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Research Article

NUMERICAL STUDY OF THE EFFECT OF ANTI-VORTEX PLATES ON THE INFLOW PATTERN IN SHAFT SPILLWAYS

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ABSTRACT
Shaft spillway is one of the structures used in dams. This spillway is constructed where it is not possible to build other spillways. The occurrence of vortex is possible in these spillways. One of the effective methods of controlling the vortex is using the vortex breaker blades, which are used in many dams to increase the discharge rate and coefficient. Using the control structure greatly controls the flow turbulence vortex and also stabilizes the flow. In this study, eddy currents in shaft spillways are examined using Flow-3D in the experimental model. The discharge coefficient in shaft spillway with 3 vortex breaker blades, 6 vortex breaker blades and 12 vortex breaker blades were studied. Then, using tables and graphs, the results were specified. The results showed that in vortex breaker structure with dimensions 5 × 8 × 10, the existence of vortex breaker has a large effect in increasing the discharge in constant water height than control and by increasing the number of vortex breakers, the passing discharge increases. Also, by increasing the height of the water on spillway, discharge rate increases and the highest occurs at high water level on spillway.

Keywords: *Shaft Spillway, Eddy Current, Vortex Breaker Blade, Flow-3d Model*

INTRODUCTION
Shaft spillway is a separate spillway that can be replaced by the side-channel spillway. The spillway is formed by a circular opening, a vertical circular adaptor and a tunnel under horizontal (or nearly horizontal) pressure that ultimately transfers the water from the reservoir to the downstream. In other words, the shaft spillway is formed from a circular crown which directs the flow into an inclined or vertical axis. The axis is connected to a low gradient tunnel. Issues of vortex in many structures are caused by entering the air into the structure and basins. This is caused at the entry of structure and when converting the flow condition from free mode to confined flow.
In shaft spillways, presence of vortex can reduce spillway performance and performance reduction may cause irreparable damages. Also it is effective in pumps, (oil, and water) reservoirs and all basins where such flows can be created. But how to influence different structures and equipment may be different. For example, air entry into the pumping system has entirely a negative impact, but incoming air into the shaft spillway channel may also be useful. Considerable researches have been done on the shaft spillways and flow patterns on them in Iran and around the world. Here, some research background in Iran and the world are mentioned. Fattor and Becchiega (2003) concluded that in shaft spillways, if the spillway is submerged, the discharge value 1.34 is equal to flow rate in the free form (design) and in the case of non-aeration to the water tunnel to spillway, we have eddy. Tang *et al.,* (2006) 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. Through experimental investigation of the effect of the bend arc radius on shaft spillway flow hydraulic, Youssefvand *et al.,* (2011) 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. Nohani and Naghshineh (2013), 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. 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 (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. Hosseini and Alemi (2010) have examined the hydraulic performance of shaft and ogee spillways using numerical modeling. 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.*, (2012) 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. 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. Mohammad *et al.*, (2012) have examined the flow pattern at the water inlet of Gotvand control-diversion dam. The results showed that by increasing the input discharge to the dam reservoir compared to control, the speed was increased in all areas around the span and along the catchment area that increases the erosion and reduces sediments.

MATERIALS AND METHODS

This study attempted to measure the flow hydraulic in shaft spillway. The main outlines of the materials and methods used in this research to achieve its objectives are as follows:

1. Specifications of physical model and the experimental results.
2. Three-dimensional numerical simulation steps by the mathematical model Flow3D.

Here, a channel with a length of 4 m and a width of 75 cm was used. Channel width is variable and it ranges from a width of 20 cm to 75 cm. the invert is made of steel sheet with a thickness of 1.5 mm and it is placed on two iron tables, each with a height of 95 cm, a width of 76 and a length of 2 m. feeding reservoir of the channel is on the table.

Approximately 20 cm from the reservoir entry to the channel, a number of perforated plates are placed to slow down the flow, which have a great effect in slowing the.

It is embedded at a distance of 75 cm to the end of shaft spillway channel.

Of course, at this point the channel width is 75 cm. Channel wall is made of glass and its height is 30 cm.

First Spillway Profile

The spillway body is made of copper. Tunnel is made of glass with a length of 51 cm and an internal diameter of 6 cm and a crest diameter of 9.56 inches.

The scale is 59.31 times smaller than the original sample. Its bend-shape part is made of two 45 degrees PVC pipe bends and of course some of the bend are cut.

The joints distance is sealed to make the inner surface as smooth as possible.

The spillway tunnel is located higher than the invert, so its tunnel is not drowned. The spillway is feather-edged.

Second Spillway Profile

The spillway body is made of tile. The material of its tunnel and bend is like the first spillway. Its crown diameter is 14.2 cm.

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Third Spillway Profile

The body is made of tile and the crown diameter is 22.4 cm and a tunnel diameter is 12.5 cm. the tunnel material is plastic.

Figure 1: A view of the physical model of shaft spillway with vortex breaker structure in laboratory

The first parameter that should be entered into the software is time. The time determined to solve the problem is 120 s. The flow after 85 seconds reaches a state that flow characteristics compared to time and place doesn't change over time, but it continues to 120 s to ensure the simulation.
In *Physics* section of software, we should first determine the turbulence model and gravity and type of flow in terms of viscosity. The laminar model cannot be used for simulation because of the flow turbulence and changes in the direction of flow at the time of flow entry to the shaft spillway. Turbulent flows are determined by the velocity fluctuations. Based on previous research, RNG turbulence model was the best option to solve this problem and model the turbulence with a good approximation. The type of fluid should be determined in *Fluids* section. In *Fluid Database,* lots of fluids are placed as default. Given that one of the fluid conditions to carry out experiments in the river or channel normal conditions is water with standard temperature. We select this option that has the viscosity 0.001 and density 1000. To model different types of vortex breaker structures and the shaft spillway and the given flume, Flow3D and AutoCAD were used simultaneously.

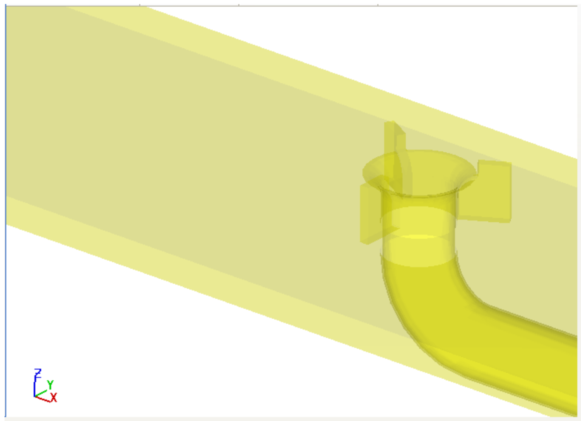

Figure 2: Displaying the model in Flow 3D

Since the desired parameters in the vicinity of spillway are of much more importance than other areas, to mesh the model, different divisions of meshes were used in different areas and in areas near the groyne, more and finer meshes were applied than other areas.

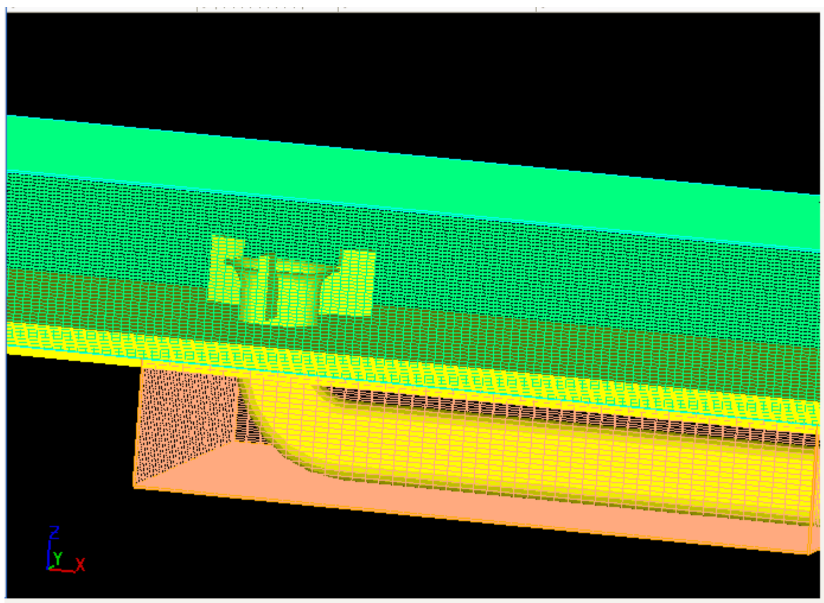

Figure 3: Meshing the test area

Finally, for the calibration as trial and error, several different meshes will be applied to obtain an optimal meshing suitable for test conditions. To validate the calibrated Flow3D model in terms of flow hydraulic by considering another input discharge other than one used in the calibration stage, the accuracy of the calibrated model was also evaluated. In this study, the experimental data of shaft spillway with 6 vortex breaker structures with dimensions of 5 × 4 × 9.5 was used for calibrating the model to correspond the results with experimental results after changing in the numerical solution model of K-ε to RNG and change in meshing for different values.

RESULTS AND DISCUSSION

Discussion and Conclusion

Based on the geometry prepared in AutoCAD and introducing boundary conditions based on discharge design of physical model in Flow3D, at this stage, the physical model was simulated.

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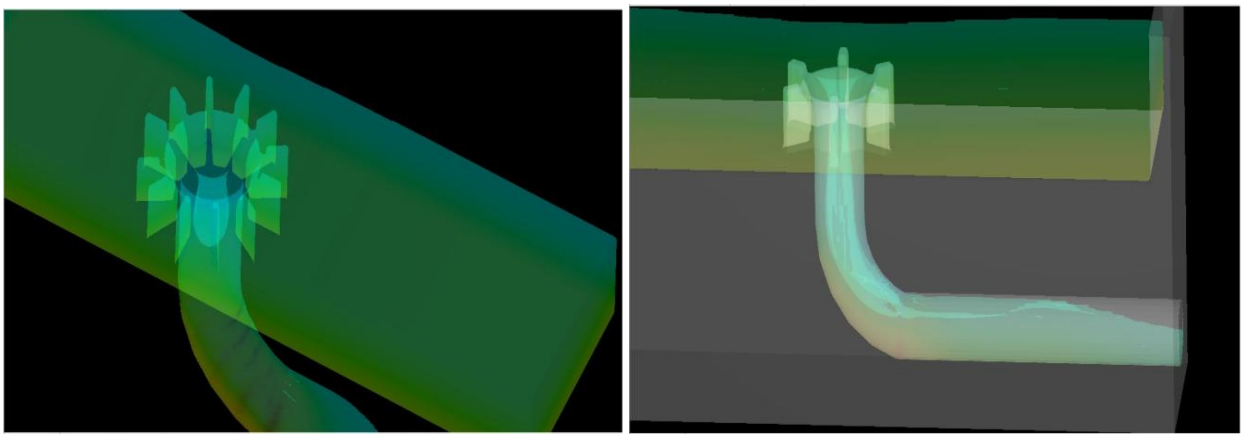

Figure 4: Sample flow with a three-dimensional view around 6 and 12 vortex breaker structures

Since in this experiment, the number of vortex breakers changes, the study aimed to investigate the effect of vortex breakers on discharge coefficient of shaft spillway. The results are presented as graphs in different modes in the following:

Comparison of Discharge - scale Curves

Table 1: Discharge-scale values

Water height (cm)	**Discharge with 3 vortex breaker structure (liters per second)**	**Discharge with 6 vortex breaker structure (liters per second)**	**Discharge with 12 vortex breaker structure (liters per second)**	**Discharge with no vortex breaker (liters per second)**
0.6	0.51	0.51	.617	0.52445
0.9	1	1.04	1.04	.884
1.1	1.35	1.32	1.355	1.15175
1.25	1.66	1.78	1.7	1.35
1.5	2.5	2.38	2.31	1.85
1.6	2.56	2.51	2.75	2.05
1.7	3.04	2.75	3.14	2.31
1.9	3.5	3.24	3.62	2.75
2	3.7	3.78	3.89	3.05
2.2	4.425	4.35	4.62	3.81

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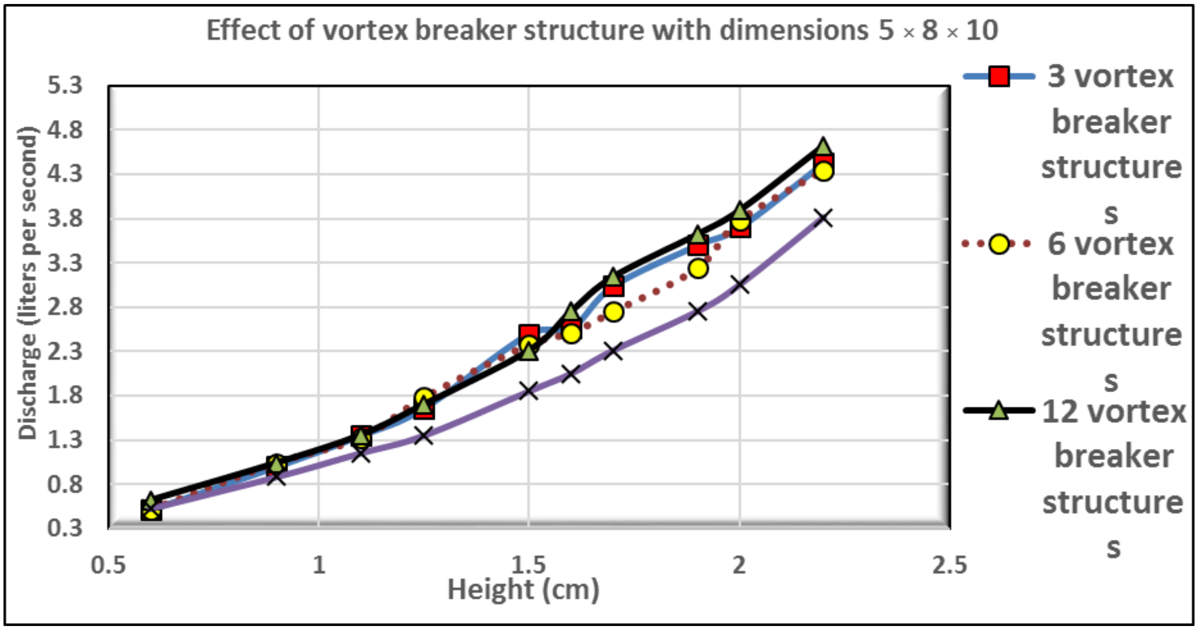

Figure 5: The effect of number of vortex breaker blades dimensions 5 × 8 × 10

Using the fitting line, the power equation extracted the coefficients of the equation ($Q = ah^n$) from the diagram that is in the table below.

Table 2: Equation fitted line coefficients Values

	A	**n**	R^2
With no vortex breaker structures	1.0436	1.50101	0.99
3 vortex breaker structures	1.887	1.6776	0.99
6 vortex breaker structures	1.888	1.6292	0.99
12 vortex breaker structures	1.2711	1.5968	0.99

According to the above table, accuracy of computations and analysis of software is acceptable given the values larger than R^2.
The following table shows the discharge coefficient for the head water over the spillway:

Table 3: Discharge-scale coefficient values

Head water (cm)	**Discharge coefficient with the effect of 3 vortex breaker structures**	**Discharge coefficient with the effect of 6 vortex breaker structures**	**Discharge coefficient with the effect of 12 vortex breaker structures**	**Discharge coefficient free of vortex breaker**
0.6	1.559	1.559	1.886	1.603
0.9	1.664	1.731	1.731	1.471
1.1	1.663	1.626	1.669	1.419
1.25	1.688	1.810	1.728	1.373
1.5	1.934	1.841	1.787	1.431
1.6	1.797	1.762	1.931	1.439
1.7	1.949	1.763	2.013	1.481
1.9	1.899	1.758	1.964	1.492
2	1.859	1.899	1.954	1.532
2.2	1.927	1.894	2.012	1.659

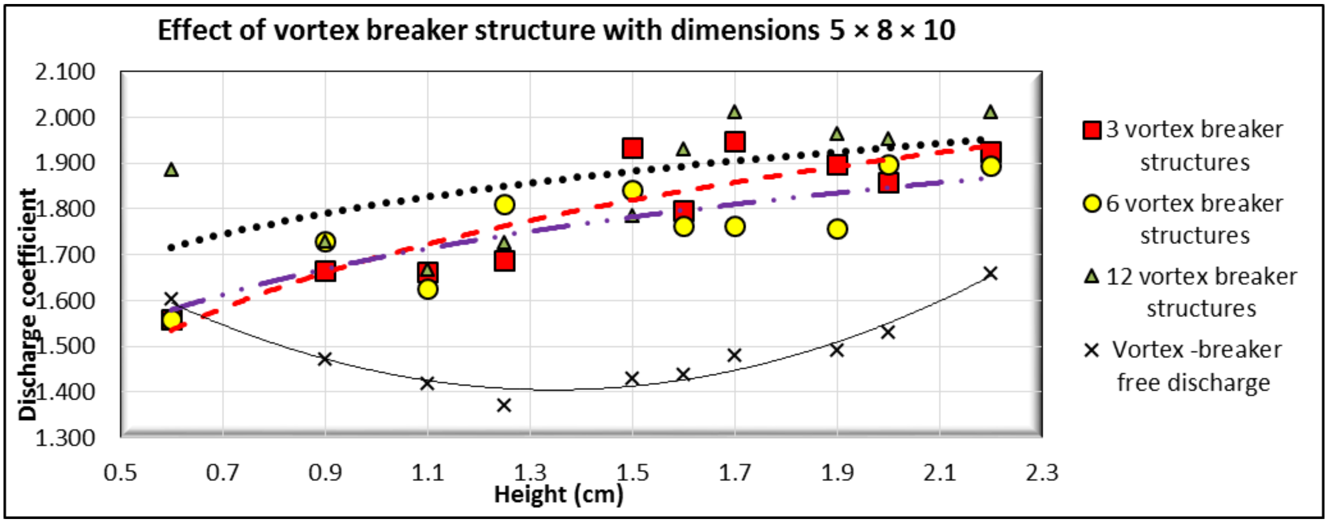

Figure 6: Diagram of discharge coefficient with increasing vortex breaker blades

According to Figure 6, it can be concluded that spillway discharge coefficient in the unstructured vortex breaker has a descending and then ascending trend, but in the presence of vortex breaker structure, discharge coefficient increase is ascending and has a highly significant difference with unstructured one that show the effect of structure on the passing discharge and as a result of increase in discharge, the trend will remain totally ascending that indicates high performance of these blades that the vortex breaker structure 12 has the greatest impact.

Results

According to Figure 5, it can be concluded that existence of vortex breaker has a great impact on increasing the discharge in the fixed water heights relative to the control condition and increasing the number of vortex breaker, passing discharge will be more. The highest relative difference between the discharge and the discharge coefficient for water height 1.7 cm in discharge 3.14 liters per second in a state where 12 vortex breaker structures are used and it will be 36% that shows the effect of structures on the input water flow into the spillway.

The least relative difference per water height 0.6 cm at discharge 0.51 l/s where 3 and 6 vortex breaker structures are used and it obtains equal to the control discharge indicates lack of effect of the structure in the low levels of water with such dimensions. It is noteworthy that by increasing the water height on spillway, discharge coefficient increases and the maximum values takes place at high water levels on the spillway. The maximum difference of discharge with control is at the height of 2.2 cm in presence of 12 vortex breaker structures and it is equal to 0.81.

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