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Research Article

NUMERICAL INVESTIGATION OF THE EFFECT OF RAMP ON THE FLOOR AND DUCT IN THE FREE SPILLWAY WALLS ON FLOW AERATION

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ABSTRACT
The most important part of a dam is its spillway and one of the biggest dangers threatening it is the cavitation. The most common way to deal with this problem is to build aerator on the way of flow on spillways. Making changes in flow characteristics and entering the air into it, aerator reduces ad loses damages caused by this phenomenon. The purpose of this study is to examine the effect of the duct in wall on the concentration of air entering to the flow using aeration ramp of floor with flow three-dimensional modeling that the results showed as expected , creating duct enhances the efficiency of aerator ramp, increases cavitation index and increases the concentration of the air entering the flow. Of course floor ramp without constructing duct is effective in reducing the risk of cavitation.

Keywords: *Spillway, Cavitation, Floor Aerator Ramp, Wall Duct, Numerical Model*

INTRODUCTION

With the increasing need for fresh water in recent years, the need for control and management of water resources is needed more than ever. Thus the construction of dams with a high flood discharge is developed and as a result the design and evaluation of risks threatening the security of dam and its components is very important. One of the most important components of the dam is spillway and the most important factor in dam failure after inadequacy of spillway capacity is cavitation. In recent years, many incidents related to cavitation have occurred at high dams in the world. In Iran also as a result of the same phenomenon, part of the spillway and even bedrock below the spillway of Karoun 1 (Martyr Abbaspoor) was destroyed. Along the high dam spillway, in parts that the flow rate increases in the presence of inequality and corrugation, flow lines are separated from the substrate and eddies are formed downstream of the detachment, due to high flow velocity in the eddy area, pressure reduction occurred and the pressure of the region will reach the water vapor pressure and cavity bubbles are formed in the area. The bubbles will explode after transmitting to a lower part and the region with higher pressure. Since the contact area of bubbles with overflow substrate is small, an extraordinary power as a result of bubble burst will be imposed on the spillway substrate that causes damage and destruction to spillway substrate (Falvey, 1990). In the past, cavitation potential was determined only by considering the flow rate, but the law could not justify the impact of pressure and severe and abnormal destruction in the downstream of the vertical arches. Dimensionless cavitation index ratio is defined as deterrent forces to cavitation factor forces which are expressed as follows:

$$\delta=(Ho+Ha-Hv)/(V^{2/}2g \quad (1)$$

Where V: flow velocity; Ho: height equal to piezometric pressure; Ha: Height equal to atmospheric pressure; Hv Height equal to water vapor pressure and g: acceleration of gravity. According to research carried out and the results provided by the USBR if the cavitation index is more than 0.25, cavitation phenomenon does not occur, when the cavitation index is between 0.20 to 0.25, the phenomenon of cavitation will have little damages that it is not mandatory to consider the aerator, and where the index is less than 0.2 the likelihood of this phenomenon increases. Experiments have shown if the cavitation number is between 0.1 and 0.2, the cavitation aerator system is necessary to prevent potential damages and if cavitation index is below 0.1, it is needed to redesign the spillway (Falvey, 1990). Karmer (2004) in venturi test showed that 5-10 percent of air is necessary to protect the concrete with a compressive strength of 10 to 20 MPa. Forrester and Anderson (1969) built a hydraulic model for Karun spillway 1 to study the corrosion scale 1:80. They did not see any pressure less than the atmosphere, and concluded that low pressures are achieved for speeds more than 40 meters per second. Erfanain and Kamanbedast (2013) 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 experimental model and also four left and right aerator channels are sufficient to prevent cavitation in the Gotvand spillway. The purpose of this study is to compare and examine the concentrations of air entered into the flow with the spillway numerical modelling in Flow-3D for three states, primary spillway, spillway with a ramp at the bottom and spillway with a ramp in the bottom and a duct in the wall.

MATERIALS AND METHODS

FLOW-3D is a computer program with general applications and many capabilities. The user can enter the data and select several models to provide a wide range of current events. In this software, finite volume and difference approximation are used to calculate the time and spatial variables in the motion equations. One of the key features of this application is the ability to model the free surface flows with the VOF method. In this method, areas that should be modeled are firstly divided into a network of smaller elements or volumes. For elements containing fluid, numerical values for each of the variables, such as pressure, temperature and speed is kept inside them. Often, these values represent volume mean of values in each element. When the flow has free surface, all cells are not full of fluids and a number of cells that are on flow surface are half-filled. The proper procedure to show the status of the cells is that the quantity F, which represents a component of the cell filled with the fluid is defined. The quantity is called the volume of fluid. The program uses a grid of rectangular cells. This network has the advantage of easy, regular and appropriate production for improving the numerical simulations that requires least memory (Flow Science Inc., 2007). Favor (Fractional Area/Volume Obstacle Representation Method) is another volume fraction technique used to determine the geometry. The volume fraction quantity is used to determine the rigid body surface. On the other hand, the quantity is also used in determining a volume of the cell which is not occupied by a rigid body (V_f). When in any cell, the volume occupied by the rigid body is determined; the rigid boundary can be determined by a method similar to VOF in the fixed network. The boundary is applied to determine the wall boundary conditions that the flow should comply with it. Since the channel geometry of a flow is constant, so the volume fraction V_f and the area fraction A_f don't change in the modelling, it is significant when two methods VOF and Favor are combined, fluid volume fraction F is defined as a part of the cell empty part (V_f) which is not occupied by the rigid body (Flow Science Inc., 2007).

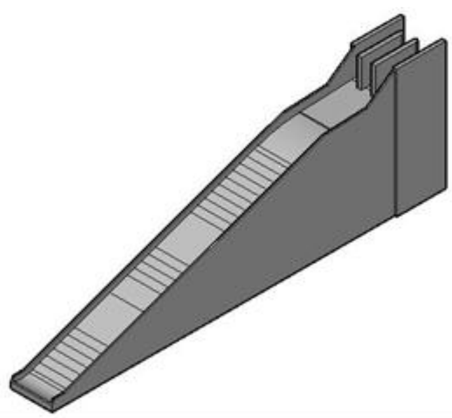

Figure 1: The primary spillway

Initially, free dam spillway model was drawn in 3D AutoCAD in real dimensions. The slope of the first part of the spillway is 5% and gradient of the main part is 36.4 percent. An arc with 17.1 degree of a circle with 100 meters radius connects these two parts together (Institute for Water Research, 2008). The projectile and other components of the spillway are also modeled and then the constructed model will be transferred to the FLOW-3D. Figure 1 shows the primary spillway model.

Boundary conditions of the numerical model in X_{Min} is considered volume flow rate, in line with X_{Max} out flow, in line with Y_{Min}, Y_{Max} and Z_{Min} wall and along with Z_{Max} the symmetry. Dimensions of meshing block cell are 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. Second and third models are also the same as the primary model with a difference that in second model in two ramp sections (185 yards and 230 meters from zero) is placed on the floor and in the third model in the two ramp sections with the same is modeled in the floor and duct with dimensions of 2 × 2 meters in the wall. The size and shape of the modelled ramp in spillway is shown in Figure 2. In this study, the results of laboratory model of free dam constructed in the Tehran Water Research Institute at the scale 1.33 are used for measuring the accuracy of software.

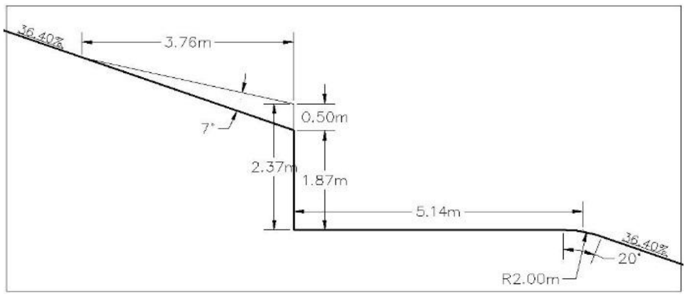

Figure 2: Size and shape of the ramp modeled in the spillway

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. At sections where the length of spillway is considered, eight points are also considered in its section where in the percentage of air is recorded, however, given that two sections out of eight sections are placed before the first ramp, in just six sections after the first and second ramps is intended the transverse profile of air entered into the flow is given. Given that the most critical findings is related to the maximum possible discharge, in this study, the results related to discharge of 2290 cubic meters per second is only mentioned.

Discussion and Conclusion

Figure 3 shows a graph of cavitation index in three spillway models in discharge of 2290 cubic meters per second.

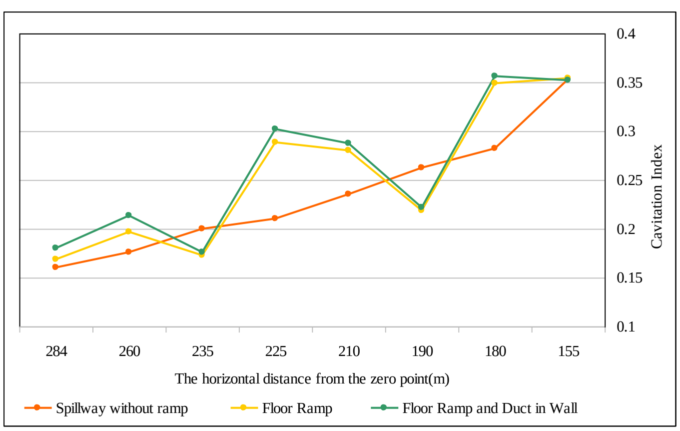

Figure 3: Changes in the cavitation index in 3 spillway models in discharge of 2290 m^3/s

Figure 4 shows the concentration of air into the flow in cross section in a distance of 190 meters from zero, Figure 5 shows the concentration of air into the flow in the cross section in a distance of 210 meters from zero, Figure 6 show the concentration of the air into the flow at a distance of 225 meters from the zero, Figure 7 shows the concentration of air into the cross section at a distance of 235 meters from zero, Figure 8 shows the concentration of air into the cross section at a distance of 260 meters from the zero and Figure 9 shows the concentration of air into the cross section at a distance of 284 meters from zero.

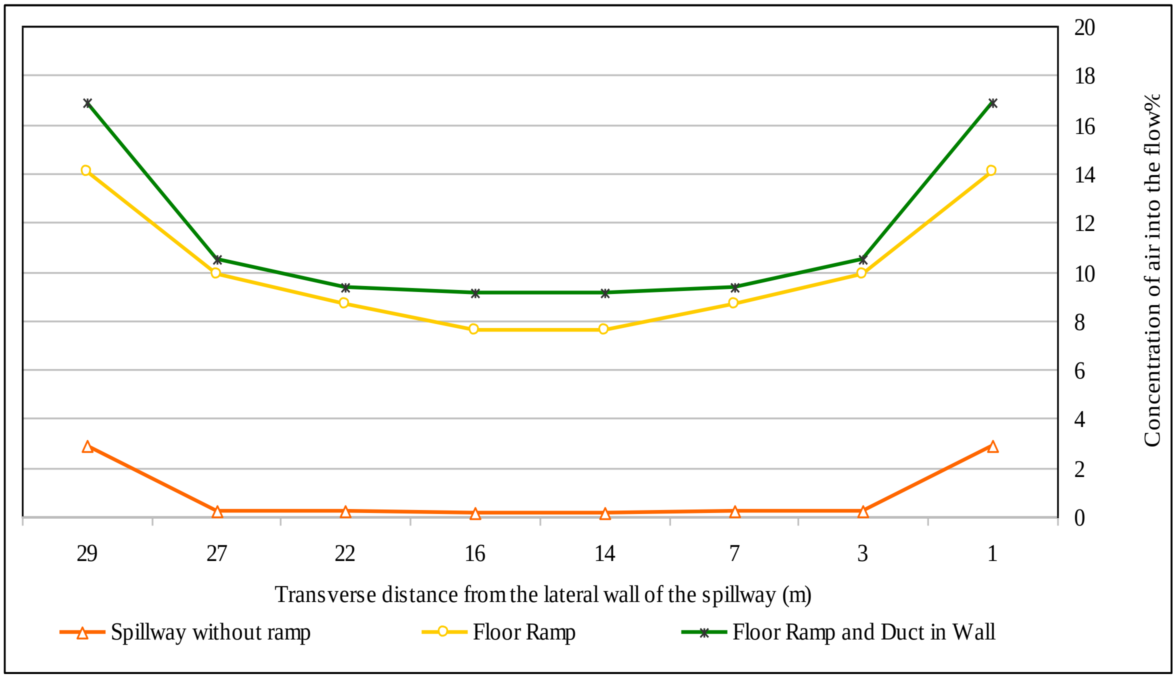

Figure 4: Changes in the concentration of air into the flow in cross section at a distance of 190 meters from the zero

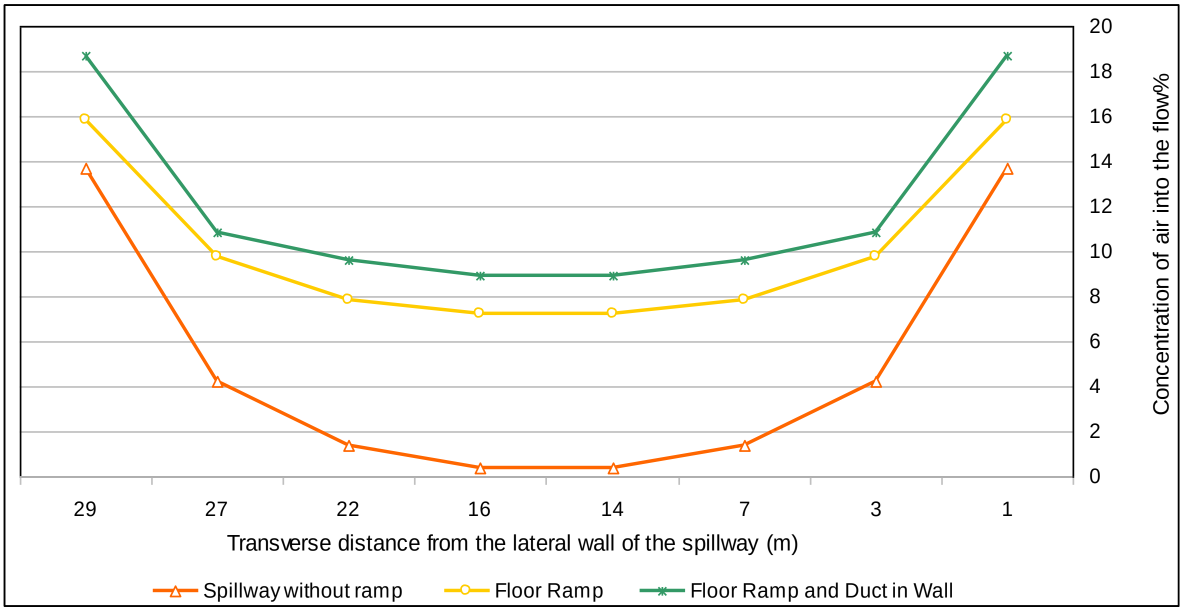

Figure 5: Changes in the concentration of air into the flow in cross section at a distance of 210 meters from the zero

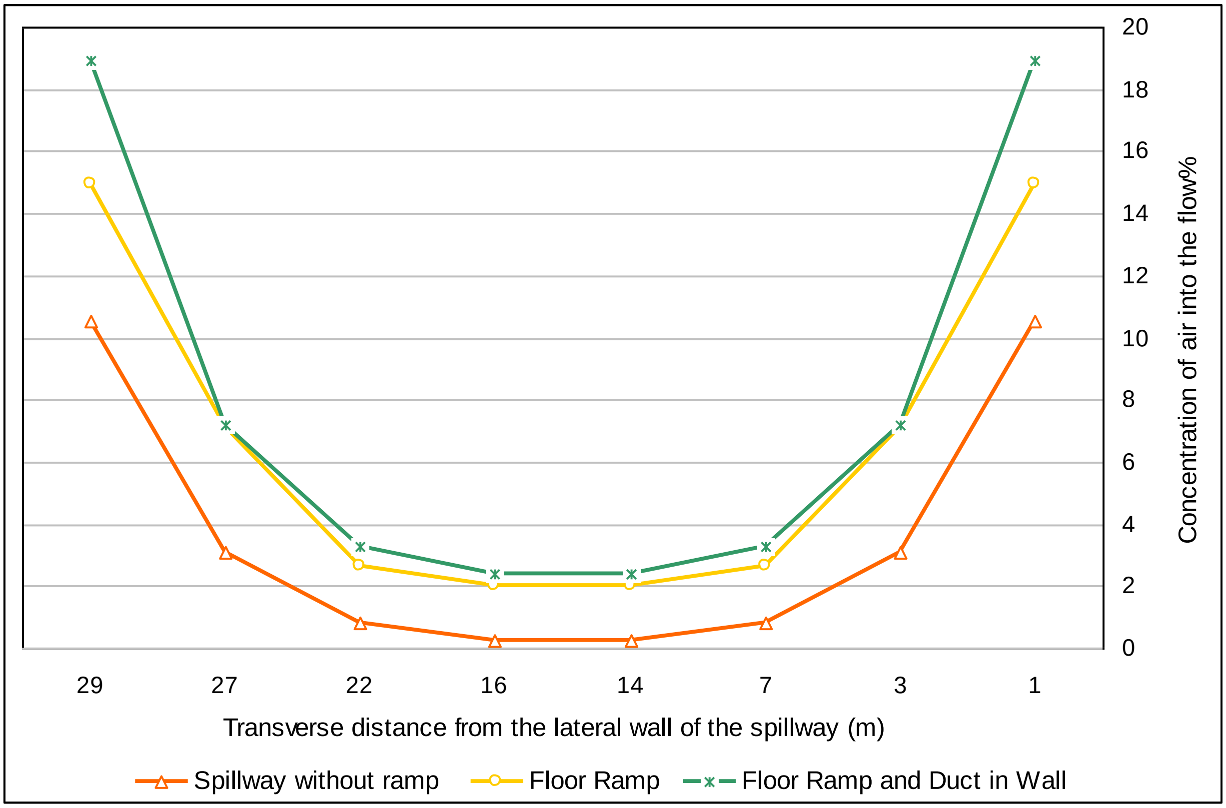

Figure 6: Changes in the concentration of air into the flow in cross section at a distance of 225 meters from the zero

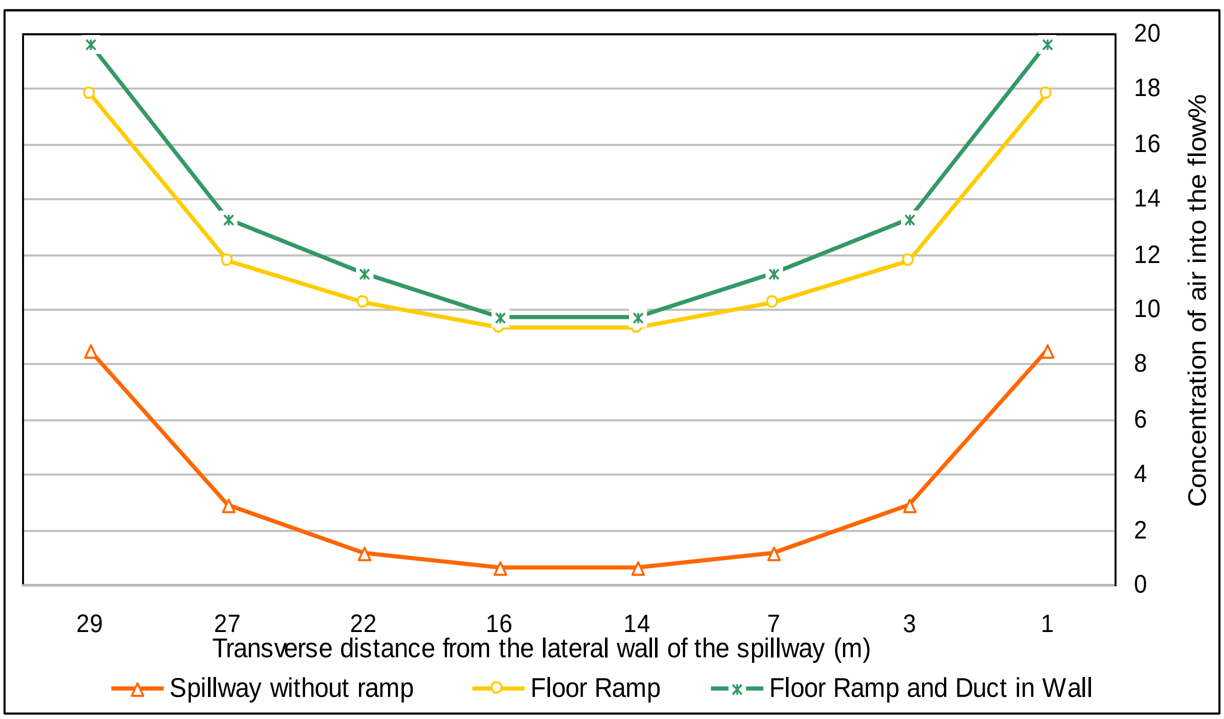

Figure 7: Changes in the concentration of air into the flow in cross section at a distance of 235 meters from the zero

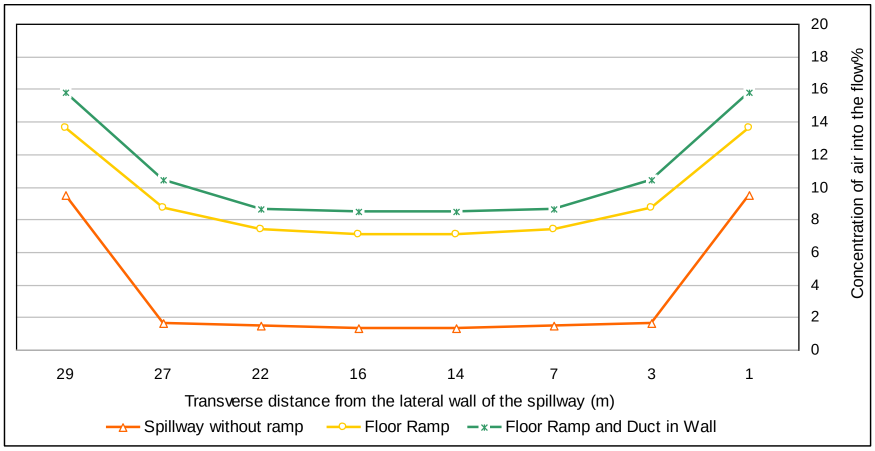

Figure 8: Changes in the concentration of air into the flow in cross section at a distance of 260 meters from the zero

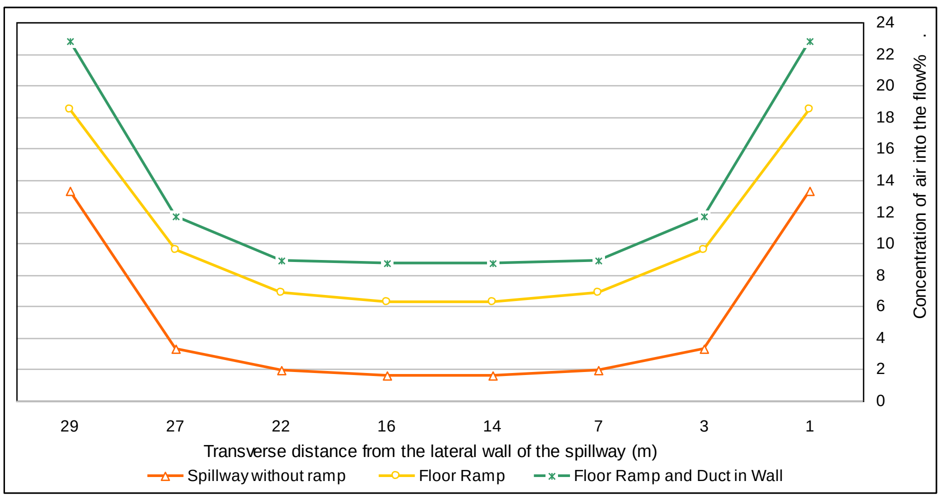

Figure 9: Changes in the concentration of air into the flow in cross section at a distance of 284 meters from the zero

Figure 3 is the cavitation index graph in three spillway models that their values are calculated using the velocity and pressure values recorded in the application from Formula 1. By examining the graphs, the positive impact of both types of aerator ramps can be considered, but ramp with duct performs better and increases the cavitation index but in two points located at a distance of 5 meters after the first and second ramps, the cavitation index declined strongly that this is due to low pressure in these areas, but given the location of these sections under the water jump and lack of water hit to the spillway bottom in the area, criticality of cavitation index doesn't imply the damages caused by this phenomenon. With regard to the six-sections that transverse profile of air drawn into the flow is drawn in it can be found that both aerator models well increased the level of air in the flow and spillway with ramps at the bottom and the duct in the wall have a better performance than the spillway that has been only located at the bottom of aerator ramp. It is noteworthy that according to the model meshing and mesh size and slope of the floor, the tested model in the quantitative software is different from the real model and the floor and walls are not completely smooth uniform modeled and they are modeled as small steps. Thus in the numerical model, the spillway performance with floor ramps is shown higher than the real value, because from the side of the walls, a little air is entered into the layer under the flow. The effect of this issue on the transverse profiles are also evident and however we go forward from the sides of the wall to the middle of a spillway, the amount of air entering the flow decreases. Considering the discharges tested in this study it is observed that whatever the water flow is reduced due to the reduction in flow velocity, cavitation index rises and also due to the reduction in the thickness of flow in the lower discharges, the concentration of air entering the flow rate is increased that this shows that by increasing the discharge the likelihood of damage caused by cavitation increases.

Conclusion

Due to the risk of cavitation in the spillways and damages may enter to the structure and increasing the cost of repair and restarting the spillway, in this study, the effect of floor aerator ramp as well as floor aerator ramp with duct in the wall was studied. The results showed that:

Both aerators "ramp in floor" and "ramp in floor and duct in the wall" increase cavitation index that adding duct into the wall increases the effectiveness of ramp in the floor.

Both aerators increase concentration of the air inside the flow that with the addition of duct in the wall as expected the concentration of air in the flow increased.

Due to cavitation index and the amount of air entering the flow, increasing the discharge increases the likelihood of damage caused by cavitation.

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