Journal of Scientific Research and Development 2 (7): 291-295, 2015
Available online at www.jsrad.org
ISSN 1115-7569

Impact of anti-vortex blade position on discharge experimental study on the coefficient of morning glory spillway

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Abstract: Morning glory spillways are one of the spillways used to discharge the flow behind the dams. These spillways are usually used in areas with constraints of manufacturing other spillways. Using the vortex control structure on the crest of these weirs largely controls the flow turbulence and also stabilizes the flow. Given the importance of the issue, some experiments were performed in this study to investigate the effect of anti-vortex plates' placement on the spillway crest. The results showed that installing anti-vortex blades installed inside the crest of morning glory spillway compared to installation outside of the spillway crest would increase the flow rate as 15% and the discharge coefficient as 31%.

Key words: Crest; Discharge coefficient; Spillways; Dams

1. Introduction

Morning-Glory spillways are a particular case of spillway, being formed by a superior structure, a vertical bend and a tunnel that allows the discharge towards downstream (Fig. 1). These structures are commonly designed for operating at free surface, even for discharges higher than the design discharge Q_d being important to avoid the change of regime because of the loss of performance in the discharge capacity. However, it would be feasible that this kind of structures might spill discharges higher than Q_d due to hydrological changes (change in the run-off of the basin, global warming, etc.). In this sense, the characterization of the flow conditions and the determination of pressures acting upon the structure in the beginning of the submergence need to be considered, being this condition particularly meaningful due to the strong instabilities of the free surface. Consequently, the stated topics will be considered in this article.

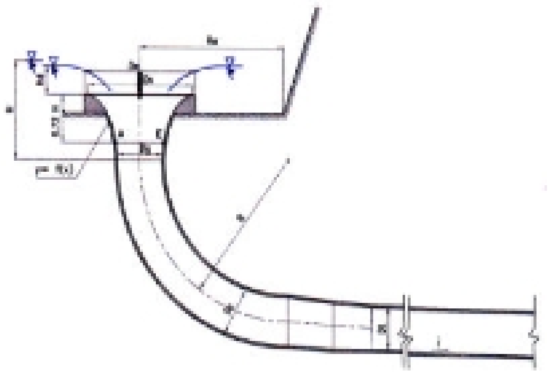

Fig. 1: Longitudinal section of a typical Morning-Glory spillway (Claudio and Bacchiega, 2003)

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For small heads, flow over the drop inlet spillway is governed by the characteristics of crest discharge. The vertical transition beyond the crest will flow partly full and the flow will cling to the sides of the shaft. As the discharge over the crest increases, the overflowing annular nappe will become thicker and, eventually, the nappe flow will converge into a solid vertical jet. The point where the annular nappe joins the solid jet is called the crotch. After the solid jet forms, a "boil" will occupy the region above the crotch; both the crotch and the top of the boil become progressively higher with large discharges. For high heads the crotch and boil may almost flood out, showing only a slight depression and eddy at the surface. Until the nappe converges to form a solid jet, free-discharging weir flow prevails. After the crotch and boil form, submergence begins to affect the weir flow and, ultimately, the crest will drown out. Flow is then governed either by the contracted jet formed by the overflow entrance, or by the shape and size of the vertical transition if it does not conform to the jet shape. Vortex action must be minimized to maintain converging flow into the drop inlet. Guide piers are often installed along the crest for this purpose (Bagheri and Nohani, 2014). Kamanbedast (2012) investigated of discharge coefficient for the morning glory spillway using artificial neural network. emamgheis and Nohani (2014), investigated the effect of sharp triangular vortex breaker blades with rectangular body on the efficiency of shaft spillway discharge. 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 present. Zomorredian et al. (2004) constructed physical models of vertical intakes, conducted experiments and concluded that the discharge number of the intake decreased with an increase in the circulation number and also that aerating the inlet of the intake had a negative effect on the discharge number of the intake. Nohani (2014) in 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. Considering the importance of this study is to investigate the effect of anti-vortex plate placement tests were performed on the spillway crest.

2. 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:

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

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:

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

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

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

In equation 5, value $\frac{\Gamma d}{Q}$ is equal to the rotation number (N_Γ). $\frac{\nu}{Vd}$ Is equal to the inverse Reynolds's number (R_e^{-1}), $\frac{dg}{V^2}$ is equal to the inverse square of the Froud number (F_r^{-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:

$$\frac{H}{d} = f_2(N_\Gamma, R_e^{-1}, f_r^{-2}, w_e^{-1}) \quad (4)$$

According to the conditions proposed by Dagget and Keulegan (1974) and Jain et al. (1978), 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.

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

As mentioned above, the vortex in shaft spillways is affected by the following factors: Structural geometry, flow parameters and fluid properties. Zomorredian (2004) 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. Therefore, the factors that reduce the tangential velocity of approach zone increase shaft spillway discharge coefficient. As such, the vortex breaker plates may be utilised as one of the main factors to reduce the tangential velocity and increase the efficiency of shaft spillways. For this reason, Hydraulic model will enable designers to predict the main structure behaviour and before constructing the structure by eliminating defects or taking into accounts measures for optimal use (Padulano et al., 2013). The physical model built, which was used in the laboratory for performing tests is according to Fig. 2, which includes a 2000 litters main reservoir that supplied water needed to perform the tests. The main flume that includes the infundibula part of morning glory spillway has a length of 250 cm, width of 90 cm and height of 40 cm and side walls of the flume was made of 8 mm glass and its floor was Plexiglas. Restraining the side walls and the flume floor against the pressure incurred was performed by angle iron. Transferring water from the main reservoir to the flume was done by 4 pumps. The discharge these pumps could transfer was 100-500 litters /minutes for the main pump, 240 litters per minute for two average pumps, 110 litters per minute for a small pump. The reason why 4 pumps were used was because for low discharges, pumps were used separately and for the high flow rate the pump combination was used. At a distance of 40 cm from the beginning of the flume, baffle screen was used to calm down the flow.

To measure the height of water, digital depth gage with accuracy of 0.01 mm was used on morning glory spillway crest. Volume method was used to measure the output discharge of the morning glory spillway (Fig. 3) so that the flow out of the morning glory spillway tunnel entered a 400 litter's reservoir, which a vertical piezometric tube was connected to the reservoir so that the water level in the piezometer was equal to the water level in the reservoir.

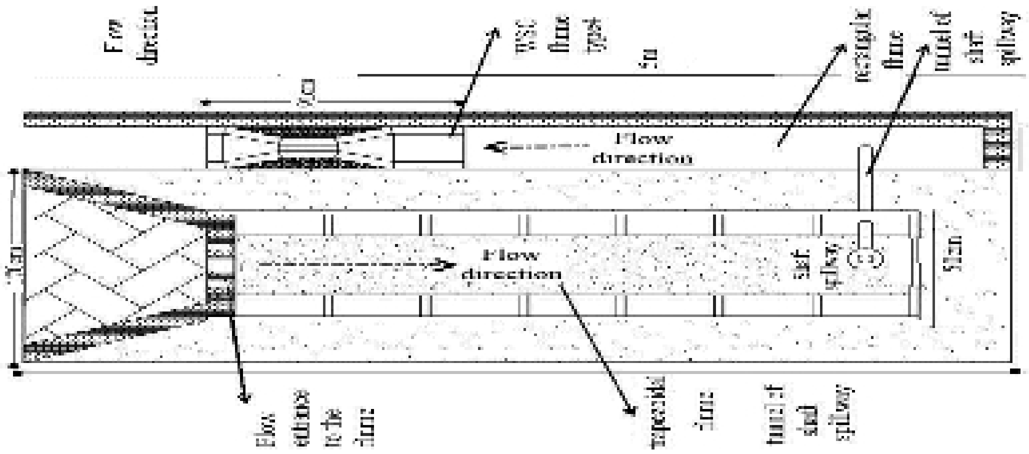

Fig. 2: Outline of hydraulic physical model used in the laboratory

In certain height intervals, some sensors were installed on the piezometer tube (6 points), the sensors were connected to a digital screen and the device recorded the time reached from one sensor to another, with determination of volume of the two sensors, discharge through the spillway was obtained by the division of volume to the time of the flow through the spillway. For increasing the accuracy, measurement was performed for 5 timeframe. To discharge the water of the reservoir to the main reservoir, a pump with a flow rate of 600 litters per minute and a single phase floor cache with a discharge of 11 litters per second were used.

Fig. 3: Instruments for measuring flow through the morning glory spillway as volumetric method

3. Results and discussion

To investigate and compare the effect of anti-vortex blades position on the morning glory weir discharge coefficient, two series of experiments were conducted in the laboratory, which are described below.

b6: Tests to measure the flow rate and flow rate coefficient in condition of using 6 vortex breaker blades 3 mm in thickness, in perpendicular position over the spillway

b7: Tests to measure the flow rate and flow rate coefficient in condition of using 6 vortex breaker blades 3 mm in thickness, in perpendicular position outside the spillway

According to Tables 1 and 2 and Figs. 4 and 5, it can be seen at the studied depths that in case of using equal numbers of vortex breaker blades, the impact of placing the blades inside the spillway would increase the flow rate and discharge coefficient much more than the case the blades are installed outside the spillway. The reason is due to the influence made by the placement position of the blades on the formation of flow lines. Thus, when the blades are installed outside of the weir crest and inlet, the vortex currents are mainly formed inside the area where the water enters the spillway nozzle, and the presence of blades outside the spillway would create no friction and collision blades against the eddy current. But, when the blades are inserted into the spillway, through breaking the flow lines overflowing circularly due to vortex, they make the direction of these lines straight and cause the passage of more current from in less time (increasing flow rate). Also, by reducing the drop due to eddy current, they increase the efficiency of the spillway (increasing the spillway flow rate coefficient).

Comparing the results from the experiments showed that installing anti-vortex blades installed inside the crest of morning glory spillway compared to installation outside of the spillway crest would increase the flow rate as 15% and the discharge coefficient as 31%.

Table 1: the morning glory spillway discharge results with 14.2cm diameter

H (Cm)	1.5	2.5	3.5	4	4.5
Q_{b6} (L/S)	1.359	1.802	2.095	2.210	2.313
Q_{b7} (L/S)	1.180	1.630	1.926	2.043	2.147

Table 2: Calculate the discharge coefficient of morning glory spillway with 14.2cm diameter

H (Cm)	1.5	2.5	3.5	4	4.5
Cd_{b6}	1.475	1.080	0.815	0.715	0.623
Cd_{b7}	1.126	0.863	0.689	0.621	0.560

In the above tables, H is the water height in cm over the morning glory spillway; Q is the passing flow rate through the spillway in litters per second; Cd is the flow rate coefficient, and "b" is the index related to the tests performed.

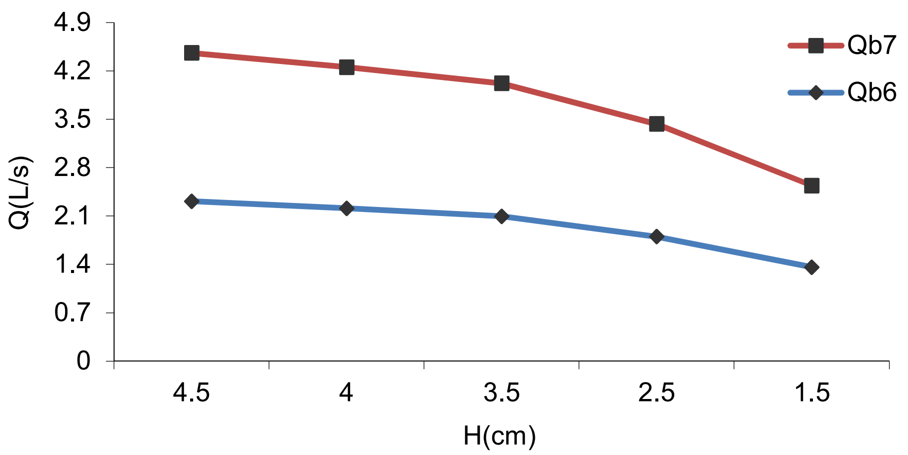

Fig.4: Variations the depth flow and discharge against position of blade anti-vortex

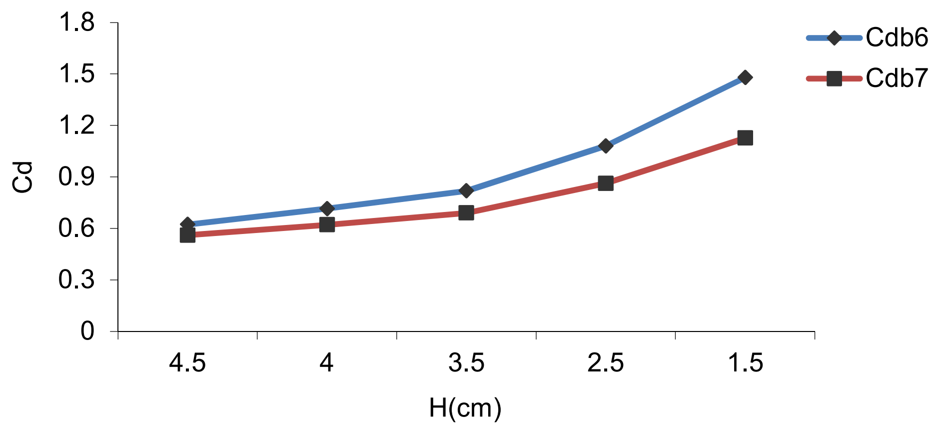

Fig.5: Variations the depth flow and discharge coefficient against position of blade anti-vortex

4. Conclusions

Some tests were performed in this study to investigate the effect of placement of anti-vortex blades on the morning glory spillway discharge coefficient. The results showed that the presence of blade can increase the efficiency of the outlet discharge of the spillway. Also, installing the vortex breaker blades in the inlet opening of the spillway crest has a greater impact on output flow rate efficiency. The results showed that installing anti-vortex blades installed inside the crest of morning glory spillway compared to installation outside of the spillway crest would increase the flow rate as 15% and the discharge coefficient as 31%.

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