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Comparison of Spillway with Floor Ramp and Duct in Wall with Spillway with Floor Ramp and Ramps in Walls on Factors Affecting Cavitation

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ABSTRACT

Cavitation in the spillway of great dams is one of the factors threatening the stability of dams. In recent years, softwares are developed numerically for modeling the flow that are very useful to examine the condition of the fluid and hydraulic structures problems along with experimental models. One of these applications which has the ability to model the flow as three-dimensional is Flow-3D. In this study, the impact of two aerator models on the factors influencing the cavitation on free dam spillway was studied by numerical models. Results showed that both aerator models are effective on factors affecting the cavitation (Flow rate and spillway floor pressure) and increases the cavitation index.

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INTRODUCTION

Increasing the construction of large dams with high flood discharge at present, assessing the risk threatening the security of these spillways are considered, the most important risk threatening to spillway after a lack of consideration of capacity for the structure is cavitation. In recent years, many incidents related to the problem of cavitation at high dams had happened around the world that has attracted the attentions of experts. In recent years in Iran, cavitation destructed Karun 1 dam. It seems that over the long dams' spillway, in parts that the flow rate is high, due to the roughness of the spillway floor, flow lines are separated from the floor and eddies are formed in the downstream of the detachment, due to the high flow rate at the eddy region, pressure had reduced and the pressure of the region is the same as the aqueous water pressure, as a result of aqueous water, bubbles are formed in this area and the bubbles are exploded after the transition to the lower part and the region with higher pressure. Since the contact area of bubbles with spillway bottom is small, an extraordinary force as a result of explosion of bubbles enters into the spillway bed. In effect of this phenomenon, small pores occur on the concrete surface, that the pores act as the secondary differential and causes more separation of the flow and finally structural damage [1]. To check the cavitation in spillways, a famous index called cavitation index is used. This formula may be written in different ways and obtains from the flow bottom pressure and it is one of the most common forms of cavitation index formulas which is given below:

$$\delta=(Ho+Ha-Hv)/(V2/2g) \quad (1)$$

Variables in the above formula are as follows: V: flow velocity, Ho: height equal to Piezomtetric pressure, Ha: height equal to atmospheric pressure, Hv: height equal to the vapor pressure, g: acceleration of gravity. Many studies have been conducted concerning the cavitation in dams that some of which are mentioned below. Forrester and Anderson by building hydraulic model in a scale of 1:80 investigated the phenomenon of cavitation on Karun 1 dam spillway. Their results showed that low pressures and cavitation occurs at speeds more than 40 meters per second [2]. Houshmand Aeeni [3], using numerical modeling of flow over the spillway of Karun 1 dam and obtaining the values of the factors affecting cavitation index, obtained the cavitation index for each station. His conclusions showed places with the probability of cavitation on spillways. Rohani Ghouchani et. al. [4] showed that with a study on the effect of roughness on the formation of cavitation by numerical modeling of Karun 1 dam by Flow-3D showed that in a fixed position with increasing roughness, cavitation index increases and the risk of damage due to cavitation decreases. Dehdar Behbehani *et*

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al. [5] using Flow-3D examined the cavitation in the spillway of Balaroud dam and concluded that the software results are close to the the results of the physical model, the difference is caused by differences in the velocity that in physical model, the velocity in the depth of 0.2 m was measured by Micro Mooline and in the software the average speed in the perpendicular direction on flow was registered, they also showed that the possibility of cavitation occurance at the bottom of the spillway is low. Erfani et. al. [6] worked on the installation place of aerator in Gotvand spillway with Flow-3D and the results showed that the software has a good agreement with physical model and also four left and right aerator channels are sufficient to prevent cavitation. The purpose of this study is to evaluate and compare the factors affecting cavitation with spillway numerical modelling in Flow-3D in three states, primary spillway, spillway with a ramp on the floor and duct in the wall and the spillway with a ramp in the floor and wall.

MATERIALS AND METHODS

Numerical Methods in recent years have rapidly developed due to advances in computer technology. In most cases, a computer based study is far less expensive than a laboratory study. The speed in the process, providing perfect information and having required values of variables in all the area includes the advantages of a numerical model. Also the adverse conditions often occur while examination usually doesn't occur in the numerical model. It should be considered that in the numerical model, the inaccessible places, unlike the laboratory models are small and in places where in laboratory model it is not possible to install the measurement equipment, in numerical models we can obtain the values of the factors needed. FLOW-3D is strong software in the field of fluid dynamics. The software is designed to investigate the behavior of one, two and three-dimensional fluid dynamically in a wide range. One of the main features of the program for hydraulic analysis is the ability to model the free surface flows with the VOF method. This software uses a network of rectangular cells. This network has the advantage of simple, regular, and adequate production to boost the numerical simulation that has the smallest memory storage [7]. FAVOR and VOF methods are examples of volume fraction methods. In these methods, an area that should be modeled is firstly divided into a network of smaller elements or volumes. For elements containing fluid, numerical values for each of the flow variables such as pressure, temperature and velocity are kept inside them. These values usually represent mean volume values for each element. When the flow has free surface, all cells are not filled with fluid and some of cells that are at the surface of flow are half-filled. Appropriate method for the quantification of cells is to define a quantity as F, which indicates part of a cell that is filled with fluid. The quantity is called the volume of fluid function. The Favor method is another volume fraction techniques used in determining the geometry. The volume fraction quantity is used to determine the rigid body. On the other hand, this quantity can be used in determining the volume of a cell which is not occupied by a rigid body (Vf). When in any cell the volume occupied by rigid body is determined, we can determine the rigid boundary with a method similar to VOF in the fixed network. The boundary is used to determine the wall boundary conditions that the flow should compile with it [7]. In this study, for numerical study of the cavitation, first free dam model is drawn three dimensionally in real dimensions in AutoCAD. The chute of the spillway first part is 5% and the chute of main part is 36.4 percent. An arc with 17.1 degree of a circle with a radius of 100 meters has linked these two parts together [8]. The projectile part and other spillway elements are modeled that of course the studied area are in the described part and then the build model was transferred to FLOW-3D. Boundary conditions of the numerical model in XMin is considered volume flow rate, in line with XMax out flow, in line with YMin, YMax and ZMin wall and along with ZMax the symmetry. Dimensions of meshing block cell is considered as 0.5 meters. The total number of cells formed in the model is 7.7 million, of which 4 million cells are active. The turbulence model is solved by Renormalized group (RNG) model, for the properties of the fluid, water characteristics at 20 ° C of defined fluids in the software was chosen that the density of water is 1000 kg per cubic meter and its viscosity is 0.001. In this study, the results of laboratory model of free dam were used that was constructed in the Tehran Water Research Institute at the scale 1.33 for validation. After calibrating the results of the model with the results of the experimental model, the second and third models are built similar to the original model, with the difference that in second model in two sections (185 meters and 230 meters from zero) ramp is located on the floor and duct in the wall and in the third model in the two ramp sections with the same shape on the floor and walls.

Ramp dimensions which are modeled in the floor and walls is so that the angle of ramp to the spillway chute is 7 °C, depending on the distance between the start point to the end point of the ramp is 3.76 m, height difference of ramp at the end point is 0.5 m. Upon completion of ramp there is a step that is1.87 m lower than spillway floor that by calculating the height of ramp the total height difference on ramp to step floor is 2.37 m. Stairs floor continues horizontally to interrupt the spillway. The horizontal length of the step (cut) is 5.14 m. The bottom of the stairs with an arc with a length of 20 ° from a circle with a radius of 2 m length is linked to the bottom of the spillway. The dimensions of duct are 2 * 2 meters which is opened from below to the cut of the ramp [8]. The dimensions of wall ramp are exactly the same as floor ramp. Figure (1) shows the initial spillway

Advances in Environmental Biology, 8(21) October 2014, Pages: 1196-1201

model, Figure 2 shows the built model of spillway with ramps on the floor and duct in the walls and Figure (3) shows the built model of spillway with ramps on the floor and walls.

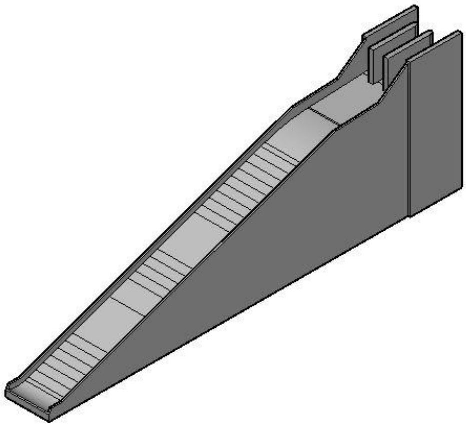

Fig. 1: The initial Spillway.

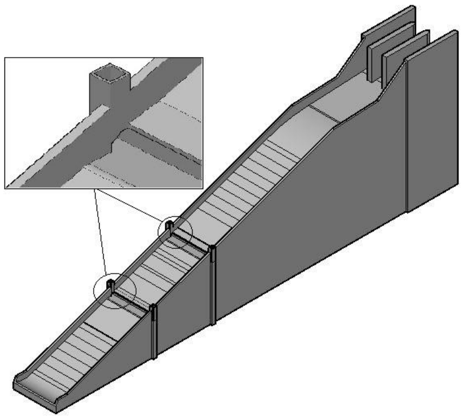

Fig. 2: Model of spillway with aeration ramp at the bottom and duct in the wall.

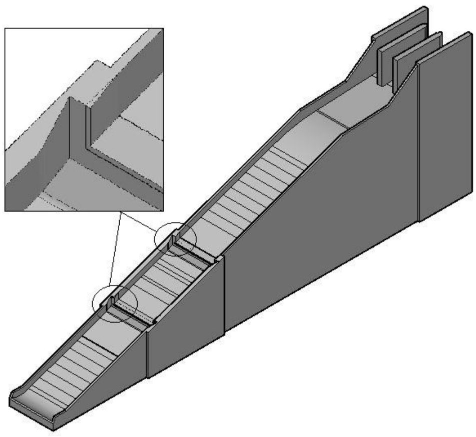

Fig. 3: Model of spillway with aerator ramps on the floor and walls.

These models were examined and tested for the three discharges with return period of 1000 years, 10,000 years and the maximum possible discharge 1226, 1545 and 2290 cubic meters per second, respectively. To record the results, eight sections in the terminal part of the spillway were considered where the probability of cavitations is high. Its two sections before the first ramp, three steps are between the first and second ramps and three other sections are located after the second ramp. It is noteworthy that results after a relative uniform of flow in selected sections for middle part of spillway were recorded and used. Given that the most critical

Advances in Environmental Biology, 8(21) October 2014, Pages: 1196-1201

findings is related to the maximum possible discharge, in this study, the results related to discharge of 2,290 cubic meters per second is only mentioned.

Discussion and Conclusion:

Following the results of the simulation of flow pattern are shown schematically. Cavitation index is calculated from the speed data and pressure by Formula 1. The results for the primary spillway, spillway with ramps on the floor and ducts on the walls and spillway with ramp in the floor and walls with ramps are given in eight points. Figure 4 shows the speed in three models of spillway in discharge of 2290 square meters per second. As can be seen in Fig. 4, making both aerator models in the flow path on spillway can reduce the flow rate and no significant difference can be seen between these two types of aerator models, although the slowdown in velocity was not impressive, but the slight decrease according to the formula of the cavitation index and the impact of velocity squared set in cavitation index can improve the cavitation index and decrease its effect.

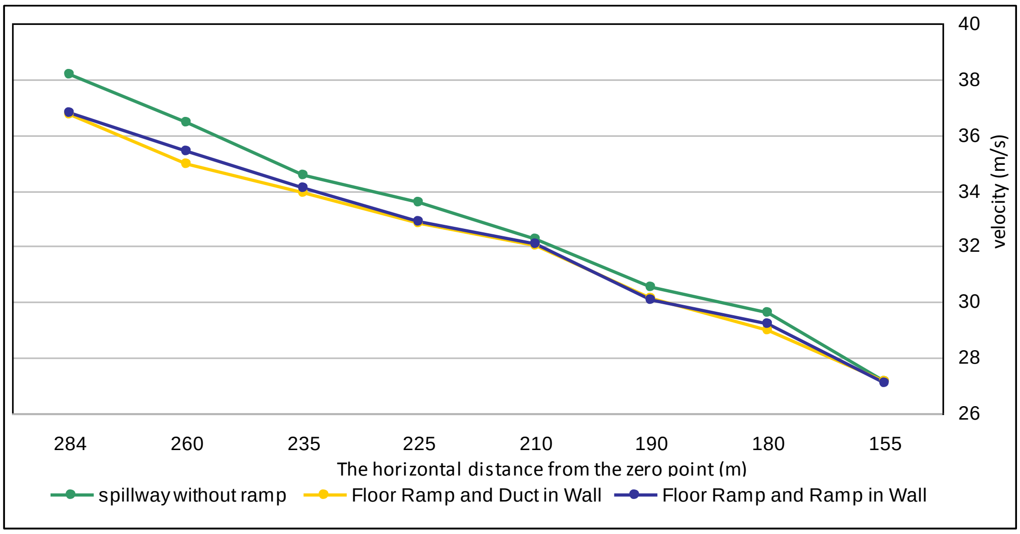

Fig. 4: Changes in the velocity in three spillway models in discharge of 2290 m3/s.

Figure 5 shows the pressure on the spillway in three spillway models in discharge of 2290 cubic meters per second. Due to the figure, the impact of both aerator ramp models can be understood on the spillway. Construction of aerator ramps significantly increases the pressure on the bottom, but it is also notable that in two sections located at a distance of five meters after ramps the pressure compared with the spillway without ramp is reduced, but this reduction is because the sections are located under water jump.

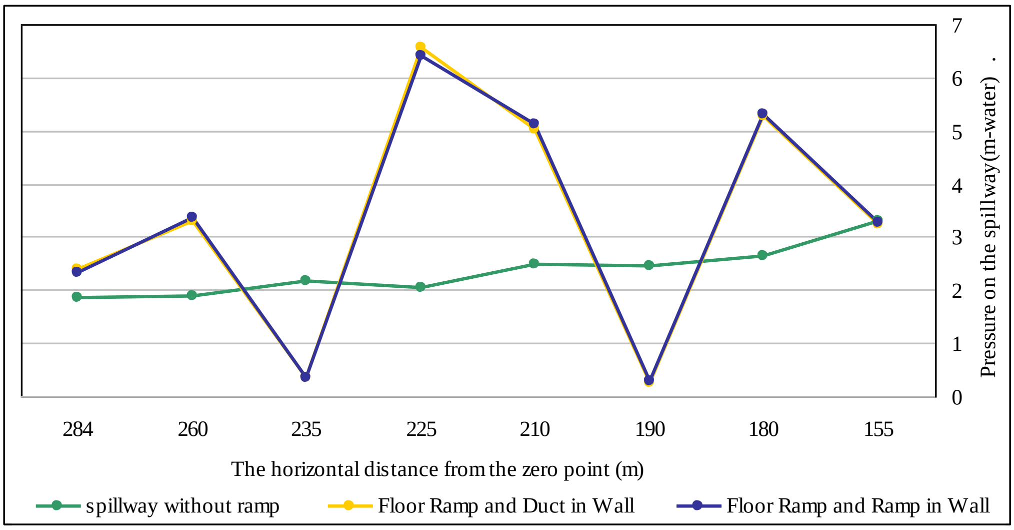

Fig. 5: Pressure changes on the spillway in three spillway models in discharge of 2290 m3/s.

Advances in Environmental Biology, 8(21) October 2014, Pages: 1196-1201

Figure 6 shows the cavitation index changes in three spillway models in discharge $2290 m^3/s$. Based on the foregoing figure, we can understand the positive impact of both aerator ramps. In both sections after first and second ramps that were also noted in the pressure, cavitation index decreases due to the low pressure, but low cavitation index in these two points is not worrying because in these sections, we won't have damage due to cavitation, because in these places, water doesn’t hit the spillways and the section is located below the water jump.

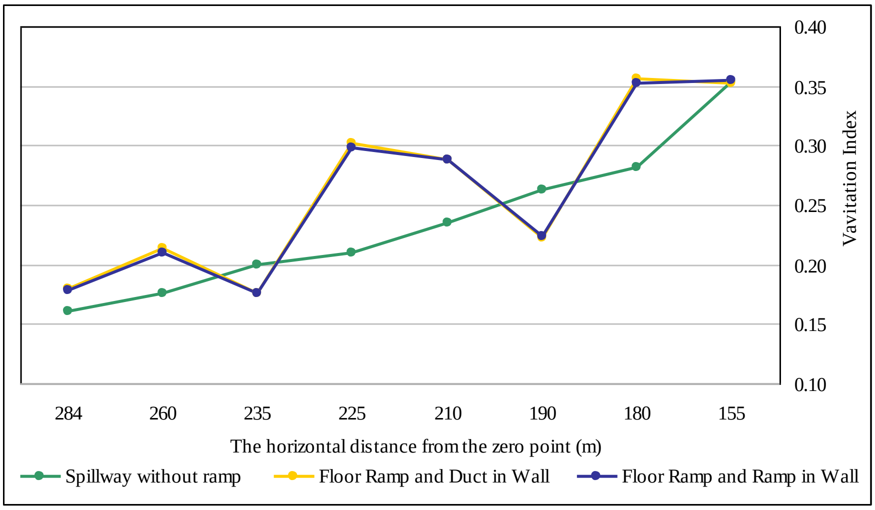

Fig. 6: Changes in the cavitation index in three models of spillway in discharge of 2290 m3/s.

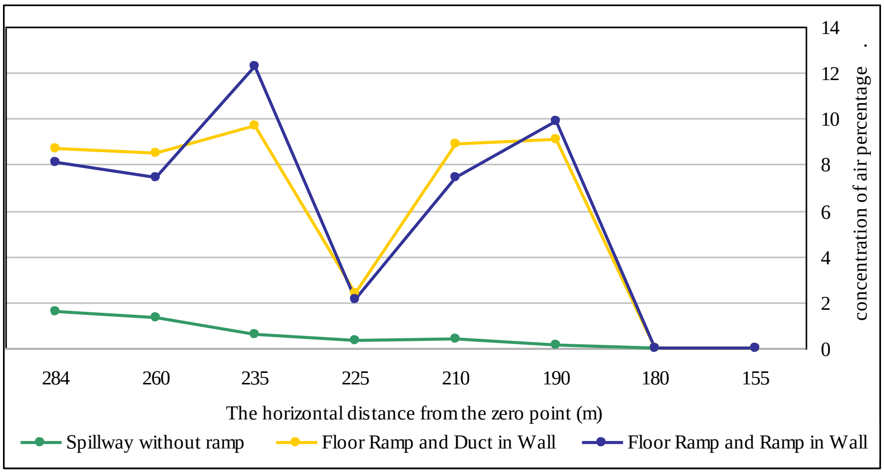

Fig. 7: Changes in the concentration of air in three spillway models at the discharge of 2290 m3/s.

Despite the positive impact of both aerator ramps, again at the end of spillway, cavitation index is critical that can be seen carefully in Figure 7 which is related to the changes in the the concentration of air in the lower layer of flow (close to the contact surface with the spillway). Air concentrations at both ends of the spillway model with aerator ramp are so that it is sufficient to protect spillway against the damage caused by cavitation. Also according to Figure 7 it can be seen that in the first stage after both ramps that is considered 5 meters after ramps, spillway with a ramp on the floor and walls acts better than the spillway with a ramp on the floor and a duct in the walls, but in subsequent sections that are further away than aerator ramps due to air distribution in this section, the performance of duct in wall was better and the air concentration is more in these four sections in spillway on the floor and duct in the wall. But totally both aerator models had a desirable performance and increased air concentration percentage to an expected level.

Conclusion:

Both aerator models of "ramp at the bottom and duct in the wall" and "ramp at the bottom and walls" had little impact on the flow rate on the spillway and cause a slight decrease in speed. Also there is no significant difference between the effect of flow rate on the spillway in these two aerator models.

Both aerator models increase the pressure on the spillway and there is no difference in these two aerator models in pressure. Both aerator models increased the cavitation index. But at two sections after ramps due to low pressure, cavitation index is decreased and critical, but since at this point, water doesn’t hit the spillway, no risk threatens the structure. In sections near the ramps of bottom, the ramp in the wall is more effective than the duct in the wall, but totally spillway with ramps on the floor and duct in wall is effective in flow aeration, but the difference is not very noticeable.

Totally both aerator models of "ramp at the bottom and duct in the wall" and "ramp at the bottom and walls" have an acceptable performance in improving cavitation index and as well as flow aeration over the spillway. Aerator consists of "ramp at the bottom and duct in the wall" and "ramp at the bottom and walls," can well raise the concentration of air inside the flow and reduce or eliminate the damage caused by cavitation. Spillway with ramps on the floor and walls in the aeration area is more effective in entering the air into the flow than spillway with ramp in the bottom and the duct in the wall.

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