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Discharge Coefficient in the Morning Glory Spillways due to Longitudinal Angles of Vortex Breakers

Seyed Habib Musavi-Jahromi*[1], Golshan Hajipour[2] and Maryam Eghdam[3]
[1]Department-Water Engineering, IAU, Shahr-e-Qods Branch, Tehran, Iran
*Corresponding Author: h-mousavi@srbiau.ac.ir
[2]Hydraulic Structures, ShahidChamran University of Ahwaz, Iran
Golshanyog@gmail.com
[3]Young Researchers and Elites club, Science and Research Branch, Islamic Azad University, Tehran, Iran
Eghdam.m@gmail.com

ABSTRACT

The main problem that usually occurs in the morning glory spillways is vortexes and circulation flow. In the submergence condition this problem will increase. In circulation flow, flow path is longer than straight flow and this cause an increasingly energy loss of water. This energy loss reduces spillway discharge coefficient. The principal reason of occurring efficiency decrement in this type of spillways is discharge coefficient reduction. In this research 170 experiments are conducted using different numbers and the angle of vortex breakers which are established on the physical model of this spillway in KWP in order to determine their effect on the increment of its discharge coefficient rate. The results of the tests and comparisons showed that establishing six vortex breakers with the angle of 45° on the spillway is the most efficient arrangement for this aspect, due to its most beneficial percentage change in discharge coefficient. Also, according to the conducted research an experimental formula is obtained based on the angle and the number of the vortex breakers and also the submerging ratio. This formula has a sufficient accuracy due to the maximum deal of RMSE that is just about 0.13.

Keywords: *Morning glory spillway, Vortex, vortex breaker, Discharge coefficient*

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INTRODUCTION

One of the most significant water conveyance structures which act as an emergency we iris the Morning Glory spillway. This kind of spillway is very effective when there is a time limit for construction of other spillways. This spillway in dam is responsible to drain the excess water at the time of the flood and prevents water spillway of dam crest and precludes dam destruction (especially when the dam is embankment) [1]. This spillway has three main parts: Cup-shape inlet funnel, vertical shaft, and horizontal diversion shaft (In some cases, a basin is constructed at the end of horizontal tunnel). One of the most important problems of this spillway is strong helical vortexes at the mouth of it that causes loss of efficiency in the system of reservoirs discharge. In the submergence condition vortexes and circulation flow problem will increase. In circulation flow, flow path is longer than straight flow and this causes increasing loss of water energy, and energy loss leads to reduce spillway discharge coefficient. Thus, discharge coefficient of this type of spillways is less than other spillways which act freely. Zomorredian, *et al*. [2] 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. Using strategies to increase in discharge and discharge coefficient of morning glory spillway is so important, and also making the best use of effective parameters can have more effect on increasing discharge and discharge coefficient of morning glory type's spillways [3]. Due to the critical role of inlet shape of morning-glory spillways on discharge capability, many inlet shapes have been studied extensively by dam designers [4,5]. One of the most effective procedure for controlling the vortex, reducing its power and decreasing the length of the streamlines is the usage of blades of vortex breakers is an effective method to increase the discharge coefficient of Morning glory spillway [6]. Anti-vortex blades reduce vortexes and circulation by flow path correction [7]. Christodoulou, et al., [8] have studied the effect of piers on the discharge capacity of a morning glory spillway. They concluded that placement of piers on the crest is an efficient way of coping with the negative effects of the vortex. The significance of piers is evident mainly for high discharges, as they can limit the stage increase to about half the value observed without piers, and also suppress water level oscillations. Kamanbedast [3] investigated of discharge coefficient for the morning glory spillway using artificial neural network. Nohani [6] investigated the effect of vortex breakers on discharge coefficient for the shaft spillways with sharp edge and wide edge with the physical model. He showed that a 20% increase in spillway discharge coefficient was experienced via using blade-vortex breaker and the increase in spillway discharge coefficient with sharp edge was more than a wide-edged. Ellesty *et al* [9] during constructing physical model of morning glory spillway and installing blade of vortex breakers concluded that the greater the length of the blade of vortex breaker, the more effective on control of the vortex. This will lead to increase of the discharge coefficient, as well the thickness of the blade of vortex greater, the discharge coefficient is lower. They found that by increasing the number of baled of vortex breaker, the optimum results are not acquired. Bagheri *et al* [10] investigated the effect of polyhedral spillway crests on the discharge intensity of the flow passing through the spillways and on the discharge coefficient of morning glory spillways, by constructing physical hydraulic models of morning glory spillways and through carrying out 180 different experiments on these spillways. They concluded that using polyhedral spillway crests caused an increase in discharge passing through the morning glory spillway and also increased the discharge coefficient of the spillway. The greatest increase was obtained when trihedral spillway crests were used. And also they found in their experiments that a seven-sided spillway crest has less impact in increase of discharge coefficient proportion to three-dimensional. According to the mentioned investigations, in the Morning glory spillways, the vortex flow can reduce discharge, discharge coefficient and the performance of spillway. Vortex-breaker is one of the effective methods to control vortex which is used in many dams in order to increase the discharge and discharge coefficient. It is worth mentioning that based on the experiments were have been done until now, putting over six blades of a vortex breaker on the spillway crest does not seem logical. Therefore, in this study considering the effect of different angled vortex breakers on the discharge coefficient of morning glory spillway based on 3 to 6 numbers of them is carried out.

MATERIALS AND METHODS

Physical Model of Morning-Glory Spillway

In this study, for determining the discharge coefficient of morning glory spillway, a physical model in the laboratory Khuzestan province Water and Power department (KWP) is used. The physical model constructed to be used in experiments carried out in the laboratory is shown in Figure (1). Model consists of several major parts. The highest part of this model is the reservoir of dam with dimensions of 1.06*0.88*1 cubic meter that three sides of it are enclosed by steel plate and on the other side of it shows a glass side to view the events occurred in the reservoir. Morning glory spill way crest radius is 17.5 cm, the radius bottleneck is 3.5cmand a height is 28.4cm which its material is Teflon and located inside the reservoir. To convey water inside the reservoir by a pump, water is pumped from a 2000 litters reservoir and after passing through atube90 degrees and regulated by the 2 taps, water enters into a small channel behind the triangular spillway with dimensions of0.2*0.2*0.2 cubicmeterwithangleof60 degrees. The water flow after passing through the triangular spill way, enter into the compartment that is constructed by two bumpers. Then water enter into the reservoir of spill way and after passing through the morning glory spillway and right angle neck and downstream tunnel with a diameter of7.62 cm, enter into the tank and operations will continue to do so.

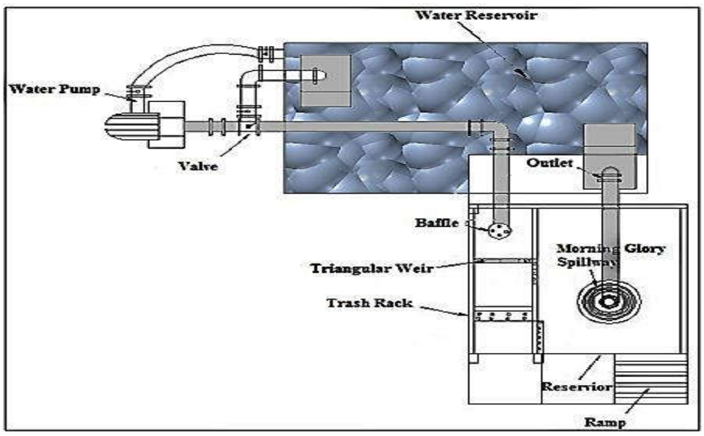

Figure 1: Plan of Physical Model

Initially to calibrate the triangular spill way from a glass tank with the dimensions specified located under the output of morning glory spillway, discharge of water was measured volumetrically, i.e. by 2 taps in the end of the output and a chronometer, water discharge were taken at 13 different heights on triangular spill way and each time five times. After calibration test, control experiments were performed at 10 different flow rates. Due to the heights of the water in the morning glory spillway, dimensions of3.5*2*3 cubic meter were provided for vortex and they are constructed with the same dimensions and Teflon material. In the first case the vortex breakers have been vertical (top face of the vortex breaker makes a zero angle with the horizon), the second case of the top face of the vortex breaker makes an angle of 15 degrees horizon and in the third case, the top face of the vortex breaker makes an angle of 30 degrees with horizon and finally, in the fourth case, the top face of the vortex breaker makes an angle of 45degreeswiththe horizon. (Figure 2).

Figure 2: The used vortex breakers with the angles of 15°, 30°, 45°, 90°

To investigate and compare the effect of angels and numbers of vortex breakers on the morning glory weir discharge coefficient, 170 experiments are conducted in the laboratory. On the account of the accurate investigation, each of the vortex breakers was located on the spillway crest with four different arrangements. In the first arrangement, three vortex breakers were located on spillway crest, in second arrangement, in third arrangement and in fourth arrangement, four vortex breakers, five vortex breakers and six vortex breakers were located on spillway crest respectively. All the arrangements were evaluated with different angels of vortex breakers. The specifications of each experiment are listed in Table (1).

Table 1: Specifications of tests

Name of the experiment	Number of vortex breaker blades	Angle of vortex breaker blades with horizon	Number of experiments
S	-	-	10
A1	3	0	10
A2	3	15	10
A3	3	30	10
A4	3	45	10
B1	4	0	10
B2	4	15	10
B3	4	30	10
B4	4	45	10
C1	5	0	10
C2	5	15	10
C3	5	30	10
C4	5	45	10
D1	6	0	10
D2	6	15	10
D3	6	30	10
D4	6	45	10

Dimensional Analysis

The discharge in morning glory spillways is expressed as follow:

$$Q = C_0 L_0 H_0^{3/2} \quad (1)$$

$$Q = C_0 \left(2\pi R_S\right) H_0^{3/2} \quad (2)$$

Where Q is the passing discharge through the spillway, C_0 is Discharge coefficient of the spillway, L_0 the length of the spillway(excluding the vortex breakers)in circular Spillways L_0 (Crest length) is perimeter of circular inlet at the beginning of the ogee curve. Crest length is $\left(2\pi R_S\right)$. H_0 is the water level over the spillway and R_S is the crest radius of it which is a function of H_0 and R_S .[11].

According to the formulas above, the parameters used in this experiment were analyzed using Buckingham theory, are as follows:

$$f\left(\rho,\sigma,v,g,V,H,D,C_d,h,\theta,t,n,b\right)=0 \quad (3)$$

Where ρ is the density, σ is surface tension, v is kinematic viscosity, g is gravity, V is fluid fast, H is depth of water over the spillway, D is diameter overflow, C_d is discharge coefficient of spillway, h is height of the vortex breaker, θ is angle of vortex breakers, t is thickness of the vortex breakers, b is the width of vortex breaker, n is the number of vortex breakers. By making dimensionless relations the mentioned parameters are written as below:

$$f\left(\frac{\sigma}{\rho DV^2},\frac{v}{VD},\frac{gD}{V^2},\frac{H}{D},\frac{t}{D},\frac{h}{D},\frac{b}{D},n,\theta\right)=0 \quad (4)$$

Where $\frac{\sigma}{\rho DV^2}$ is Weber number $\left(W_e\right)$, $\frac{v}{VD}$ is Reynols number $\left(R_e\right)$ and $\frac{gD}{V^2}$ is diverse of the Froud number $\left(F_r\right)$ .Since the dimension of the vortex breaker and diameter of morning glory spillway is fixed, so $\frac{t}{D},\frac{h}{D},\frac{b}{D}$ can be ignored. Also the researchers do not use the Reynolds and Froud numbers due to their less importance [12, 13]. Thus, the main used parameters are represented below:

$$C_d=\left(n,\theta,\frac{H}{D},W_e\right) \quad (5)$$

Considering the marked level of water on the spillway's crest and ineffectiveness of $\left(W_e\right)$, the Weber number is ignored. Therefore, the other three parameters are used for analyzing and conducting this investigation.

RESULTS AND DISCUSSION

The results of the analysis of experimental data are represented in Figures (diagrams) and tables. In view of the measurements and data from the experiments, discharge graphs based on H_0, for all categories were drawn according to the Figure (3). Charts of this Figure clearly illustrate that there is a dramatic increment in the discharge at the first levels of each examination where the vortex formation and strong waves from this phenomenon occurred. Eventually, the vortex reaches to a relative balance as it is clear at the end of the graphs. (Figure3). In addition, using the experimental data obtained from 170 experiments the discharge coefficient was calculated at every turn by Formula (2). The percentage of incremental change in coefficient discharge because of installing vortex breakers on the spillways according to the each arrangement of Table (1) comparing to the status which there was no vortex breaker established on the spillway is represented in diagrams of Figure (4).Comparing the results from the experiments showed that by putting the vortex breakers on the crest of the spillway, discharge coefficient increases, as well by increasing the angle of vortex to horizon up to 45 degrees and raising the number of vortex breakers, a greater discharge coefficient is occurring. Generally, the upward trend is occurred by raising the angels up to 45 degrees but as it can be seen when the angel of anti-vortex blades are increased by 180 degrees the efficiency of the spillway decreases. Hence, increasing the angels of vortex breakers more than 45 degrees might not be logically effective. The reason that in cases where the anti-vortex blades are installed on the crest, the morning glory spillway discharge coefficient is greater than the simple circular shape is that the vortex breakers decrease the vortex and water spin and flow lines enter the spillway more regular and the flow through the morning glory spillway increases. As it has been mentioned previously when the vortex breakers with the degree of 45 are installed on the spillway crest, the incremental rate of discharge coefficient is higher than the other angels of anti-vortex blades. Therefore, the percentage of incremental change in coefficient discharge of each arrangement of vortex breakers with angle of 45° is higher than all the other arrangements. Additionally, for these kinds of vortex breakers as the Figure (5) shows when the number of them increases, the more efficiency is obtained. Finally, the maximum discharge coefficient was observed when there are six 45° anti-blades on the spillway crest. The increase of observed discharge coefficient in a constant flow rate compared with the baseline in the fixed discharge of 0.0041 m^3/s using three vortex breakers of 45° showed 450.8%

increase in the discharge coefficient. Four vortex breaker of 45°, caused 480.2% increase in the discharge coefficient, five vortex breakers of 45°, caused 491.9% increase and six vortex breaker of 45° caused 545.7% increase of discharge coefficient. (Figure 5).

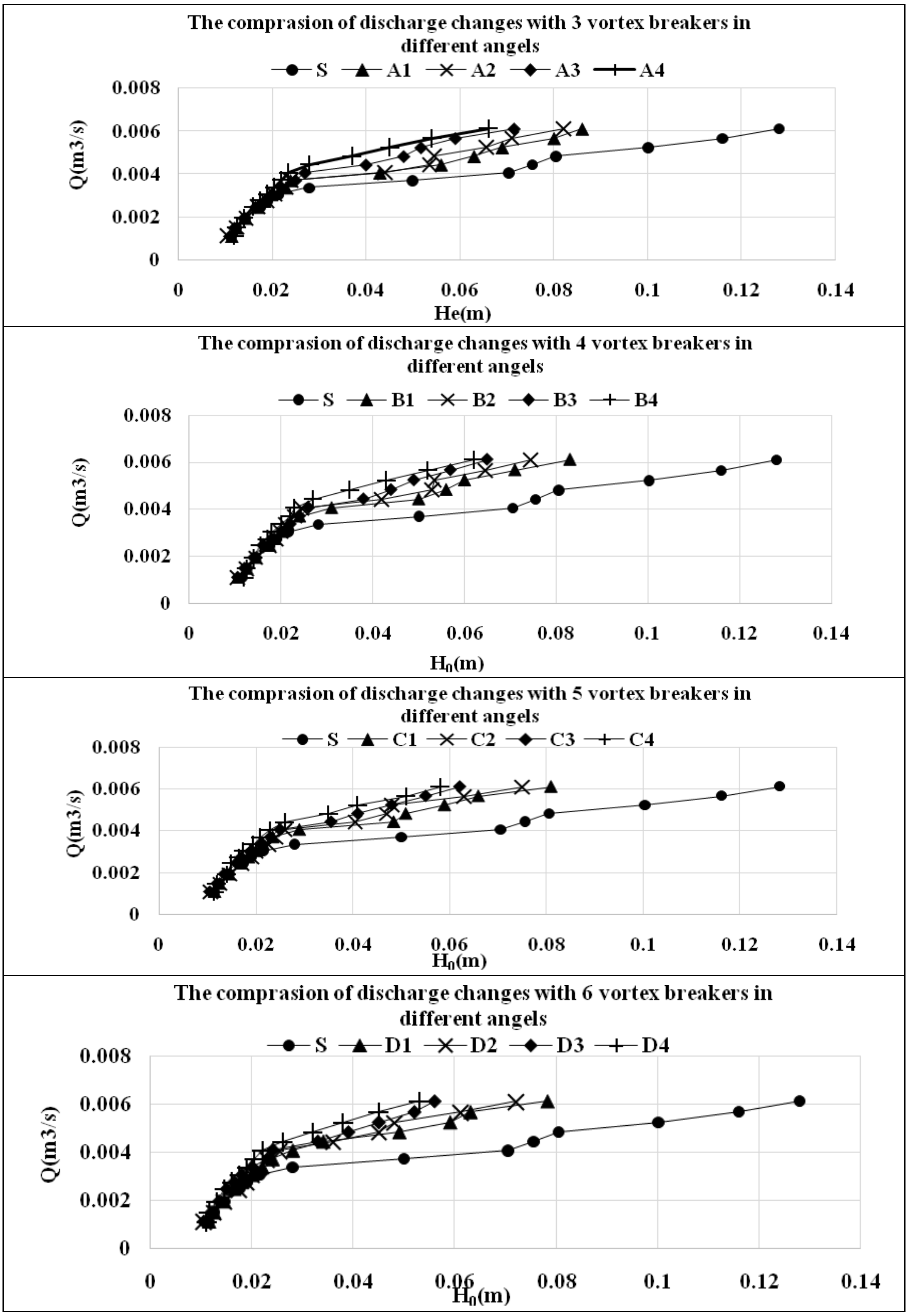

Figure 3: The comprasion of discharge changes in different experiments

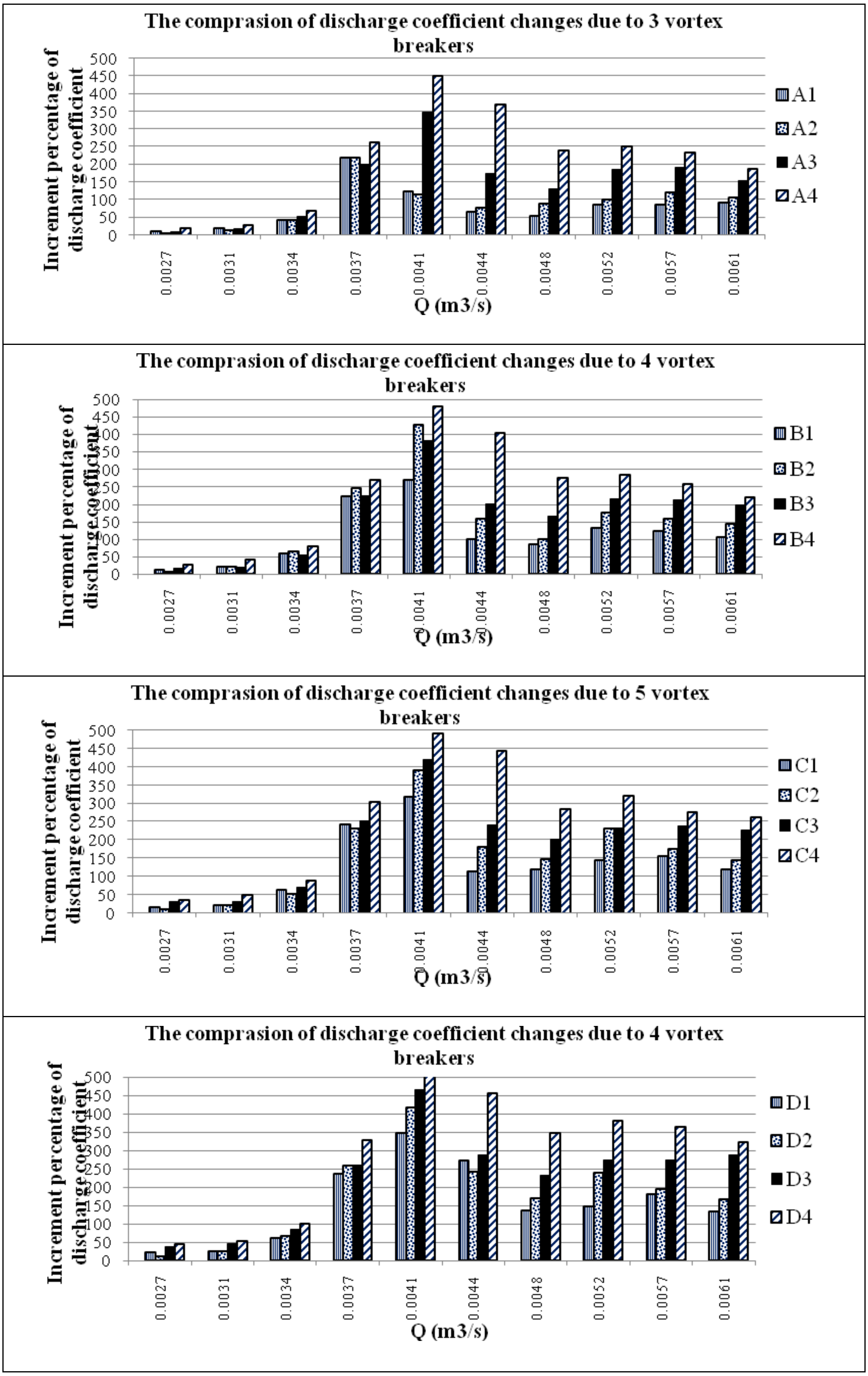

figure 4: the comprasion of discharge coefficient changes in different experiments

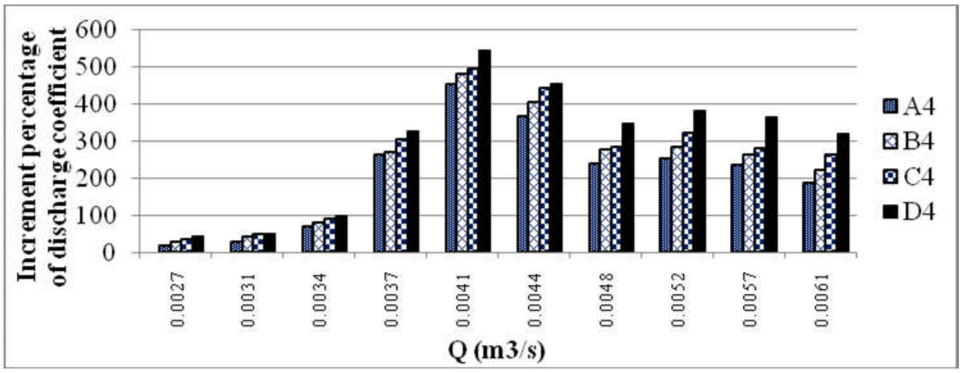

Figure 5: the comprasion of discharge coefficient changes due to different number of 45° vortex breakers

Additionally, according to the conducted research and compared results of each experiment, an experimental formula for calculating the discharge coefficient of a morning glory spillway based on the angle and the number of the vortex breakers and also the submerging ratio is estimated through spss which is represented below:

$$C_d = 2.63 \times (\exp(\frac{H}{D}))^{-2.93} + (-1.21) \times (n \times \theta)^{-0.02} \qquad (6)$$

where θ is the angel that vortex breakers make with the horizon in radian. This angle should be assumed as π for vertical vortex breaker that makes a zero angle with the horizon. The other parameters are described previously, for evaluating the experimental formula the r^2 (regression) of coefficient discharges from equation (6) for each experiment are estimated as it is represented in table (2). the table shows the minimum deal of r^2about 0.97 which is by far high regression. Furthermore, the RMSE (root mean square error) of the results of equation (6) are compared to the coefficient discharges based on equation (2) (table 2). The table illustrates the maximum deal of rmse just about 0.13 which shows the considerable accuracy of the experimental formula. Thus, the experimental obtained formula can be trustable in order to estimate the coefficient discharge of the morning glory spillways which have installed vortex breakers on their crests.

Table 2-the rmse & r^2 deals according to the comparison of obtained C_d from equations (2) & (6)

NAME OF THE EXPERIMENT	RMSE	R2	NAME OF THE EXPERIMENT	RMSE	R2
A1	0.11	0.97	C1	0.09	0.97
A2	0.09	0.97	C2	0.06	0.97
A3	0.06	0.98	C3	0.09	0.98
A4	0.07	0.98	C4	0.13	0.99
B1	0.09	0.97	D1	0.07	0.98
B2	0.08	0.97	D2	0.07	0.97
B3	0.06	0.98	D3	0.12	0.98
B4	0.10	0.99	D4	0.13	0.99

CONCLUSIONS

Conclusions that can be drawn from this research through investigating and analyzing the above tables and figures, are that using45^{0}vortex breakers in all arrangements have higher efficiency than the other angels of vortex breakers which were used in this investigation. Also, the highest efficiency with 45^{0}vortex breakers is obtained by six numbers of them. as it was mentioned before putting over six blades of a vortex breaker on the spillway crest does not seem logical base on pervious researches. in addition, it is obvious that raising the angle of vortex breakers from 15° to 45° degree is increasing the increment percentage of discharge coefficient and end up in higher efficiency. However, the higher angle of 90° does not increase the efficiency a lot. Thus, the higher angle of 45 degrees did not consider in this

study, but further studied can be conducted in the future. it is worth mentioning that the obtained experimental formula based on the angle and the number of the vortex breakers and also the submerging ratio can be used for similar investigations because of the sufficient accuracy due to the maximum deal of rmse that is about just 0.13.
generally, according to the above conclusions, for preferable hydraulic conditions, ease of construction and reduced cost and time of projects performing compared with simple circular morning glory spillways; installing anti-vortex blades on the spillway inlet and using different modes of number and angle of guide blades can be introduced for morning glory spillways as a proposed option for the replacement of circular inlet to further investigate. for final construction recommendations, more research and testing are needed.

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