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Experimental Study of Pyramid Vortex Breakers Effect on the Discharge Coefficient of Submerged Morning Glory Spillway

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ABSTRACT: Morning glory spillway is built upstream of the dam in the reservoir to convey water from the reservoir to the downstream. The main problem of the spillway is the swirling flow and vortex around the spillway's axis. By increasing the submergence height, the vortex will increase which leads to the reduction of flood conveyance efficiency due to a decrease in the discharge coefficient of the spillway. It is well known that the vortex breakers are the best for increasing the discharge coefficient of the morning glory spillway. In the present article, a physical model of morning glory spillway is designed and constructed to study the effect of the number and characteristics of pyramidal vortex breakers on the discharge coefficient of the spillway. 209 experiments have been conducted in the Hydraulic Laboratory of SRBIAU, Tehran. Applying non-linear regression analyses, empirical equations were obtained for estimating the discharge coefficient of morning glory spillway with pyramidal vortex breakers. Through comparison of results of the new equations and observed data, the determination coefficients of training and testing data for triangular and square pyramidal vortex breakers was calculated as 0.99 and 0.926, respectively. Also, sensitivity analysis is performed to investigate the efficient variables on the discharge coefficient of morning glory spillway with pyramidal vortex breakers. Findings show that pyramidal vortex breakers in a group of six increase the discharge coefficient significantly. The discharge coefficient performance due to pyramidal vortex breakers existence increases by 11.80% up to 16.13% compared to the non vortex breaker morning glory spillway.

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1. INTRODUCTION

Morning Glory Spillway (MGS) is one of the spillways that convey flood from the dam reservoir downstream. Vortices and spiral flows affect streamlines not to be formed toward the spillway shaft. As a result, the efficiency and discharge coefficient of the MGS will be decreased [1]. The normal practice for decreasing vortex forces and as a result increasing the discharge coefficient is installing the vortex breakers on the crest of MGS. Fattor and Bacchiega (2001) investigated at the early stages of submergence in the MGS and showed that this state is unstable and intense [2]. Tavana et al. (2011) undertook laboratory research to find out the effects of height and number of vortex breakers on the MGS discharge coefficient. It is concluded that the vortex breakers increase of the discharge coefficient [3]. Nohani and Jamali-Emamgheis (2015) studied the effect of vortex breakers with a group of six on the discharge coefficient of MGS through a laboratory model. It has been concluded that by increasing the length of the vortex breaker, the more influence on the efficiency of spillway discharge is observed [4]. Musavi-Jahromi et al. (2016) used a physical model of MGS to investigate the effect of inclined vortex breakers on the discharge coefficient. Findings showed that utilizing a group of six 45-degree vortex breakers is the most effective approach to increase the discharge coefficient significantly [5]. In the present article, a physical study of MGS was undertaken using square and triangular pyramidal vortex breakers in a group of three, four, and six to investigate their influences on the discharge coefficient of the submerged spillway. Studies conducted by hydraulic structure scholars in the field have not yet probed the effect of pyramidal vortex breakers on weakening vortexes in the MGS.

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2. METHODOLOGY

2.1. Dimensional Analysis

Buckingham Method was used for dimensional analysis, and the final equation of dimensional analysis is concluded to be as follows:

$$C_d = f\left(F_r^{-2}, \frac{H}{D}, \frac{h}{D}, \frac{b}{D}, \frac{t}{D}, R_e^{-1}, W_e^{-1}, n\right) \quad (1)$$

Where C_d is the discharge coefficient of MGS, F_r is the Froude Number, H is the water level over the crest of spillway,

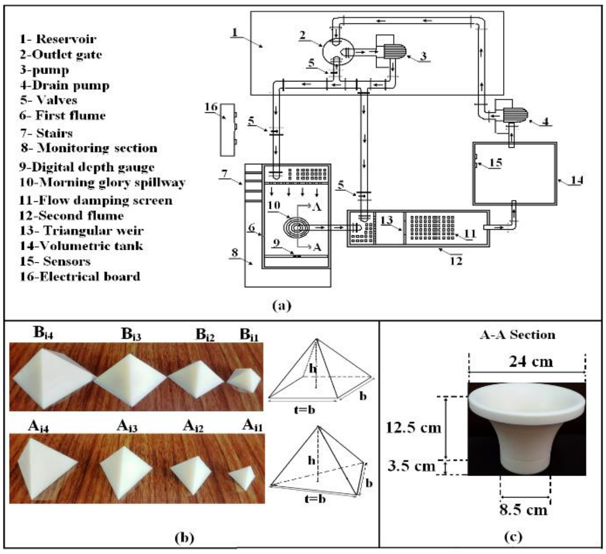

Fig. 1. Details of physical model set up (a) Plan view of model (b) Pyramidal vortex breakers (c) Funnel dimensions of the MGS

D is the diameter of the crest, h is the height of vortex breakers, t is the thickness of vortex breakers, b is the width of vortex breakers, n is the number of vortex breakers, R_e is the Reynolds Number, and W_e are the Weber Number. In the present study, the bases of the pyramids were considered equilateral triangle and square (b=t). Also, the Weber and Reynolds Numbers were large enough that neglected due to their little effect on the vortex [6-8].

2.2. EXPERIMENTAL SETUP

A physical model of MGS as Figure 1a was stabilized in the Hydraulic Laboratory of SRBIAU, Tehran. Physical model setup including a reservoir, first flume, second flume, volumetric tank, MGS, triangular weir, pumps, valves, water transfer equipments, bypass, gauging equipments and vortex breakers. The flow discharge range was between 5.5 l/s up to 7.6 l/s. Water circulation of the laboratory setup was undertaken using two pumps. Flow discharge was measured frequently and as a result, the triangular weir through volumetric discharge tank was calibrated. However, at the same time, the discharge from the model of MGS was measured by triangular weir at the second flume. In the present study, pyramidal vortex breakers with triangular (A_{ij}) and square (B_{ij}) bases were tested in the vertical state on the crest of MGS and groups of three (i=3), four (i=4) and six (i=6) in different sizes (j=1,2,3,4) for various discharges. Dimensions of vortex breakers are represented in Figure 1b and Table 1. Moreover, details of the funnel dimension of the MGS demonstrate in Figure 1c. The final part of the MGS is the outlet tunnel which its diameter is as same as transition diameter.

3. RESULTS AND DISCUSSION

In this research, to find the optimum number and size of the pyramidal vortex breakers, the discharge coefficient performance (% P) are represented according to Equation 2 and Figure 2:

Table 1. Gaeometric parameters of pyramids

A_{i4},B_{i4}	A_{i3},B_{i3}	A_{i2},B_{i2}	A_{i1},B_{i1}	
0.170	0.136	0.102	0.068	h/D
0.208	0.167	0.125	0.083	b/D

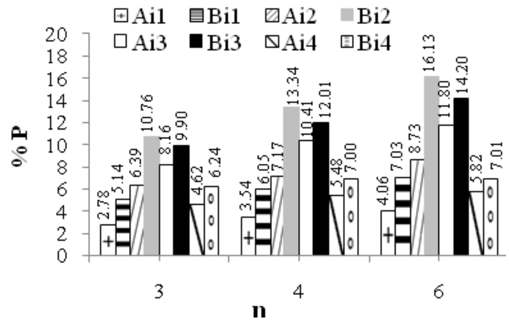

Fig. 2. Variation of discharge coefficient performance versus the number of pyramidal votex breakers

$$\% P = \frac{1}{n}\sum \frac{C_{d(i,j)} - C_{d(M)}}{C_{d(M)}} \times 100 \quad (2)$$

Where $C_{d(M)}$ is the discharge coefficient of non-vortex breaker MGS, $C_{d(i,j)}$ is the discharge coefficient of MGS with pyramidal vortex breakers, and n is the number of test for equal depths.

According to Figure 2, the discharge coefficient performance due to pyramidal vortex breakers existence in a group of six increases by 11.80% up to 16.13% compared to the non-vortex breaker MGS. Applying nonlinear regression analyses using SPSS mathematical software, empirical equations were obtained for estimating the discharge coefficient of MGS with pyramidal vortex breakers. Accordingly, the Equations 3 and 4 are in orifice control for triangular and square, respectively as follows:

$$C_d = 0.721\times(\exp(\frac{H}{D}))^{-2.646} + 45.82\frac{b}{D} - 56.064\frac{h}{D} + 0.013(n)^{0.54} + 1.304(F_r)^{-1.138} - 0.279 \quad (3)$$

$$C_d = 0.556\times(\exp(\frac{H}{D}))^{-2.528} + 53.01\frac{b}{D} - 65\frac{h}{D} + 0.032(n)^{0.417} + 1.024(F_r)^{-0.729} - 0.26 \quad (4)$$

Subject to the present test limitations of 0.083≤ b/D≤0.208, 0.068≤ h/D≤0.17 and 0.115≤ H/D≤0.621. Through comparison of results of the new equations and observed data, the determination coefficients of training and testing data for triangular and square pyramidal vortex breakers was calculated as 0.99 and 0.926, respectively. Besides, by removing each dimensionless parameter from equations 3 and 4, sensitivity analysis was performed using SPSS mathematical software. Sensitivity analysis of equation 3 showed that it is sensitive to H/D, b/D, h/D, n and F_r, respectively. Besides, Equation 4 is sensitive to n, b/D, h/D, H/D and F_r, respectively.

4. CONCLUSIONS

Findings showed that pyramidal vortex breakers in a group of six cause the discharge coefficient of MGS to be increased, significantly.

5. ACKNOWLEDGMENT

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