the shaft spillway, some tests were performed in this study. The results showed that by increasing the depth, the flow rate and flow rate coefficient will increase. Increased thickness of the vortex breaker blades causes a reduction of 24% in the flow rate and 19.2% reduction in the discharge coefficient. Increased thickness of the vortex breaker blades will cause reduced effective length of the shaft spillway, and thereby, reduced outlet discharge from the spillway.

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